Effects of Reducing and Enforcing Speed Limits in Selected Arterial Roads in Bogota

López, José Segundo
International Data Coordinator
WRI Ross Center
segundolopez@wri.org

Pérez-Barbosa, David
Mobility and Road Safety Advisor
WRI Ross Center
david.perezbarbosa@wri.org

Lleras, Natalia
Project Manager, Mobility and Road Safety
Espacio
natalia@espacio.org

Hidalgo, Darío
Former Director and Former Senior Advisor
Espacio and WRI Ross Center
dariohidalgo965@gmail.com

Adriazola-Steil, Claudia
Director of Health & Road Safety
WRI Ross Center
claudia.adriazola@wri.org

Received: August 16, 2020. Revised: August 31, 2021. Accepted: September 19, 2021. Published: October 18, 2021

*How to cite this text: López, J., Pérez-Barbosa, D., Lleras, N., Hidalgo, D., and Adriazola-Steil, C. (2021) **Effects of Reducing and Enforcing Speed Limits in Selected Areas of Bogota**. *International Journal of Engineering, Social Justice and Peace*, 8(2), pages 50-71.*

In Bogota, the speed limit in five corridors with highest concentration of traffic crashes victims in the city was reduced from 60 to 50 km/h since November 2018. For understanding the impacts of managing speeds, speed records for 3 different periods (November to February) between 2017 and 2019 were examined, as well as the evolution of road crashes with injuries and the number of fatalities. The average speed reduction in the corridors with speed management was 1.48 km/h during daytime and 3.04 km/h during nighttime. In arterial corridors without speed management, the average speed reduction was 0.7 km/h during daytime and 2.2 km/h during nighttime. The speed management measure influenced a reduction of 16.6% in the number of fatalities and an increase of 10.5% in the number of crashes with injuries. The number of crashes with injuries did not decrease as expected, but the severity of the crashes decreased and the type of incidents with

injuries changed. The average count of runover crashes was also reduced by 10%. Notorious changes in the geographical distribution of crashes with injuries and fatalities along the corridors with speed management indicate the need to implement stricter enforcement measures to increase speed management effectiveness during nighttime.

Key Words:

Speed management, road safety, road crashes, traffic crashes, road crash victims

José Segundo López is International Data Coordinator for mobility and road safety at WRI Ross Center for Sustainable Cities. Segundo holds a bachelor's degree in civil engineering from Universidad de los Andes and a master's degree in civil engineering with emphasis on transportation at the same university.

David Pérez-Barbosa is a Mobility and Road Safety Advisor at WRI Ross Center for Sustainable Cities, with interest in road safety, active mobility and transport-based social exclusion. David is a civil engineer from the National University of Colombia and holds Master and Doctor of Engineering degrees from Hiroshima University, Japan.

Natalia Lleras is the Healthy Cities Lead and Vivo Mi Calle Project Director at Despacio. Prior to Despacio, Natalia was a Mobility and Road Safety Project Manager at WRI. Her work focused on helping cities implement sustainable and safe mobility solutions through research, street design and the development of public policies.

Darío Hidalgo, PhD is a Civil Engineer from Universidad de los Andes, Colombia, with MSc and PhD degrees from the Ohio State University. He has 32 years of experience in sustainable urban mobility and road safety in Latin America, Asia and Africa. He has authored and co-authored more than 90 academic publications.

Claudia Adriazola-Steil has worked in the transport sector for almost 20 years. As Director of Health and Road Safety at WRI Ross Center for Sustainable Cities, she focuses on the intersection of sustainable mobility, climate change, public health and equity.

Introduction

In Bogota, from 2007 to 2016 the annual number of road crash deaths ranged between 500 and 600 after a previous decade of continued decline (Vergel, Hidalgo, and Bray Sharpin, 2018). To improve road safety, in 2017, Bogota adopted a safe system approach and developed a new Road Safety Plan 2017-2026 (RSP) using vision zero principles (Welle et al., 2018). The background analysis of the plan indicated that in 2016 the percentage of fatalities affecting vulnerable road users reached 96% and that 72% of the fatalities occurred in arterial roads (Alcaldía Mayor de Bogotá, 2018). The risk of being involved in a road crash also increased during off-peak hours as speeds increased (Hidalgo et al., 2018).

Studies in Bogota show that speeding is the highest risk factor, among the five World Health Organization (WHO) risk factors prioritized to achieve the goals of the UN Decade of Action in Road Safety (JH-IIRU; Universidad de los Andes, 2019). Managing speeds has also proven to improve road safety (OECD Transport Research Centre, 2006). For this reason, the development of a Speed Management Program (SMP) was included in the RSP to help reach its annual goal of reducing the number of road crash victims by 3.5% (Alcaldía Mayor de Bogotá, 2018).

The main technical objective of the SMP was to align the speed limits and operational speeds of a road with their function and context in the most critical areas of the city. Based on victims' counts and speeds data, the action plan of the SMP prioritized the locations where speed limits needed to be reviewed and enforced through infrastructure measures and police control (Alcaldía Mayor de Bogotá, 2019). The use of data in this case implied that corridors selected were the ones with the highest potential of saving human lives by speed management. The SMP started with five arterial corridors and has been gradually expanded since. In May 2020, the speed limit of 50 km/h was extended to all the arterial corridors in the city of Bogota, becoming the first city nationwide to implement this measure, something that has saved lives.

