Chapter 7

Bus Rapid Transit Systems Road Safety: A Case Study of Mexico City

Jaime Santos-Reyes, Vladimir Ávalos-Bravo and
Diego Padilla-Pérez

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/65583

Abstract

The book chapter presents a statistical analysis of historical data of bus rapid transit (BRT) lines A&B accidents that have occurred in Mexico City from 2005 to 2015. Some of the key conclusions are the following: (a) 484 accidents have occurred when considering both lines A and B. The most critical years have been 2008, 2011 and 2012; the least critical year, on the other hand, has been 2010; (b) overall, the frequency of accident occurrence has been decreasing in both lines; (c) the most critical seasons of the year have been the following: autumn (27.7% in line A) and winter (32% in line B); (d) the frequency of accidents increases when approaching the end of the week (Thursday and Friday) and the frequency of accidents decreases sharply at weekends; (e) 48.28 and 54.47% of accidents have occurred at the three peak (i.e. morning, afternoon, evening/night) in lines A and B, respectively; (f) 64.8% (22/73) of pedestrians have been killed when collided with the BRT buses; and (g) the most critical section of the BRT lane has been identified with 38 (11.87%) accidents and for the case of line A. Future work includes statistical significance tests on the data.

Keywords: accident, bus rapid transit (BRT), statistical analysis, road safety, traffic safety

1. Introduction

The first bus rapid transit (BRT) system was implemented in Curitiba, Brazil, in 1974, and has become a global phenomenon in the twenty-first century [1]. Major new BRT projects have been adopted in many countries worldwide (e.g. Australia, China, India, Indonesia, United States, Iran, Turkey, Europe, etc.); in fact, it is believed that about 168 cities from 39 countries have adopted the system [2, 3]. The success of BRT systems has been attributed to the following advantages [1]: (a) the time of implementation is shorter than for rail-based mode of transport, (b) the implementation costs are a fraction of those for rail-based mass transit system and (c) easy network connectivity, that is, parts of the network can operate on normal streets, it is much cheaper and faster to establish a full network using bus-based mass transit.

However, there is no rigid definition of precisely what constitutes a BRT system. It is thought that the lack of a common definition of BRT has caused confusion in discussions of the technology since its inception [1]. The authors argue that the lack of a common understanding of what constitutes a BRT system has led to branding problems. There is currently no official definition of what constitutes a BRT. Two definitions are as follows:

"A high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service."— ITDP [4].

"An enhanced bus system that operates on bus lanes or other transit ways in order to combine the flexibility of buses with the efficiency of rail….It also utilizes a combination of advanced technologies, infrastructure, and operational investments that provide significantly better service than traditional bus service."— USFTA [5].

On the other hand, research on BRT has been widely reported in the literature on several issues, for example, research from a social perspective [6–11], studies being conducted on the economics of BRT systems [12–14], research has also been conducted from a technical performance perspective [15–20], the environmental impact of the implementation of BRT systems has also been addressed by several authors [13, 16, 21], and some aspects on road safety have been reported in the literature, for example, see [6, 15].

However, there is no evidence of studies being conducted explicitly on accidents associated with BRT systems. This may be relevant in understanding, for example, deficiencies in the current rod safety associated with BRT systems. Further, it may help to better understand urban mobility. The book chapter gives an account of the ongoing research project concerning a statistical analysis of historical accident data analysis associated with BRT systems in Mexico City, in particular, those accidents that have occurred in BRT lines A&B, and for the time between 2005 and 2015.

2. BRT systems worldwide and in Mexico City

2.1. BRT systems worldwide

As mentioned in the 'Introduction' section, the BRT system emerged as an option to the transport problem in some developing cities in Latin America. However, BRT systems have not only become popular in Latin America but also become a popular means of transport worldwide, due its value, serviceability, accessibility, flexibility relative and network coverage [1, 2, 19]. Further, many studies have shown that BRT systems can be a cost-effective way to provide a service of high-performance transport [22, 23].

For example, the system has been expanded in such a way that currently BRT systems are in operation in 206 cities spread over five continents (**Figure 1**). Further, it is believed that the BRT systems worldwide transport 33.3 million passengers per day [2]. Furthermore, the world's leading regions are Latin America and Asia, covering 108 cities. **Figure 1** shows the countries that have invested heavily in BRT transport systems, for example, Brazil (34 cities, 847 km of length), Mexico (11 cities, 340 km) and Colombia (six cities, 205 km).

2.2. BRT systems in Mexico City

The Metropolitan area of Mexico City has been regarded as the third largest agglomeration in the world. It is believed that the population is about 21.4 million people; further, the population density is about 6000 inhabitants/km^2 [24]; it is thought that about 600 new motor cars are being registered each day. The Metro underground mass transit system served for a long time as the dominating mode of transportation with approximately 250 km of length and 4.5 million trips per day [24]. Further, the traditional transport systems were typically composed of overcrowded and slow private bus and minibus lines. Furthermore, the buses were old, poorly maintained and highly polluted. These transport shortcomings prompt the capital City's decision-makers to solve the problem with investments in road infrastructure; initially, they built additional motorways; however, it was clear that those measures induced more traffic congestion and the project only served a small percentage of the city's inhabitants. It is thought for this reason; the idea of implementing BRT systems came up as the best solution for solving congestion and air pollution problems [24] (see **Figure 1** and **Table 1**).

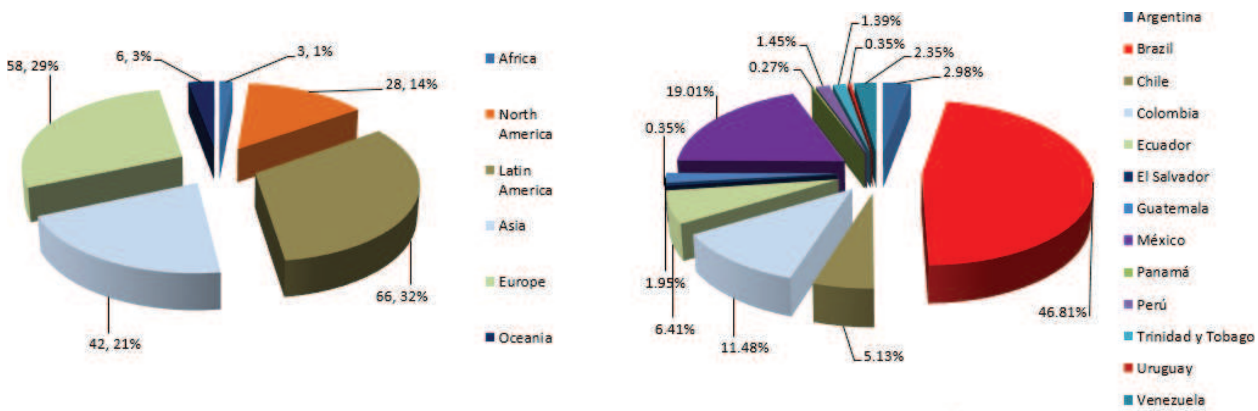

Figure 1. Number of cities worldwide that have adopted BRT transport systems.

Characteristics	Line A	Line B	Line C	Line D	Line E	Total
Length	30 km	20 km	17 km	28 km	10 km	**105 km**
Starting operations	June 2005	December 2009	February 2011	April 2012	November 2013	–
No. of stations	44	34	29	32	16	**155**
Passengers/day	480,000	180,000	140,000	65,000	55,000	**920,000**

Table 1. Some characteristics of the four BRT lines in Mexico City [25].

In 2002, the Mexico City government planned a BRT corridor running across the centre of the capital city. In 2005, the first corridor of the BRT line (i.e. BRT line A) started operations along one of the key avenues with 30 km of length (**Figure 2** and **Table 1**). It is thought along this avenue, the BRT system has improved mobility by 50%. The success of line A prompted the opening of line B; in 2008, along another of the key avenues of the city, this was followed by the opening of line C, in 2011 [24]; a year later, line D started its operations (April 2012). Further extensions are already implemented and others are planned and in construction. **Figure 2** shows a map of the four lines and **Table 1** shows some of the key features of the two BRT lines being considered in the present analysis.

