DIFFERENCES IN ROAD-TRAFFIC CRASH RATES DURING CONSTRUCTION AND NON-CONTRUCTION TIMES ON ARTERIAL STREETS: A COMPARATIVE STATISTICAL ANALYSIS

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ABSTRACT

Different studies over the past 30 years have shown an increase in the rates of crash frequencies during road construction time, but this trend is not reported as valid for all cities. A question is raised whether higher rates are observed in arterial roads in Bogotá, Colombia. It is possible to apply descriptive statistics and hypothesis tests to prove them and identify the variables that affect the accident rate during road construction. Our research aims to verify the incidence of high impact construction zones, in the crash rate at the arterial road network of Bogotá. We use descriptive statistics and inferential statistical tests to analyze whether crash rates are statistically higher during construction time than during non-construction time at the same highway sections considering different crash severities (damages-only, injuries, and fatalities). Our database considered 871 road links that make up 68 artery corridors for the city of Bogota, and 5.450 road construction zones, from 2015 to 2019. An analysis by corridor was performed, in which we identified seven patterns in the behavior of accident rates influenced by the presence of a road intervention in the corridor. Within the patterns, it was evident that some corridors reported an increase in the accident rate during the time of construction, while others showed a decrease in the same comparison. We used the Wilcoxon test to establish the statistical significance of our conclusions, with a significance level of 10%. We also found that those construction interventions that do not require excavation of more than half a meter there was a decrease in the accident severity, as damages-only crashes, diminished during the construction time, while for those interventions that include excavation greater than half a meter there was an increase in overall accident rates during construction time.

1. INTRODUCTION

According to the World Health Organization, road crashes are the first leading cause of death and disabling injury among children and young adults between the ages of 5 and 29 and are the 8th leading cause of death in the world at all ages, with 1.35 million deaths each year. It is also a problem that affects 3 times more the countries of emerging economies than the countries with advanced economies (World Health Organization, 2018).

Traffic crashes in construction sites are continuing a problem in many countries around the world. For example, 87,606 crashes occurred in work zones, which led to over 37,000 injuries and 576 fatalities in 2010 in the US (National Highway Traffic Safety Administration, 2013). Large cities in the developing world carry out large-scale construction projects continually e.g., approximately 45% of the roads will be under construction in the next 4 years in Bogota Colombia. The main safety concerns are the road users and the construction workers.

The findings of previous studies that examine the safety impacts of work zones varied significantly because of the differences in locations, data size, data quality, and analysis approaches. Traffic-related crash rates and behavior depend on city-specific conditions such as drivers' behaviors, safety regulations and standards during construction, environmental conditions, and soon (Yang, Ozbay, 0zturk and Xie, 2015).

Road construction safety regulation requires that contractors take sufficient safety measures to protect human lives. Construction works always affect mobility conditions, even when a large part of the work aims to improve the conditions of the existing roads and the city mobility in general, but contractors are required to maintain safety and smoothness in traffic flow on the road construction site, (Instituto de Desarrollo Urbano IDU, 2016).

Construction of new infrastructure and building projects in Bogota are required to present a traffic management plan -PMT (for its words in Spanish) to the local mobility authority. A PMT should include strategies and technical alternatives to provide safe, and operational conditions to the different road users through optimized planning, scheduling, and operating mechanisms. In the particular case of Bogotá, those plans are classified into two main categories COI (Consolidation of infrastructure works) and COOS (Consolidated public service infrastructure works) (Movilidad, 2021).

To establish whether the PMT mechanisms implemented in the working zone are efficient and effective in mitigating work zone safety impacts on the traveling public and the workers we perform a long-term analysis for arterial roads in Bogota. We were interested in investigating changes in vehicle crashes by three different severities, questioning whether the rates of registered road crashes are higher during construction periods and non-construction time.

Several studies have been carried out at the global level to develop an understanding of the potential risk factors associated with work zone crash occurrences (Di, Shi, Zhang, Svirchev, & Hu, 2016; Jin, Saito, & Eggett, 2008; Rao, Wu, Xia, Ou, & Kluger, 2018; Rouphail, Yang, & Fazio, 1988; Theofilatos, Ziakopoulos, Papadimitriou, Yannis, & Diamandouros, 2017; Ullman, Finley, & Ullman, 2004; Zhang & Hassan, 2019).

The findings from these studies varied significantly because of the differences in data availability, locations, methods of analysis, but there is a general agreement about accident rates being higher during construction time when compared to non-construction rates in most advanced economies (Yang, Ozbay, 0zturk and Xie, 2015).

However, there is very little research on this topic in large Latin-American cities as is the case of Bogota, Colombia. Considering that Bogota has a vision zero plan towards road safety to reduce the number of crashes with fatalities by the year 2038, and in addition, during the next few years the city will begin the construction of multiple high-impact projects including the first Metro line, regional light rail (REGIOTRAM), new BRT corridors our research takes relevance.

Our study focuses on comparing long-term traffic crash rates in the arterial road network of the city of Bogota during construction and non-construction time using data for 2015 to 2018. Different statistical methods are applied to test statically significant differences of central trend measures.

We used non-parametric tests such as the Wilcoxon test (Wilcoxon, 1945), to test our hypothesis discriminating by different crash severities, different road types, and for different arterial corridors in the city of Bogota.

2. METHOD

2.1 Research framework

This study uses statistical techniques to identify patterns of behavior in accident rates during construction and non-construction time in Bogotá, Colombia. This statistical analysis is carried out through descriptive statistics (minimum, maximum, mean, standard deviation) and non-parametric statistical tests such as the Wilcoxon test. Crash rates were calculated using per million vehicle miles traveled (MVMT).

Our research consisted of two phases: First, the construction of the database needed; second one the statistical data analysis and hypothesis testing. From this point forward, a brief description of the process is made considering the main components of our research framework: road infrastructure description, types of construction zones, crash severity and time windows, the data sources, data grouping, and methods of analysis.

2.1.1 Road Infrastructure

The road subsystem in the city of Bogota is divided into 4 main types of the road network, the first one refers to the main arterial road network, which is responsible for providing accessibility and connection for the city with the region and the country. The second type is the complementary arterial road network, which is intended for medium and long-range travel within the city.

These first two networks add up in total 2.634 km. The third type is the intermediate road network, which functions as an alternative to decongest the city and has a total length of 3.204 km. Finally, there is the local road network to connect the housing units with the other arterial roads and is composed of 6.134 km of small streets. Our research analyses included the main and intermediate arterial networks with a total of 68 road corridors, and 400 kilometers (figure 1).