The aim of this study is to discuss the social impacts of managing speeds in the five arterial corridors where the speed limit was lowered from 60 to 50 km/h since November 2018, as well as to analyze the effect of this measure in other arterial corridors of the city where speed management was not implemented. In the following sections we provide a literature review on the effect of speed management on road safety outcomes and its impacts for society, a description of the data used for this analysis, and a discussion of the results, the limitations, future research, and recommendations for practitioners and policy makers.

Introduction

Speed increases the probability of being involved in a road crash and the crash severity (Islam, El-Basyouny and Ibrahim, 2014; OECD/ITF, 2018). Greibe (2005) estimated that a 15% reduction in the average speed of a road can result in a 45% reduction of fatalities. Furthermore, road crash risk is related to the variability of travel speed around a mean average value, and research suggests the importance of minimizing speed variation in order to reduce this risk (Archer et al., 2008), as higher speed variance leads to more traffic conflicts.

Critics to speed management, especially against speed limit reductions, claim that it affects travel times. However, the literature shows that travel time is not significantly affected by speed management. It is estimated that the change in the mean traffic speed generated by a speed limit change is around 25%. (Elvik *et al.*, 2004; Forbes *et al.*, 2012). Kamy-Lukoda (2010) found that the speed limit reduction from 30 miles per hour (mph) (48 km/h) to 20 mph (32 km/h) on residential roads resulted in an average reduction of 1.3 mph (2 km/h) in the mean speed on all roads (Islam *et al.*, 2014), and a study of the impact of speed limit reduction from 60 to 50 km/h in urban areas in Victoria, Australia, found a statistically insignificant reduction of only 2–3 km/h in the mean speed and 85th percentile speed (Horeau *et al.*, 2006).

But, far more benefits can be obtained by reducing speed limits to adequate level in urban environments. Achieving reductions in motor vehicle speeds is also considered one of the most important government policies to encourage walking and cycling (Pucher and Buehler, 2010), enhance social welfare (Nitzsche and Tscharaktschiew, 2013), and improve air quality levels due to the reduction of emissions (Baldasano *et al.*, 2010). Also, social justice is associated with road safety as the inequality in the distribution of income and goods often is associated with the increased vulnerability and exposure to risk of people (Azetsop, 2010).

The recommended safe speed limit for cities is 50 km/h and 30 km/h in the locations where pedestrians and motor vehicles interact (OECD/ITF, 2018; World Health Organization, 2018). Research studies in Australia in relation to the reduction of the urban speed limit from 60 to 50 km/h indicated a minimal impact on individual travel times and large benefits to society as a result of the reductions in crash traumas (Archer *et al.*, 2008).

One of the most statistically robust efforts to define the relationship between speed and crash risk identifies a strong statistical relationship for speeds between of 25 to 120 km/h (Elvik *et al.*, 2004; Forbes *et al.*, 2012). According to their model, as the mean traffic speed is reduced, the number of crashes and the severity of injuries are usually reduced. For instance, it has been estimated that every 1.6 kilometer-per-hour (1 mph) reduction in vehicle speeds on urban streets results in a 6 percent decrease in traffic fatalities (Bray Sharpin *et al.*, 2017).

Objectives

Considering a perspective of social justice, we consider the following research questions:

- What is the impact of this speed management measure in the mean speeds of the selected corridors? Has the measure impacted the speeds of other arterial corridors in Bogota?
- How do these changes in speed impact on the number of lives saved, the ultimate purpose of speed management plans?
- Have there been any noticeable changes in the geographical distribution of road crash victims after the implementation of the speed management measure? What do these changes represent in terms of social impacts?

Data and Methods

In this section we describe how data were collected and analyzed, under the context of the speed management plan implementation in Bogota.

Speed Data

In 2016, Bogota launched a traffic control centre with state-of-the-art traffic sensors, which included 350 Wi-Fi/Bluetooth devices capable of detecting individual speeds for road segments and full corridors (Hidalgo et al., 2018). These devices capture mobile phone signals from smart phones with open Wi-Fi or Bluetooth technology. The system registers the time and date, and identifies the segment of the capture. This data is anonymous and impossible to track back (Hidalgo et al., 2018).

The minimum speed registered is 4 km/h, to exclude walking trips, and there is no differentiation of vehicle type, as only the speed at which any mobile device travels is captured. 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 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 speed database for Bogotá has close to 1.46 million records as every week it collects around 300 speed samples per hour per road segment (Hidalgo et al., 2018).

Corridors with speed management

The reduction of the speed limit in Av. Américas, Carrera 68, Av. Boyacá, Av. Ciudad de Cali and Calle 80 (see Figure 1) started in November 2018, with the traffic police penalizing drivers who exceeded the speed limit with pedagogic tickets during one month with the intention of raising awareness on the new speed limit. A month later, in December 2018, the economic penalties to drivers who exceeded the speed limit started.

Corridors selected for this study

Two types of corridors were compared: corridors with and without speed management. The corridors without speed management were selected if they intersect or are located within 1 km from a corridor with speed management. Based on this, 13 corridors without speed management were considered (see Figure 1 and Table 2).

Three periods were considered for the speed analysis:

- Period 1: from 15 Nov 2016 to 13 Feb 2017; 8,034,264 observations
- Period 2: from 15 Nov 2017 to 13 Feb 2018; 9,761,694 observations
- Period 3: from 15 Nov 2018 to 13 Feb 2019; 9,122,299 observations

Figure 1: Corridors with and without speed management included in the analysis. Source: own elaboration.