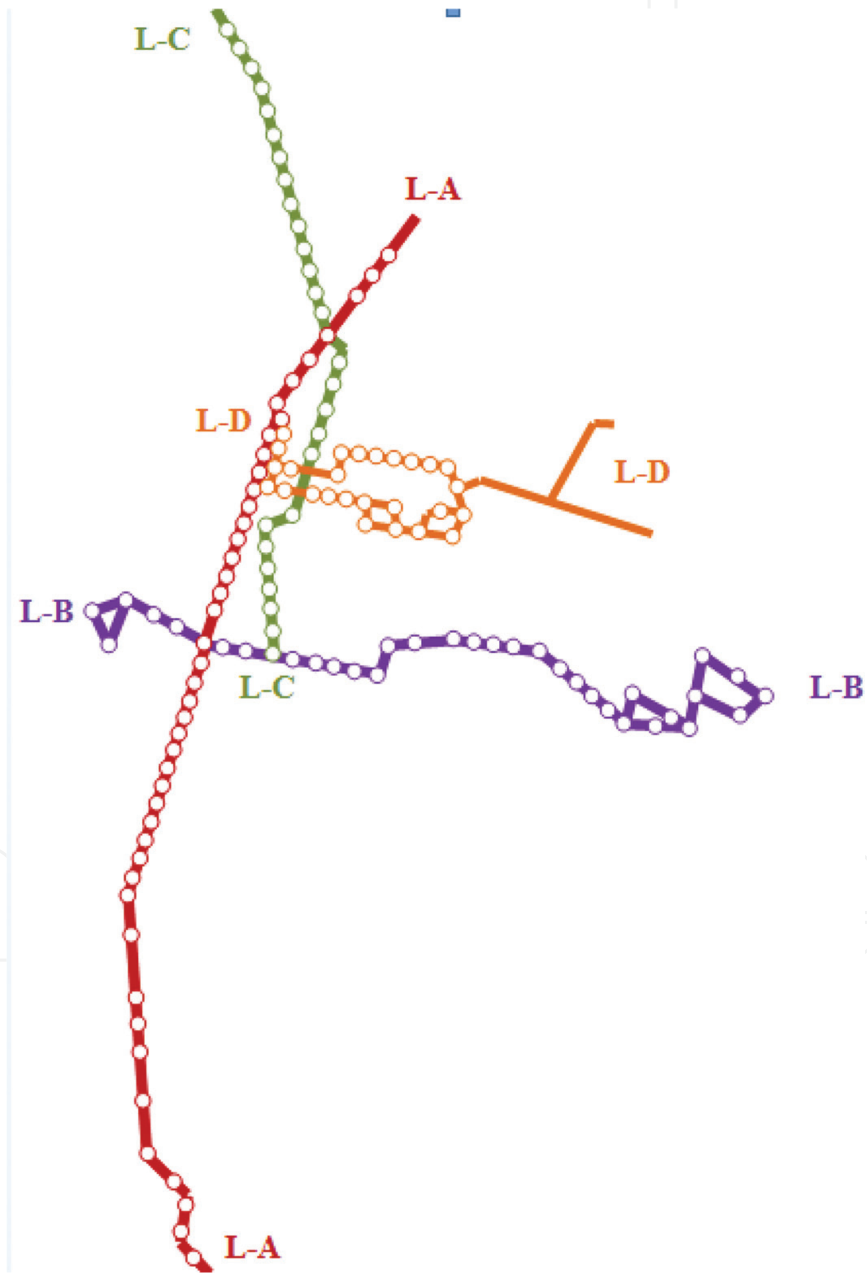

Figure 2. Four BRT lines in Mexico City.

http://dx.doi.org/10.5772/65583

3. Analysis and results

A BRT system database-related accident in Mexico City has been built. The database covers accident data since the opening of the first BRT system in 2005 until 2015. The historical data have been collected through the following sources: (a) data from the organization running the system [25], (b) incident/accident reports from the police and (b) data being collected from the mass media reports when accidents occur (i.e. TV, newspapers, online news, etc.).

Overall, a study associated with traffic accidents consists of analysing different variables intended to provide insight into their behaviour, location of occurrence (i.e. urban and sub-urban), the time of occurrence, date, class and type of accident, type of vehicle involved, the causes of the accident, driver details and class of victims (i.e. fatal and non-fatal). In this particular case, all the accidents are related to urban location. In what follows, some of the variables considered in the analysis are listed below [26]:

a. Accident occurrence time (year, month, weekday, hour).

b. Type of traffic accident (fatal and not fatal).

c. Vehicle involved in the collision with a BRT (motorcar, passenger van, cargo van, cargo truck, minibus, motorbike and bicycle).

d. Type of collision (between the BRT unit and motorcar, pedestrian, motorbike and cyclist).

e. Victims (driver, passenger, pedestrian and cyclist).

f. Age and gender of the victims.

g. Location of the accidents.

The variable associated with the immediate cause of the accidents has not been considered in the analysis presented here. It may be argued that an accident has multiple causes and needs to be fully analysed, see, for example, [27]. In the subsequent subsections, the main results associated with these variables are presented and the most relevant results are discussed in Section 4.

3.1. BRT accidents per year

As mentioned in Section 2.2, the BRT line A started operations in 25, whereas line B in 28 (**Table 1**). It has been found that 484 accidents have occurred in lines A&B combined. That is, 350 in line A (**Figure 3a**) and 134 in line B (**Figure 3b**). When considering line A separately, there has been a mean of 31.8 accidents per year. Further, **Figure 3a** shows a tendency of decreasing the frequency of accidents in this particular line. On the other hand, line B registered a mean of 16.7 accidents per year.

From **Figure 3**, it also can be observed that in both lines A and B, the frequency of the occurrence of accidents increased in the subsequent years once they have initiated operations. For example, the frequency of occurrence of accidents in line A reached the highest, 4 years after initial operations (i.e. 2008) with a total of 66 (18.85%; 66/350). Similar results have been seen for the case of the BRT line B in 2009 (23.8%; 32/134). Interestingly, both lines show a similar increasing trend in accident occurrence in the most recent years, that is, 2014–2015 (line A) and 2013–2015 (line B). Finally, it also can be seen that the year 2010 has been the least critical year for both lines (i.e. 10 accidents registered in line A and 8 in line B).

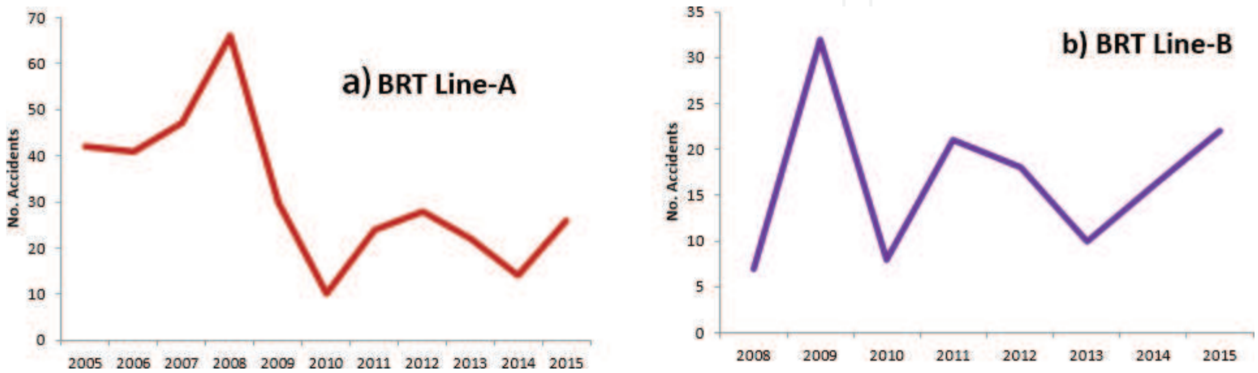

Figure 3. Accidents per year: (a). BRT Line-A; (b). BRT Line-B.