Figure 1: Main and complementary arterial network included in research analysis.

2.1.2 Types of construction interventions and their traffic management plan

As stated before, the traffic management plan (PMT) is a technical tool used to propose the strategies, alternatives, and different activities needed to reduce the impacts on traffic flow and safety during construction time. PMT contains actions required to deal with infrastructure closures and displacement of road users, as pedestrians, cyclists, transit buses, trucks, and light-duty vehicles.

All actions contained in the PMT must favor the road safety of all users and construction workers. These traffic management plans are classified according to the type of intervention which can be works or events.

They are also classified by the intensity of the impacts and the complexity of the construction process as high, medium, and low. In our investigation, three different types of PMT were considered, which are:

2.1.2.1 COI-ALTA

The Consolidated Works of Infrastructure (COI) is a standard regulation instruction manual designed by the District Secretariat of Mobility of Bogota for those PMT that does not require an excavation license for their execution. A total of 3708 COI PMT were included for our study.

COI-high denomination used in our research refers to the type of complexity. Impacts include traffic lights on road corridors, partial or total closure of lanes, partial or total use of the access platform, partial or total closures to pedestrian bridges, and total closures of bike paths located on the road.

2.1.2.2 COOS-ALTA

The Consolidated Public Service Infrastructure Works (COOS) is the PMT instruction manual developed by the District Secretariat of Mobility of Bogota for works that require an excavation license with a depth greater than 0.5. In this type of works, the width and depth of the excavation must be specified to determine the safety distances and type of element to be used for the enclosure.

COOS-high denomination refers again to the impact or level of affectation explained for the COI-ALTA. There were 1729 PMT considered for this investigation.

2.1.2.3 COI-TRONCAL

The Consolidated Works of Infrastructure (COI) is the type of PMT that applies to construction zones in Bogota´s BRT system - TransMilenio There were only 13 COI-TRONCAL PMT included in our analysis.

2.1.3 Crash severity and time windows

Crashes were classified by severity into 3 categories, the crashes that caused fatalities were defined as "Fatalities (DE)". If the crash caused injuries, or injuries and material damage, the severity will be defined as "Injuries (WO)". If only material damage occurred, the severity of the crash will be defined as "damage only (DO)".

Three different time windows of analysis were defined: Before construction time (BF), corresponding to crash rates before a road intervention happened and a work zone was established. During construction time labeled as PMT), corresponding to crash rates while the work zone was active. After construction time (AF), corresponding to crash rates after road intervention was finished.

The before and after time windows had the same duration as every intervention, to avoid bias. They were also placed immediately before and after each intervention for a better understanding of the direct impact they have on road safety conditions.

2.2 Data sources

2.2.1 IPAT

The Police Report on Traffic Accidents (Informe Policial de Accidentes de Tránsito, IPAT) is an official record used in Bogotá by the specialized bodies of Urban Traffic Police, as a tool that allows the primary collection of crash data. This report is aimed at allowing clear and probable identification of causes hypotheses and at facilitating the implementation of actions related to road safety for the national, departmental, municipal, or local government and representatives of civil society. (For more information about IPAT, its manual is available online)

2.2.2 SIGAT

SIGAT is the acronym for Sistema de Información Geográfica de Accidentes de Tránsito (Geographic Information System for Traffic Accidents). This database is linked to Registro Nacional de Accidentes - RNAT (National Registry of Traffic Accidents, in English) and its main function is to consult if a vehicle is reported in the database of Police Reports of Traffic Accidents (IPAT) registered in the District Secretary of Mobility of Bogotá. We used this database as our main source to compute crash rates between 2015 and 2018.

2.3 Grouping of data for construction and non-construction time

The database used to make the descriptive statistics and run the nonparametric test had 22 variables, and 5.450 entries, corresponding to the number of PMT or construction work zones in the 68 road corridors that were considered for the study. Table 1 shows the variables considered in our analysis.

VARIABLE	DESCRIPTION
COD	Corresponds to the number or key assigned to each PMT.
ADDRESS	Place where the PMT is developed, and the accident record is kept.
CORRIDOR	Name of road corridor.
PMT TYPE	Typology of the PMT that was carried out.
SECTION	Code assigned to each road section belonging to a particular corridor.
START	Start date of PMT implementation.
END	End date of PMT implementation.
DURATION	Time in days when the PMT was applied.
LENGHT	Distance in meters in which the PMT was applied.
VOL VEH	Corresponds to the average daily hourly traffic (TPDH).
BF_DO	Accidents before construction time with damages only.
BF_WO	Accidents before construction time with wounded people.
BF_DE	Accidents before construction time with deceased people.
BF_TO	The total number of accidents before construction time.
PMT_DO	Accidents during construction time with damages only.
PMT_WO	Accidents during construction time with wounded people.
PMT_DE	Accidents during construction time with deceased people.
PMT_TO	The total number of accidents during construction time.
AF_DO	Accidents after construction time with damages only.
AF_WO	Accidents after construction time with wounded people.
AF_DE	Accidents after construction time with deceased people.
AF_TO	The total number of accidents after construction time.

Table 1: Attributes of the database.

2.4 Method of analysis

We used R Studio, a statistical software (Gentelman and Ihaka, 1993) with packages as dplyr (Wickham and François, 2020), ggplot2 (Wickham, 2016), lubridate (Wickham and Grolemund, 2011), reshape2 (Wickham, 2011), nortest (Gross and Ligges, 2015), car (Fox and Weisberg, 2019), MVN (Korkmaz, Goksuluk, and Zararsiz, 2014) among other packages to analyze the crash rates associated with the 5450 construction work zones. We developed a descriptive statistical analysis, including mean, standard deviation, minimum value, and maximum value. We used Wilcoxon test (Wilcoxon, 1945) a non-parametric test to perform hypothesis testing, to probe statistical significance difference between crash rates in different time windows, discriminating t by severity, (Damage Only (DO), Injuries (WO), Fatalities (DE), and total (TO)). We used Wilcoxon for the hypothesis testing at the city level, by the corridor, and by type of PMT.

The Wilcoxon test used is also known as the Wilcoxon range sum test or Mann-Whitney test and represents a non-parametric alternative to the t-test of two unpaired samples, where it is checked whether two samples come from equidistributed populations. Some conditions that must be considered for the application of this test are that the data must be independent, ordinal, and the phenomenon of homoscedasticity must be presented among the groups to be compared.