Road crash injuries and fatalities

For this study, we used road crash data from 2014 to 2019 provided by DSM. Only the information from November to May is used in order to review the influence of speed management in the counts. There are five periods that will be considered for the analysis of road crash injuries and fatalities:

- Period A: from 1 Nov 2014 to 31 May 2015; 3,410 observations
- Period B: from 1 Nov 2015 to 13 May 2016; 3,483 observations
- Period C: from 1 Nov 2016 to 13 May 2017; 3,563 observations
- Period D: from 1 Nov 2017 to 13 May 2018; 4,142 observations
- Period E: from 1 Nov 2018 to 13 May 2019; 4,059 observations

Analysis

The speed data analysis included:

1. 256 road sections: 108 sections in the corridors with speed management and 148 sections in the corridors without speed management. There are speed records for each road section characterized as V_{pstk} , where:

$p = 1, 2, 3$	Period of analysis
$s = 1, 2, \dots, 256$	Road section of analysis
$t = 0, 1, \dots, 23$	Time of the day (by hour)
$k = 1, 2, \dots$	Identifier for a device with captured speed

2. Average speeds were calculated by section, time of the day and period (Equation 1).

$$\bar{V}_{pst} = \frac{\sum_{k=1}^{n_{pst}} V_{pstk}}{n_{pst}} ; \quad \text{for each } p, s, t \in \text{OBJ}(1)$$

In equation (1), n_{pst} corresponds to the number of devices with speeds captured by each period, time of the day and road section of analysis.

3. Calculation of the changes in speed before and after the implementation of the speed management measure by corridor and period of the day (whole day, day or night).

Before speed management:

$$\Delta \bar{V}_{(1-2)st} = \frac{\sum_s \sum_t (V_{2st} - V_{1st})}{\sum_s \sum_t i_{st}} \quad \text{for each } t \in \text{Period}, s \in \text{Corridor (2)}$$

After speed management:

$$\Delta \bar{V}_{(2-3)st} = \frac{\sum_s \sum_t (V_{3st} - V_{2st})}{\sum_s \sum_t i_{st}} \quad \text{for each } t \in \text{Period}, s \in \text{Corridor (3)}$$

Where $\sum i_{st}$ is the total number of speed observations, including each hour of the day for each period and corridor under analysis.

4. Calculation of descriptive statistics related to speeds for each corridor, and examination of road crash injuries and fatalities. Statistical significance was tested using a two-tailed t -test for speeds and a Pearson Chi-square test for the analysis of crashes by type and severity.
5. We made a classification of the traffic crashes into: run over (affecting pedestrians), crash (involving bicycles, motorcycles and vehicles) and others (more relatively unusual events such as a rollover or a passenger fall from a motorcycle, etc.). For purposes of this

publication, only the traffic crashes with injuries or fatalities were considered.

6. We analyzed the variation in the spatial distribution of victims, with a visualization of the crash rates along different sections of the corridors where speed management was implemented.

Results

In this section we discuss how average speeds changed after speed management implementation, the observed effects on speed in the corridors without speed management, the changes in the counts of road crashes with victims and the observed changes in the geographical distribution of victims.

Changes in average speeds with speed management

In general, a progressive reduction of the average speed could be observed for all the corridors with speed management, even before the speed management measure came into effect. It can be attributed to the increasing traffic congestion in Bogotá, which is also the main reason for the decrease in circulation speeds in the period 3.

The evolution of average speeds by time of the day, and the comparison of the periods before and after the implementation of the speed limit (see Figure 2), show that speeds decreased more sharply in the early morning hours (before 6 am) and late at night (after 8 pm). During daytime, little or no effects are fully evident for all the corridors.

Figure 2: Changes in mean speeds by time of the day and corridor after speed management.

Based on the observed trends, the day is divided into two periods of analysis: daytime (6 am - 8 pm) and night time (8 pm - 6 am). Figure 3 shows a speed profile by time of the day in Avenida Américas, the corridor with the largest average reduction in speeds. The changes in speed

for all the corridors and periods, with two-tailed t-tests to observe the statistical significance of the variations can be observed in Table 1.

Figure 3: Speed profile by times of the day in a section of Av. Américas.

Table 1: Descriptive statistics of circulation speeds by corridor and period

	Day			Night			Day	Night
	V_{mean}	V_{85}	σ_v^2	V_{mean}	V_{85}	σ_v^2	ΔV	ΔV
Av. Boyacá	25.4	29.3	14.9	42.7	53.1	101.8		
Period 1	26.5	30.6	18.6	44.8	55.4	110.2		
Period 2	25.4	29.3	14.5	42.7	53.3	103.9	-1.1*	-2.2*
Period 3	24.4	27.9	11.7	40.7	50.5	91.4	-1.0*	-2.0*
Av. Cali	22.5	26.3	15.2	37.2	49.0	109.9		
Period 1	23.6	27.9	17.9	39.4	51.8	119.9		
Period 2	22.3	26.2	15.6	37.5	49.8	120.9	-1.3*	-2.0
Period 3	21.2	24.6	11.4	34.3	44.7	84.4	-1.1*	-3.2**
Avenida Américas	31.4	37.2	33.1	47.8	57.1	90.2		
Period 1	32.7	38.9	36.4	50.0	59.9	99.6		
Period 2	31.5	37.7	38.1	48.5	58.0	92.5	-1.2	-1.5
Period 3	29.9	35.1	24.7	44.7	53.5	78.5	-1.7	-3.8**
Calle 80	25.8	30.5	18.8	45.2	56.8	110.5		
Period 1	26.3	30.8	16.5	45.5	57.5	113.6		