3.2. Accidents per month

Figure 4 shows the frequency of accident occurrence per month for the two BRT lines considered in the present analysis. Overall, it can be seen that line A has an increasing tendency of accident occurrence towards the end of the year; April has been the lowest accident occurrence with 5.1% (18/350) and November registered the highest number of accidents with 12% (42/350). Line B, on the other hand, shows a decreasing tendency of accident occurrence towards the end of the year. December registered the highest number with 12.68% (17/134) and July registered the lowest with 4.47% (6/134).

In an attempt to understand the trend of accident occurrence, for example, in line A (i.e. the oldest of the two lines being considered in the analysis), the data have been plotted by month and year. The results are shown in **Figure 5**. It can be seen that the highest frequency of occurrence has been the following months: August (2005) and November (2008) with 11 and 12 accidents, respectively. As mentioned in the previous sections, 2010 has been a year with the lowest number of accidents, that is, only 10 events have been registered. On the other hand, the year 2008 registered the highest number of accidents (18.85%; 66/350). In fact, zero accidents have been registered in 2010 and for the following months: January, June, August, September and October.

Another aspect that should be highlighted by observing at **Figure 5** is the fact that November has been the month with the highest frequency of accidents 12% (42/350) when considering

http://dx.doi.org/10.5772/65583

the 11 years altogether, that is, 2005–2015. On the other hand, it has been found that April has been the month with the lowest number of accidents for the same period of time, that is, 18 (5.1%; 18/302).

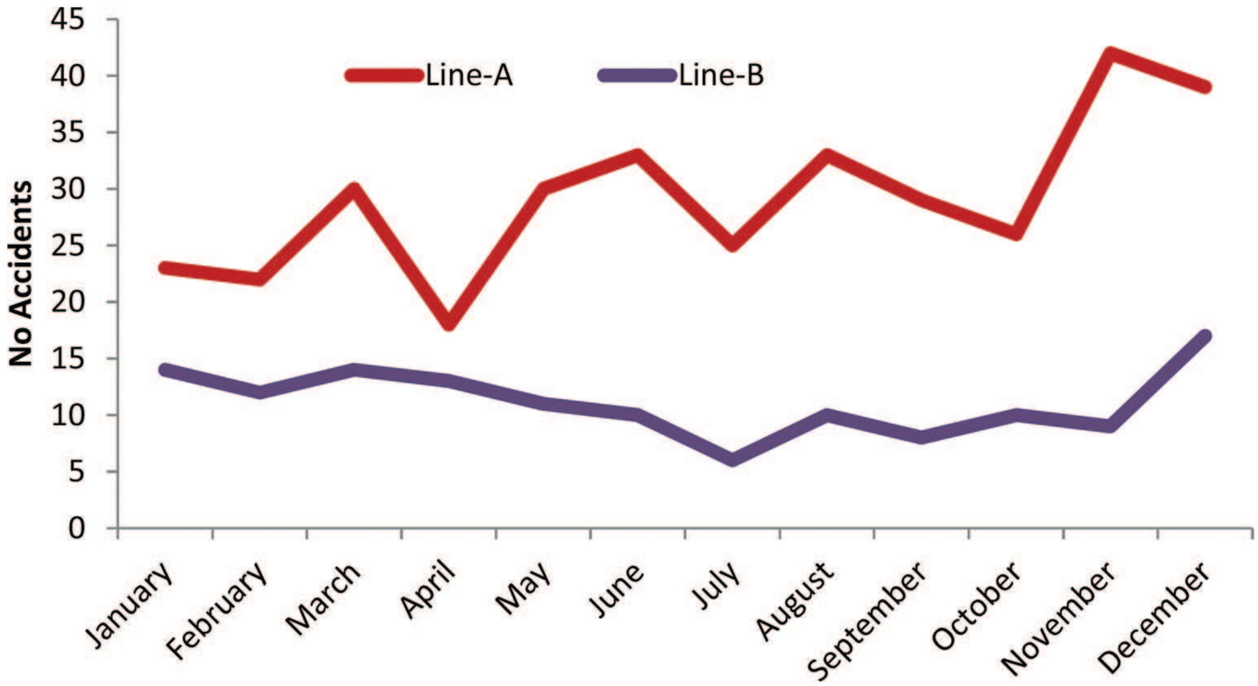

Figure 4. BRT accidents per month.

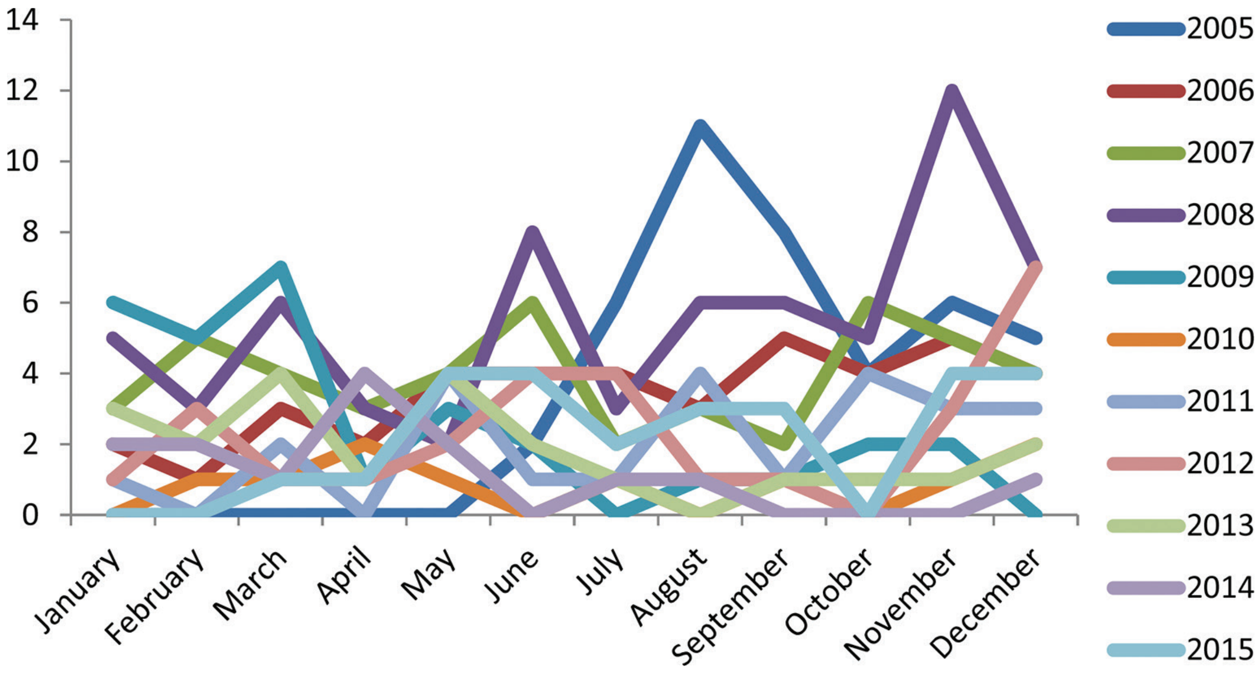

Figure 5. BRT line A accidents per month and for the 10-year period of analysis (2005–2015).

Finally, it was decided to investigate what were the most critical seasons of the year regarding accident occurrence. The results are shown in **Figure 6**. It can be seen that 27.7% (97/350) of accidents occurred during autumn for the case of line A. On the other hand, winter has been the critical season of the 8-year period for the case of line B (32%; 43/134). It is interesting to see how the pattern of accident occurrence is opposing when considering the seasons of the year for both lines. This may require further research to understand what are the 'external' factors that have an influence on this.