For the Wilcoxon test, the equality in the averages of the accident rates during construction times and not construction was adopted as a null hypothesis, which would mean that there would be no statistically significant evidence that the rates were different; in addition, two alternative scenarios were adopted, the first of which was determined by greater, in which, if the null hypothesis was rejected, the hypothesis that the accident rate of the non-construction time was higher was accepted, compared to the accident rate in construction times; the second alternative hypothesis consists of less and is the opposite of the first because in this case there would be a statistically significant difference in the rates which would lead to the conclusion that the crash rates at construction time are lower than the rates under construction.

3. RESULTS

Our results are presented in tables by city level, by corridors, and by PMT type. These results are presented as follows. First, descriptive statistics and Wilcoxon test results for the entire city. The second will follow the Wilcoxon test results of crash rate difference sorted by corridors. Third, we present descriptive statistics and Wilcoxon test results of crashes sorted by PMT.

Tables 3, 4, 5, 6, 9, and 10 present a summary of the results of the Wilcoxon tests for two different alternative hypotheses: i) depending on the case one of the rates (before or after the construction zone) is greater than the crash rate during construction; ii) one of the rates (before or after the construction zone) is less than the crash rate during construction.

The columns of all tables show the previously described accident rates, and its rows vary according to the classification of accidents used. At the city level, there is only one row corresponding to its name: Bogotá D.C. In the case of accidents sorted by corridors, each row corresponds to the name of the 58 corridors that make part of the arterial network of Bogotá. In the case of accidents sorted by PMT, each row corresponds to the type of traffic management plan.

3.1 City level

Table 2 shows a summary of the descriptive statistics for the previously described crash rates, according to the defined classification of accidents. These statistics show the range, mean, standard deviation, and sum of these variables.

Bogotá	BF_DO	BF_WO	BF_DE	BF_TO	PMT_DO	PMT_WO	PMT_DE	PMT_TO	AF_DO	AF_WO	AF_DE	AF_TO
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	3344.999186	5163.536933	395.9703834	5163.536933	3297.470898	1584.079157	2059.077505	3297.470898	15733.43452	1374.36379	271.3092127	15733.43452
Mean	22.71796736	9.743536421	0.484200592	32.94570438	22.801404	9.761602591	0.833701646	33.39670824	23.67714855	8.616248479	0.317818644	32.61121567
Standard deviation	104.0366236	80.99744194	9.505221487	137.4338887	99.17866335	49.84571701	29.43411908	119.7213343	226.1061631	42.7806412	5.061184979	232.010722
Sum	123812.9221	53102.27349	2638.893227	179554.0889	124267.6518	53200.73412	4543.673968	182012.0599	129040.4596	46958.55421	1732.111611	177731.1254

Table 2: Results of descriptive statistics at the city level.

At the city level of the city, the Wilcoxon test was run with a total of 5,450 work zones in arterial corridors. In general, we could not find statistical differences in crash rates during construction and non-construction times. We observed a raised in Damages Only (DO) crash rates after the construction zone is lifted but this test is considered inconclusive. Therefore, we decided to analyze by Corridor and by type of PMT.

CITY LEVEL	N	PMT_DO/BF_DO	PMT_DO/AF_DO	BF_DO/AF_DO	PMT_WO/BF_WO	PMT_WO/AF_WO	BF_WO/AF_WO	PMT_DE/BF_DE	PMT_DE/AF_DE	BF_DE/AF_DE	PMT_TOT/BF_TOT	PMT_TOT/AF_TOT	BF_TOT/AF_TOT
Bogota DC	5450	0,206	0,096	0,223	0,105	0,177	0,662	0,751	0,413	0,206	0,139	0,106	0,247

Table 3: Wilcoxon test results at a city level for alternative hypothesis where the crash rate in non-construction is greater than the crash rate during construction.

Note: Values shown are p-values. The green value corresponds to p-values less than 0.1. Damage ONLY (DO), Wounded (WO), Deceased (DE), and Total (TO) severities are considered when comparing each of the temporary windows: Before (BF), During (PMT), and After (AF).

CITY LEVEL	N	PMT_DO/BF_DO	PMT_DO/AF_DO	BF_DO/AF_DO	PMT_WO/BF_WO	PMT_WO/AF_WO	BF_WO/AF_WO	PMT_DE/BF_DE	PMT_DE/AF_DE	BF_DE/AF_DE	PMT_TOT/BF_TOT	PMT_TOT/AF_TOT	BF_TOT/AF_TOT
Bogota DC	5450	0,794	0,904	0,777	0,894	0,823	0,338	0,250	0,588	0,795	0,861	0,894	0,753

Table 4: Wilcoxon test results at a city level for alternative hypothesis where the crash rate in non-construction is less than the crash rate during construction.

Note: Values shown are p-values. The yellow value corresponds to p-values bigger than 0.9. Damage ONLY (DO), Wounded (WO), Deceased (DE), and Total (TO) severities are considered when comparing each of the temporary windows: Before (BF), During (PMT), and After (AF).

3.2 By corridor

We perform the hypothesis analysis in 58 arterial corridors. Table 5 shows, the p-value of the Wilcoxon test, performed to find statistically significant differences between the crash rates of the different time windows considering the three levels of crash severities.

Tables 5 and 6 shows p-values smaller than 0.1 in green color, and p-values bigger than 0.9 in yellow color. P-values equal to 1 are shown in red color as this was an indication that the hypothesis was completely rejected. Cells without color correspond to those p-values that do not fit any of the previously described categories.

