Escola de Camins
Escola Tècnica Superior d'Enginyeria de Camins, Canals i Ports
UPC BARCELONATECH

Public Transport road safety risk for pedestrians and cyclists?

Case Study of Santiago de Chile

MASTER FINAL THESIS

Final Thesis developed by:
Rimbaud, Axel

Directed by:
Estrada, Miquel

Master in:
Urban Mobility

Barcelona, **28 June 2023**

Department of Civil Engineering School

Public Transport road safety risk for pedestrians and cyclists?

Case Study of Santiago de Chile

Abstract

This research examines the severity of the road crashes involving public transport buses in Santiago de Chile from 2017 to 2021, particularly crashes involving pedestrians and cyclists. The study reveals that public transport buses play a significant role in fatal crashes, they are involved in 26.2% of the pedestrian fatalities; 26.9% of the cyclist fatalities and 19.5% of all fatalities. Pedestrians constitute the majority (55.8%) of fatalities in bus-related crashes.

For crashes between pedestrians and public transport buses, older and male pedestrians are more likely to be involved in a fatal crash. Those crashes are more likely to be fatal at night, at an intersection or with a bus turning or restarting.

Female bus drivers are less likely to be involved in pedestrian fatal crashes, suggesting the importance of increasing their representation.

The research also evaluates the impact of the implementation of an integrated public transport system "Transantiago" in Santiago, which significantly reduced fatalities in crashes involving buses. The findings support the implementation of integrated transport systems and indicate potential safety benefits for other Chilean cities (which have a higher rate of fatalities in crashes involving public transport buses).

During the 2017-2021 period, fatalities in bus-related crashes have notably decreased. Factors such as the reduction of the number of kilometres travelled by public transport and roll out of a new bus fleets seem to have help this reduction. However, other factors like: the 2019 Chilean protests, the COVID-19 pandemic, the increase of number of female drivers, new bus lanes with automated enforcement and bus maintenance improvement may have contributed to this reduction as well.

This research emphasizes the need for targeted road safety policies for buses and proposes a set of recommendations to be implemented by Public Transport Authorities.

Keywords: Road Safety; Public transportation; Public transport buses; Pedestrian-bus crashes; Cyclist-bus crashes; Severity; Female drivers; Transantiago; Red Metropolitana de Movilidad; Safe System

¿Riesgo del transporte público para la seguridad vial de los peatones y ciclistas?

Caso de Estudio de Santiago de Chile

Resumen

Esta investigación examina la severidad de los siniestros de tránsito que involucran buses de transporte público en Santiago de Chile desde 2017 hasta 2021, particularmente los siniestros con peatones y ciclistas involucrados. El estudio revela que los buses de transporte público tienen un impacto en los siniestros fatales, ya que representan el 26,2 % de las muertes de peatones; 26,9% de las muertes de ciclistas y 19,5% del total de las víctimas fatales. Los peatones constituyen la mayoría (55,8%) de las muertes en siniestros de tránsito con buses del transporte público involucrado.

En los atropellos a peatones por buses del transporte público, es más probable que los peatones mayores y hombres estén involucrados en un siniestro fatal. Es más probable que los siniestros fatales entre peatones y buses ocurran de noche, en una intersección o cuando un autobús gira o reinicia su marcha.

Es menos probable que las conductoras de bus se vean involucradas en un atropello fatal a peatones, lo que sugiere la importancia de aumentar la proporción de mujeres conductoras.

La investigación también evalúa el impacto de la implementación de un sistema integrado de transporte público "Transantiago" en Santiago, que redujo significativamente las fatalidades que involucran autobuses. Los resultados respaldan la implementación de sistemas de transporte públicos integrados e indican posibles beneficios a nivel de seguridad vial para otras ciudades chilenas (que tienen una tasa más alta de muertes en siniestros de tránsito que involucran buses del transporte público).

Durante el periodo 2017-2021, las muertes en siniestros de tránsito con buses del transporte público involucrados han disminuido significativamente. Factores como la cantidad de kilómetros recorridos por los buses y el despliegue de una nueva flota de buses parecen haber aportado a esta diminución. Pero otros factores como: el estadillo social de 2019, la pandemia de COVID-19, el aumento de la cantidad de conductoras, nuevas pistas "solo bus" acompañadas con cámaras de fiscalización y un mantenimiento mejorado de los buses pueden haber contribuido a esta disminución también.

Esta investigación enfatiza la necesidad de crear políticas de seguridad vial para el sistema de bus del transporte público y propone un conjunto de recomendaciones para ser implementadas por las autoridades de transporte público.

Palabras clave: Seguridad Vial; Transporte público; Siniestros de tránsito; Buses del transporte público; Peatones; Ciclistas; Severidad; Conductoras; Transantiago; Red Metropolitana de Movilidad; Sistema Seguro

Foreword

This document deals with road traffic injuries, numbers and models are presented and discussed. It is important to remember that those numbers represent people who have died or got injured. Behind each value there are some broken hearts, unfinished dreams and destroyed families. In order not to forget this fact, this thesis is dedicated to three road crashes victims and their loved ones.

To Valeria Andrea Gazzano Archiles, killed after being hit by a bus driver, while she was cycling. She was, and always will be, 21 years old. Her fight to create a just and fair society will continue through her friends and family.
To the sisters Isabel (18) and Eugenia (7) La Cruz Pappaterra, who have been killed while crossing the street outside of school by a bus driver who did not respect a red traffic light. Even 5 years later they are still angels for their parents.

Thanks and acknowledgements

From the Universitat Politècnica de Catalunya (UPC), I would like to thank Miquel Estrada, my thesis director, for all his help and advises, David De Zea Graells who helped me so much getting the right statistical tools and Ahmad Aiash who helped me understand the crash severity models.

From the Directorio de Transporte Público Metropolitano de Santiago (DTPM), I wish to thank Margarita Castañeda, Pablo Arriagada, Paula Valenzuela and Daniela Rubio from the "Convivencia Vial" team for their help but more importantly for their work every day to make public transport safer in Santiago de Chile.

From the Comisión nacional de Seguridad de Tránsito de Chile (CONASET), I am deeply indebted to Pilar Basterrica and Carla Medina who have been working on the Chilean road safety data for years and always helped me understand them better.

I would also like to extend my gratitude to Ariel Lopez, for his insightful suggestions but also for working to make visible the issue of crashes involving public transport buses in Santiago.

Many thanks to my road safety mentor Matts-Ake Belin who is always available to answer my questions and help me having a holistic vision of road safety and the safe system.

I very much appreciate the help of Laurent Carnis in order to keep my research goals clear.

I also wanted to thank Pedro Scarpinelli, Martin Galanternik and Govert Schermers. With the guidance of Govert, Pedro, Martin and me, made a draft of safe system road safety plan for public transport buses during this year Delft Road Safety Training course. Working together with them was a great experience and helped me create the list of recommendations presented in this research.

I would like to acknowledge the assistance of Erik Jenelius from KTH, for his public transport course and for his advice for this thesis.

I am also grateful to Paola Tapia, Gloria Hutt and Juan Carlos Muñoz, the 3 last Chilean Minister of Transport and Telecommunications. I believe their work has been central in the diminution of fatalities in crashes involving public transport buses. They also have been opened to talk about those subjects with the civil-society organizations like the one I represent.

I would like to express a special thanks to Chantal Perrichon, president of the "Ligue contre la violence routière" for her work and her inconditional support over the years.

I am extremely grateful to all the past and current members of the Movimiento contra el Exceso de velocidad Letal (MEL) for their work and time to help avoiding road crashes in Chile. Finally, I would like to thank both my Chilean and French families for always believing in me and for giving me the drive to keep working to improve road safety.

Table of content

Index of tables

Index of figures

1. Introduction and objective

Every year 1.35 million people die and up to 50 million get injured on the world's roads, making of road crashes the leading cause of death for children and young adults (aged between 5 and 29 years old). According to the World Health Organization (WHO), *"road traffic injuries is the eighth leading cause of death for all age groups surpassing HIV/AIDS, tuberculosis and diarrhoeal diseases"* (WHO, 2018). On top of that "*road traffic crashes are estimated to cost countries approximately 3% of their GDP, with the economic losses in low- and middle-income countries equivalent to 5% of GDP*" (WHO, 2017).

As many cities and countries are putting effort to reduce the number of people killed and seriously injured on the roads, public transport authorities have an important role to play. Public Transport has the potential of improving the level of road safety. According to the International Association of Public Transport (UITP, from the French: L'Union Internationale des Transports Publics), "*the role of public transport is currently overlooked in most road safety planning even though cities with higher public transport have proven to cut their traffic fatality rate by half*" (UITP, 2020).

According to the American Public Transportation Association (APTA, 2016) "*public transportation is one of the safest ways to travel. It is ten times safer per mile than traveling by car because it has less than a tenth the per-mile traffic casualty (injury or death) rate as automobile travel. Public transit-oriented communities are five times safer because they have about a fifth the per capita traffic casualty rate as automobile-oriented communities. In addition, crash rates tend to decline as public transit travel increases in a community. Contrary to popular perceptions, public transit travel is significantly safer than automobile travel*".

While the level of safety of bus drivers and bus passengers is higher than most other road users. Public transport has other road safety implications. There are many possible conflicts between the bus network and active mobility users. Indeed, buses are heavy vehicles which can caused death or serious injuries at low speed (ITF, 2016), have many drivers vision blind spots (SAAQ, 2022) and high turn radius (NACTO, 2016a). For instance, in the city of Santiago de Chile more than 30% of the users involved in road crashes where a pedestrian or cyclist lost their life, are buses drivers (Rimbaud, 2022).

As systematic perspective to road safety management like the Swedish Vision Zero (Belin, 2021) or the Dutch Sustainable Safety (Vegman, 2021) have been more important in the last years. Many countries have adopted a "safe system" approach to road safety (ITF, 2022). The guiding principles are that (ITF, 2016):

- *"People make mistakes that can lead to crashes. The transport system needs to accommodate human error and unpredictability.*
- *The human body has a known, limited physical ability to tolerate crash forces before harm occurs. The impact forces resulting from a collision must therefore be limited to prevent fatal or serious injury.*
- *Individuals have a responsibility to act with care and within traffic laws. A shared responsibility exists with those who design, build, manage and use roads and*

vehicles to prevent crashes resulting in serious injury or death and to provide effective post-crash care.
- *All parts of the system must be strengthened in combination to multiply their effects, and to ensure that road users are still protected if one part of the system fails."*

According to these visions, as people make mistake and that leads to crashes, it is important to make sure those crashes are not severe or fatal. On top of that, public authorities also have a big share of the responsibility to make sure the system they put in place is safe. In case of public transport buses, the element contributing to high crash severity should be studied, especially the one involving the less protected road users like pedestrians and cyclists. Besides, as urban bus public transport is mainly managed by public authority, they must make themselves responsible for the safety of the bus system. Finally, it is important to investigate how changes in the public bus system can have an impact on the number of fatalities.

Objective

The main objective of this research will be to study and offer solutions to prevent road crashes involving public transport buses in Santiago de Chile, particularly crashes involving pedestrians and cyclists.

In order to achieve this objective, this research will be to answer the following questions:

- What is the impact public transport buses on road safety in Santiago?
- Which risk factors increase the severity of road crashes between public transport buses and pedestrians in Santiago?
- Which risk factors increase the severity of road crashes between public transport buses and cyclists in Santiago?
- How does Santiago compare to other cities in term of public transport bus road safety?
- What were the effects on road safety of the public transport bus policies implemented in Santiago?
- Which strategies and measures could be put in place to improve road safety of public transport buses?

To fulfil this objective and answer those questions, this document will study the factors influencing the severity of road crashes between public transport buses and pedestrians or cyclists in the case of the Santiago de Chile. On top of that, the impact of changes in public transport bus system in Chile on road crash fatalities involving a public transport bus will be investigated. In the first part of this document, the specific context of road safety and public transport buses will be presented. The second part will consist of a literature review of the possible factors influencing the severity of road crashes, especially road crashes involving pedestrians, cyclists and buses. Models to estimate the impact of those parameters will be presented, as well as models to evaluate the effect of road safety policies. In the fourth part, the methodology and data used to select the important factors involved in high severity crashes between public transport buses and cyclists or pedestrians will be introduced, as well as the methods to evaluate the effect of public transport buses system. The results will be then presented in the fifth part and discussed in the sixth part. Finally, in part seven, some recommendations to improve the road safety level of public transport networks will be listed and described.

2. Context

2.1. Road safety in Chile

Road safety is a problem increasingly important in Chile, the number of reported fatalities increased from 1483 in 2017 to 1688 in 2021, which represents an increase of 13.8%. According to the provisional data for 2022, the number of reported fatalities is even higher, reaching 1745 lost lives and making it the worst year since 2008 (CONASET, 2023). In Chile, road crashes are the first cause of death for people aged between 5 to 44 years old (WHO, 2020).

Pedestrians, cyclists and motorcyclists, sometime refers as vulnerable or unprotected road users as they are not shielded by some type of structure, are some of the users most impacted by road crashes (Fresard et al., 2017). Between 2017 and 2021, they represented 48% of the road fatalities in Chile.

2.2. Public transport buses in Santiago

In the 80's, the public transport buses in Santiago were mostly deregulated. This started to change in 1990 with the publication of the Supreme Decree No. 212 from the Ministry of Transport and Telecommunications. This decree regulated public passenger transport services, it was followed by a call for concession, where the colour of the buses and a mandatory registration of the routes with the ministry of transport was stipulated. This increased the environmental and operational requirements. The colour of the buses was unified (yellow with a white roof). Additionally, a feeder service to the metro stations (Metrobus) was created, thereby allowing a service (Metro + Bus) which had a discount compared to its separate trips. However, in this system, drivers were competing for passengers, and this led to high speeding and dangerous driving behaviours.

The public transport system of the Santiago Metropolitan Region changed its structure in 2007. In February of that year, all the planning of the system was left in the hands of the Ministry of Transport and Telecommunications through the Transantiago Coordination, which physically and fare-integrated all the urban public transport buses in the city, operated by private companies, and the Santiago Metro, through a single means of electronic access (DTPM, 2018).

The migration started at the end of 2005 with part of the fleet migration to the new operators (Cooperativa, 2007). However, the operational changes were implemented done as a “big bang”, changing all the routes and reducing the vehicle fleet in one go. Unfortunately, when the system started functioning most of the infrastructure and operating conditions were not in place. Also, the bus fleet was not enough to cope with the level of demand. This led to waiting times and crowding levels worse than those in the previous bus system. In Chile, Transantiago has been considered by many as one of the worst public policies ever implemented in the country (Muñoz et al 2014).