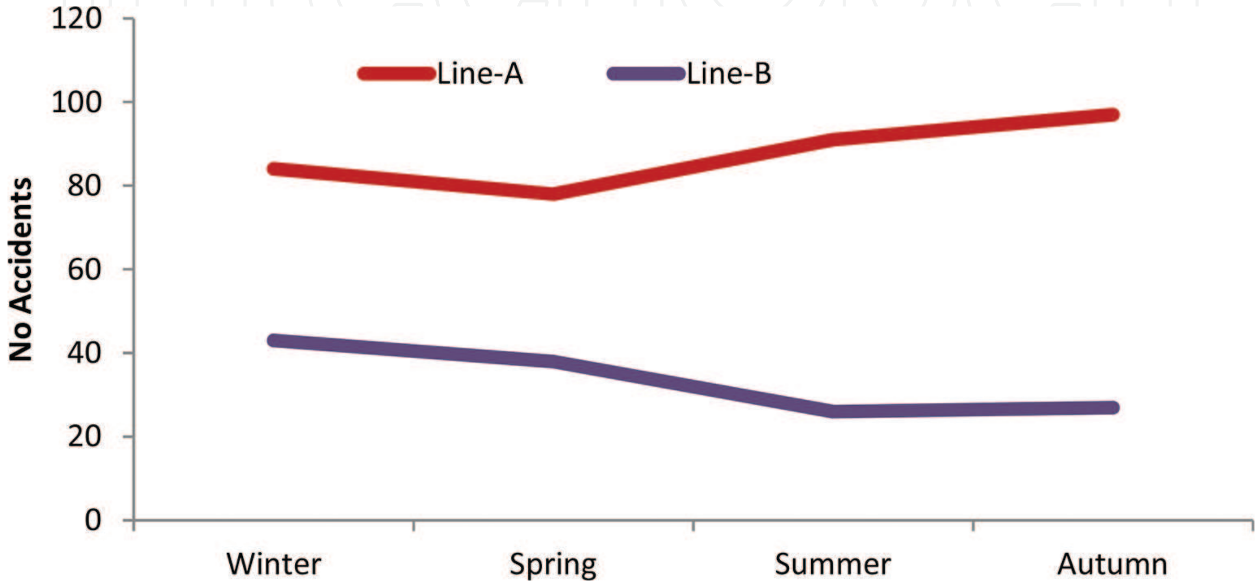

Figure 6. BRT accidents per season of the year.

3.3. Accidents per weekdays

In an attempt to identify some trends of accident occurrence during the days of the week, an analysis of the data was conducted to address this very issue. **Figure 7a** shows the results of the analysis. Overall, it can be seen that the frequency of accidents tends to increase when reaching Friday for the case of line A (23.7%; 83/350).

This is followed by Wednesday and Thursday with 70 (20%; 70/350) and 49 (14%; 49/350) accidents, respectively. The most critical weekdays for the case of line B, on the other hand, have been Thursday (22.3%; 30/134), Tuesday (20.8%; 28/134) and Wednesday (19.4%; 26/134), as shown in **Figure 7b**. Further, the data show that in both lines there is a sharp decreasing tendency of accidents at the weekends (**Figure 7**).

3.4. Accidents per hour

As with the previous sections, a detailed analysis of the data being collected has been conducted for the distribution of accidents per hour. The range of the BRT operational time has been considered from 04:00 h to Midnight. **Figure 8** and **Tables 2** and **3** show the results of the analysis. The distribution of accidents that have occurred in line A per hour and for the period between June 2005 and 31 December 2015 can be seen. Overall, the distribution of accident occurrence for this particular BRT line can be explained on the basis the following three ranges of time (**Figure 8**): (a) 04:00–13:59 h, (b) 14:00–19:59 h and (c) 20:00–24:00 h. In the time range (a), an increase in the occurrence of accidents is observed, reaching a maximum of 38 (10.85%; 38/350) and subsequently reduced to 36 accidents. The figure shows the most critical period in accident occurrence in the case (b). That is, 171 accidents have been reported, representing 48.8% of the total that occurred in this line. From **Figure 8**, it can also be seen that between 16:00 and 17:59 h, there was the peak of accidents with 63 (18%; 63/350). Finally, the time range (c), a very sharp drop of accident occurrence, can be seen from **Figure 8**.

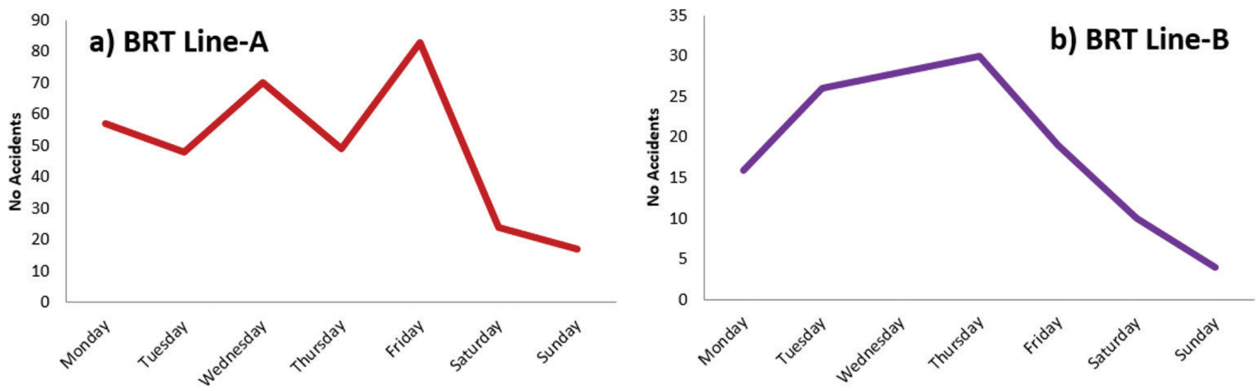

Figure 7. Distribution of accidents per day: (a). BRT Line-A; (b). BRT Line-B.

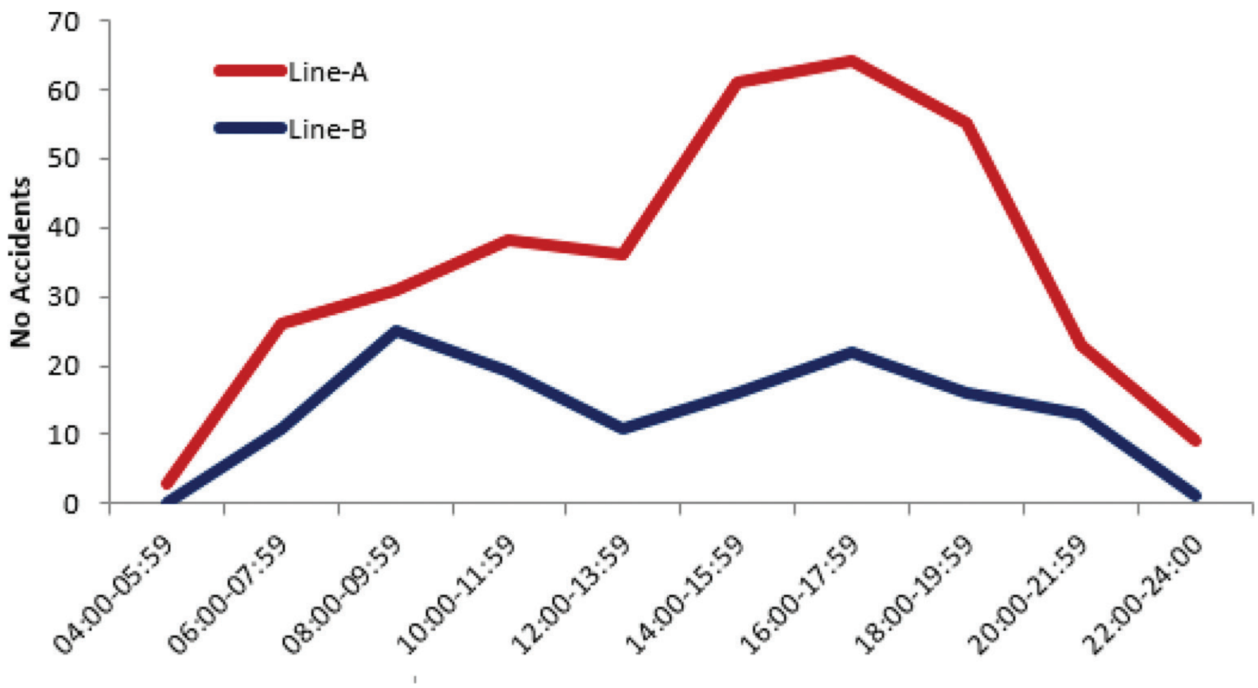

Figure 8. Accidents per hour.