CORRIDOR	N	PMT_DO/BF_DO	PMT_DO/AF_DO	BF_DO/AF_DO	PMT_WO/BF_WO	PMT_WO/AF_WO	BF_WO/AF_WO	PMT_DE/BF_DE	PMT_DE/AF_DE	BF_DE/AF_DE	PMT_TOT/BF_TOT	PMT_TOT/AF_TOT	BF_TOT/AF_TOT
AUTONORTE	321	0,478	0,319	0,336	0,341	0,464	0,534	0,949	0,292	0,029	0,394	0,194	0,217
AV.AMERICAS	215	0,587	0,060	0,069	0,869	0,976	0,936	0,882	0,929	0,682	0,699	0,480	0,345
AV.CARACAS	462	0,035	0,236	0,571	0,956	0,519	0,061	0,709	0,228	0,103	0,441	0,359	0,230
AV.CIRCUNVALAR	105	0,702	0,006	0,003	0,153	0,033	0,138	0,500	0,815	0,977	0,483	0,001	0,002
AV.CORDOBA	8	0,899	0,708	0,428	0,815	0,815	0,977	1,000	1,000	1,000	0,909	0,819	0,500
AV.P.MAYO	169	0,561	0,058	0,062	0,046	0,085	0,568	0,050	0,147	0,963	0,105	0,046	0,267
AV.SUBA	66	0,769	0,772	0,530	0,711	0,089	0,021	0,500	0,977	0,789	0,891	0,514	0,119
CL1	7	0,605	0,815	0,789	1,000	1,000	1,000	1,000	1,000	1,000	0,605	0,815	0,789
CL100	52	0,072	0,730	0,988	0,422	0,556	0,368	1,000	1,000	1,000	0,173	0,714	0,950
CL116	46	0,252	0,305	0,581	0,053	0,140	0,963	1,000	1,000	1,000	0,133	0,132	0,639
CL11SUR	46	0,929	0,583	0,400	0,853	0,013	0,005	0,186	0,211	0,977	0,938	0,030	0,011
CL127	80	0,602	0,443	0,201	0,032	0,101	0,735	0,977	1,000	0,500	0,351	0,291	0,303
CL13	173	0,338	0,076	0,114	0,889	0,437	0,124	0,292	0,186	0,186	0,742	0,185	0,024
CL134	41	0,599	0,318	0,348	0,708	0,606	0,606	1,000	1,000	1,000	0,534	0,269	0,348
CL147	50	0,394	0,233	0,211	0,180	0,164	0,583	1,000	1,000	1,000	0,219	0,043	0,241
CL170	73	0,918	0,923	0,676	0,280	0,545	0,714	1,000	0,969	0,969	0,776	0,898	0,853
CL19	80	0,227	0,069	0,186	0,204	0,722	0,871	0,572	0,500	0,395	0,189	0,090	0,278
CL24	125	0,464	0,694	0,820	0,001	0,296	0,976	0,789	0,500	0,211	0,041	0,585	0,921
CL26	215	0,322	0,773	0,808	0,174	0,222	0,475	0,977	0,899	0,860	0,266	0,775	0,848
CL26SUR-KR78K	15	0,050	0,962	0,993	0,977	0,899	0,899	1,000	1,000	1,000	0,091	0,989	0,993
CL32	6	0,950	0,969	0,295	0,500	0,899	0,394	1,000	1,000	1,000	0,911	0,953	0,428
CL34	25	0,550	0,062	0,054	0,102	0,143	0,990	1,000	1,000	1,000	0,301	0,085	0,066
CL43SUR	13	0,663	0,864	0,791	0,071	0,899	0,363	1,000	1,000	1,000	0,394	0,946	0,946
CL45	30	0,695	0,312	0,131	0,380	0,361	0,278	0,815	0,815	0,500	0,699	0,297	0,117
CL53	57	0,174	0,023	0,180	0,793	0,723	0,853	1,000	0,977	0,977	0,431	0,059	0,141
CL57	16	0,982	0,605	0,054	0,264	0,534	0,630	0,815	0,815	0,815	0,819	0,637	0,265
CL6	48	0,431	0,084	0,033	0,592	0,748	0,934	0,978	0,963	0,292	0,567	0,337	0,228
CL63	37	0,105	0,056	0,524	0,164	0,620	0,500	0,815	0,500	0,500	0,098	0,135	0,743
CL66A	6	0,186	0,963	0,969	0,977	1,000	0,888	1,000	1,000	1,000	0,395	0,963	0,950
CL68	39	0,225	0,147	0,335	0,270	0,775	0,977	1,000	0,978	0,978	0,138	0,444	0,826
CL7	10	1,000	0,963	0,963	0,500	1,000	0,122	1,000	1,000	1,000	0,500	0,963	0,963
CL72	166	0,549	0,919	0,965	0,365	0,164	0,769	0,102	0,201	0,860	0,181	0,804	0,830
CL80	229	0,247	0,184	0,482	0,385	0,706	0,050	0,400	0,075	0,201	0,214	0,393	0,452
CL85	26	0,977	0,966	0,500	0,663	0,209	0,541	1,000	1,000	1,000	0,974	0,916	0,228
CL92	65	0,202	0,704	0,942	0,228	0,377	1,000	1,000	1,000	1,000	0,121	0,500	0,910
CL94	6	0,977	0,969	0,963	1,000	1,000	0,547	1,000	1,000	1,000	0,977	0,969	0,963
DIAG16	33	0,610	0,608	0,408	0,723	0,541	1,000	0,211	0,292	0,909	0,525	0,294	0,510
K15	21	0,500	0,500	0,500	1,000	1,000	0,796	1,000	1,000	1,000	0,500	0,500	0,500
KR10	44	0,258	0,066	0,312	0,930	0,973	0,777	0,708	0,417	0,400	0,741	0,902	0,662
KR11	101	0,611	0,484	0,147	0,596	0,823	0,031	1,000	1,000	1,000	0,619	0,739	0,390
KR13	83	0,644	0,503	0,503	0,998	0,942	0,958	1,000	1,000	1,000	0,975	0,619	0,061
KR15	80	0,636	0,195	0,065	0,481	0,985	0,572	0,977	0,977	0,500	0,586	0,655	0,334
KR17	17	0,780	0,500	0,092	0,209	0,223	0,500	1,000	1,000	1,000	0,743	0,361	0,172
KR17-KR19	15	0,963	0,909	0,605	0,977	1,000	0,313	1,000	1,000	1,000	0,969	0,909	0,428
KR19	105	0,720	0,666	0,565	0,842	0,685	0,406	1,000	1,000	1,000	0,812	0,785	0,496
KR24	64	0,085	0,391	0,737	0,301	0,322	0,444	1,000	1,000	1,000	0,047	0,423	0,713
KR27	46	0,257	0,731	0,946	0,362	0,225	0,053	1,000	0,977	0,977	0,332	0,610	0,891
KR36	19	0,898	0,572	0,047	0,969	0,500	0,882	1,000	1,000	1,000	0,929	0,605	0,030
KR50	52	0,985	0,951	0,693	0,147	0,883	0,969	0,977	1,000	0,500	0,941	0,960	0,835
KR60	19	0,606	0,292	0,292	0,500	0,708	0,981	1,000	1,000	1,000	0,417	0,292	0,500
KR68	182	0,443	0,813	0,843	0,005	0,167	0,870	0,204	0,078	0,292	0,030	0,512	0,942
KR7	232	0,865	0,950	0,781	0,294	0,699	0,529	0,312	0,277	0,383	0,606	0,817	0,842
KR72	496	0,737	0,442	0,207	0,719	0,619	0,820	0,517	0,397	0,336	0,903	0,401	0,231
KR80	54	0,779	0,460	0,292	0,182	0,223	0,503	0,292	0,500	0,899	0,449	0,402	0,402
KR86	194	0,067	0,188	0,638	0,414	0,350	0,605	0,730	0,915	0,773	0,096	0,200	0,654
KR9	38	0,675	0,232	0,201	0,909	0,815	0,650	0,977	1,000	0,500	0,778	0,431	0,308
NQS	395	0,002	0,139	0,791	0,041	0,080	0,500	0,952	0,516	0,066	0,003	0,165	0,819
TV39-TV42	6	0,977	1,000	0,500	0,815	0,395		0,500	0,500	1,000	0,815	0,395	0,186