However, it is estimated that this policy helped reduced externality. The number of road crashes involving buses has been reduced for several reasons including: drivers working shorter shifts, drivers not competing anymore in the street, vehicles better maintained and not circulating anymore with their doors opened (Muñoz et al 2014).

In 2013, the Metropolitan Public Transport Directory of Santiago (DTPM) was created with greater responsibilities and a more preponderant role in the field of regulation, control and supervision of the System. This entity is in charge to ensure the proper coordination of the different modes that participate in public transport in the city of Santiago (DTPM, 2013).

In 2017, maximum pollutant emission levels for public buses were set in Santiago. This legal framework pushed the bus fleet to change incorporating cleaner vehicles. by the end of 2019, 996 zero- or low-emission buses were circulating in Santiago which represent 14% of the total fleet (SLOCAT, 2021).

As part of this change in 2019, a new system named “Red Metropolitana de Movilidad” or “Red” was presented. This new system has higher vehicles standards and separated tenders for bus fleet and bus operation. Also, the transition to this new system is to be done progressively with various tenders (RED, 2019, 2021). Learning from the failure of Transantiago implementation, the system “Red” should be slowly rolled out over many years.

One of the advantages of the new model is that it allows supervision of the maintenance and increases safety standard of the buses. The new buses have a better visibility and come with a speed limitation system. It is expected that the roll out of this new fleet would bring some road safety benefits (DTPM, 2022a).

The evolution of the Santiago public transport system can be seen in Figure 1.

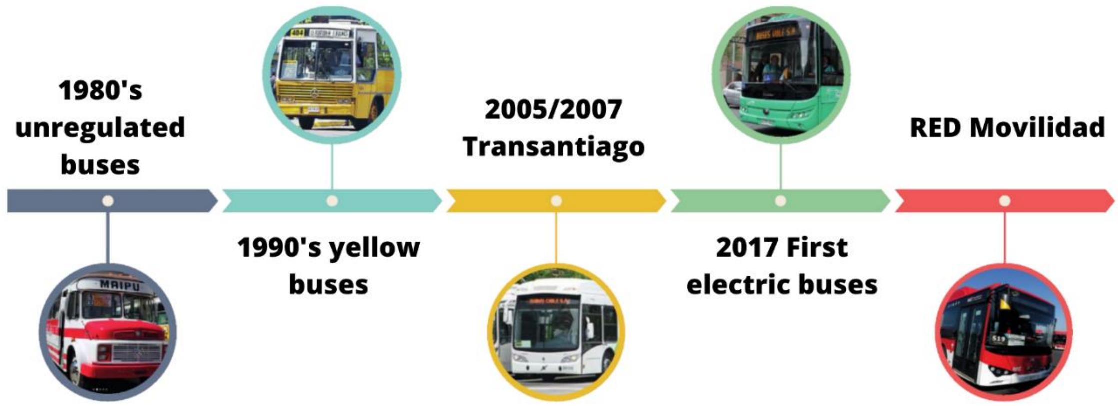


Figure 1 - Evolution of the public transport bus system in Santiago de Chile (Tapia, 2023)

Finally, the public transport in Santiago has been impacted by various crisis lately. In 2019, big demonstrations happened in Santiago and then spread to the rest of the country. During the first days of the manifestation, 80 of the 136 metro stations on the network were damaged, 11 of them completely destroyed after being set on fire (bnamericas, 2019). Between Octobre 2019 and July 2021, 125 public transport have been burned (24 horas, 2021). In March 2020, some mobility restrictions were put in place in Santiago because of COVID 19 pandemic. This provoked a strong reduction of the number of trips in the city as well as the traffic flow (MTT, 2020).

Those events had a big impact on the public transport buses demand, the number of yearly transactions decrease from 892 million in 2018 to 789 million in 2019, and then 296 million and 381 million in 2020 and 2021 respectively (DTPM, 2022a).

2.3. Impact on road safety of public transport buses

With the destruction of many stations of the Santiago Metro network during the Chilean 2019 protests (Estallido Social) and the sanitary restriction due to the COVID-19 pandemic, the number of cyclists in the street of Santiago sharply grew. This was accompanied by an increase in the number of cyclists fatalities in the city (MDSF, 2020). While part of the cyclist fatalities increases was due to a higher exposition, other factors like the increase of speed and the lake of traffic rule enforcement were also involved. This created a strong social movement requesting better cyclist infrastructure and road safety. Many massive demonstrations were organized with the slogan "No más ciclistas muertos" or "no more dead cyclists" in English (Revolución Ciclista, 2021).

Many of the cyclist fatalities which appeared in the press were due to crashes involving a bus driver from the public transport. This created a great concern for the level of road safety risk of the public transport in Santiago. The speed of the bus started to be monitored and it showed that most of the public transport buses were speeding very frequently (Cooperativa, 2022).

On top of that, it was shown that between 2011 and 2020, bus drivers represented 32% of road users involved in pedestrian fatalities and 33.3% of the users involved in cyclist fatalities (Rimbaud, 2022). However, this information considers all bus drivers and not only the bus drivers from the public transport. In Santiago and in Chile, other types of buses also circulate, like school buses, private buses, and coaches travelling between cities (coaches).

In 2022, with the change of government, a new team was created in the Public Transport Authority of Santiago (DTPM) on the matter of the "road coexistence". This team oversees the harmonizing the traffic of buses from public transport with other road users. One of their goals is to reduce road crash fatalities involving buses from the public transport, especially involving pedestrians and cyclists (DTPM, 2022b).

2.4. Road crash policy evaluation

To evaluate the effect of a road safety policy, many researchers use a pre-post analysis (Novoa et al, 2011, Martínez-Gabaldón et al, 2020, Pérez et al., 2023). As the road crash policy can apply to an entire country or city, it is sometime not possible to have a control group. In those cases, it is important to control for effect like time trend, seasonality, kilometres travelled or previous safety interventions in the research models (Martínez-Gabaldón et al, 2020).

In the case of this research, two important elements must be controlled. On one hand, the bus traffic flow which has decreased with the 2019 protests and the COVID-19 pandemic. On the other hand, the bus average speed which has increased with the change in traffic flow a congestion. Literature on the effect of speed will be presented.

Kilometres travelled by buses
Vehicle kilometre travelled (VKT) is measure of exposure. It accounts for the number of vehicles and the distance travelled by those vehicles. It is applicable for crash risk models. Traditional methods account for exposure through linear crash rate. However, the relationship between exposure and number of crashes might depend on different factors like the vehicle types. Therefore, the linear relationship between crashes and VKT will need to be verified before being used. (Gross, 2021).

Average Speed
According to Elvik et al. (2019), the relationship between speed and road safety is the same at driver level as at the aggregate level (mean traffic speed).

The relationship between a change of speed and change of fatal road crashed was modelled by Nilsson (2004) using a power model. This model was then detailed further taking into consideration the type of roads and speed limits (Elvik, 2012).

The effect of policy change which has an impact on the average speed, follows the following formula:

$$C_a = C_b . (\frac{V_a}{V_b})^{\alpha} \tag{1}$$

With:

- C_a number of crashes after the change
- C_b number of crashes before the change
- V_a average speed after the change
- V_b average speed before the change
- α exponent, this exponent depends on the type of crashes (fatal, injury, all) and the type of road (urban, rural, motorway)

Elvik et al. (2019) proposed a new exponential model which can be more appropriated for lower speed. It can be formulated in the following way:

$$C_a = C_b . e^{(\beta(V_a - V_b))} \tag{2}$$

With:

- C_a number of crashes after the change
- C_b number of crashes before the change
- V_a average speed after the change
- V_b average speed before the change
- β coefficient, this exponent depends on the type of crashes (fatal, injury, all) and the type of road (urban, rural, motorway)

3. Literature

In order to reduce climate change effects, lower emissions threating public health, encourage physical activity and reduce congestion, many cities and countries around the world are promoting the use of public transport and active mobility (mainly walking and cycling). This is aligned with various of the Sustainable Development Goals (SDGs) for the United Nations. Indeed, two of the SDGs focus on those topics. The SDG target 3.6 deals with road traffic injuries and aims by 2030 to halve the number of global deaths and injuries from road traffic crashes (WHO, 2021a). While part of the Sustainable Cities and Communities agenda, the indicator 11.2.1 monitors the proportion of population that has convenient access to public transport, by sex, age and persons with disabilities (SDG, 2023).

These indicators are even more important in Latin America where most of the passenger travel via public transport (averaging 68% of all trips). This region has the world's highest per capita bus use and leads in the implementation of Bus Rapid Transit systems (BRT), with BRTs present in 54 cities as of 2019 (SLOCAT, 2021).

The safety of pedestrians and cyclists and their interactions with public transport is becoming more and more important. This is also reflected in the number of publications on the topic. Searching in the Scopus database for related documents; there is a strong increase from 11 publications on the matter in 2010 to 45 publications in 2021 (See Figure 2).

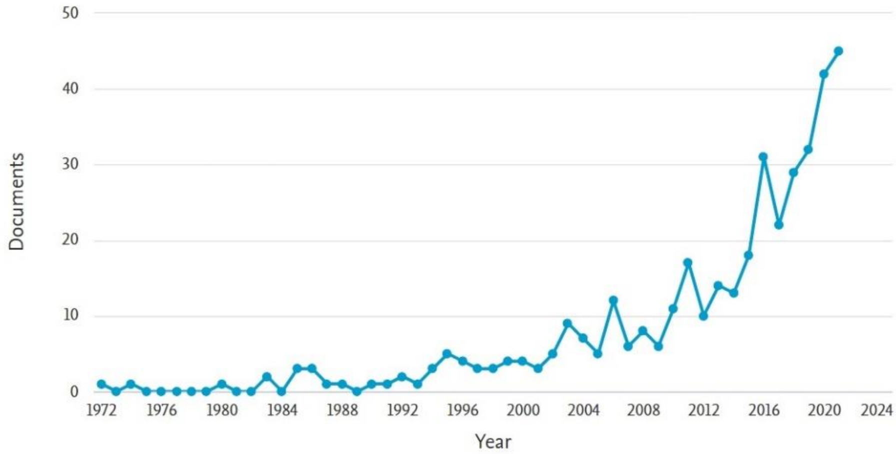


Figure 2 - number of publications on the Scopus platform related to crashes involving pedestrians, cyclists and buses (Scopus, 2023).

To study the severity of road crashes, its relationship with one or multiple explanatory variables (risk factors) are estimated and modelled. In the following section, a literature review of the risk factors which have been linked to higher road crash severity will be presented, followed by the models used to evaluate such relationship. Finally, some models used to evaluate the impact of road safety policies will be introduced.

3.1. Road crash severity risk factors

In this subsection, the literature about various risk factors which can be linked to higher crash severity will be presented. In is noteworthy, that most of the studies on the topic focus on vehicles crashes, or crashes between pedestrians and vehicles. Also in Greater

London, pedestrians account for two-thirds of fatalities involving public transport buses (Edwards et al., 2018).

Speed

Speeding is one of the main issues for road safety it is estimated that "*in high-income countries, speed contributes to about a third of deaths on the roads. In low-and middle-income countries this proportion is likely to be greater, given the higher proportion of deaths among vulnerable road users*" (WHO, 2017).

Speed has two types of effects. First at higher speed, the probability of occurrence of a crash increases, secondly at higher speed if the crash does occur, the impact is more serious.

Road user gender

The road user gender is an important factor related to severe and fatal road crashes. At global level, males under 25 are 2.7 times more likely to be involved in a fatal road crash than their female counterparts. Part of this gap comes down to user behaviour and travel patterns, as male might be more risk takers and in low- and middle-income countries, they may travel longer distances (Yan and Job, 2021). On the other hand, it was found that fatality risk in a given crash is 17% higher for a female than for a male of the same age because vehicles and safety systems are mostly designed for male safety (NHTSA, 2013).

Various study focusing on crash severity have shown that males are more likely to be involved in a severe road crash than females, for example, in the case of Barcelona, Spain (Aisah and Robusté, 2022), Guangdong Province, China (Zhang et al 2014), Scotland (Olowosegun et al. 2022), in central Ohio, United States (Lee et al 2023).

Bus Driver Gender

While the impact of gender on road crash severity is relevant for all road users, it is especially important for bus drivers.

In the city of Bogota, between 2013 and 2017, 18% of the road crashes involving a woman bus driver were injury crashes, while 28% of the road crashes involving a male driver were injury crashes. Likewise, the proportion of fatal crashes within the crashes with victims (injuries or deaths) is 0.4% for women and 1.3% for men (Moscoso et al. 2020). Similarly, in a study done in Santiago de Chile, most of the companies interviewed indicated that women have a lower crash rate than men or that these crashes are less serious. The companies also pointed out that female drivers have a better relationship with bus users compared to men, that women are kinder, empathetic, calm, greet passengers properly and they know how to cope well in conflictive situations, without escalating problems (BID, 2019).

Age

The age of the road users, especially for pedestrians and cyclists, is a very important. Indeed, very young and older people are more fragile and might not be able to recover from a serious injury (Rimbaud, 2020a). Various studies found an increase injury severity for road users of 65 years old or older (Aisah and Robusté, 2022, Chen and Fan, 2018).

The age and experience also have a strong link with people capabilities and behaviour. Young and unexperienced drivers are more likely to be involved in a crash (Vic roads, 2017), while older drivers, can lose little by little, their driving capacity. Vision related problems that may affect driving often occur as a consequence of a natural aging process. (Thorslund and Strand, 2016).

Days of week and weekends

The day of the week or if a day is during the weekend has in influence on the traffic flow (which has an impact on driving speed), the purpose of the trips and also the behaviour of the road users (alcohol consumption, lack of sleep). Weekends are usually associated with higher crash severity (Chen and Fan, 2018, Aisah and Robusté, 2022, Olowosegun et al. 2022).

Time of the day

In the same way, the time of the day has a strong impact on the traffic flow and the congestion, which in turn has an impact on driving speed.

The time of the day will also have an impact on the level of fatigue (Akerstedt et al., 2004) and the consumption of drugs and alcohol. In Chile, between 2010 and 2019, more than 20% of the fatal road crashes are related to alcohol between 04:00 and 5:59, while it is lower than 5% between 10:00 and 16:59 (Rimbaud, 2020a).