Time period	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
04:00–05:59	0	0	0	0	1	0	0	1	0	0	1	**3**
06:00–07:59	2	2	2	3	5	1	2	5	1	1	2	**26**
08:00–09:59	4	3	5	7	6	2	0	1	2	0	2	**32**
10:00–11:59	7	3	3	7	3	2	3	3	3	3	2	**39**
12:00–13:59	3	2	3	6	4	2	4	3	3	3	3	**36**
14:00–15:59	7	7	10	12	1	2	3	6	8	2	3	**61**
16:00–17:59	6	9	6	14	7	1	5	5	3	4	4	**64**
18:00–19:59	9	10	10	16	1	0	2	1	2	0	4	**55**
20:00–21:59	4	2	6	1	1	0	4	3	0	0	2	**23**
22:00–Midnight	0	3	2	0	1	0	1	0	0	1	2	**1**
Unknown	0	0	0	0	0	0	0	0	0	0	1	**1**
Total	**42**	**41**	**47**	**66**	**30**	**10**	**24**	**28**	**22**	**14**	**26**	**350**

Table 2. Accidents per hour and year in line A.

The results of the distribution of accidents per hour during the 8-year period between 2008 and 2015, for the case of line B, are also shown in **Figure 8** and **Table 3**. The highest number of accidents occurred during the following ranges of time: (a) 08:00–09:59 h with 25 (18.65%; 25/134) accidents and (b) 20 (14.92%; 20/134) accidents occurred in the time range of 16:00–17:59 h. The lowest number of accidents reported during the afternoon was 11 (8.2%), which occurred in the time range from 12:00 to 13:59 h. Finally, the range of time is from 20:00 to 24:00 h, a very sharp decline in the occurrence of accidents, that is, 14 (10.44%).

Time period	2008	2009	2010	2011	2012	2013	2014	2015	Total
04:00–05:59	0	0	0	0	0	0	0	0	**0**
06:00–07:59	1	1	2	2	1	3	0	1	**11**
08:00–09:59	2	7	2	4	2	2	3	2	**25**
10:00–11:59	2	9	1	1	0	0	1	3	**19**
12:00–13:59	0	2	0	0	5	1	1	2	**11**
14:00–15:59	0	4	1	3	2	2	3	1	**16**
16:00–17:59	1	4	1	4	4	1	3	3	**22**
18:00–19:59	1	3	1	4	1	1	2	3	**16**
20:00–21:59	0	2	0	3	2	0	3	2	**13**
22:00–Midnight	0	0	0	0	1	0	0	0	**1**
Unknown	0	0	0	0	0	0	0	0	**0**
Total	**7**	**32**	**8**	**21**	**18**	**10**	**16**	**22**	**134**

Table 3. Accidents per hour and year in line B.

http://dx.doi.org/10.5772/65583

3.5. Accidents on peak hours

An analysis of the BRT line users data was conducted; it has been found that for line A, there are three peak hours during the operational day: morning (06:00–08:00 h), afternoon (13:00–15:00 h) and at evening/night (17:00–20:00 h). Overall, 48.28% (169/350) of accidents occurred during the three ranges of peak hours. The results also show that the evening/night peak hours are where 14.23% of accidents have occurred.

As with the case of line A, the same analysis was performed for line B. The results show that 54.47% (73/134) of all the line accidents occurred within three ranges of peak hours in this line. Similarly, 25% of the accidents occurred in the evening/night peak hours.

Effectively, these accidents have affected traffic congestion and consequently the urban mobility. See Section 4.4 for the discussion about this.

3.6. Victims of the accidents

Figure 9 shows the results of the victims as a result of the collisions with BRT buses. Given the lack of data from 2005 to 2007, it should be pointed out that the results shown in **Figure 9** are data available only from 2008 to 2014. The results show that a high percentage of collisions have been those associated with BRT units and pedestrians with 64.8% (64/73). Those related to collisions with cyclists with 8.1% followed this; finally, 1.1% are related to collisions with motorbike users. **Figure 9** also shows that the highest number of collisions with pedestrians occurred in 2012 with a total of 15 (20.5%; 15/73).

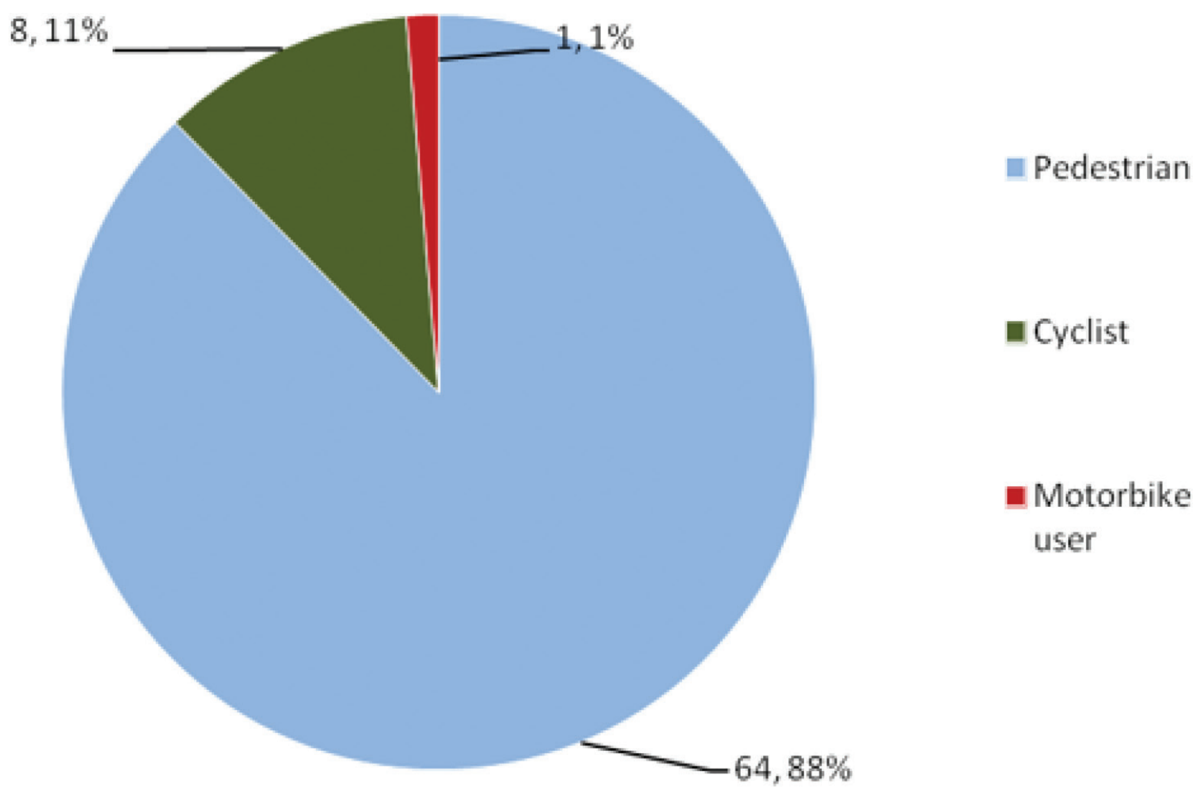

Figure 9. Victims of the accidents.

3.7. Fatal versus non-fatal

This subsection presents the results of the degree of injuries as results of the collision between the pedestrians and BRT units (**Table 4**). As mentioned in the previous sections, the results presented here are limited to 73 registered data associated with the consequences of such collisions (2008–2014). There have been 22 (30.1%; 22/73) fatal incidents and 51 (69.9%; 51/73) non-fatal accidents as a consequence of the collisions. **Table 4** shows the results associated with pedestrians being killed by the collisions; it can be seen that 45.5% have been killed in BRT line A with the highest percentage of those being male.

Line	Gender	10–14yo	15–19yo	20–24yo	25–29yo	30–34yo	35–39yo	40–44yo	45–54yo	55–64yo	Over 65yo	Total
Line A	MF	00	10	10	00	00	00	00	20	11	00	**51**
Line B	MF	00	10	00	11	10	01	00	00	11	10	**53**
	Total	**0**	**2**	**3**	**2**	**1**	**1**	**0**	**3**	**4**	**1**	**22**

F = Female, M = Male, yo = years old.