Period 2	25.7	30.9	21.7	46.2	57.9	114.4	-0.6	0.7
Period 3	25.3	29.9	18.3	44.0	55.0	103.3	-0.4	-2.2*
Carrera 68	24.0	28.5	19.9	45.7	55.8	102.1		
Period 1	24.9	29.6	22.0	47.4	57.9	113.7		
Period 2	24.5	28.8	18.7	45.7	55.7	97.4	-0.4	-1.7
Period 3	21.2	25.4	17.6	41.7	51.2	86.9	-3.2***	-4.0***
Average reduction with speed management ^a							-1.48	-3.04
Average reduction with speed management ^b								-2.26

Where V_{mean} : average, V_{85} : percentile 85 of speed, σ_v^2 : Variance, speeds in km/h.

ΔV : Change in speed with respect to the former period (highlighted: after speed management)

a) day and night average, b) average for all corridors and periods

*: difference is significant at 90% level, **: 95% level, ***: 99% level; according to two-tailed t-test for statistical significance.

Effects for corridors without speed management

Table 2 shows the changes in average speeds by corridor, period of the day and period of analysis, where speed limits were not reduced by May 2019.

Table 2: Average speeds of the corridors without speed management.

Time of day	Day			Night			Day		Night		
Period											
Corridor	1	2	3	1	2	3	ΔV_{1-2}	ΔV_{2-3}	ΔV_{1-2}	ΔV_{2-3}	
Av. 1 Mayo	23.9	24.0	23.6	40.3	39.6	38.7	0.2	-0.4	-0.7	-0.9	
Av. Esperanza	22.4	22.2	22.6	37.4	36.4	34.9	-0.2	0.4	-1.0	-1.5	
Av. Suba	30.1	29.2	29.1	48.6	48.2	45.9	-0.9	-0.1	-0.4	-2.3	
Av. V/cencio	12.9	12.6	12.8	20.6	23.1	21.4	-0.3	0.2	2.4	-1.7	
Calle 100	17.2	19.1	18.1	39.1	38.6	36.3	1.9	-1.0	-0.4	-2.3	
Calle 127	20.7	20.6	20.3	42.1	41.2	40.8	-0.1	-0.2	-0.9	-0.4	
Calle 13	24.9	25.0	24.0	44.1	44.9	41.5	0.1	-1.0	0.8	-3.4	
Calle 26	40.5	39.0	36.4	64.0	62.4	58.4	-1.5	-2.6	-1.6	-4.0	
Calle 53	23.9	23.8	24.3	40.1	39.5	37.7	-0.1	0.5	-0.6	-1.8	
Calle 63	19.8	19.3	16.1	33.9	33.3	26.8	-0.5	-3.2	-0.6	-6.5	
Calle 72	17.6	17.8	17.4	33.6	32.7	31.4	0.2	-0.5	-0.9	-1.2	
Carrera 80	16.5	15.9	16.5	29.6	28.2	27.7	-0.5	0.6	-1.4	-0.6	
NQS	32.2	30.8	30.2	58.6	57.5	54.5	-1.5	-0.6	-1.1	-2.9	
Total general	26.3	25.8	25.2	46.3	45.6	43.3	-0.5	-0.6	-0.7	-2.2	

ΔV : Change in speed with respect to the former period (highlighted: after speed management)

After speed management was implemented, speeds decreased more than 2 km/h during night-time in six corridors, and in general speeds decreased in all other corridors without the new 50 km/h speed limit during night-time. Average reduction of speeds was 0.57 km/h for the day period and 2.25 km/h for the night period.

Count of road crashes with injured and fatal victims in the corridors with speed management

The information of traffic crashes with injuries and fatalities (period November – May) was used to evaluate the effects from the speed management implementation. Table 3, shows the number of crashes by period, corridor and severity.

Table 3: Count of events with injuries and fatalities in the corridors.

	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	Average 2014 - 2018	Change between (F) and (E)
Crashes with injuries^{a)} (37.1**)	3190	3250	3344	3937	3894	3430.25	13.5%
Carrera 68	201	188	228	225	222	210.5	5.5%
Av. Boyacá	387	346	358	447	426	384.5	10.8%
Av. Cali	210	248	235	313	302	251.5	20.1%
Av. Américas	110	92	114	117	102	108.25	-5.8%
Calle 80	123	101	81	146	128	112.75	13.5%
Injuries - 5 corridors (30.5**)	1031	975	1016	1248	1180	1067.5	10.5%
5 corridors / city	32.3%	30.0%	30.4%	31.7%	30.3%	31.1%	
Fatalities^{a)} (32.6***)	227	243	225	219	171	228.5	-25.2%
Carrera 68	8	5	9	17	12	9,75	23.1%
Av. Boyacá	36	31	38	23	30	32	-6.3%
Av. Cali	13	26	25	10	17	18,5	-8.1%
Av. Américas	11	8	9	11	2	9,75	-79.5%
Calle 80	4	11	7	5	3	6,75	-55.6%
Fatalities - 5 corridors (36.9**)	72	81	88	66	64	76,75	-16.6%
5 corridors / city	31.7%	33.3%	39.1%	30.1%	37.4%	33.6%	

(): values for Pearson chi-square test - $\chi^2(20)$. *: statistical significance at 90% level; **: 95%; ***: 99%. A) Number of events in the city

The five corridors with the new 50km/h speed limit concentrate from 30 to 40% of the serious and fatal crashes in Bogota. When comparing the results of the period E with the previous 4-years average, we observe that crashes with injuries decreased while crashes with fatalities increased.