The time of the day also has a relationship with nighttime and lighting which will discussed in the following subsection.

Nighttime and lighting

Pedestrians have a higher risk of being involved in a crash at night than during daytime. For drivers, that are no substantial differences between road crash risk between day and night when other factors like alcohol are controlled for. One of the main problems is the difficulties for drivers to detect pedestrians. One explanation is that the ability to steer a vehicle is not affected by darkness, therefore the drivers do not realize of the reduced visibility and do not adjust their driving behaviour (Fors and Lundkvist, 2009). Nighttime fatal injury are 4 times more likely at midblock location and 4.9 times more likely at intersections than during the day. The presence of nighttime lighting reduces greatly fatal crashes (Siddiqui et al. 2006).

Weather

Adverse weather conditions like cold or high temperatures, rain, snow, strong winds can have an impact on the likelihood and the severity of road crashes. Many studies from the Nordic countries focus snowy and icy road conditions (Malin et al., 2019), while research in Asia study the link between heavy rain or high temperature on the likelihood of fatal or serious crashes (Zhai et al, 2019).

As Chile is a very long country, it has very different climates. Between 2010 and 2018, less than 1% of the fatal crashes occurred with rain or drizzle in the region of Atacama, while more than 24% of the traffic fatalities occurred with rain or drizzle in the region of Los Lagos (the lakes). In the region of Santiago, adverse weather conditions were present in less than 5% of the fatal crashes (Rimbaud, 2020b). Additionally, on top of the weather condition itself, the roadway surface condition like the presence of snow, ice or water have an impact on crash severity (Chen and Fan, 2018).

Road characteristics
The location and road characteristics have an impact on the crash severity. Elements like the presence of curves lead to higher risk (Chen and Fan, 2018), the absence of junction control (Olowosegun et al. 2022) or the number and width of driving lanes (Chimba et al 2010) can have an impact on the crash severity.

Manoeuvres
The driver manoeuvres at the moment of a road crash can affect the vehicle speed as well as the energy transferred between the vehicle and pedestrians or cyclists impacted. This can lead to higher crash and severity rate (Shrinivas et al 2023). Specifically for buses, when they travel on the left lanes and make left turns, they have a higher probability to be involved in a road crash (Chimba et al 2010).

3.2. Road crash severity model

Many different models are used to investigate road crashes severity. Some of the most commonly used are:

- logit models (Lee et al, 2023)
- Binary Probit models **(**Aiash and Robusté, 2022), which assume a normal distributed errors
- Ordered Probit Models (Olowosegun et al. 2022), which are used to estimate relationships between an ordinal dependent variable with more than two outcomes (e.g., low, middle or high etc.), and a set of independent variables,
- Multinomial Logit Model (Shankar and Mannering, 1996, Chimba et al 2010, Zhang et al 2014, Chen and Fan, 2018, Hubbert and Doustmohammadi, 2019), used to estimate relationships between a discrete and nominal dependent variable with more than two outcomes (e.g., turning right, driving straight or turning left, etc), and a set of independent variables

4. Methodology

The methodological approach followed in this research will be presented in this section.

4.1. Study area

The chosen study area is the operation area of the Metropolitan Public Transport Authority of Santiago de Chile (DTPM). This includes the province of Santiago (which is formed by 32 municipalities) and the municipalities of San Bernardo and Puente Alto. This area had a population of 6,782,636 inhabitants as of 2019 (INE, 2017).

Greater Santiago is also composed of the following, or part of the following, municipalities Colina, Peñaflor, Lampa, Pirque, San José de Maipo and Padre Hurtado. however, the impact of buses on the road safety in those areas will not be studied as they have different public transport systems. Road crashes happening in rural areas have been removed from this study, as some of them happened in the motorway to access the Santiago.

For the rest of the document, Santiago will be used to refer to this study area.

4.2. Data

The road crash data used are historical data gathered by the Chilean Police (Carabineros de Chile) and integrated in its national system (SIEC2). Those data are then reviewed by the Chilean commission for road safety (CONASET) and share to the public. This database is composed of four tables, “crash”, “people”, “vehicles” and “people-vehicles”. The police do not report fatality up to 30 days after the crash. According to the CONASET, the police records fatalities up to 24 hours after the crash until 2018, and up to 48 hours after the crash since 2019 (CONASET, 2023)

The data have been recomplicated at road user level. For each road user, various indicators are used or calculated. Those indicators can be separated in four categories:

- User information
- Crash condition information
- Crash location information
- Involved driver information

All those parameters are put in relation with the level of severity of the road user. The levels are separated in three levels, fatal injuries (“fallecidos” in the database), severe injuries (“graves” or “menos graves” in the database) and slight or no injuries (“leves” o “ilesos” in the database).

User information

The type of road users is defined by the information provided in the Chilean Police database (“people-vehicles” table). Users of personal mobility vehicles will be counted and referred as cyclists.

The user information used are the gender and the age which are highly relevant for road safety as they have an impact on the behaviour and capacity of the users.

Crash condition information
The date and time of the crash were used to set the time range of the crash (early morning, morning peak, between peaks, afternoon peak, late afternoon), and if the crash occurred on a weekday or during the weekend. The date and time were also used to compute if a crash occurred during the day or at night. This was calculated using the latitude and longitude coordinates of the municipality where the crash occurred and the Sunriset method from the R maptools package (R documentation, 2023)

The weather conditions recorded by the police were used and were separated between good (clear) and bad (Drizzle, rain, mist snow and cloudy) weather conditions.

Crash location information
The crash location information was computed from the “crash” table from the Chilean police information. The type of intersection, the number of lanes and the road direction have been used in this research.

Involved driver information
To check if a road user has been involved in road crash involving a vehicle from the urban public transport, the type of service has been checked and matched to "LOC. COLEC. URBANO" (Urban Public Transport).

For road users involved in crash with a bus from the public transport, the driver information will be taken from the involved urban public transport driver if there is only urban public transport bus involved in the crash.
For other road users, the driver information will be taken from any involved driver if this driver is unique. As cyclists are considered as drivers, cyclist drivers will be removed beforehand when studying cyclists impacted by other drivers.

The gender and age of the driver are taken from “people-vehicles” table. The driver manoeuvres are taken from the “vehicle” table. The “people” table was used to evaluate if a driver was impaired and if a driver is Chilean.

Geolocation
To know the position of the crashes, the geolocated road crashes data of Greater Santiago from the CONASET (Chilean Road safety agency) was used. This information was then merged with the data already processed using the Road Crash ID available in both databases.

However, this data does not contain the total traffic crashes registered in the region, but only those that it was possible to geocode in the urban area, which corresponds to approximately 90% (CONASET, 2022).

New bus fleet
While the amount of new type of buses is not available, this research uses the proportion of Euro VI and electrics buses provided by Santiago public transport authority to estimate the proportion of new buses (DTPM, 2022).

Average bus speed
The monthly average bus speed was requested to DTPM via the Chilean "transparency law" for the period 2012-2021.

4.3. Descriptive statistics

In order to present and describe the data, the two following tables will be made and shared:

- Severity crashes between pedestrians and public transport buses
- Severity crashes between cyclists and public transport buses

Additionality three comparison tables will be created to display possible differences:

- Fatal pedestrian crashes with or without public transport buses involved
- Fatal cyclist crashes with or without public transport buses involved
- Fatal pedestrians or cyclists crashes with or without public transport buses

For all those tables, a Chi-Square test will be performed in order to identify parameters relevant for the severity of the crash or the comparison.

As road crashes and especially fatal road crashes are sparse events, a significant level of 10% will be used in this research.

4.4. Crash severity modelling

In order to predict the severity of a crash involving pedestrians and public transport buses and crashes involving cyclists and public transport buses, Multinomial Logit (MNL) models have been created. MNL models are some of the most used models in the literature to check the relationship between severity and parameters.

For multinomial logit models, the probabilities follow the following formula:

$$P_n(i) = P\left(U_{in} \geq U_{jn}\right) \forall\, j \neq i$$

(3)

With:

- $P_n(i)$ the probably of crash n to result in severity i
- U_{in} the utility of crash n to result in severity i

The utility follows a utility function which can be expressed in the following way:

$$U_{in} = e^{\beta_i X_i} + \varepsilon_{in}$$

(4)

With:

- U_{in} the utility of crash n to result in severity i
- X_i a vector of explanatory variables that determine the severity
- β_i a vector of estimable coefficients for injury outcome i
- ε_{in} unobservable utility component (Captures attributes that we do not include in the model, related to alternative or individual)

Finally, the probably of crash n to result in severity i can be expressed as follow:

$$P_n(i) = \frac{e^{\beta_i X_i}}{\sum_j e^{\beta_j X_j}} \tag{5}$$

In this research the Odds Ratio (OR) of each parameter will be used to present the results.

$$OR_n(i) = e^{\beta_i X_i} \tag{6}$$

Where $OR_n(i)$ represents the Odds Ratio of crash n to result in severity i

Using the data from the descriptive statistics done, for each user group (cyclist, pedestrians) three models will be created. One of them includes only parameters significant at 10%; a second one uses only parameters significant at 20% and a third model with all available parameters.

Finally, this research will use the Akaike Information Criterion (AIC) of each model to compare the goodness of fit and present one model for each impacted user groups (pedestrians, cyclists). AIC can be expressed with the following formula:

$$AIC = 2K - 2\ln(LL) \tag{7}$$

With:

- K the number of independent variables in the model
- LL the log-likelihood estimate

The AIC is a useful metric for this research as many parameters are part of the models and the AIC penalises the addition of new independent variables.

Normalization

To valid the impact on road crash severity of a specific normalized parameter a test of proportion will be used. This test of proportion will assess if two proportions (p_1 *and* p_2) are significantly different.

In order to reject the Null Hypothesis $H_0: p_1 = p_2$
and accept the Alternative Hypothesis $H_A: p_1 \neq p_2$

The following z test can be done:

$$z = \frac{\widehat{p_1} - \widehat{p_2}}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1} + \frac{1}{n_2})}} \tag{8}$$

With:

- $\widehat{p_1}, \widehat{p_2}$ proportion 1 and 2
- $\hat{p}$ average proportion
- n_1, n_2 sample size of proportion 1 and 2

This test will be used to validate if female drivers provoke fatal road crashes at a different rate than male drivers.

4.5. Policy effect modelling

Transantiago implementation

As mentioned in more detail in the context of this research, in 2005-2007 the public bus system changed completely in Santiago. The road safety impact of this policy be analysed with a pre-post study. While most of the change to the system occurred in 2007, in 2005 part of the operation was transferred to the new operators. For that reason, it was decided to use all data available in the before period 2002-2004 (data before 2002 do not have information people-vehicle), this period will be compared to the 5 years following the implementation 2008-2012. A t-test will be conducted in order to do check if there was a significant change in the average yearly number of fatalities.

The change in the number of fatalities in road crashes involving public transport buses will then be compared with the change in the number fatalities in road crashes not involving public transport buses to control for other factors.

Red Metropolitana de Movilidad new bus standard roll out

Since 2017, a fleet of buses is being slowly rolled out, the possible impact of this change will be investigated. In 2019, 2020 and 2021 the public transport system has been impacted by various crisis (Chilean protests, COVID-19 pandemic); therefore, it is important to cater for the changes of traffic flow and commercial bus speed.

To account for the change traffic flow, this research will check if there is a linear relation between bus traffic flow and fatalities during the previous years (2008-2016). If this linear relation is verified, then the fatality (involving a public transport bus) rate by million kilometres travelled by public transport buses will be used instead of the number of fatalities with a public transport bus involved. Then, in order to take into account the change of average speed, an exponential model will be used adapting Elvik et al (2019).

This model will also take into consideration the progressive roll out of the new bus fleet and the average bus speed in Santiago with the following formula:

$$R = \left(a\ (k_{New\ buses}) + \ b\ (1 - k_{New\ buses})\right).\ e^{\beta V} \tag{9}$$

With:

- R rate of road crash fatalities involving a bus from public transport by kilometres travelled by public transport buses (in fatalities by 1 million kilometres travelled)
- $k_{New\ buses}$ the proportion of public buses with the new standard (in %)
- V yearly average speed during working days (in km/h)
- β coefficient for the speed
- a and b will be parameters to be determined by the model. “b” will represent the level of safety of old bus fleet and “a” the new bus fleet

5. Results

In this section, the results of this research will be presented. Firstly, the safety impact of public transport buses in all road users. The crashes involving pedestrians and cyclist will be studied and modelled in more details. Furthermore, this research will present some results on the impact of bus driver gender on road crash fatalities. Then the fatal crash hotspots will be mapped and briefly described. The effects of public transport bus system changes will be analysed and finally the buses road safety situation in Santiago will be compared to other cities in Chile and in the world.

5.1. Road Safety impact of Public Transport buses

The number and the proportion of road crashes with a public transport bus involved was computed for each user type group (Table 1).

Table 1 – Number and proportion of road crash fatalities with a public transport bus involved by user type in Santiago (2017-2021)

User type	Total Fatalities	Fatalities with Public Transport involved
Pedestrians	515	**135 (26.2%)**
Cyclists	104	**28 (26.9%)**
Riders of motorized 2- and 3-wheelers	309	29 (9.4%)
Drivers of 4-wheeled cars and light vehicles	161	23 (14.3%)
Passengers of 4-wheeled cars and light vehicles	109	13 (11.9%)
Drivers of buses	7	3 (42.9%)
Passengers of buses	11	9 (81.8%)
Drivers and passengers of heavy trucks	13	0 (0.0%)
Others	14	2 (14.3%)
Total	1243	242 (19.5%)

The two groups with the higher proportion of fatalities in a road crash with a bus from the public transport involved, are pedestrians and cyclists with 26.2% and 26.9% respectively. This shows that it was a good choice to study specifically the impact of public transport on those two user groups. Pedestrians represent the majority (55.8%) of the fatalities in road crashes involving a public transport bus. More riders of motorized 2- and 3-wheelers died in a crash with a public transport bus than cyclists (29 motorcyclists and 28 cyclists), yet the proportion is much smaller (9.4% for motorcyclists and 26.9% for cyclists). In total 19.5% of the fatalities in study area occurred in a crash with a bus from the public transport.

The number of fatalities with a bus from the public transport system has been plotted per group and per year in Figure 3.