Table 5: Wilcoxon test results at by arterial corridor for alternative hypothesis where the crash rate in non-construction is greater than the crash rate during construction.

Note: Values shown are p-values. The green value corresponds to p-values less than 0.1. Damage ONLY (DO), Wounded (WO), Deceased (DE), and Total (TO) severities are considered when comparing each of the temporary windows: Before (BF), During (PMT), and After (AF).

CORRIDOR	N	PMT_DO/BF_DO	PMT_DO/AF_DO	BF_DO/AF_DO	PMT_WO/BF_WO	PMT_WO/AF_WO	BF_WO/AF_WO	PMT_DE/BF_DE	PMT_DE/AF_DE	BF_DE/AF_DE	PMT_TOT/BF_TOT	PMT_TOT/AF_TOT	BF_TOT/AF_TOT
AUTONORTE	321	0,523	0,682	0,665	0,661	0,539	0,469	0,063	0,819	0,979	0,607	0,807	0,784
AV.AMERICAS	215	0,415	0,941	0,932	0,132	0,024	0,065	0,143	0,092	0,361	0,302	0,521	0,656
AV.CARACAS	462	0,965	0,764	0,429	0,044	0,481	0,939	0,300	0,781	0,902	0,559	0,641	0,771
AV.CIRCUNVALAR	105	0,301	0,995	0,997	0,853	0,969	0,871	0,977	0,500	0,500	0,520	0,999	0,998
AV.CORDOBA	8	0,181	0,428	0,708	0,500	0,500	0,500	1,000	1,000	1,000	0,211	0,292	0,606
AV.P.MAYO	169	0,441	0,943	0,939	0,954	0,916	0,435	0,978	0,896	0,186	0,896	0,954	0,734
AV.SUBA	66	0,239	0,238	0,480	0,301	0,918	0,981	0,815	0,500	0,395	0,112	0,496	0,884
CL1	7	0,605	0,500	0,395	1,000	1,000	1,000	1,000	1,000	1,000	0,605	0,500	0,395
CL100	52	0,932	0,278	0,014	0,608	0,472	0,651	1,000	1,000	1,000	0,835	0,294	0,053
CL116	46	0,775	0,722	0,459	0,971	0,911	0,186	1,000	1,000	1,000	0,885	0,883	0,406
CL11SUR	46	0,104	0,500	0,664	0,164	0,990	0,996	0,963	0,909	0,500	0,071	0,975	0,991
CL127	80	0,406	0,565	0,806	0,972	0,908	0,288	0,500	1,000	0,977	0,656	0,716	0,706
CL13	173	0,665	0,925	0,887	0,113	0,567	0,878	0,819	0,963	0,963	0,260	0,816	0,977
CL134	41	0,425	0,699	0,668	0,428	0,500	0,500	1,000	1,000	1,000	0,489	0,746	0,668
CL147	50	0,616	0,778	0,800	0,846	0,853	0,472	1,000	1,000	1,000	0,790	0,960	0,772
CL170	73	0,088	0,081	0,333	0,734	0,470	0,308	1,000	0,091	0,091	0,233	0,106	0,152
CL19	80	0,776	0,932	0,818	0,808	0,286	0,135	0,572	0,977	0,789	0,813	0,911	0,726
CL24	125	0,540	0,309	0,183	0,999	0,709	0,025	0,395	0,815	0,909	0,960	0,417	0,080
CL26	215	0,680	0,229	0,193	0,829	0,782	0,531	0,500	0,181	0,209	0,736	0,227	0,153
CL26SUR-KR78K	15	0,978	0,054	0,011	0,500	0,181	0,211	1,000	1,000	1,000	0,969	0,017	0,011
CL32	6	0,101	0,047	0,791	0,977	0,181	0,181	1,000	1,000	1,000	0,140	0,078	0,708
CL34	25	0,475	0,946	0,953	0,925	0,882	0,705	1,000	1,000	1,000	0,715	0,923	0,942
CL43SUR	13	0,417	0,176	0,295	0,953	0,181	0,015	1,000	1,000	1,000	0,705	0,071	0,071
CL45	30	0,333	0,736	0,889	0,658	0,682	0,688	0,500	0,500	0,815	0,318	0,733	0,895
CL53	57	0,835	0,979	0,829	0,238	0,318	0,748	1,000	0,500	0,500	0,583	0,946	0,867
CL57	16	0,030	0,605	0,960	0,779	0,534	0,201	0,500	0,500	0,500	0,221	0,417	0,799
CL6	48	0,586	0,926	0,969	0,428	0,282	0,388	0,050	0,186	0,819	0,448	0,675	0,782
CL63	37	0,901	0,948	0,492	0,853	0,419	0,074	0,500	0,977	0,977	0,907	0,872	0,269
CL66A	6	0,963	0,186	0,091	0,500	1,000	0,977	1,000	1,000	1,000	0,789	0,186	0,101
CL68	39	0,801	0,866	0,685	0,762	0,252	0,128	1,000	0,050	0,050	0,872	0,572	0,189
CL7	10	1,000	0,186	0,186	0,977	1,000	0,500	1,000	1,000	1,000	0,977	0,186	0,186
CL72	166	0,453	0,081	0,035	0,637	0,837	0,880	0,925	0,853	0,209	0,820	0,197	0,171
CL80	229	0,754	0,817	0,520	0,617	0,296	0,233	0,664	0,946	0,853	0,787	0,608	0,549
CL85	26	0,028	0,041	0,541	0,417	0,860	0,978	1,000	1,000	1,000	0,030	0,094	0,795
CL92	65	0,805	0,302	0,061	0,795	0,647	0,500	1,000	1,000	1,000	0,884	0,507	0,094
CL94	6	0,500	0,091	0,186	1,000	1,000	1,000	1,000	1,000	1,000	0,500	0,091	0,186
DIAG16	33	0,417	0,422	0,612	0,336	0,500	0,500	0,909	0,819	0,211	0,500	0,724	0,510
K15	21	0,815	0,977	0,977	1,000	1,000	1,000	1,000	1,000	1,000	0,815	0,977	0,977
KR10	44	0,752	0,939	0,712	0,075	0,028	0,212	0,428	0,663	0,664	0,267	0,103	0,348
KR11	101	0,393	0,521	0,855	0,415	0,185	0,231	1,000	1,000	1,000	0,385	0,264	0,613
KR13	83	0,361	0,503	0,503	0,003	0,061	0,970	1,000	1,000	1,000	0,026	0,386	0,941
KR15	80	0,370	0,810	0,937	0,538	0,016	0,045	0,500	0,500	0,815	0,420	0,350	0,670
KR17	17	0,257	0,583	0,929	0,860	0,824	0,572	1,000	1,000	1,000	0,297	0,682	0,857
KR17-KR19	15	0,186	0,211	0,605	0,500	1,000	0,977	1,000	1,000	1,000	0,091	0,211	0,708
KR19	105	0,294	0,348	0,448	0,173	0,335	0,699	1,000	1,000	1,000	0,194	0,223	0,514
KR24	64	0,919	0,618	0,271	0,714	0,693	0,612	1,000	1,000	1,000	0,955	0,586	0,294
KR27	46	0,761	0,281	0,062	0,667	0,801	0,583	1,000	0,500	0,500	0,684	0,404	0,118
KR36	19	0,136	0,572	0,970	0,091	0,815	0,971	1,000	1,000	1,000	0,092	0,605	0,985
KR50	52	0,019	0,054	0,322	0,896	0,147	0,143	0,500	1,000	0,977	0,066	0,044	0,174
KR60	19	0,500	0,819	0,819	0,977	0,428	0,091	1,000	1,000	1,000	0,663	0,819	0,606
KR68	182	0,559	0,188	0,158	0,995	0,834	0,020	0,828	0,938	0,819	0,970	0,490	0,059
KR7	232	0,136	0,051	0,220	0,710	0,305	0,132	0,736	0,777	0,661	0,395	0,184	0,159
KR72	496	0,263	0,559	0,793	0,282	0,382	0,472	0,500	0,619	0,678	0,098	0,599	0,769
KR80	54	0,225	0,546	0,714	0,823	0,783	0,188	0,819	0,583	0,181	0,556	0,603	0,603
KR86	194	0,933	0,813	0,364	0,589	0,653	0,499	0,305	0,098	0,243	0,904	0,801	0,347
KR9	38	0,345	0,789	0,818	0,211	0,500	0,605	0,500	1,000	0,977	0,239	0,597	0,714
NQS	395	0,998	0,861	0,210	0,959	0,920	0,351	0,051	0,516	0,938	0,997	0,836	0,182
TV39-TV42	6	0,500	1,000	0,977	0,500	0,789	0,977	0,977	0,977	1,000	0,500	0,789	0,963