The examination of the hourly percentage distribution of traffic injuries and fatalities in Bogota (period E) shows that the proportion of road crash fatalities is higher than the proportion of road crash injuries during nighttime (see Figure 4). This indicates that the reduction in average speeds during nighttime has a positive impact in the number of road crash fatalities.

Figure 4: Hourly percentual distribution of crashes with injuries and fatalities.

Table 4 shows the count of events with injuries and fatalities by type, period of the analysis (A, B, C, D, E) and period of the day (day and night). The events were grouped in 3 main types: runover (collision involving pedestrians), crash (collision crashes mostly) and others (rollover crash, passenger fall for motorcycles, and other less common collision types) (see American National Standard, 2017).

Table 4: Count of events by type in the corridors with speed management.

Period ^a	Day						Night					
	A	B	C	D	E	G	A	B	C	D	E	G
Carrera 68	155	142	180	179	169	3.0%	53	50	57	62	64	15.3%
Runover	47	30	45	39	38	-5.6%	17	20	19	21	19	-1.3%
Crash ^b	77	78	108	109	96	3.2%	26	26	28	36	39	34.5%
Others	31	34	27	31	35	13.8%	10	4	10	5	6	-17.2%
$\chi^2(8) = 7.2$ ^c	9.8						7.4					
Av. Boyacá	264	246	277	339	310	10.1%	158	129	115	130	146	9.8%
Runover	77	73	72	85	68	-11.4%	75	52	38	45	46	-12.4%
Crash ^b	159	142	169	220	194	12.5%	71	70	71	74	86	20.3%
Others	28	31	36	34	48	48.8%	12	7	6	11	14	55.6%
$\chi^2(8) = 20.0^{**}$ ^c	10.4						13.6					
Av. Cali	150	191	179	240	212	11.6%	71	82	80	83	106	34.2%
Runover	47	52	55	43	43	-12.7%	32	23	31	26	30	7.1%
Crash ^b	84	111	104	170	136	16.0%	34	53	43	53	66	44.3%
Others	19	28	20	27	33	40.4%	5	6	6	4	10	90.5%
$\chi^2(8) = 24.9^{***}$	19.3						9.3					
Av. Américas	90	80	97	91	89	-0.6%	32	19	24	34	16	-41.3%
Runover	26	17	16	11	16	-8.6%	8	6	8	7	3	-58.6%
Crash ^b	56	52	72	63	61	0.4%	21	11	16	25	11	-39.7%

Others	8	11	9	17	12	6.7%	3	2	0	2	2	14.3%
$\chi^2(8) = 11.7^c$					13.1						4.9	
Calle 80	89	87	67	105	91	4.6%	39	24	22	45	41	26.2%
Runover	25	21	19	18	16	-22.9%	18	9	6	15	8	-33.3%
Crash ^b	53	58	39	71	62	12.2%	17	13	15	24	28	62.3%
Others	11	8	9	16	13	18.2%	4	2	1	6	5	53.8%
$\chi^2(8) = 11.1$					7.3						8.8	
5 corridors	748	746	800	954	871	7.3%	353	304	298	354	373	14.0%
Runover	222	193	207	196	181	-11.5%	150	110	102	114	106	-10.9%
Crash ^b	429	441	492	633	549	10.1%	169	173	173	212	230	26.5%
Others	97	112	101	125	141	29.7%	34	21	23	28	37	39.6%
$\chi^2(8) = 50.4^{***}$					32.9	***					21.1	***
Total city	2479	2543	2643	3048	2975	11.1%	931	940	920	109	108	11.6%
										4	4	
Runover	823	785	786	805	727	-9.1%	376	332	313	305	299	-9.8%
Crash ^b	1293	1386	1459	1817	1781	19.6%	460	523	523	681	669	22.4%
Others	363	372	398	426	467	19.8%	95	85	84	108	116	24.7%
$\chi^2(8) = 123^{***}$					72.3	***					56.6	***
Corridors/ city	30%	29%	30%	31%	29%		38					
							%	32%	32%	32%	34%	

a) Letters were assigned to periods as shown in Table 3

b) Refers mostly to collision crashes, events with bicycles involved are counted under the category crashes according to the Colombian regulation

c): Pearson chi-square test - $\chi^2(8)$, *: statistical significance at 90% level; **: 95%; ***: 99%

For most of the corridors, a reduction in the percentage of runover events were observed during the periods analyzed (95% of traffic fatalities in Bogota are caused by runover events that affect pedestrians). Runover events are more severe than crashes, and the analysis shows that there has not been a noticeable reduction in the number of crashes, but there is a reduction in the severity of the events.

Geographical Analysis

Geographical distribution of injuries and fatalities and income level

Corridors selected for speed management seem to be associated with the income level. This is probably a result of the use of crash data of injuries and fatalities for its prioritization. (Alcaldía Mayor de Bogotá, 2018). More specifically, corridors with run-over hotspots in low-income areas were the ones selected originally what might imply that positive results for this type of crash were mostly among low-income level residents. The hotspots (locations with a high concentration of events) of two-vehicle crashes and run over events, the prioritized corridors and the classification of the land use by income level can be observed in Figure 5 and Figure 6 respectively.