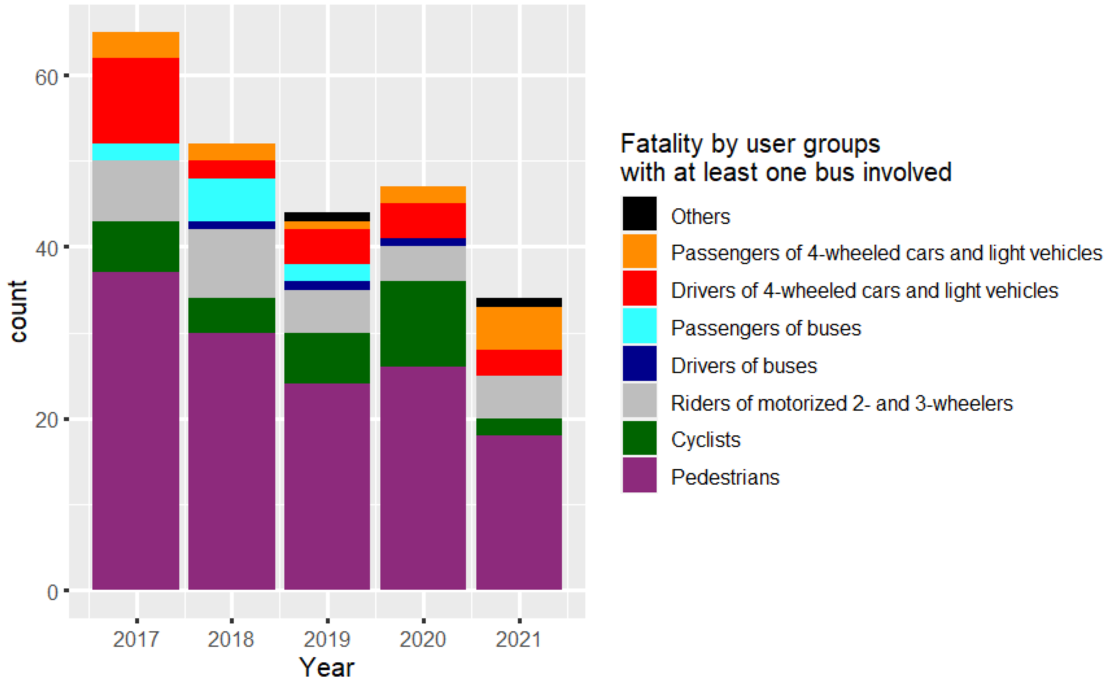


Figure 3 - Number of fatalities involving a public transport bus by year and road user type in Santiago (2017-2021)

The number of fatalities in a road crash involving a public transport bus follows a decreasing trend. The possible explanations of this trend will be study in part 5.10. It is also interesting to note a strong increase of the number of cyclist fatalities in 2020 when the COVID-19 lockdown started in Santiago.

5.2. Crashes between pedestrians and public transport buses

The impact on pedestrians involved in road crashes with a public transport bus can be seen in Table 2. This table displays the number of pedestrians who suffered fatal injuries, severe injuries, or slight injuries or unhurt.

Table 2 - Injury severity of pedestrian involved in a road crash with a public transport bus in Santiago (2017-2021)

	Fatal injuries (N=135)	Severe injuries (N=504)	Slight injuries or pedestrians unhurt (N=694)	Total pedestrians impacted (N=1333)	p value
Gender					< 0.001
Male	98 (72.6%)	274 (54.4%)	330 (47.6%)	702 (52.7%)	
Female	37 (27.4%)	230 (45.6%)	364 (52.4%)	631 (47.3%)	
Age Range					< 0.001
Unknown	5	12	20	37	
0 to 9 years	2 (1.5%)	11 (2.2%)	30 (4.5%)	43 (3.3%)	
10 to 17 years	3 (2.3%)	38 (7.7%)	58 (8.6%)	99 (7.6%)	
18 to 29 years	15 (11.5%)	105 (21.3%)	178 (26.4%)	298 (23.0%)	
30 to 44 years	26 (20.0%)	98 (19.9%)	150 (22.3%)	274 (21.1%)	
45 to 64 years	48 (36.9%)	158 (32.1%)	178 (26.4%)	384 (29.6%)	
65 years and above	36 (27.7%)	82 (16.7%)	80 (11.9%)	198 (15.3%)	

	Fatal injuries (N=135)	Severe injuries (N=504)	Slight injuries or pedestrians unhurt (N=694)	Total pedestrians impacted (N=1333)	p value
is Weekend?					0.119
Weekday	108 (80.0%)	404 (80.2%)	586 (84.4%)	1098 (82.4%)	
Weekend	27 (20.0%)	100 (19.8%)	108 (15.6%)	235 (17.6%)	
Weather Condition					0.597
Bad condition	9 (6.7%)	47 (9.3%)	58 (8.4%)	114 (8.6%)	
Good condition	126 (93.3%)	457 (90.7%)	636 (91.6%)	1219 (91.4%)	
Day or Night?					0.009
Night	56 (41.5%)	169 (33.5%)	200 (28.8%)	425 (31.9%)	
Day	79 (58.5%)	335 (66.5%)	494 (71.2%)	908 (68.1%)	
Crash Time Range					0.117
00:00 - 07:59	22 (16.3%)	72 (14.3%)	80 (11.5%)	174 (13.1%)	
08:00 - 09:59	15 (11.1%)	55 (10.9%)	84 (12.1%)	154 (11.6%)	
10:00 - 17:59	54 (40.0%)	221 (43.8%)	311 (44.8%)	586 (44.0%)	
18:00 - 19:59	11 (8.1%)	62 (12.3%)	105 (15.1%)	178 (13.4%)	
20:00 - 23:59	33 (24.4%)	94 (18.7%)	114 (16.4%)	241 (18.1%)	
Is Junction?					0.528
Junction	70 (51.9%)	265 (52.6%)	346 (49.9%)	681 (51.1%)	
Not Junction	48 (35.6%)	193 (38.3%)	265 (38.2%)	506 (38.0%)	
Others	17 (12.6%)	46 (9.1%)	83 (12.0%)	146 (11.0%)	
Number of Lanes					0.488
Unknown	0	0	2	2	
1	4 (3.0%)	7 (1.4%)	10 (1.4%)	21 (1.6%)	
2	43 (31.9%)	138 (27.4%)	213 (30.8%)	394 (29.6%)	
3	3 (2.2%)	32 (6.3%)	38 (5.5%)	73 (5.5%)	
4	58 (43.0%)	237 (47.0%)	310 (44.8%)	605 (45.5%)	
5 or more	27 (20.0%)	90 (17.9%)	121 (17.5%)	238 (17.9%)	
Road direction					0.526
Two-way	65 (48.1%)	227 (45.0%)	325 (46.8%)	617 (46.3%)	
Two-way with central separation	46 (34.1%)	173 (34.3%)	212 (30.5%)	431 (32.3%)	
One-way	24 (17.8%)	104 (20.6%)	157 (22.6%)	285 (21.4%)	
Driver Gender					0.124
Unknown	1	3	4	8	
Female	3 (2.2%)	21 (4.2%)	41 (5.9%)	65 (4.9%)	
Male	131 (97.8%)	480 (95.8%)	649 (94.1%)	1260 (95.1%)	
Driver Age Range					0.213
Unknown	2	23	70	95	
18 to 29 years	4 (3.0%)	44 (9.1%)	55 (8.8%)	103 (8.3%)	
30 to 44 years	31 (23.3%)	137 (28.5%)	173 (27.7%)	341 (27.5%)	
45 to 64 years	83 (62.4%)	257 (53.4%)	339 (54.3%)	679 (54.8%)	
65 years and above	15 (11.3%)	43 (8.9%)	57 (9.1%)	115 (9.3%)	
Driver Is Chilean?					0.989
Unknown	4	20	53	77	
Chilean	126 (96.2%)	465 (96.1%)	615 (95.9%)	1206 (96.0%)	
Foreigner	5 (3.8%)	19 (3.9%)	26 (4.1%)	50 (4.0%)	
Driver Is Impaired?					0.201
Unknown	4	26	66	96	
Impaired	1 (0.8%)	0 (0.0%)	4 (0.6%)	5 (0.4%)	
Not impaired	130 (99.2%)	478 (100.0%)	624 (99.4%)	1232 (99.6%)	

	Fatal injuries (N=135)	Severe injuries (N=504)	Slight injuries or pedestrians unhurt (N=694)	Total pedestrians impacted (N=1333)	p value
Driver manoeuvre					< 0.001
Driving straight	64 (47.4%)	280 (55.6%)	283 (40.8%)	627 (47.0%)	
Emergency braking	9 (6.7%)	25 (5.0%)	39 (5.6%)	73 (5.5%)	
Other Manoeuvre	6 (4.4%)	53 (10.5%)	110 (15.9%)	169 (12.7%)	
Restarting	15 (11.1%)	38 (7.5%)	43 (6.2%)	96 (7.2%)	
Turning left	15 (11.1%)	32 (6.3%)	69 (9.9%)	116 (8.7%)	
Turning right	21 (15.6%)	64 (12.7%)	120 (17.3%)	205 (15.4%)	
Unknown	5 (3.7%)	12 (2.4%)	30 (4.3%)	47 3.5%)	

According to the Chi-Square test, the parameters with a significant impact (10%) on the severity of road crashes between pedestrians and public transport buses are the pedestrian gender, the pedestrian age, if it is day or night and the bus driver manoeuvre. Those parameters will be discussed further.

The pedestrian gender

While males represent close to half (52.7%) of the pedestrians involved a crash with public transport bus, they represent 72.6% of the fatalities. This seems aligned with literature as male can be more risk takers.

The pedestrian age

While young adults (18-29 years) represent 23% of the pedestrians involved a crash with public transport bus, they only represent 11.5% of the fatalities. This can be surprising as some literature indicates that they can be more risk takers, however they are also less "fragile" and less likely to die from a crash than older pedestrians.

The pedestrians who seem more likely to be died in this kind of crash, are people aged from 45 to 64 years and above 65 years.

Nighttime

Only 28.8% of the pedestrians are impacted by a public transport bus at night, while 41.5% of pedestrian fatalities happen at night. This is aligned with the literature as it is harder to detect pedestrians at night. Also, there is less congestion at night, which can lead to higher driving speed.

Bus driver manoeuvre

When the bus drivers restart or turn left, correlates with higher crash severity. Those manoeuvres are associated with 7.2% (restart bus) and 8.7% (turn left) of the pedestrian impacted by a bus, while those manoeuvres represent 11.1% (restart bus) and 11.1% (turn left) of the pedestrian fatalities involving a public transport bus.

5.3. Comparison between pedestrian fatalities with or without public buses

To learn about the specificities of the road crashes involving public transport buses and pedestrians, those crashes have been compared to crashes between pedestrians and other vehicles. The comparison for pedestrian fatalities can be seen in Table 3.

Table 3 - Comparison between pedestrian fatalities with or without a public bus involved in Santiago (2017-2021)

	Pedestrian fatalities with public transport bus not involved (N=380)	Pedestrian fatalities with public transport bus involved (N=135)	Total pedestrian fatalities (N=515)	p value
Gender				0.777
Male	271 (71.3%)	98 (72.6%)	369 (71.7%)	
Female	109 (28.7%)	37 (27.4%)	146 (28.3%)	
Age Range				0.357
Unknown	46	5	51	
0 to 9 years	17 (5.1%)	2 (1.5%)	19 (4.1%)	
10 to 17 years	11 (3.3%)	3 (2.3%)	14 (3.0%)	
18 to 29 years	51 (15.3%)	15 (11.5%)	66 (14.2%)	
30 to 44 years	57 (17.1%)	26 (20.0%)	83 (17.9%)	
45 to 64 years	104 (31.1%)	48 (36.9%)	152 (32.8%)	
65 years and above	94 (28.1%)	36 (27.7%)	130 (28.0%)	
is Weekend?				0.029
Weekday	267 (70.3%)	108 (80.0%)	375 (72.8%)	
Weekend	113 (29.7%)	27 (20.0%)	140 (27.2%)	
Weather Condition				0.068
Bad condition	47 (12.4%)	9 (6.7%)	56 (10.9%)	
Good condition	333 (87.6%)	126 (93.3%)	459 (89.1%)	
Day or Night?				0.003
Night	215 (56.6%)	56 (41.5%)	271 (52.6%)	
Day	165 (43.4%)	79 (58.5%)	244 (47.4%)	
Crash Time Range				0.002
00:00 - 07:59	95 (25.0%)	22 (16.3%)	117 (22.7%)	
08:00 - 09:59	17 (4.5%)	15 (11.1%)	32 (6.2%)	
10:00 - 17:59	110 (28.9%)	54 (40.0%)	164 (31.8%)	
18:00 - 19:59	54 (14.2%)	11 (8.1%)	65 (12.6%)	
20:00 - 23:59	104 (27.4%)	33 (24.4%)	137 (26.6%)	
Is at Junction?				< 0.001
Junction	122 (32.1%)	70 (51.9%)	192 (37.3%)	
Not Junction	223 (58.7%)	48 (35.6%)	271 (52.6%)	
Others	35 (9.2%)	17 (12.6%)	52 (10.1%)	
Number of Lanes				0.267
Unknown	2	0	2	
1	8 (2.1%)	4 (3.0%)	12 (2.3%)	
2	120 (31.7%)	43 (31.9%)	163 (31.8%)	
3	28 (7.4%)	3 (2.2%)	31 (6.0%)	
4	146 (38.6%)	58 (43.0%)	204 (39.8%)	
5 or more	76 (20.1%)	27 (20.0%)	103 (20.1%)	
Road direction				0.194
Two-way	192 (50.5%)	65 (48.1%)	257 (49.9%)	
Two-way with central separation	101 (26.6%)	46 (34.1%)	147 (28.5%)	
One-way	87 (22.9%)	24 (17.8%)	111 (21.6%)	
Driver Gender				0.053
Unknown	38	1	39	
Female	23 (6.7%)	3 (2.2%)	26 (5.5%)	
Male	319 (93.3%)	131 (97.8%)	450 (94.5%)	
Driver Age Range				< 0.001
Unknown	96	2	98	

	Pedestrian fatalities with public transport bus not involved (N=380)	Pedestrian fatalities with public transport bus involved (N=135)	Total pedestrian fatalities (N=515)	p value
10 to 17 years	2 (0.7%)	0 (0.0%)	2 (0.5%)	
18 to 29 years	75 (26.4%)	4 (3.0%)	79 (18.9%)	
30 to 44 years	106 (37.3%)	31 (23.3%)	137 (32.9%)	
45 to 64 years	79 (27.8%)	83 (62.4%)	162 (38.8%)	
65 years and above	22 (7.7%)	15 (11.3%)	37 (8.9%)	
Driver Is Chilean?				0.913
Unknown	83	4	87	
Chilean	285 (96.0%)	126 (96.2%)	411 (96.0%)	
Foreigner	12 (4.0%)	5 (3.8%)	17 (4.0%)	
Driver Is Impaired?				0.001
Unknown	99	4	103	
Impaired	26 (9.3%)	1 (0.8%)	27 (6.6%)	
Not impaired	255 (90.7%)	130 (99.2%)	385 (93.4%)	
Driver Manoeuvre				< 0.001
Driving straight	213 (56.1%)	64 (47.4%)	277 (53.8%)	
Emergency braking	15 (3.9%)	9 (6.7%)	24 (4.7%)	
Other Manoeuvre	16 (4.2%)	6 (4.4%)	22 (4.3%)	
Restarting	10 (2.6%)	15 (11.1%)	25 (4.9%)	
Turning left	15 (3.9%)	15 (11.1%)	30 (5.8%)	
Turning right	12 (3.2%)	21 (15.6%)	33 (6.4%)	
Unknown	99 (26.1%)	5 (3.7%)	104 (20.2%)	

The parameters with statistically significant differences are: "is weekend", "weather condition", "is day", "crash time", "is at a junction", "driver gender", "driver age", "driver is impaired", "driver manoeuvre". Each of those differences will be discussed in this section.