Table 4. Fatal pedestrian collisions.

The results also show that the highest frequency of fatalities occurred to those between the ages of the following ranges: 20–24 and 45–54 with three being killed in each category.

When considering individual lines, the highest frequency of occurrence is associated with line A with 12 (23.5%). The results also show that the most vulnerable population to collisions are young pedestrians in the range between 15 and 19 years old.

3.8. Location of the accidents on the BRT corridor

This subsection presents the results associated with the identification of the BRT lanes where the accidents occurred. For illustrative purposes, only the results regarding line A are shown here (**Figures 10** and **11**). The top five BRT lane sections with the highest number of accident occurrence were the following (**Figure 11**):

1. Lane 15 between stations 14 and 15 (L15 (S14-S15)) with 38 (11.87%).
2. Lanes 12 and 13 with 22 (6.87%) each.
3. Lane 22 with 18 (5.62%).
4. Lane 17 with 17 (5.31%).
5. Lanes 36 and 37 with 15 (4.687%) each.

http://dx.doi.org/10.5772/65583

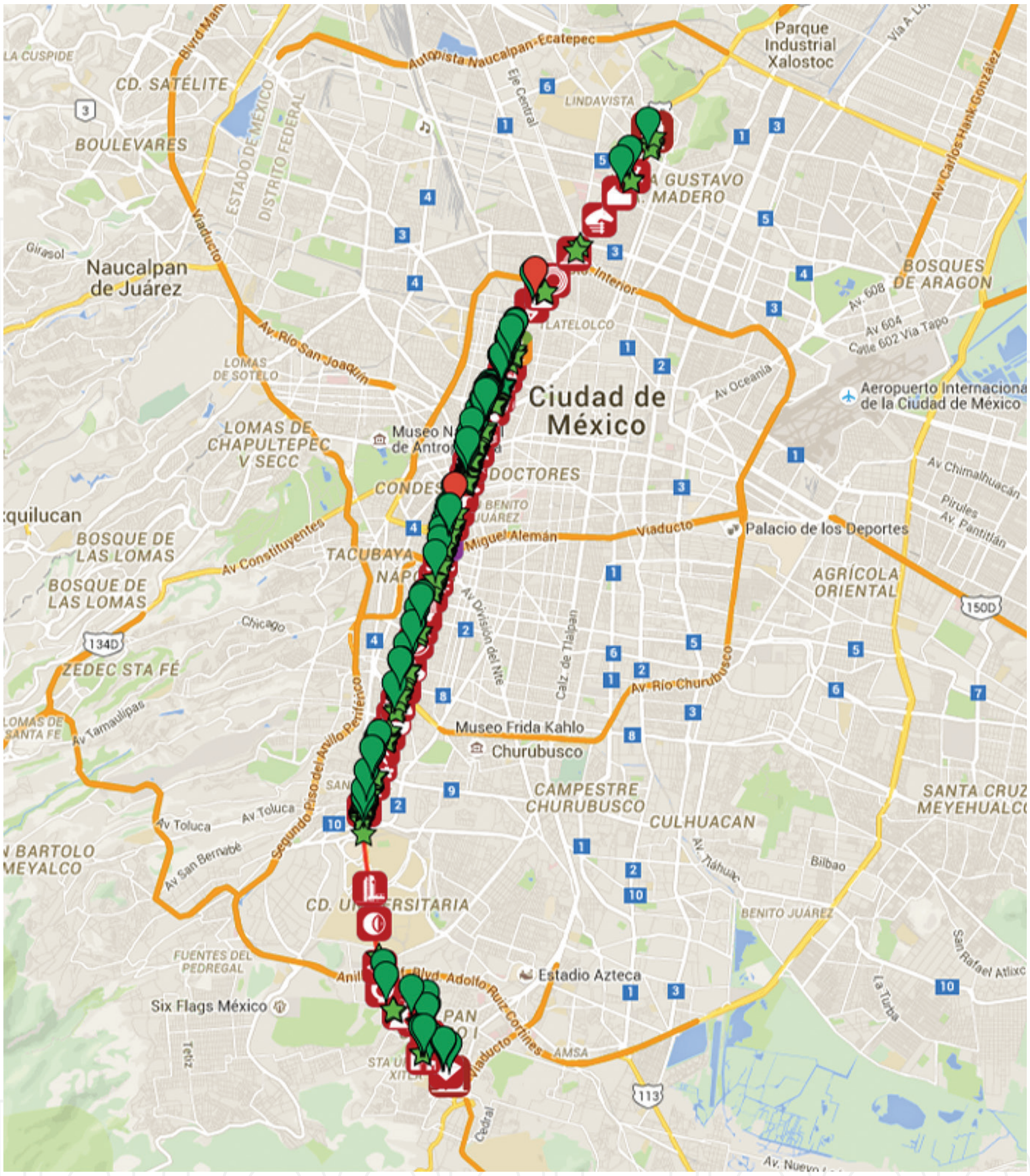

Figure 10. Location of the accidents for the case of the BRT line A.

4. Discussion and conclusion

One of the biggest challenges facing megacities, such as Mexico City, lies in lagging infrastructure. That is, these cities continue to add population, without the infrastructure paralleled the growth [28]. An example of a lack of infrastructure is that related to transportation [28]. Further, in the ultra-dense environment of developing country megacities, traffic congestion