Figure 5: Two-vehicle crashes hotspots, socioeconomic level and selected corridors for speed management in Bogotá.

Figure 6: Run over hotspots, socioeconomic level and selected corridors for speed management in Bogotá.

Changes in Geographical distribution of serious and fatal victims

Figure 7 shows the geographical variation of reported incidents with at least one victim (injured or fatal) in the period when the speed management measures were implemented and compared to the average during the previous four years, corresponding to periods A-D. The method used for estimating the change was to compare the kernel density before (A-D) and after (E) speed management was put into place.

The locations that registered a high number of reported road crashes with victims before the measure was implemented were the locations with the highest decrease in the density of road crashes with victims. Nevertheless, the density of reported victims in nearby locations increased. This could be due to a risk compensation phenomenon (Santana Palacios, 2015); if speeds were enforced in a certain location (hot spots before the measure), in other nearby locations without speed enforcement we observed that speeds increased. A study case can be observed in Avenida Boyacá where the number of victims and crash severity - estimated as the percentage of fatalities

in the total amount of victims – at the main hot spot decreased by 84%, but at the same time, a hot spot - with 99% of statistical significance - was generated in Avenida de las Américas with Avenida Boyacá, where the severity increased by 7%.

Figure 7: Change in Killed and Seriously Injured (KSI) victims after, in the five corridors where speed management measures were implemented.

Discussion and Conclusions

After the Speed Management Plan was implemented in the five targeted arterial corridors, reductions in average speeds between 2 and 4 km/h could be observed. Average speeds during

daytime were not largely affected, which can be largely attributed to the usual traffic congestion. Nevertheless, statistically significant speed changes were observed in the night period (8 pm – 6 am), which are periods with lower traffic volumes. These changes in the travel speeds during night time resulted in the reduction of the average speeds in all the targeted corridors, which could explain the reduction in fatal incidents.

The average speed reduction was 3.04 km/h, which is equal to 3.24 seconds less per kilometer or a total delay of 33 seconds in a 10 km journey. By achieving a reduction of the circulation speeds as enforced speed limit dictates, this delay would be represented in an additional 2 minutes in the average travel time. The most critical speeding periods occurred between 2 am and 4 am. During this period, 42.7% of drivers traveled faster than 50 km/h before speed management, and this percentage decreased to 34.6% after speed management implementations.

We observed a network effect derived from the speed management measures that were noticeable in the other assessed arterial corridors without any plans for speed management, indicating an average reduction of 2.2 km/h for corridors without speed management, especially in sections located close to the corridors with speed management. We believe that some drivers might have assumed that the speed management operations could be extended to corridors where no plans were in place, which is nevertheless a favorable misassumption for road safety.

Speed reductions were somehow as predicted by the literature; yet we aim to discuss how the benefits of it were reflected in the context of Bogotá. Traffic-related fatalities in the arterial corridors where speed reduction was implemented decreased by 16.6%. This can be considered an outstanding result from two points of view: 1) it surpasses the annual goal of the RSP, with an expected – and very modest - reduction of 3.5% in the total number of fatalities, and 2) it surpasses the approximate 12% reduction that would have been expected from a speed reduction of 3 km/h. (Bray Sharpin et al., 2017).

On the other hand, the increase in the number of traffic-related injuries is still a concern as the expected result was a reduction in the number of both traffic-related injuries and fatalities. In the corridors with speed management, the number of run over events (associated mostly with pedestrian fatalities) decreased by 9% in the city and 11% in the five corridors, while road crashes have increased between 10% and 26%. In other words, the number of events in those corridors did not decrease, but we can argue that the severity of the events did. In other words, many of these road new traffic injuries could have been fatalities that were avoided due to lower speeds on the roads.

We observed a geographical variation of overall crashes with injured, as the emerging hot spots of incidents could now be located in areas with fewer probabilities of high severity crashes and conflicts with pedestrians (see Figure 7). Similarly, the risk compensation phenomenon could also be associated with the higher amount of crashes with injuries, as the crashes in emerging hot spots also increased their associated severity. Therefore, more locations being enforced with help of digital technologies could improve results in the reports of traffic crashes with victims (Alcaldía Mayor de Bogotá, 2019).

The reduction of run over events can be easily associated with fewer pedestrian fatalities. Moreover, in Figure 6 we can observe that the run over hotspots are located in the south-west districts of the city, which correspond to locations of lower income levels than the city average. The prioritization was based on the geographical concentration of traffic-related victims – characterized by the presence of hotspots (see Figure 5 and Figure 6), something that can explain why the biggest change was related to run over events in low to mid-low level income residential areas. Pedestrians in low-income areas have a larger vulnerability than any other road users in Bogota, and we can argue that they felt the benefits of speed management in a bigger proportion than other road users in Bogota.

A speed management program with good results can contribute not only to save lives – which is naturally the primary objective -, but also contribute to avoid human and economic losses for families – especially low-income vulnerable families – and to reduce poverty and income gaps as well. It has been shown that fatality rates are higher in low-income groups than in high-income groups of society (GRSP, 2016), and that poor people are at the same time more particularly vulnerable due to several factors such as costs of medical treatment, loss of a family's income earner, long-term disabilities, lack of insurance and savings, etc. (Jung and Sul, 2014; GRSP, 2016).