Is weekend?

There are more pedestrian fatalities on weekend involving other road users (29.7%) than public transport bus drivers (20%). This make sense since bus drivers are professional drivers and should have less risky behaviours (alcohol or other drugs consumption, lack of sleep) on weekends than other users.

Is day?

There are more pedestrian fatalities at night involving other road users (56.6%) than public transport bus drivers (41.5%). The same way as is weekend, this make sense as bus drivers are professional drivers and should have less risky behaviours (alcohol or other drugs consumption, lack of sleep) at night than other users.

Crash time

There is strong difference on the time of pedestrian fatalities depending on if they happened involving a public bus driver or other road user. Similarly, as with the "is day" parameters, there are more fatalities involving road user at early and late hours. It is interesting to note that the morning peak (08:00 to 09.59) represents a bigger proportion of fatalities involving public bus drivers (11.1%) while it represents only 4.5% for other road users. It is the opposite for the that afternoon peak (18:00 to 19:59) which represent 8.1% of the pedestrian fatalities involving a public transport bus, while this time range represent 14.2% of the pedestrian fatalities with other users. Finally, 40% of the pedestrian fatalities involving a public bus occur between the morning and afternoon peaks.

Weather condition
Pedestrian fatalities involving public buses are less impacted by bad weather condition (6.7%) than pedestrians fatalities involving other vehicles (12.4%). This might be because buses are bigger vehicle and less impacted by wind and travelling at lower speed and therefore less impacted by rain.

Is junction?
The majority of pedestrian fatalities involving a public transport bus occurs at a junction (51.9%) this is more than for fatalities involving other vehicles (32.1%). This makes sense as buses are heavy vehicles with blind spots and high turning radius.

Driver gender
Only 2.2% of the pedestrians killed in a road crash involving a public bus were impacted by a female driver however there is very little female bus driver in Santiago (5.1% in average between 2017 and 2021). This proportion is 6.7% for other drivers, yet, it is very likely that the ratio of female driver would be higher. This seems to confirm that male drivers are more dangerous drivers.

Driver age
Most pedestrian fatalities involving a public transport bus happened with an older bus driver (61.2% of the drivers aged between 45 and 64 years and 11.6% aged more than 65 years) while for pedestrian fatalities involving other vehicles, most of the drivers were young (26.8% of the drivers aged between 18 and 29 years and 37.3% aged between 30 and 44 years). While these are significant differences, they might be explained by older bus drivers. It would be interesting to normalize this data with the number of drivers.

Driver is impaired?
The rate of impaired drivers involved in a pedestrian fatal crash is higher for other drivers (9.3%) than public transport bus drivers (0.8%). This does make sense bus drivers are professional drivers. Nonetheless, this must be taken with cautious as the police does not perform drug checks to drivers after crashes (Rimbaud, 2019).

Driver manoeuvre
Looking at the proportion of manoeuvres involved in pedestrian fatalities, there is big difference in the representation of turns and vehicles restart. For fatalities involving a public bus they represent 37% (11.1% restarting, 11.1% turning left, 14.8% turning right) while for the fatalities involving other vehicles, they only represent 9.7% of the fatalities. It is important to note that the higher number of unknown manoeuvres for crashes involving other users, can partly be explained by the difference of methods. Indeed, for pedestrians involved in a crash with a public bus, the driver manoeuvre would be set to unknown, if it is unknown in the police database or if 2 or more buses are involved. While for other crashes it would be set to unknown, if it is unknown in the police database or if 2 or more vehicles are involved. Which is more likely.

5.4. Crashes between cyclists and public transport buses

The impact on cyclists of road crashes involving a public transport bus can be seen in Table 4. This table displays number of cyclists which resulted dead, with severe injuries, or with slight injuries or unhurt.

Table 4 - Injury severity of cyclist involved in a road crash with a public transport bus in Santiago (2017-2021)

	Fatal injuries (N=28)	Severe injuries (N=169)	Slight injuries or cyclists unhurt (N=315)	Total impacted cyclists (N=512)	p value
Gender					0.092
Male	20 (71.4%)	140 (82.8%)	235 (74.6%)	395 (77.1%)	
Female	8 (28.6%)	29 (17.2%)	80 (25.4%)	117 (22.9%)	
Age Range					0.340
Unknown	1	2	11	14	
0 to 9 years	0 (0.0%)	0 (0.0%)	1 (0.3%)	1 (0.2%)	
10 to 17 years	2 (7.4%)	12 (7.2%)	14 (4.6%)	28 (5.6%)	
18 to 29 years	9 (33.3%)	50 (29.9%)	123 (40.5%)	182 (36.5%)	
30 to 44 years	6 (22.2%)	52 (31.1%)	89 (29.3%)	147 (29.5%)	
45 to 64 years	9 (33.3%)	37 (22.2%)	60 (19.7%)	106 (21.3%)	
65 years and above	1 (3.7%)	16 (9.6%)	17 (5.6%)	34 (6.8%)	
is Weekend?					0.123
Weekday	19 (67.9%)	142 (84.0%)	257 (81.6%)	418 (81.6%)	
Weekend	9 (32.1%)	27 (16.0%)	58 (18.4%)	94 (18.4%)	
Weather Condition					0.179
Bad condition	0 (0.0%)	7 (4.1%)	22 (7.0%)	29 (5.7%)	
Good condition	28 (100.0%)	162 (95.9%)	293 (93.0%)	483 (94.3%)	
Day or Night?					0.007
Night	15 (53.6%)	45 (26.6%)	82 (26.0%)	142 (27.7%)	
Day	13 (46.4%)	124 (73.4%)	233 (74.0%)	370 (72.3%)	
Crash Time Range					0.435
00:00 - 07:59	4 (14.3%)	20 (11.8%)	38 (12.1%)	62 (12.1%)	
08:00 - 09:59	0 (0.0%)	19 (11.2%)	38 (12.1%)	57 (11.1%)	
10:00 - 17:59	10 (35.7%)	76 (45.0%)	138 (43.8%)	224 (43.8%)	
18:00 - 19:59	6 (21.4%)	22 (13.0%)	51 (16.2%)	79 (15.4%)	
20:00 - 23:59	8 (28.6%)	32 (18.9%)	50 (15.9%)	90 (17.6%)	
Is Junction?					0.770
Junction	16 (57.1%)	78 (46.2%)	140 (44.4%)	234 (45.7%)	
Not Junction	11 (39.3%)	80 (47.3%)	155 (49.2%)	246 (48.0%)	
Others	1 (3.6%)	11 (6.5%)	20 (6.3%)	32 (6.2%)	
Number of Lanes					0.758
Unknown	0	0	2	2	
1	0 (0.0%)	2 (1.2%)	2 (0.6%)	4 (0.8%)	
2	11 (39.3%)	52 (30.8%)	95 (30.4%)	158 (31.0%)	
3	1 (3.6%)	13 (7.7%)	29 (9.3%)	43 (8.4%)	
4	10 (35.7%)	68 (40.2%)	139 (44.4%)	217 (42.5%)	
5 or more	6 (21.4%)	34 (20.1%)	48 (15.3%)	88 (17.3%)	
Road direction					0.936
Two-way	12 (42.9%)	76 (45.0%)	152 (48.3%)	240 (46.9%)	
Two-way with central separation	9 (32.1%)	51 (30.2%)	86 (27.3%)	146 (28.5%)	

	Fatal injuries (N=28)	Severe injuries (N=169)	Slight injuries or cyclists unhurt (N=315)	Total impacted cyclists (N=512)	p value
One-way	7 (25.0%)	42 (24.9%)	77 (24.4%)	126 (24.6%)	
Driver Gender					0.795
Unknown	0	2	4	6	
Female	2 (7.1%)	8 (4.8%)	19 (6.1%)	29 (5.7%)	
Male	26 (92.9%)	159 (95.2%)	292 (93.9%)	477 (94.3%)	
Driver Age Range					0.581
Unknown	1	14	34	49	
18 to 29 years	0 (0.0%)	0 (0.0%)	1 (0.4%)	1 (0.2%)	
30 to 44 years	1 (3.7%)	16 (10.3%)	27 (9.6%)	44 (9.5%)	
45 to 64 years	8 (29.6%)	41 (26.5%)	86 (30.6%)	135 (29.2%)	
65 years and above	14 (51.9%)	88 (56.8%)	136 (48.4%)	238 (51.4%)	
Driver Is Chilean?	4 (14.8%)	10 (6.5%)	31 (11.0%)	45 (9.7%)	
Unknown					N/A
Chilean	5	35	95	135	
Foreigner	23 (100.0%)	134 (100.0%)	220 (100.0%)	377 (100.0%)	
Driver Is Impaired?					N/A
Unknown	5	35	95	135	
Not impaired	23 (100.0%)	134 (100.0%)	220 (100.0%)	377 (100.0%)	
Driver Manoeuvre					0.221
Driving straight	20 (71.4%)	98 (58.0%)	148 (47.0%)	266 (52.0%)	
Emergency braking	0 (0.0%)	2 (1.2%)	4 (1.3%)	6 (1.2%)	
Other Manoeuvre	4 (14.3%)	26 (15.4%)	71 (22.5%)	101 (19.7%)	
Restarting	0 (0.0%)	11 (6.5%)	14 (4.4%)	25 (4.9%)	
Turning left	1 (3.6%)	7 (4.1%)	27 (8.6%)	35 (6.8%)	
Turning right	1 (3.6%)	13 (7.7%)	28 (8.9%)	42 (8.2%)	
Unknown	2 (7.1%)	12 (7.1%)	23 (7.3%)	37 (7.2%)	

According to the Chi-Square test, the parameters which have a significant impact (10%) on the severity of road crashes between cyclists and public transport buses are the cyclist gender and if it is day or night. Even if bus driver manoeuvre is not significant however it will still be discussed.

Cyclist gender

The gender of the cyclist does not seem to have a clear impact on crash severity. Out of all the cyclists impacted by a public transport bus, 22.9% were female. Women represent 28.6% of the fatalities and 17.2% of the serious injuries.

Nighttime

Nighttime seems to have a big impact on the severity of crashes between cyclists and public transport buses. 27.7% of the cyclists are impacted by a public bus at night but 53.6% of the fatalities occurred at night.

Bus driver Manoeuvres

The bus driver manoeuvre "driving straight" seems to be linked to a higher injury severity. This manoeuvre represents 52% of the total cyclists impacted by a public transport bus driving straight, while it represents 71.4% of the corresponding fatalities. This can be explained as cyclists sometimes use bus lanes and share the space with buses which driving straight, reach higher speed.

5.5. Comparison between cyclist fatalities with or without public transport buses

To learn about the specificities of the road crashes involving public transport buses and cyclists, those crashes have been compared to crashes between cyclists and other vehicles. Only two parameters are statically significant (Cyclist gender, Bus driver age), they will be discussed in the following part as well as bus driver manoeuvre. The full results are available in Annex 1.

Cyclist gender

Male cyclists are more represented in fatal crashes without public transport bus (86.8%) than with public transport bus (71.4%).

Bus driver age

Older drivers are more represented in cyclist fatal road crashes involving public transport buses (66.7% older than 45 years or older) than for the cyclist fatal road crashes involving other vehicles (45.6% older than 45 years or older).

5.6. Comparison between crashes involving buses and pedestrians and crashes involving buses and cyclists

To learn about the differences between of the road crashes involving public transport buses and pedestrians on one side, and public transport buses and cyclists on the other side, those crashes have been compared. Only two parameters are statically significant (Pedestrian/cyclist age and bus driver manoeuvre), they will be discussed in the following part. The full results are available in Annex 2.

Pedestrian or cyclist age

In fatal crashes involving public transport buses the pedestrians killed are older than the cyclists. 27.7% of the pedestrian fatal victims are 65 years or older, while this group only represent 3.7% of the cyclist fatalities. This might because the number of elderly cyclists is lower.

Bus driver manoeuvres

Pedestrians are more impacted by turns and restarting of public transport buses than cyclists. Those manoeuvres represent 37.8% of the fatalities for pedestrians and 7.2% for cyclists. On the other hand, cyclists are more impacted by public transport buses driving straight (71.4%).

5.7. Location

The fatal crashes involving pedestrians or cyclists and public transport buses have been mapped and are visible in Figure 4.

Figure 4 - Heatmap of pedestrians and cyclist fatalities with a bus from the public transport involved in Santiago (2017-2021)

While there are fatal crashes in many parts of the cities, it seems that there is a high concentration on the accesses to the city. The avenues Santa Rosa and Vicuña Mackenna to the south and the avenues Departamental and Liberdador O-Higgins (La Alamada) to the west.

Six “blackspots”, with higher number of fatalities, have been visited as part of this research. They are visible in Figure 5 and will be described in Table 5.