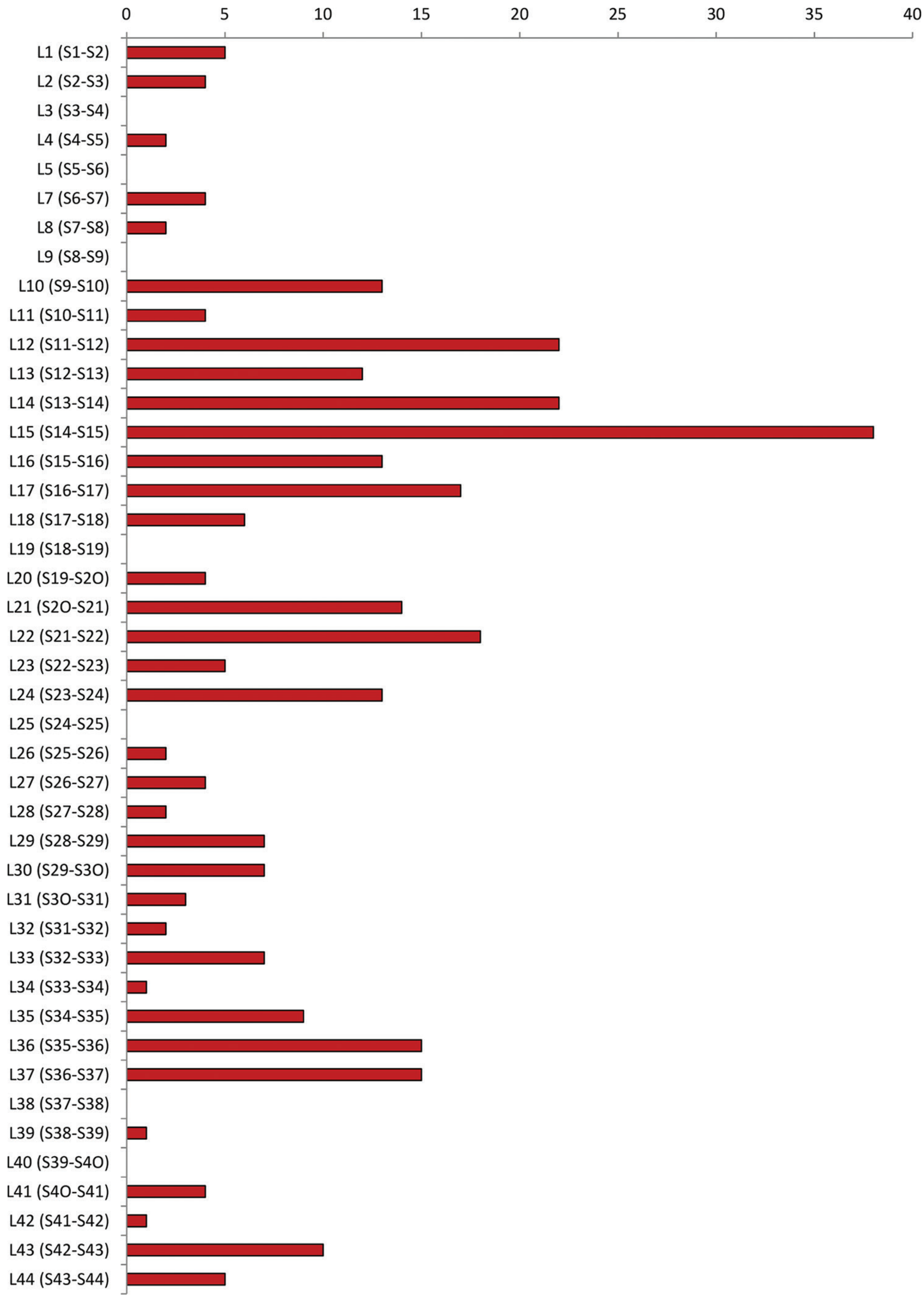

Figure 11. Distribution of the accidents that occurred in the lanes (L) between the stations (S) of the BRT line A.

http://dx.doi.org/10.5772/65583

is also worsening and effectively affecting the urban mobility [28, 29]. In recent years, Mexico City has implemented a number of policies aiming at improving the transport infrastructure by adopting, for example, bus rapid transit (i.e. Metrobus) systems.

Given the above, it becomes essential to prevent accidents associated with BRT systems in order to improve, among other things, road safety associated with BRT systems and therefore the urban mobility of the inhabitants of the capital city (**Figure 12**). In an attempt to understand BRT-related accidents, the authors have built a BRT accident database for the case of Mexico City. Some results of a statistical analysis of these have been presented here. The aim has been to understand, *inter alia*, the general pattern of the frequency of accidents occurrence during the day, weekdays, months, and year and to locate the BRT lanes of major occurrence. However, the variable associated with the cause of these accidents has not been considered here (however, it should be mentioned that the immediate cause of most of the accidents has been that motor cars at regular lanes crossed over BRT lanes). That is, it may be argued that BRT-related accidents should be fully analysed to understand the causal factors leading to their occurrence; this may be the only way to gain a better understanding of the multicausal factors and prevent future recurrence [27]. This may be regarded as a limitation of the present analysis. It also should be mentioned that given the lack of data some of the variables such as pedestrians being killed during the collisions are reported from 2008 to 2015 only (Sections 3.6 and 3.7).

Figure 12. Example of a BRT accident in the city and affecting urban mobility [33].

Overall, it has been found that there have been 484 accidents when considering both lines A and B and the most critical years have been 2008, 2011 and 2012; the least critical year, on the other hand, has been 2010 (Section 3.1). The latter is quite surprising given the fact that by this year there were the two lines operating (lines A and B). However, at this stage we are unable to explain as to why 2010 registered only 18 accidents. The results also show a general tendency of decreasing the frequency of accident occurrence for the lines considered in the analysis. This may be explained given the fact that the road conditions, among other things, have been improved in recent years. For example, a study associated with an assessment of road conditions found that there were many deficiencies associated with road infrastructure endangering public safety [30]. For example, the report stresses that there had been only one traffic light to control the pedestrians crossing in several wide intersections. Further, it is believed that pedestrians are expected to take 11 s during the crossing; no pedestrian traffic lights and sidewalks in poor condition and with no ramps for the disabled were found in the study. The report also found that unfortunately heavy good vehicles (HGVs) still are allowed to circulate in avenues where Metrobus circulates in counterflow and carrying up to 150 passengers on board. Effectively, this (HGV) represents an additional risk factor for accidents. The human factors component is also crucial in road accident occurrence [31]. The CENAPRA [30] report found that pedestrians carelessly cross (the street) endangering their safety; further, the results of BRT accident analysis have been found that human error has been a contributing factor for accident occurrence; motor car drivers (HGV and BRT drivers) very often ignored the red lights [27].

The results have also highlighted that when considering the accident occurrence by month, the most critical seasons of the year have been during autumn (line A: 27.7%; 97/350), and winter (line B: 18%; 18/134). Again, at this stage of the ongoing research project, we are unable to comment on the reasons for this; however, we can say that by conducting a comprehensive accident analysis we may be able to find the causal factors of the accidents and shed some light on the reasons for this [27]. It also has been found that the frequency of accidents at weekends decreases sharply for both lines (Section 3.3). This was expected given the fact that most of the commuters avoid going to the city centre and prefer staying home and this is in line with the number of riders reported at the weekends.

However, what is clear is that when accidents occur, megacities such as Mexico city usually cause traffic congestion which in turn causes slower speeds, longer travel times and increased vehicular queuing, that is, when traffic demand is great enough that the interaction between vehicles slows the speed of the traffic stream, this results in congestion (**Figure 12**). Another of the findings of the study is that accidents occur throughout the whole BRT operational hours (i.e. 06:00 till midnight). In other words, accidents have occurred in peak hours, for example, it has been found that 48.23% (169/350) of accidents have occurred at the three peak hours in line A; 14.23% occurred at evening/night peak hours. Similarly, 25% occurred for the same peak hours in line B (Section 3.5). This raises the following question: do BRT accidents affect mobility in megacities such as Mexico city? Vermeiren [32] argue that urban growth decreases individual mobility and argue, "An individual is considered highly mobile when he or she is able to easily and comfortably reach his or her destination(s) in space and time." Effectively, this is dependent, among other things, on the city's transportation network free of accidents. The following examples illustrate what happens when accidents associated with BRT occur in Mexico City [33]:

"Although there were no injured the (BRT) service was interrupted as passengers had to descend and wait another (BRT) unit. This accident further complicated traffic on the 4 South Av which was particularly affected by the increase in vehicle load as a result of the day back to school."

"A (BRT) collision occurred at Insurgentes Av…, causing traffic chaos…The police arrived on the scene to expedite the affected traffic in the area."

http://dx.doi.org/10.5772/65583

Further, Kotkin [28] argue that traffic congestion has a number of negative effects, for example, (a) motorists and passengers lost time. As a non-productive activity for the affected people, congestion reduces the city's economic health; (b) delays, which may result in late arrival for employment, meetings and education, resulting in lost business, disciplinary action and other personal losses; (c) wasted fuel increasing air pollution and CO_2 emissions owing to increased idling, acceleration and braking; (d) affectation of emergency services, for example, blocked traffic may interfere with the passage of emergency vehicles travelling to their destinations where they are urgently needed; (e) higher probability of collisions due to tight spacing and constant stopping and going.

In summary, the results presented here have shown a number of trends that may help to better plan to prevent congestion and improve, among other things, urban mobility in the Capital City. Some of the key conclusions are the following:

a. Four hundred and eighty-four accidents have occurred when considering both lines A and B. The most critical years have been 2008, 2011 and 2012; the least critical year, on the other hand, has been 2010.

b. Overall, the frequency of accident occurrence has been decreasing in both lines.

c. The most critical seasons of the year have been the following: autumn (27.7% in line A) and winter (32% in line B).

d. The frequency of accidents increases when approaching the end of the week (Thursday and Friday) and the frequency of accidents decreases sharply at weekends.

e. 48.28 and 54.47% of accidents have occurred at the three peaks (i.e. morning, afternoon and evening/night) in lines A and B, respectively).

f. 64.8% (22/73) of pedestrians have been killed when collided with the BRT buses.

g. The most critical section of the BRT lane has been identified with 38 (11.87%) accidents and for the case of line A.

Acknowledgements

The project was funded under the following grant: SIP-IPN: No. 2016149.