Table 6: Wilcoxon test results at by arterial corridor for alternative hypothesis where the crash rate in non-construction is less than the crash rate during construction.

Note: Values shown are p-values. The green value corresponds to p-values less than 0.1. Damage ONLY (DO), Wounded (WO), Deceased (DE), and Total (TO) severities are considered when comparing each of the temporary windows: Before (BF), During (PMT), and After (AF).

3.3 By PMT type

Tables 7 and 8 show a summary of the descriptive statistics for the previously described crash rates, according to the defined classification of accidents. These statistics show the range, mean, standard deviation, and sum of these variables.

COI-ALTA	BF_DO	BF_WO	BF_DE	BF_TO	PMT_DO	PMT_WO	PMT_DE	PMT_TO	AF_DO	AF_WO	AF_DE	AF_TO
Minimum	0	0	0	0	0	0	0	0	0	0	0	
Maximum	3344.99919	5163.53693	395.970383	5163.53693	3297.4709	1584.07916	490.330442	3297.4709	1985.78336	1374.36379	271.3092127	2045.01696
Mean	22.87013	10.12827	0.594041	33.59244	23.98458	10.30154	0.5601593	34.84628	20.27924	8.401647	0.3162106	28.9971
Standard deviation	117.27334	94.89802	11.276667	157.49235	109.75658	54.65265	10.909148	129.35503	71.61943	45.675955	5.5224075	92.11875
Sum	84802.45658	37555.62479	2202.703957	124560.7853	88934.81148	38198.1097	2077.070634	129209.9918	75195.43724	31153.30872	1172.509017	107521.255

Table 7: Results of descriptive statistics for COI-ALTA.

COOS-ALTA	BF_DO	BF_WO	BF_DE	BF_TO	PMT_DO	PMT_WO	PMT_DE	PMT_TO	AF_DO	AF_WO	AF_DE	AF_TO
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	1064.67306	749.921325	76.2950083	1064.67306	1239.30942	749.921325	2059.077505	2059.0775	15733.43452	670.893258	77.2701849	15733.43452
Mean	22.35298	8.984521	0.2522784	31.58978	20.18608	8.677053	1.426607	30.28974	31.01735	9.141264	0.3236568	40.48227
Standard deviation	67.86485	36.972009	3.4676177	79.54107	71.63501	37.743989	49.760847	96.20247	387.45294	35.981352	3.9179715	389.14788
Sum	38648.30551	15534.23741	436.1892699	54618.73219	34901.74026	15002.62442	2466.603334	52370.96801	53629.00333	15805.24548	559.6025935	69993.8514

Table 8: Results of descriptive statistics for COOS-ALTA.

We perform the hypothesis analysis in 3 types of PMT. Tables 9 and 10 show, the p-value of the Wilcoxon test, performed to find statistically significant differences between the crash rates of the different time windows considering the three levels of crash severities.

Table 9 shows p-values smaller than 0.1 in green color, and p-values bigger than 0.9 in yellow color. P-values equal to 1 are shown in red color as this was an indication that the hypothesis was completely rejected. Cells without color correspond to those p-values that do not fit any of the previously described categories.