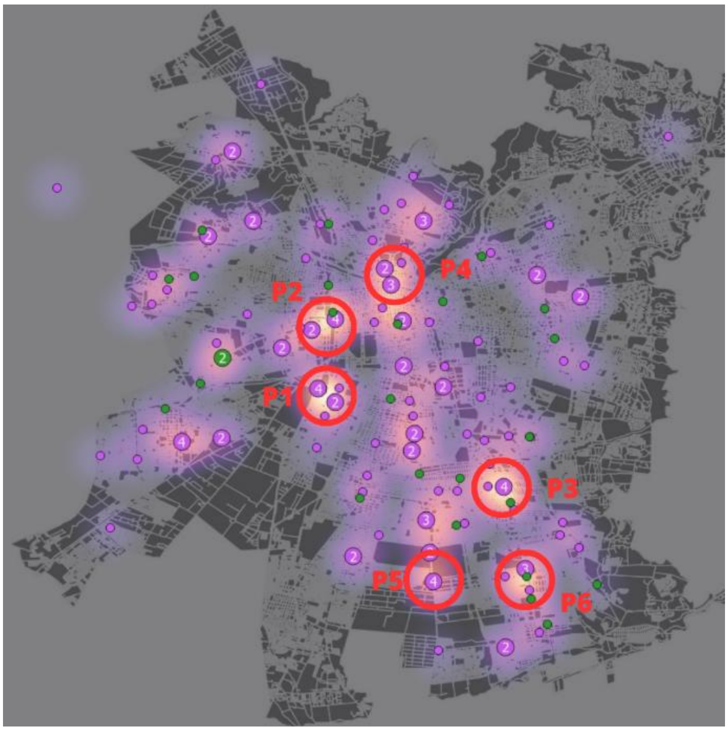
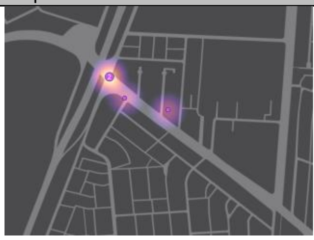
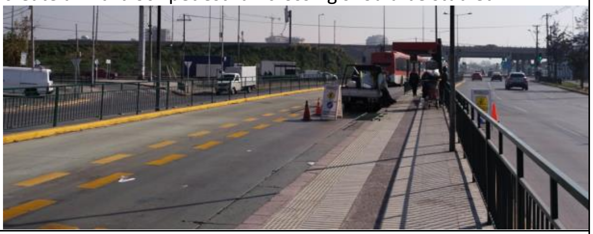
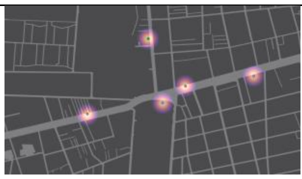
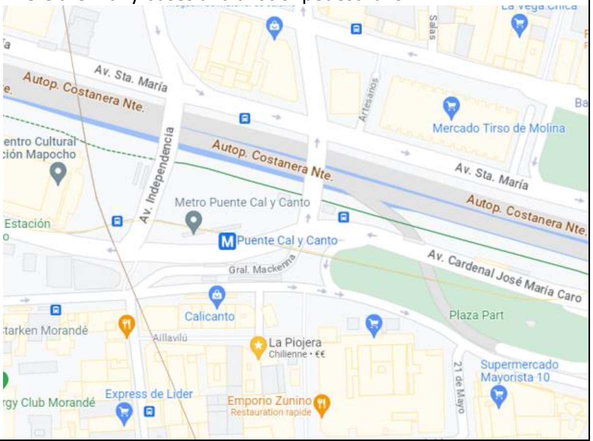
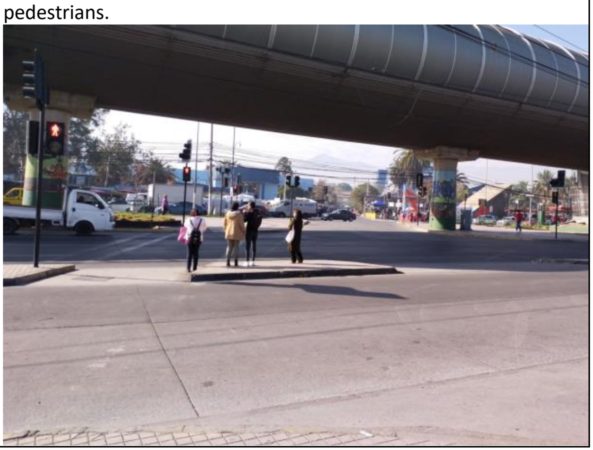


Figure 5 - Blackspots of pedestrians and cyclist fatalities with a bus from the public transport involved in Santiago (2017-2021)

Table 5 - Description of the location of the pedestrian or cyclist fatalities involving public transport buses in Santiago (2017-2021)

	Municipality	Map	Comments
1	Pedro Aguirre Cerda		On the avenue Departamental close to the avenue Padre Alberto Hurtado, four pedestrians have been killed. This avenue is in an East-West direction and close to the city centre situated to the north. Also, just north of this point is the “Lo Valledor” market which attracts a lot of people. For those crashes, the police registered that they occurred on a “stretch of straight road” and they were caused by “the imprudence of pedestrians”. It can be assumed that those pedestrians tried to cross this avenue. However, there are not many crossings, this avenue is very large, and the bus corridor makes it even harder to cross. A possibility to create a mid-block pedestrian crossing should be studied. 
2	Estación Central / Santiago		Four pedestrian and one cyclist fatalities occurred close to the “Estación Central”, the main train station of the city and an area with many shops and business. In front of this station is the avenue Liberador Bernardo O’Higgins (Alameda) which is one the principal avenues of Santiago. Four out of the five fatalities in the area occurred on this avenue. The avenue is very hard to cross, and some crossings lead to the median strip but do not connect to the other side of the street. The intersections are not complete. 
< 3	Florida		Four pedestrians died at the intersection between avenue Vicuña Mackena and Rojas Magallanes, close to the metro station Rojas Magallanes. According to the police data, the pedestrians died in four different crashes at the exact same location. The exit of this metro station is very complicated, indeed there is very little space for pedestrian and a barrier forbid to cross straight (many pedestrians still do it to avoid having to cross three times instead of one). The intersection is incomplete. 

<table>
<tr><td></td><td></td><td></td><td>The metro station entrance and exit are in the middle of the avenue. There is, on one side, cars going north to south, while on the other side, there is a bus corridor going in both directions, and car going south to north. The police registered those three out of four fatal crashes occurred at intersection with traffic lights.
This metro station and the bus corridor attract a lot of pedestrians however the pedestrian's infrastructure is lacking with little space and many avoidable crossings.</td></tr>
<tr><td>4</td><td>Recoleta/ Santiago</td><td></td><td>In the area of the metro station Cal y Canto, two pedestrians have been killed by public transport buses. This area is complicated to navigate with different roads turning and merging. Also, the area is situated between the city centre and the markets of "La Vega". There are many buses and a lot of pedestrians.

</td></tr>
<tr><td>5</td><td>La Pintana</td><td></td><td>Four pedestrians got killed in the avenue Santa Rosa, in of from of "La Pintana" Square, close the municipality town hall. This avenue has two times five lanes (including two central bus lanes). Some buses also turn westbound at that point. The avenue is not easy to cross and there are many buses travelling and turning in this area.
</td></tr>
<tr><td>6</td><td>Puente Alto</td><td></td><td>Like blackspot 3, blackspot 5 is on avenue Vicuña Mackena, close to the metro station Hospital Sótero del Río, in front an important hospital. Three pedestrians and one cyclist got killed in a crash involving a public bus in this area. The metro exit seems safer as pedestrian can exit on the pavement and not in the middle of the avenue. Still, the area is complicated, with the avenue, bus corridors, local bus services and car driving fast. Finally, there are many shops on the pavements, which makes circulation harder for pedestrians.
</td></tr>
</table>

5.8. Bus driver gender

To study in more details, the effect of the bus driver gender on the severity of the crash, the study period was increase from 2017-2021 to 2014-2021 as the Santiago Public Transport Authority record drivers' gender since 2014.

A Chi-squared test (see Table 6) shows that the gender of the driver has a significant impact on the severity of pedestrian injuries (p =0.035). This effect cannot be seen for crashed involving cyclists.

Table 6 - Pedestrian injury severity depending on bus driver gender in Santiago (2014-2021)

	Fatal (N=274)	Severe (N=907)	Slight or unhurt (N=1299)	Total (N=2480)	p value
Driver Gender					0.035
Unknown	5	8	15	28	
Female	4 (1.5%)	30 (3.3%)	59 (4.6%)	93 (3.8%)	
Male	265 (98.5%)	869 (96.7%)	1225 (95.4%)	2359 (96.2%)	

This data was normalized using the number of drivers by gender for the period 2014-2021. The results can be seen in Table 7 – Table 7.

Table 7 – Number public transport bus driver and involvement in fatal road crash by gender in Santiago (2014-2017)

	Gender	2014	2015	2016	2017	2018	2019	2020	2021	2014-2021 Driver Year
Number bus driver	Male	17029	17868	18466	17535	17425	19192	15620	14781	137916
	Female	264 (1.53%)	325 (1.79%)	485 (2.56%)	599 (3.30%)	965 (5.25%)	1271 (6.21%)	803 (4.89%)	889 (5.67%)	5601 (3.90%)
Number of bus drivers involved in a pedestrian fatality	Male	45	41	48	35	30	23	25	18	265
	Female	0 (0.00%)	1 (2.38%)	0 (0.00%)	1 (2.78%)	0 (0.00%)	1 (4.17%)	1 (3.85%)	0 (0.00%)	4 (1.49%)
Rate of male driver involved in pedestrian fatality for 10.000 drivers	Male	26.4	22.9	26.0	20.0	17.2	12.0	16.0	12.2	**19.2**
	Female	0.0	30.8	0.0	16.7	0.0	7.9	12.5	0.0	**7.1**

During this period, 3.90% of the driver-year were female drivers but they were only involved in only 1.49% of the pedestrian fatalities.

The rate of pedestrian fatalities for 10 000 bus driver per year is 19.2 for male drivers and 7.1 for female drivers. Which means that female drivers have a rate 62.8% lower than man. This result is significant and was verified with a test of proportion (p-value = 0.05873).

5.9. Road crash severity models

In the following section the evaluation of the different injury severity models will be presented and the description of the elected models for both pedestrian and cyclist fatalities in road crashes involving public transport buses.

Note: The parameters checking whether a bus driver is Chilean or impaired have been removed as they only have one value for cyclist fatalities involving a public transport bus.

Severity of road crashes between pedestrians and public transport buses
For crashes between pedestrians and public transport buses, the multinomial logit model using all the available model yield the best results (see comparison in Table 8).

Table 8 - Models evaluation for crashes between pedestrians and public transport buses

	AIC	Delta AIC	Number of independent variables	Log likelihood
Multinomial logit (all parameters)	1653.69	0	64	-757.64
Multinomial logit (10% significance parameters)	1705.28	51.59	28	-823.74
Multinomial logit (20% significance parameters)	1713.65	59.96	44	-810.57

The multinomial logit model has the lowest AIC and was chosen as the study severity model for road crashes between pedestrians and public transport bus. The result can be seen in Table 9. For each parameter, it shows the likelihood of injury (fatal, severe) via the odds ratio.

Table 9 - Results of the Multinomial logit on severity of road crash between pedestrians and public transport buses in Santiago (2017-2021)

Outcome	Characteristic	Odds Ratio	Confidence Interval	p-value	Outcome	Odds Ratio	Confidence Interval	p-value
Fatal	**Gender**				Severe			
	Male	—	—			—	—	
	Female	0.34	0.20, 0.58	<0.001		0.89	0.66, 1.22	0.5
	Age Range							
	0 to 9 years	—	—			—	—	
	10 to 17 years	0.61	0.08, 5.03	0.6		2.07	0.76, 5.62	0.2
	18 to 29 years	0.78	0.15, 4.04	0.8		1.40	0.57, 3.46	0.5
	30 to 44 years	2.13	0.43, 10.6	0.4		1.58	0.63, 3.95	0.3
	45 to 64 years	2.77	0.58, 13.3	0.2		2.33	0.96, 5.67	0.063
	65 years and above	4.90	0.99, 24.3	0.052		2.54	0.99, 6.51	0.051
	is Weekend?							
	Weekday	—	—			—	—	
	Weekend	1.06	0.56, 2.02	0.9		1.21	0.81, 1.81	0.4

Outcome	Characteristic	Odds Ratio	Confidence Interval	p-value	Outcome	Odds Ratio	Confidence Interval	p-value
	Weather Condition							
	Bad condition	—	—			—	—	
	Good condition	1.77	0.63, 4.98	0.3		0.95	0.55, 1.65	0.9
	Day or Night?							
	Night	—	—			—	—	
	Day	0.46	0.19, 1.11	0.085		0.66	0.39, 1.10	0.11
	Crash Time Range							
	00:00 - 07:59	—	—			—	—	
	08:00 - 09:59	1.65	0.52, 5.24	0.4		1.12	0.56, 2.21	0.8
	10:00 - 17:59	1.46	0.53, 4.02	0.5		1.22	0.67, 2.20	0.5
	18:00 - 19:59	0.65	0.23, 1.81	0.4		0.86	0.48, 1.56	0.6
	20:00 - 23:59	1.36	0.60, 3.06	0.5		0.86	0.50, 1.48	0.6
	Is Junction?							
	Junction	—	—			—	—	
	Not Junction	0.73	0.42, 1.28	0.3		0.86	0.61, 1.21	0.4
	Others	1.40	0.59, 3.31	0.4		0.59	0.32, 1.10	0.10
	Number of Lanes							
	1	—	—			—	—	
	2	0.23	0.05, 1.14	0.071		0.39	0.11, 1.45	0.2
	3	0.10	0.01, 0.72	0.022		0.51	0.13, 2.01	0.3
	4	0.22	0.04, 1.18	0.078		0.41	0.10, 1.58	0.2
	5 or more	0.17	0.03, 1.11	0.064		0.29	0.07, 1.24	0.10
	Road direction							
	Two-way	—	—			—	—	
	Two-way with central separation	1.70	0.78, 3.72	0.2		1.72	1.08, 2.74	0.023
	One-way	0.78	0.36, 1.71	0.5		1.07	0.67, 1.71	0.8
	Driver Gender							
	Female	—	—			—	—	
	Male	2.12	0.59, 7.62	0.3		1.84	0.94, 3.63	0.077
	Driver Age Range							
	18 to 29 years	—	—			—	—	
	30 to 44 years	2.19	0.66, 7.19	0.2		1.07	0.60, 1.92	0.8
	45 to 64 years	3.02	0.97, 9.38	0.056		1.00	0.57, 1.73	>0.9
	65 years and above	3.42	0.88, 13.3	0.076		1.29	0.62, 2.67	0.5
	Driver manoeuvre							
	Driving straight	—	—			—	—	
	Emergency braking	2.07	0.77, 5.57	0.15		0.75	0.36, 1.58	0.5
	Other Manoeuvre	0.37	0.13, 1.04	0.058		0.54	0.33, 0.87	0.011
	Restarting	4.17	1.80, 9.68	<0.001		1.66	0.89, 3.08	0.11
	Turning left	0.92	0.42, 2.04	0.8		0.48	0.28, 0.81	0.006
	Turning right	0.79	0.37, 1.70	0.5		0.59	0.37, 0.93	0.023
	Unknown	4.07	0.24, 68.6	0.3		0.56	0.05, 6.60	0.6

According to the significant results from Table 9, it can be said about the severity of crashes between pedestrians and public transport buses that:

- Crashes involving female pedestrians are less likely to be fatal than crashes involving male pedestrians.
- Crashes involving older pedestrians (aged 65 of more) are much more likely to be fatal or severe than crashes involving younger pedestrians.
- Crashes involving an older bus driver (45 years old or older) are more likely to be fatal
- Crashes involving a bus restarting (from a bus stop) are much more likely to be fatal
- Crashes occurring at night are more likely to be fatal

Severity of road crashes between cyclists and public transport buses

For crashes between pedestrians and public transport buses, the multinomial logit model using only parameters significant at 10% yielded the best results (see comparison in Table 10) and this model's results are available in Table 11.