Therefore, speed management in this case might have helped reducing the social inequities because of having more impact in low income and residential areas. Nevertheless, it is important to consider the issue with the increase in vehicle crashes, which include not only cars but motorcyclists. Motorcycles have become progressively an essential travel mode for residents of low-income households (Moscoso et al., 2020), and at the same time have become the road user with the second highest risk of road traffic death. In 2017, 93% of the traffic fatalities affected vulnerable users (49% pedestrians, 33% motorcyclists and 11% cyclists) (Alcaldia Mayor de Bogota, 2019). Future versions of speed management plans must consider issues like geographical and temporary coverage, and a better understanding of motorcyclists' and motorists' behavior on road to make enforcement operations more effective and extend the benefits of SMPs to a larger scale that leads to reductions in the number of traffic-related injuries.

Limitations and Further Research

We did not include measures of traffic volume in this analysis, as our data do not reflect accurately the actual traffic volumes in each period and stretch of corridor where measurements were taken. There is a need for traffic volume data and information of the built environment, in order to make a more robust analysis of the effects of the speed limit reductions, and changes in observed speeds, on crashes and their severity.

One of our objectives was to check the reductions in mean speeds are due to the speed management, but we did not include information of the physical environment and infrastructural characteristics of the corridors. Similarly, we do not have any information of the victims that suffered injuries or fatalities in traffic, our geocoded information tells us where and when the crash occurred, but limited information on the people that were involved.

Also, this speed measurement method may be influenced by intersection delays, depending on the location of the signal detection devices. Our speed data source has proven its utility for the analysis of speed effects due to a high number of observations, but at the same time having information of speed by type of vehicle is necessary for a deeper understanding of whether there are differentiated effects of speed management by type of vehicle or road user.

In addition, detailed information of control and enforcement made by the traffic authorities was unavailable to us at the moment of writing this publication. We understand that changes in speed were also followed by increased enforcement, which helped in compliance of speed limit, especially at night.

We did not discuss in detail the reasons that made the impact of the speed management measures more efficient in certain specific corridors, as it could be observed in the results, where we report the observed crash effects as trends. This type of analysis would be necessary in order to clarify cause-effect mechanisms and understand how to make speed management more effective in future speed management implementations.

We identified motorcyclists as one of the key actors involved in the increase of traffic-related injuries, and it is necessary to collect more information concerning this specific group, where there is a high potential of saving lives and reduce social inequities by improving road safety for them.

The study focuses on short term impacts. Further analysis over longer term impacts would be useful for a better understanding of these phenomena. There is also a need to review norms and regulations related to road-design, so that speeds are largely controlled by design rather than by enforcement (Tiwari, 2011).

Further research should also include a detailed analysis of impacts of the measure in traffic speeds per direction as the decrease in average speeds –when travel speeds are high- might improve traffic flow as a result of having denser flow.

Acknowledgements

Funding for this project was provided by the Bloomberg Initiative for Global Road Safety BIGRS (<https://www.bloomberg.org/program/public-health/road-safety/#overview>), sponsored by Bloomberg Philanthropies (<https://www.bloomberg.org/>). We thank Camilo Cardona from WRI Ross Center, and Juan Pablo Hidalgo and Juliana Vega from Despacio who collaborated with data analysis. We also thank the District Secretariat of Mobility, Juan Pablo Bocarejo, Claudia Díaz, Sergio Tovar, Jady Pérez, Daniela Gutiérrez and María Carolina Lecompte, from BIGRS embedded staff in Bogotá, Diego Vargas. Results and recommendations of this project are the responsibility of the authors and do not necessarily reflect the views of the institutions involved.

Credit authorship contribution statement

Jose Segundo López: Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Writing – original draft. **David Pérez-Barbosa:** Data curation; Formal analysis; Investigation; Methodology; Visualization; Writing – original draft. **Natalia Lleras:** Conceptualization; Writing – original draft. **Darío Hidalgo:** Conceptualization; Methodology; Validation; Writing – review & editing. **Claudia Adriazola-Steil:** Conceptualization; Validation; Writing – review & editing.

References

- Alcaldía Mayor de Bogotá (2018). *Plan Distrital de Seguridad Vial 2017 – 2026*. Retrieved from <https://redempresarial.movilidadbogota.gov.co/sites/default/files/Plan%20Distrital%20de%20Seguridad%20Vial.pdf>.
- Alcaldía Mayor de Bogotá. (2019). *Programa de Gestión de la Velocidad - Documento base*. Retrieved from: <https://www.movilidadbogota.gov.co/web/sites/default/files/Paginas/2019-03-18/Programa%20de%20Gesti%C3%B3n%20de%20la%20Velocidad%20para%20Bogot%C3%A1.pdf>.
- Archer, J., Fotheringham, N., Symmons, M. and Corben, B. (2008). *The Impact of Lowered Speed Limits in Urban and Metropolitan Areas*. Monash University Accident Research Centre. Retrieved from: <https://www.monash.edu/muarc/archive/our-publications/reports/muarc276>.
- Azetsop, J. (2010). Social Justice Approach to Road Safety in Kenya: Addressing the Uneven Distribution of Road Traffic Injuries and Deaths across Population Groups, *Public Health Ethics*, 3(2), 115–127. doi:10.1093/phe/phq013
- Baldasano, J. M., Gonçalves, M., Soret, A., & Jiménez-Guerrero, P. (2010). Air pollution impacts of speed limitation measures in large cities: The need for improving traffic data in a metropolitan area. *Atmospheric Environment*, 44(25), 2997-3006. doi: 10.1016/j.atmosenv.2010.05.013.
- Bray Sharpin, A., Banerjee, S.R., Adriazola-Steil, C., & Welle, B. (2017). *The Need for (Safe) Speed: 4 Surprising Ways Slower Driving Creates Better Cities*. Retrieved from: <https://www.wri.org/insights/need-safe-speed-4-surprising-ways-slower-driving-creates-better-cities>
- Elvik, R., Christensen, P. and Amundsen, A. (2004) *Speed and road accidents: An evaluation of the Power Model*, TOI report 740. Retrieved from: <http://www.trg.dk/elvik/740-2004.pdf>.
- Forbes, G. J. et al. (2012) *Methods and Practices for Setting Speed Limits: An Informational Report*. U.S. Federal Highway Administration. Retrieved from: https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwas12004/.