PMT TYPE	N	PMT_DO/BF_DO	PMT_DO/AF_DO	BF_DO/AF_DO	PMT_WO/BF_WO	PMT_WO/AF_WO	BF_WO/AF_WO	PMT_DE/BF_DE	PMT_DE/AF_DE	BF_DE/AF_DE	PMT_TOT/BF_TOT	PMT_TOT/AF_TOT	BF_TOT/AF_TOT
COI-ALTA	3708	0,010	0,067	0,652	0,016	0,005	0,467	0,573	0,088	0,073	0,002	0,005	0,482
COI-TRONCALES	13	0,500	0,500	0,277	0,977	1,000	0,500	1,000	1,000	1,000	0,605	0,500	0,201
COOS-ALTA	1729	0,968	0,561	0,047	0,779	0,962	0,753	0,796	0,940	0,756	0,977	0,938	0,187

Table 9: Wilcoxon test results by PMT type with the greater alternative hypothesis

Note: Values shown are p-values. The green value corresponds to p-values less than 0.1. Damage ONLY (DO), Wounded (WO), Deceased (DE), and Total (TO) severities are considered when comparing each of the temporary windows: Before (BF), During (PMT), and After (AF).

Table 10 shows p-values smaller than 0.1 in green color, and p-values bigger than 0.9 in yellow color. P-values equal to 1 are shown in red color as this was an indication that the hypothesis was completely rejected. Cells without color correspond to those p-values that do not fit any of the previously described categories.

PMT TYPE	N	PMT_DO/BF_DO	PMT_DO/AF_DO	BF_DO/AF_DO	PMT_WO/BF_WO	PMT_WO/AF_WO	BF_WO/AF_WO	PMT_DE/BF_DE	PMT_DE/AF_DE	BF_DE/AF_DE	PMT_TOT/BF_TOT	PMT_TOT/AF_TOT	BF_TOT/AF_TOT
COI-ALTA	3708	0,990	0,933	0,348	0,984	0,995	0,533	0,428	0,913	0,927	0,998	0,995	0,518
COI-TRONCALES	13	0,815	0,583	0,777	0,500	1,000	0,977	1,000	1,000	1,000	0,605	0,583	0,853
COOS-ALTA	1729	0,032	0,439	0,953	0,221	0,038	0,248	0,211	0,062	0,248	0,023	0,062	0,813

Table 10: Wilcoxon test results by PMT type with the less alternative hypothesis

Note: Values shown are p-values. The green value corresponds to p-values less than 0.1. Damage ONLY (DO), Wounded (WO), Deceased (DE), and Total (TO) severities are considered when comparing each of the temporary windows: Before (BF), During (PMT), and After (AF).

4. DISCUSSION

The results of the hypothesis testing, using the Wilcoxon test allow us to identify a total of 7 patterns when considering the behavior of the crash rates during construction and non-construction periods. Patterns describe growth or decrease in the crash rates, influenced by work zone in the arterial corridors. Figure 2 shows a diagram that describes the seven different patterns:

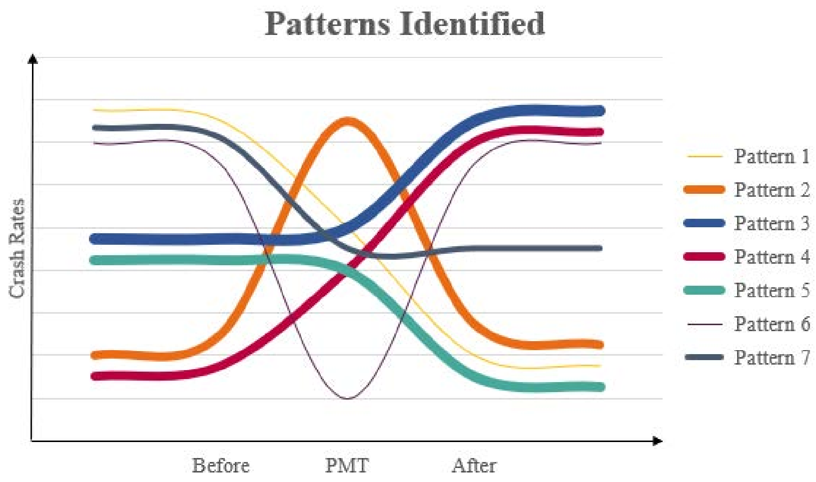


Figure 2: Patterns identified in crash rates during construction time.

The first pattern is represented in yellow in Figure 2. Includes the behavior observed in the CL26SUR-KR78K corridor, where it is evident that during the application of the PMT (construction time) the crash rate is lower than the rate observed before the intervention. Besides, there is also a downward trend in the crash rates, compared with the rates before and during construction time.

The second pattern Figure 2 (orange) includes the behavior observed in 5 corridors with two different severity (DO and WO). We observed a higher crash rate during construction time than the rates observed during periods of non-construction, whether before or after the road intervention.

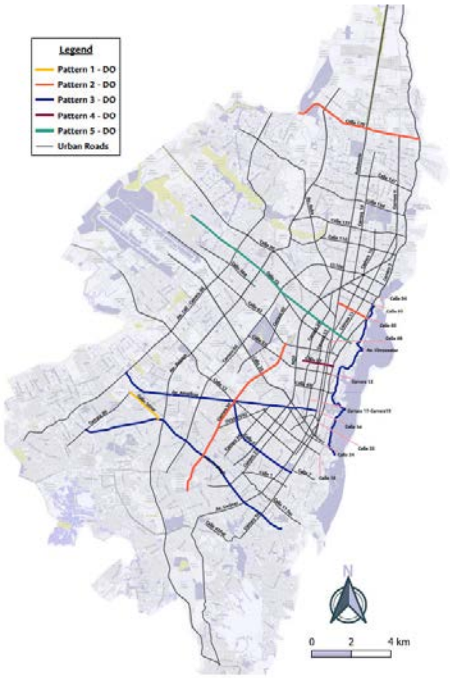
The third pattern, represented in blue in Figure 2 and includes seven arterial corridors, in different severities. These corridors show an increase in the crash rates after construction, and those rates are higher than the rates from before the construction.

A fourth pattern, represented in burgundy in Figure 2, includes the behavior of five arterial corridors. We observed an increase in crash rates, during and after the construction time.