Table 10 - Models evaluation for crashes between cyclists and public transport buses

	AIC	Delta AIC	Number of independent variables	Log likelihood
Multinomial logit (10% significance parameters)	603.9	15.46	6	-295.83
Multinomial logit (20% significance parameters)	609.53	21.09	10	-294.46
Multinomial logit (all parameters)	642.24	53.8	64	-241.3

Table 11 - Results of the Multinomial logit on severity of road crash between cyclists and public transport buses in Santiago (2017-2021)

Outcome	Characteristic	Odds Ratio	Confidence Interval	p-value	Outcome	Odds Ratio	Confidence Interval	p-value
Fatal	**Gender**				Severe			
	Male	—	—			—	—	
	Female	1.42	0.51, 3.99	0.5		0.61	0.35, 1.05	0.077
	Day or Night?							
	Night	—	—			—	—	
	Day	0.19	0.07, 0.50	<0.001		0.89	0.53, 1.49	0.7

The model with the lowest AIC, is the model using parameters with 10% significance. This model only has two parameters: the cyclist gender and if it is day or night.

According to the significant results this model, it can be said that about the severity of crashes between cyclists and public transport buses that:

- Crashes involving a female cyclist are less likely to be severe
- Crashes occurring during daytime are less likely to be fatal

The model for cyclists does not yield very many significant results as only two parameters are significant. This might be due to the sample size of 512 cyclists impacted by public transport buses against 1333 pedestrians but also the relatively low number of severe injuries (169 for cyclists and 504 for pedestrians) and fatal injuries (28 for cyclists and 135 for pedestrians) involving public transport buses.

5.10. Public transport policies effects

In order to study the impact of changes made to public transport buses system, the same methodology was used to evaluate the number of road crashes involving a bus driver in the study area for the data from 2002 to 2016. The full results for the 20 years period (2002-2021) can be seen in Figure 6.

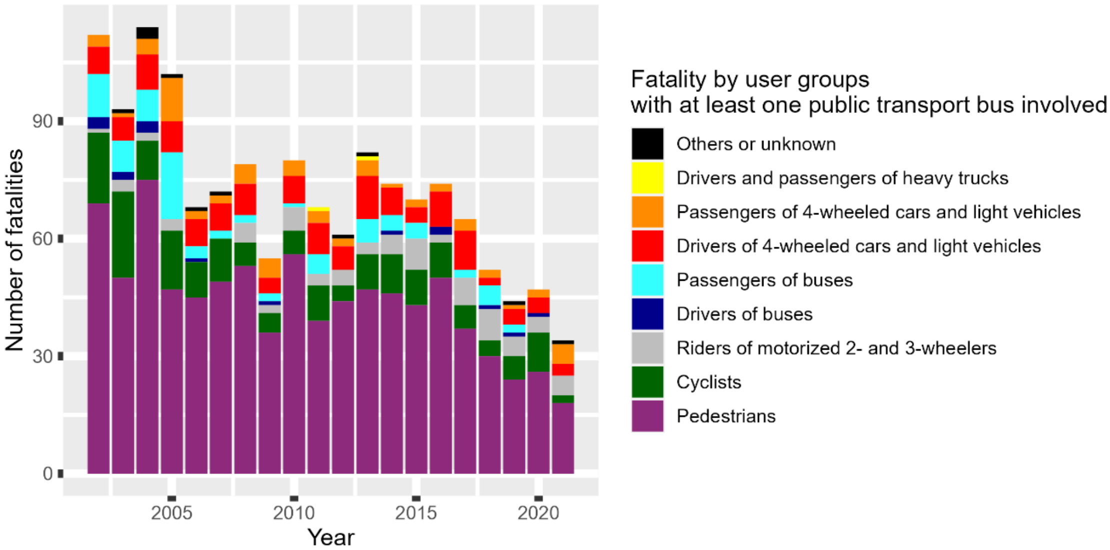


Figure 6 - Fatalities by user group with a public transport bus involved in Santiago (2002-2021)

Impact of Transantiago implementation

A big drop in the number of fatalities involving a bus from the public transport system can be observed after the implementation of the "Transantiago" system (2005-2007). Between the 2002-2004 and 2008-2012 periods, the yearly average fatalities decreased by 35.5% from 106.3 to 68.6 (p-value = 0.001804307). It is also interesting to note that the number of bus passengers killed in a road crash involving a bus from public transport has strongly decreased. The number has been divided by 4.5 (decrease by 77.8%) between 2002-2004 and 2008-2012, going from 9 to 2 deaths per year (p-value = 0.000959898).

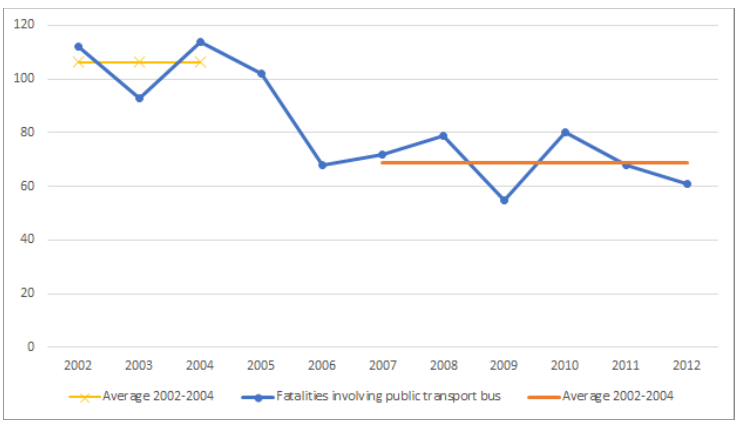


Figure 7 - Number of fatalities in road crashes involving public transport buses in Santiago (2002-2012)

During the same time (2002-2004 compared to 2008-2012) road crash fatalities not involving public transport buses decreased by 19.8% (p-value = 0.012554476). Taking this variation as a baseline, this research finally reaches a reduction of 19.5% (p-value = 0.046017913) for crashes involving public transport buses from the Transantiago implementation. For the bus passenger, there was a 72.3% reduction in the number of fatalities (p-value = 0.003037477).

Impact of the "Red Metropolitana de Movilidad" new bus standard roll out
During the 2017-2021 period, there was a decrease in the number of fatalities involving public transport bus. There was a 47.6% reduction in the average number of fatalities involving public transport between the periods 2008-2016 and 2017-2021 (p-value = 0.000624386), while there were no significant differences for crashes not involving public transport bus. As there is a strong correlation (-0.8) between the proportion of new buses and the number of fatalities from 2016-2021, this research will study the impact of the roll out of the new "Red" bus fleet.

As mentioned in the context and the methodology sections, the progressive roll out of the new "Red" bus standard will be evaluated accounting for the changes in average speed and in the distance travelled by public transport buses.

Firstly, a linear regression was done to verify a linear relationship between number of kilometres travelled by public transport bus and corresponding fatalities (2008-2016 period). This gave the following relationship:

$$F = 0.150203\ d_{travelled} \tag{10}$$

With

- F yearly number of fatalities involving a involving a public transport bus
- $d_{travelled}$ yearly distance travelled by public transport buses (in million kilometres travelled)

As this model fits very well the data (Adjusted R-squared = 0.9831), a linear relationship between distance travelled by buses and number of crashes involving public transport will be used for the rest of this research. The rate of fatalities involving public transport bus per million kilometres travelled will be used to evaluate the effect of the introduction of the new bus fleet and has been calculated for the period 2008-2021 (Figure 8).

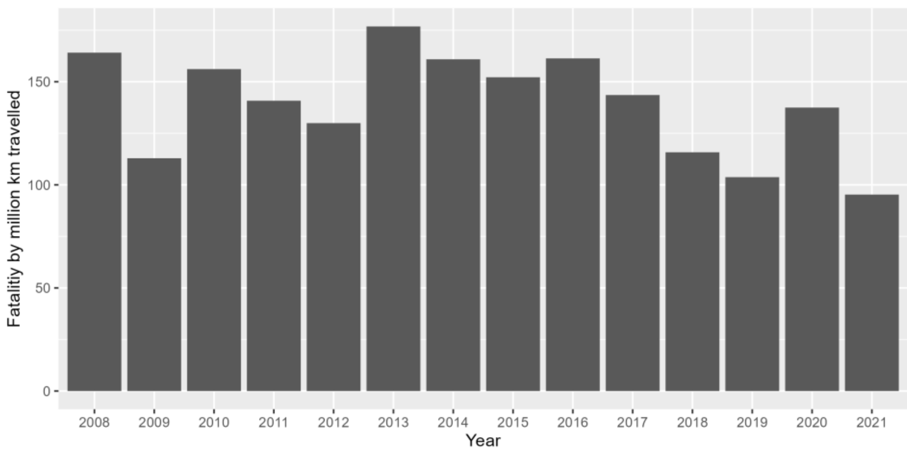


Figure 8 - Fatality rate involving public transport buses by million km travelled in Santiago (2008-2021)

While there was a 47.6% decrease in the average number of fatalities in road crashes involving public transport buses between the periods 2008-2016 and 2017-2021, the corresponding rate per million kilometres travelled by public transport buses only decreased by 26.4% (p-value = 0.007887).

In order to quantify the impact of speed and the new bus fleet, this research calculated the coefficient of formula (9) using the Broyden-Fletcher-Goldfarb-Shanno (BFGS) method from the optimx r package. The results can be seen in the following formula:

$$R = \left(0.3820774\,(k_{New\ buses}) + 2.599946\,(1 - k_{New\ buses})\right).\ e^{\,0.202736573\,V} \quad (11)$$

The actual and predicted road crash fatality rate per million km travelled by public transport buses can be seen in Figure 9.

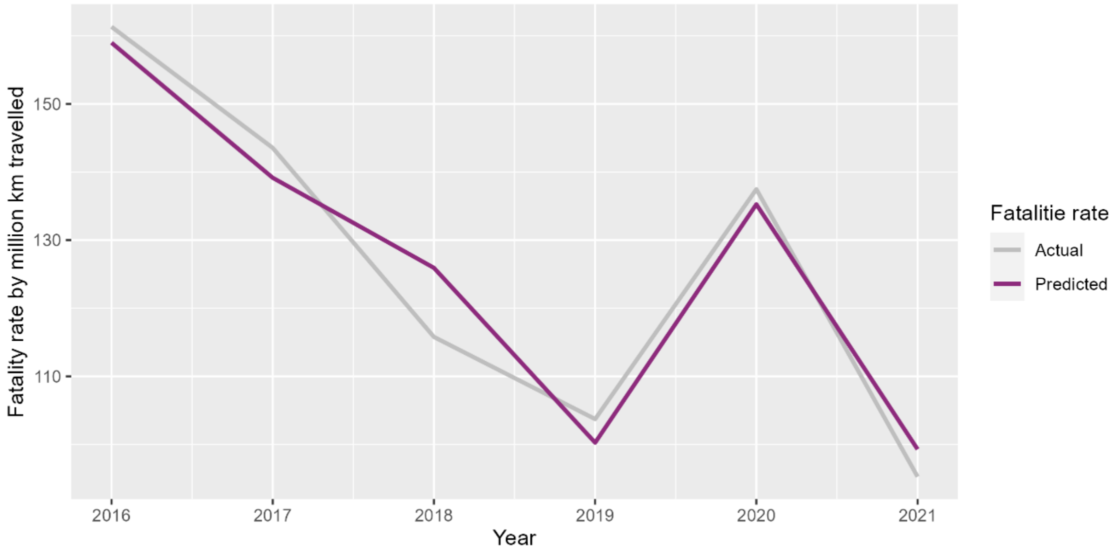


Figure 9 - actual and predicted road crash fatality rate per million km travelled by public transport in Santiago (2016-2021)

While this model fits the data well (R-Squared 0.953960567), it seems to overestimate the impact on the new bus fleet. Indeed, with a constant average speed, the roll out from 0% of new buses ($k_{New\ buses} = 0$) to 100% of new buses ($k_{New\ buses} = 1$) would represent a reduction of 85.3%. in the rate of fatalities in road crashes involving public transport buses.

This result seems unrealistic, and it is probable that other parameters played a role in this decrease. This will be explored further in the discussion part of this research.

5.11. Comparison with other cities

A comparison has been made with other cities in Latin America (Buenos Aires, Bogota), Chile (Greater Concepción and Greater Valparaiso) and a referent for bus road safety (Greater London). This part will be introduced as part of the results section, as the data presented for other Chilean cities have been computed using the same methodology as the one used for Santiago.

City of Buenos Aires (Argentina)
In the city of Buenos Aires, the number of pedestrian fatalities involving a passenger transport is very high as well. According to the data from the Observatory of Mobility and Road Safety of the City of Buenos Aires, (OMSV for its acronym in Spanish), between 2017 and 2021, 36.2% of the pedestrian fatalities involved a passenger transport vehicle (OMSV, 2022). However, it is important to note that this proportion include public transport buses but also other buses like coaches, so it needs to be compared with Santiago carefully.