Author details

Jaime Santos-Reyes*, Vladimir Ávalos-Bravo and Diego Padilla-Pérez

*Address all correspondence to: jrsantosr@hotmail.com

Grupo de Investigación SARACS, ESIME, ZAC, Instituto Politécnico Nacional, México City, México

References

[1] Weinstock, A., Hook, W., Replogle, M., Cruz, R. Recapturing Global Leadership in Bus Rapid Transit-A Survey of Select U.S. Cities. USA: Institute for Transportation & Development Policy; 2011.

[2] Global BRT Data. Produced by bus rapid transit across latitudes and cultures and EMBARQ, in partnership with IEA and SIBRT [Internet]. 2014. Available from: http://brtdata.org. [Accessed: 1 June 2016].

[3] Hidalgo, D. Bus rapid transit: worldwide history, key systems and future directions. Encyclopedia of sustainability science and technology [Internet]. 2011. Available from: http://www.springerreference.com/docs/html/chapterdbid/308766.html. [Accessed: 1 June 2016].

[4] ITDP (Institute for Transportation and Development Policy). Bus Rapid Transit Planning Guide. 3rd ed. USA: ITDP; 2007.

[5] USFTA (U.S. Federal Transit Administration). Boston Silver Line Waterfront Bus Rapid Transit (BRT) 2007 Project evaluation [Internet]. 2007. Available from: http://www.docstoc.com/docs/857934/Boston-Silver-Line-Waterfront-Evaluation. USA [Accessed: March 23, 2011].

[6] Yazici, M., Levinson, H., Ilicalli, M., Camkasen, N., Kamga, C. A bus rapid transit line case study: Istanbul's Metrobus System. Journal of Public Transportation. 2013;**16**(1):153–177.

[7] Delmelle, E.C., Casas, I. Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia. Transport Policy. 2012;**20**:36–46. DOI: http://dx.doi.org/10.1016/j.tranpol.2011.12.001

[8] Lin, Z., Wu, J. Summary of the application effect of bus rapid transit at Beijing south-centre corridor of China. Journal of Transportation Systems Engineering & Information Technology. 2007;**7**(4):137–142. DOI: http://dx.doi.org/10.1016/S1570-6672(07)60034-8

[9] Mejía-Dugand, S., Hjelm, O., Baas, L., Alberto Ríos, R. Lessons from the spread of bus rapid transit in Latin America. Journal of Cleaner Production. 2014;**50**:82–90. DOI: http://dx.doi.org/10.1016/j.jclepro.2012.11.028

[10] Rizvi, A., Sclar, E. Implementing bus rapid transit: A tale of two Indian cities. Research in Transportation Economics. 2014;**48**:194–204. DOI: http://dx.doi.org/10.1016/j.retrec.2014.09.043

[11] Munoz, J.C., Batarce, M., Hidalgo, D. Transantiago, five years after its launch. Research in Transportation Economics. 2014;**48**:184–193. DOI: http://dx.doi.org/10.1016/j.retrec.2014.09.041

[12] Tirachini, A. The economics and engineering of bus stops: Spacing, design and congestion. Transportation Research-Part A. 2014;**59**:37–57. DOI: http://dx.doi.org/10.1016/j.tra.2013.10.010

[13] Cervero, R., Kang, C.D. Bus rapid transit impacts on land uses and land values in Seoul, Korea. Transport Policy. 2011;**18**:102–116. DOI: http://dx.doi.org/10.1016/j.tranpol.2010.06.005

[14] Hensher, D.A., Golob, T.F. Bus rapid transit systems: A comparative assessment. Transportation. 2008;**35**:501–518. DOI: http://dx.doi.org/10.1007/s11116-008-9163

[15] Hidalgo, D., Lleras, G., Hernández, E. Methodology for calculating passenger capacity in bus rapid transit systems: Application to the Transmilenio system in Bogotá, Colombia. Research in Transportation Economics. 2012;**39**(1):139–142. DOI: http://dx.doi.org/10.1016/j.retrec.2012.06.006

[16] Nugoro, S.B., Fujiwara, A., Zhang, J. The influence of BRT on the ambient PM10 concentration at roadside sites of Trans Jakarta Corridors. Procedia Environmental Sciences. 2010;**2**:914–924. DOI: http://dx.doi.org/10.1016/j.proenv.2010.10.103

[17] Currie, G., Delbosc, A. Assessing bus rapid transit system performance in Australasia. Research in Transportation Economics. 2014;**48**:142–151. DOI: http://dx.doi.org/10.1016/j.retrec.2014.09.012

[18] Clifton, G.T., Mulley, C., Hensher, D.A. Bus rapid transit versus heavy rail in suburban Sydney—Comparing successive iterations of a proposed heavy rail line project to the pre-existing BRT network. Research in Transportation Economics. 2014;**48**:126–141. DOI: http://dx.doi.org/10.1016/j.retrec.2014.09.010

[19] Hensher, D.A., Li, Z., Mulley, C. Drivers of bus rapid transit systems e influences on patronage and service frequency. Research in Transportation Economics. 2014;**48**:159–165. DOI: http://dx.doi.org/10.1016/j.retrec.2014.09.038

[20] Tao, S., Corcoran, J., Mateo-Babiano, I., Rohde, D. Exploring bus rapid transit passenger travel behaviour using big data. Applied Geography. 2015;**53**:90–104. DOI: http://dx.doi.org/10.1016/j.apgeog.2014.06.008

[21] Wöhrnschimmel, H., Zuk, M., Martínez-Villa, G., Cerón, J., Cárdenas, B., Rojas-Bracho, L., Fernández-Bremauntz, A. The impact of a bus rapid transit system on commuter's exposure to Benzene, CO, PM2.5 and PM10 in Mexico City. Atmospheric Environment. 2008;**42**:8194–8203. DOI: http://dx.doi.org/10.1016/j.atmosenv.2008.07.062

[22] Levinson, H., Zimmerman, S., Clinger, J., Gast, J., Rutherford, S., Bruhn, E. Implementation guidelines. Transit Cooperative Research Programme Report 90. In: Transportation Research Board, editor. Bus Rapid Transit (Vol. 2). Washington, D.C.: National Academies; 2003.

[23] Wright, L., Hook, W. Bus Rapid Transit Planning Guide. New York, NY, USA: Institute for Transportation & Development Policy; 2007.

[24] MB (Mercedes-Benz). BRT in Mexico City, Mexico: Metrobus linea 3 corridor – An example of a successful BRT solution in one of the biggest cities in the world. Mexico: MB (Mercedes-Benz); 2013.

[25] Metrobus. Fichas técnicas [Internet]. 2016. Available from: http://www.metrobus.cdmx.gob.mx/fichas.html [Accessed: 5 June 2016]

[26] INISG (National Institute of Statistics and Geography). Methodological summary of road traffic accidents statistics in urban and suburban areas. Mexico: NISG; 2009.

[27] Santos-Reyes, J., Ávalos-Bravo, V. A preliminary analysis of two bus rapid transit accidents of Mexico City's transport system. Procedia Engineering. 2014;**84**:624–633. DOI: http://dx.doi.org/10.1016/j.proeng.2014.10.479

[28] Kotkin, J., Cox, W., Modarres, A., Renn, A.M. The Problem with Megacities. USA: Chapman University Press; 2003.

[29] Heinrichs, D., Krellenberg, K., Hansjürgens, B., Martínez, F. Risk Habitat Megacity. Springer; 2012. 366 p. DOI:10.1007/978-3-642-11544-8.

[30] NCIP (National Center for Accident Prevention). Road safety audit in Metrobus line 2. Mexico: Secretary for Prevention and Health Promotion; 2009.

[31] AASHTO (American Association of State Highway and Transportation Officials). A Policy on Geometric Design of Highways and Streets. USA: AASHTO; 2001.

[32] Vermeiren, K., Verachter, E., Kasaija, P., Loopmans, M., Poesen, J., Rompaey, A.V. Who could benefit from a bus rapid transit system in cities from developing countries? A case study from Kampala, Uganda. Journal of Transport Geography. 2015;**47**:13–22

[33] El Universal. Carambola de transporte público en el D.F. Available from: http://fotos.eluniversaldf.mx/coleccion/muestra_fotogaleria.htmal?idgal=13339 [Accessed: 5 June 2016].