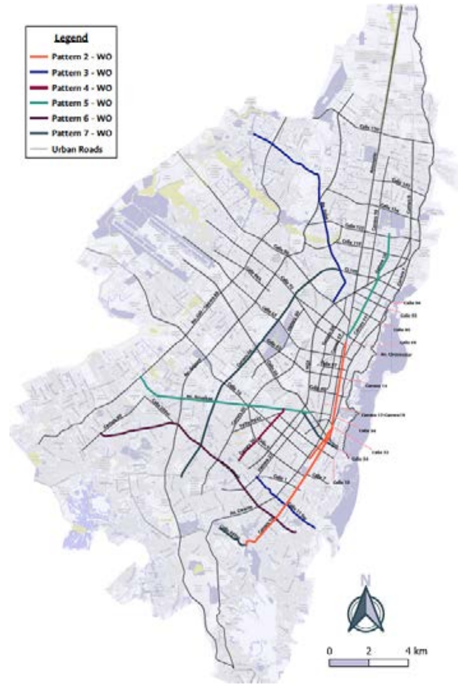
The fifth pattern groups those corridors with smaller crash rates during and after construction. We found six corridors whit this pattern marked in green mint color in Figure 2.

A single arterial corridor presented the sixth pattern when we observe crash rates are significantly lower during construction, and greater crash rates before and after construction (Figure 2 dark purple color).

In the seventh and last pattern crash rates during the construction time decreased compared to before the intervention started, and after the construction zone was lifted these remained lower than before the constructions (Figure 2. dark grey).

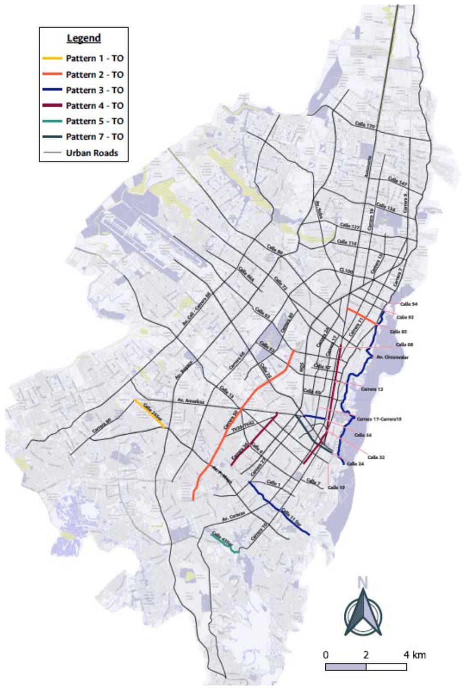


(A) Damage Only



(B) Injured

(C) Fatalities



(D) Total crashes

Figure 3: Maps of crash rates behavioral patterns in arterial corridors for Bogotá.

Figure 3 shows the map with the arterial streets of the city of Bogota, where the different patterns of crash rates during construction and non-construction time are highlighted, according to the severity of the accident (Damaged Only(A), Injuries (B), and Fatalities (C)) and in all records(D). Pattern one was depicted with a yellow color, pattern two with an orange color, pattern three with blue, pattern four with burgundy, pattern five with mint green, and pattern seven with a dark blue tone.

4.1 By PMT type

Performing the Wilcoxon test by type of PMT, we find results and p-values that allow us to reject the null hypothesis of equality in the crash rates and suggest a statistically significant difference among the crash rates, at least in two out of three types of intervention.

For the typology of COI-ALTA (construction that does not require excavation) it is evident that, for the severity of OD, WO, and TO there was a decrease in the accident rates during the construction time, compared to before and after the work began, this behavior resembles pattern 6 identified for the corridors. This result might be associated with a lower speed that is common during construction. Besides, for the severity of DE, there is behavior pattern 3, being greater the accident rate once the construction is finished.

For interventions that required a PMT of type COOS-ALTA (construction that does require excavation), we found a lower crash rate during construction for damage-only crashes. Injuries and fatalities crash rates after the intervention are lower than during the active construction period. For all construction types considering all crash severities, a behavior pattern 2 was identified, in which the average of accidents is greater during the construction than in times of non-construction.

We choose to use a non-parametric hypothesis test method because we did not assume normality on crash rates, as the articles in the literature did (Jin, Saito, and Eggett, 2008). Assuming normality can bring a clear bias towards lower rates, due to most of the city traffic is channeled through a few sections of the arterial network, leaving a lot of corridors with zero accidents in the time windows defined.

Some of the corridors with high traffic volumes and therefore high crash rates are Avenida Ciudad de Cali, Avenida Boyacá, Carrera 68, Calle 80 and Avenida Las Américas. According to Bogotá´s Secretary of mobility, “these five corridors gather nearly 25% of traffic in Bogota´s arterial streets ”.

As to the statistical tests used, instead of using a paired t-test, two-way ANOVA, and Tukey test, our research team decided to use the Wilcoxon test as these were a better suit for the properties of the studied population (Zimmerman and Zumbo, 1993).

5. CONCLUSIONS

Our research focused on the descriptive analysis of crash data to explore long-term work zone characteristics such as crash severity, crash rate, type, and location using the non-parametric Wilcoxon test to explore differences in accident rates on arterial roads in the city of Bogotá between 2015 and 2019.

A total of 5.450 works were analyzed in 58 arterial road corridors of the city, where it was found that for the severity of damage only, 3 corridors within them the Calle 170 and the Calle 85, show an increase in accident rates during the construction time, which is presumed to be a direct result of the intervention on the road, also presenting this same phenomenon with the severity of injuries for the corridors of Carrera 10 and Carrera 13.

A completely different behavior was found for the Primero de Mayo Avenue, where for crash with injuries it was statistically demonstrated that the accident rates were lower during construction time, which can be associated with a correct design and application of the PMT. The corridors of Calle 24, Calle 43Sur, and Carrera 68 also showed a correct application of the PMT, managing to reduce accidents with injuries in construction time and once the intervention is lifted.

As well as the patterns described above, a total of seven different patterns were found in the behavior of accident rates during construction time in a city as peculiar as Bogota, where its road planning was guided in a disorderly way by an inordinate growth in a very short time.

This study represents the first approach to understand the response of the city in terms of mobility, before a high-impact road intervention, whose importance lies in the current projection of the city to develop mega works for the next five years, such as the metro. Future research could include the study of crash characteristics before, during, and after the work zone periods to highlight both the safety similarities and differences between work zone and non–work zone locations. Additionally, undertaking analysis to explore the correlation of road conditions as determinants in the behavior of accident rates, or exploring if the problem lies in the structure of the traffic management plan.

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