- GRSP - Global Road Safety Partnership. (2016). *Poverty and Road Safety*. Positioning Paper. Retrieved from: <https://www.grsproadsafety.org/wp-content/uploads/New-Fact-Poverty-PDF.pdf>
- Greibe, P. (2005). *Hastighedens betydning for trafiksikkerheden - danske og udenlandske studier*. Retrieved from: <https://www.trafitec.dk/sites/default/files/publications/hastsik.pdf>.
- Hidalgo, D., Lopez, S., Lleras, N., & Adriazola-Steil, C. (2018). Original road safety research: Using big data for improving speed enforcement and road safety engineering measures: An application in Bogota, Colombia. *Journal of the Australasian College of Road Safety*, 29(2), 12-19.
- Hoareau, E., Newstead, S., & Cameron, M. (2006). *An evaluation of the default 50 km/h speed limit in Victoria*. Monash University Accident Research Centre. Retrieved from: <https://www.monash.edu/muarc/archive/our-publications/reports/muarc261>.
- Islam, M. T., El-Basyouny, K., & Ibrahim, S. E. (2014). The impact of lowered residential speed limits on vehicle speed behavior. *Safety science*, 62, 483-494.
- Jung, N. & Sul, J. (2014). *Handbook of measuring socio-economic consequences of traffic crashes*.
- Johns Hopkins International Injury Research Unit (JH-IIRU), & Universidad de los Andes (2019). Bloomberg Initiative for Global Road Safety (BIGRS) 2015 - 2019. *Data Technical Report - Round 8*, May 2019. Bogota, Colombia.
- Kamya-Lukoda, G. (2010). *Interim evaluation of the implementation of 20 mph speed limits in Portsmouth*. Final Report, Department for Transport, UK. Retrieved from: <https://www.cyclinguk.org/sites/default/files/document/migrated/news/speed-limits-portsmouth.pdf>
- López, S., Hidalgo, D., & Lleras, N. (2018). *Soporte técnico para la reducción del límite de velocidad de 60 a 50 km/h*. Bogota, Colombia.
- Moscoso, M., López, J. S., Montoya, V., Quiñones, L. M., Gómez, L.D., Lleras, N., Adriazola-Steil, C, & Vega, J. (2020). *Las Mujeres y Transporte en Bogotá: Las cuentas*. Bogotá: Despacio & WRI. Retrieved from: www.despacio.org/hacemos
- Nitzsche, E., & Tscharaktschiew, S. (2013). Efficiency of speed limits in cities: A spatial computable general equilibrium assessment. *Transportation research part A: policy and practice*, 56, 23-48. doi: 10.1016/j.tra.2013.08.004.
- OECD/ITF. (2018). *Speed and crash risk*. Retrieved from: <https://www.itf-oecd.org/sites/default/files/docs/speed-crash-risk.pdf>.
- OECD/ECMT Transport Research Centre. (2006). *Speed Management*. Retrieved from: <http://www.internationaltransportforum.org/Pub/pdf/06Speed.pdf>.

- Pucher, J., & Buehler, R. (2010). Walking and cycling for healthy cities. *Built environment*, 36(4), 391-414. doi: 10.2148/benv.36.4.391.
- Santana Palacios, M. (2015). *Wrecked by Work? Examining work-Related Motorcycle Crashes in Colombia*. University of California, Los Angeles. Retrieved from: <https://babel.banrepultural.org/digital/collection/p17054coll23/id/907/>.
- Tiwari, G. (2011). Road Safety: Decade of Action with Research. *International Journal of Injury Control and Safety Promotion*, 18:1, 1-2. doi: 10.1080/17457300.2011.557475.
- Vergel, E., Hidalgo, D., & Bray Sharpin, A. (2018). *Paving the pathways to change: The politics of Road Safety in Bogota*. Retrieved from: <https://odi.org/en/publications/paving-the-pathways-to-change-the-politics-of-road-safety-in-bogot%C3%A1/>.
- Welle, B., Sharpin, A. B., Adriazola-Steil, C., Alveano, S., Obelheiro, M., Imamoglu, C. T., ... & Bose, D. (2018). *Sustainable and safe: A vision and guidance for zero road deaths*. Retrieved from: <https://www.wri.org/research/sustainable-and-safe-vision-and-guidance-zero-road-deaths>
- World Health Organization (WHO). (2018). *Global status report on road safety 2018*. World Health Organization. Retrieved from: https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/.