Bogota (Colombia)
Using the data from the Secretary of Mobility of Bogotá, bus drivers represent 19.7% of the users involved in a fatal pedestrian crash and 25.2% for fatal cyclist crashes. Those proportion include public transport buses but also other buses like coaches. The proportion of the representation of buses is slightly lower than in Santiago while it includes more type of buses (Secretaria de Movilidad de Bogotá, 2022).

With the implementation of its Bus Rapid Transit, TransMilenio, the city of Bogota has observed reduction of road fatalities. It is estimated that the creation of a BRT corridor in Avenida Caracas (first corridor of the TransMilenio) has reduced in 52% the number of fatalities (Duduta et al. 2013). The existence of more integrated BRT system in Bogota might explain the lower proportion of fatalities in bus-related crashes.

Greater London (United Kingdom)
Transport for London (TfL), the transport authority for Greater London is a frontrunner city in terms of public transport bus safety. As part of their bus action plan, they set out to create a "*safe and secure bus network, with no one killed on or by a bus by 2030*" (TfL, 2022). In 2022, they reached a 65% reduction in the number of people killed in collisions involving London buses (compared to their 2005-09 baseline), while the total number of people killed in all collisions was reduced by 52% (TfL, 2023).

The comparison between Greater London and Santiago can be seen in Table 12.

Table 12 - Number and rate of traffic fatality in Santiago and London (2017-2021)

	Santiago	Greater London
Population	6,782,636	8,797,000
Traffic fatalities involving a bus from public transport	242	42
Total fatalities	1243	539
Proportion of traffic fatalities involving a bus from public transport	19.5%	7.8%
Rate of traffic fatalities involving a bus from public transport (rate for 1 million inhabitant)	35.7	4.8
Rate of traffic fatalities not involving a bus from public transport (rate for 1 million inhabitant)	147.6	56.5
Rate of traffic fatalities (rate for 1 million inhabitant)	183.3	61.3

Fatalities involving a bus from public transport only represent 7.8% of traffic fatalities in Greater London. The rate of traffic fatalities in Greater London is 3 times lower than in Santiago, however it is 7.5 lower if we only consider the fatality rate involving a public transport bus. It shows that the road safety differences between London and Santiago are even bigger at public transport level.

Greater Concepción and Greater Valparaiso (Chile)
Using the same methodology, the ratios of involvement of public transport in fatal road crashes were also computed for the metropolitan area of the Greater Valparaíso and Greater Concepción which are the second and third most populated urban areas in Chile. Those cities have a public transport bus system similar to Santiago's system before the implementation of Transantiago. In those urban area, bus drivers compete between themselves and can have riskier driving behaviours.

For the area of Greater Concepción, the municipalities of Concepción, Talcahuano, Coronel, Hualqui, Penco, Lota, Tome, San Pedro de la Paz, Chiguayante and Hualpen were considered.
For the area of Greater Valparaíso, the municipalities of Valparaíso, Villa Alemana, Viña del mar, Concon and Quilpue were considered. The results can be seen in Table 13.

Table 13 - Number and rate of pedestrians and cyclists killed in a crash involving a public transport bus in Santiago, Concepción and Valparaíso (2017-2021)

	Santiago	Greater Concepción	Greater Valparaíso
Population	6,782,636	1011161	1009370
Pedestrian fatalities involving a public transport bus	135	36	33
Pedestrian fatalities	515	117	85
Proportion of pedestrian fatalities involving a public transport bus	26.2%	30.8%	38.8%
Rate of pedestrian fatalities involving a public transport bus (rate for 1 million inhabitant)	19.9	35.6	32.7
Rate of pedestrian fatalities (rate for 1 million inhabitant)	75.9	115.7	84.2
Cyclist fatalities involving a public transport bus	28	4	3
Cyclist fatalities	104	8	4
Proportion of traffic fatalities involving a public transport bus	26.9%	50.0%	75.0%
Rate of cyclist fatalities involving a public transport bus (rate for 1 million inhabitant)	4.1	4.0	3.0
Rate of cyclist fatalities (rate for 1 million inhabitant)	15.3	7.9	4.0
Traffic fatalities involving a public transport bus	242	55	46
Total fatalities	1243	218	182
Proportion of traffic fatalities involving a public transport bus	19.5%	25.2%	25.3%
Rate of traffic fatalities involving a public transport bus (rate for 1 million inhabitant)	35.7	54.4	45.6
Rate of traffic fatalities (rate for 1 million inhabitant)	183.3	215.6	180.3

For cyclists, the proportion of road crash fatalities involving a public transport bus is much higher (50% for Greater Concepción and 75% for Greater Valparaíso). However, the total number of cyclists fatalities and the associated rate are low which might be explained by low levels of cycling in those cities.

For pedestrians, the proportion of road crash fatalities involving a public transport bus is higher in Greater Concepción (30.8%) and Greater Valparaíso (38.8%) than in Santiago (26.2%). The rates of pedestrian fatalities involving a bus from public transport are similar between Greater Concepción and Greater Valparaíso, while in Santiago it is much lower (39% lower compared to Greater Valparaíso).

In total, the proportions of road crashes fatalities involving public transport buses are higher in Greater Concepción (25.2%) and Greater Valparaíso (25.3%) than in Santiago (19.5%)

In the case of Greater Valparaíso, the data were recompiled for the 2002-2021 period, and no significant differences were found between the number of fatalities involving a public transport bus in the 2002-2011 and 2012-2021 periods.

6. Discussion

6.1. Road crash severity parameters

Some parameters of the road crash severity models will be discussed further in order to provide useful recommendations to public authorities.

Bus driver manoeuvres and junction

The driver manoeuvre at the moment of the crash gives a lot of information about the configuration of the crash and possible countermeasures. For pedestrians crashes with public transport buses, there is a high fatality risk, when the bus driver restart from a bus stop. Also, when comparing the proportion of pedestrian fatalities with or without a public transport bus (Figure 10), there is a much bigger proportion of turns (left or right) and restart as driver manoeuvre when a public bus is involved.

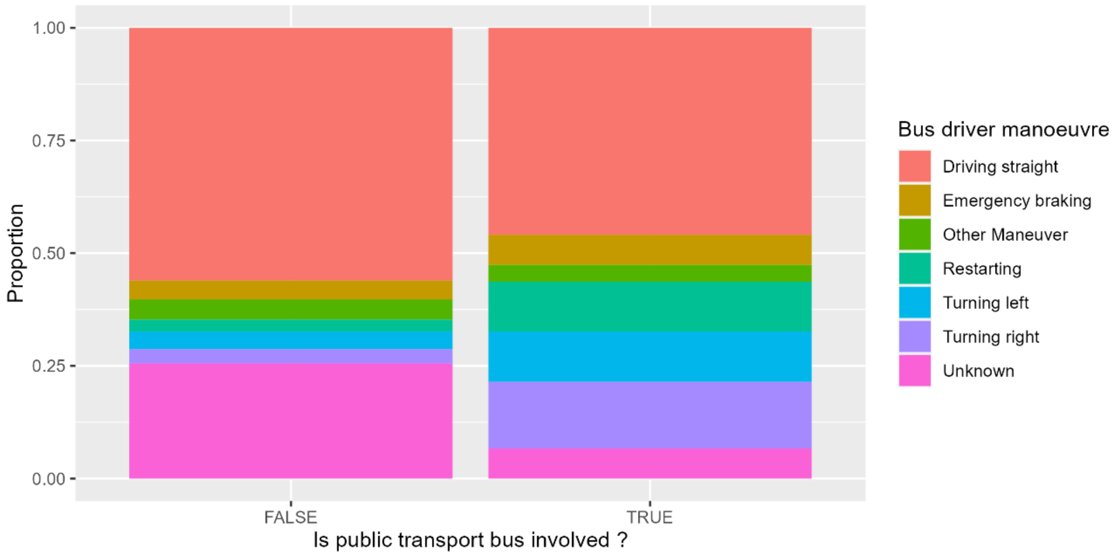


Figure 10 - Proportion of pedestrian fatalities with or without public transport buses involved in Santiago (2017-2021)

On top of that, the majority of pedestrian fatalities involving a public transport bus occurs at a junction (51.9%). This is more than for fatalities involving other vehicles (32.1%).

This is why, the public authorities should look at bus restarts and turns with special attention to avoid pedestrian fatalities.

To reduce crashes involving turning buses, the following type of interventions could be useful:

- **Reduce bus turns:** designing a bus network with routes with as little turns as possible.
- **Improve pedestrian safety from turning buses:** introducing road safety measures which provide protection from turning vehicles like banning left turn, turning traffic signals, Leading Pedestrian Intervals (LPI) or Curb Radius Reduction (FHWA, 2021, 2022).
- **Improve bus safety and crashworthiness:** improving buses standard to avoid crashes (better driver visibility, pedestrian and cyclist detection systems, driving

assistance) and to reduce their severity (Improved bus front and side design, pedestrian and cyclist Frontal Crashworthiness). Those safety measure could also apply for restarting buses.

The situation for crashes between public transport buses and cyclists is different (see Figure 11).

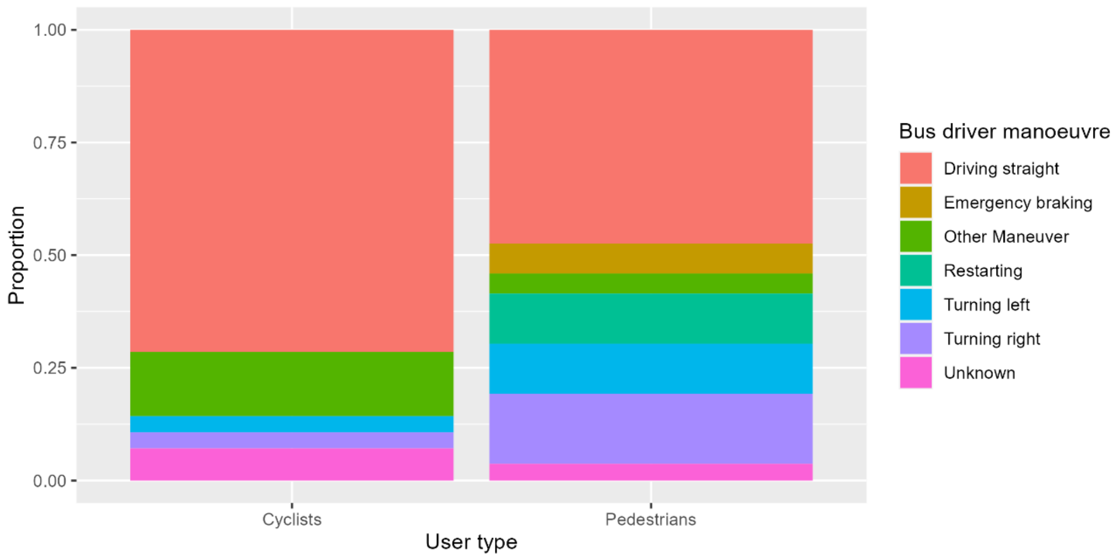


Figure 11 - Proportion of fatalities involving a public transport bus with cyclists and pedestrians in Santiago (2017-2021)

The vast majority of public transport buses involved in a cyclist fatality were driving straight. This makes sense as in many cases, cyclists use the bus lanes to cycle when there is no specific cycling infrastructure which very common in Santiago, especially in low-income neighbourhoods. According to Mora et al, (2021) "*the weak, fragmented governance structure of Santiago, Chile, coupled with significant inequality in the distribution of resources, has produced a non-continuous bike network of different standards and characteristics*".

To reduce cyclist fatalities crashes involving buses driving straight, the following type of interventions could be useful:

- **Create a safe and continuous cycling network:** improve cycling infrastructure to offer a safe cycling environment avoiding conflicts between cyclists and buses
- **Reduce bus speeds:** bus speed is a critical factor in the occurrence and severity of crashes involving buses. Reducing speeding would be benefit road safety.
- **Improve bus safety and crashworthiness:** as mentioned for pedestrian crashes with turning bus, some bus standard measure could be put in to avoid crashes and reduce their severity.

Bus driver gender

The results of this research show that female bus drivers are less likely (62.8%) to be involved in a pedestrian fatality than male bus drivers. This confirms the literature on the subject. The public transport authority already works to incorporate more of female staff and especially female drivers. In 2022, 7% of the drivers were women while they were only 1.5% in 2014 (DTPM, 2023) This initiative seems to be very positive at road safety level and should be extended.

6.2. Introduction of an integrated public transport bus systems in Chile

In term of crashes involving public transport buses, the implementation of the integrated public bus transport systems Transantiago has been very positive with a 19.5% fatality reduction compared to the crashed not involving public transport buses.

During the 2017-2021 period, the proportion of road crash fatalities involving a public transport bus was of 19.5% in Santiago. Before the implementation of this system (2002-2004), this proportion was much higher (29.7%). This proportion is similar to the proportion in Greater Concepción (30.8%) more recently (during the 2017-2021 period) and it is lower than the proportion in Greater Valparaíso (38.8% during the 2017-2021 period).

This indicates potential benefits of the integration of public transport systems in other Chilean cities. It is very likely that such projects will lead to a decrease in the number of fatalities. However, those systems must be carefully implemented and avoid the errors made in Santiago.

6.3. Public transport policies during the 2017-2021 period

During the 2017-2021 period, there has been a decrease in the number and the rate of fatalities in road crashes involving public transport buses (while there was no decrease for crashes involving other vehicles).

Impact of the "Red Metropolitana de Movilidad" new bus standard roll out
This research proposed a model using the speed and number of new buses rolled out to new "Red" bus system. This model represented well the data and seems to indicate a positive impact of the new bus standard on road safety.

This system has also been implemented in the city of Punta Arenas at the southern end of the country (DTPR, 2020). The extension of this system of other Chilean cities should bring road safety benefits.

Yet, the model proposed in this research seems to overestimate the impact of the new bus fleet and some other factors have played a role in the reduction of number of fatalities. Some possible contributing factors to the reduction in number of fatalities in road crashes involving public transport buses will be explained in the following subsections.

The impact of COVID-19 pandemic
The restrictions put in place to fight against COVID-19 pandemic had a great impact on the mobility patterns in Santiago. With the traffic flow reduction, speeding increased. Deaths associated with speeding in urban areas rose by 39% in 2020 (EMOL, 2021) Additionally as the Chilean police was busy with other duties (sanitary controls), the level of enforcement dropped. While those effects impact public transport buses and other vehicles, it is probable that it impacts public transport bus drivers less, as they are professional drivers, and they must stop more frequently. Also, some new buses have a speed control system which will reduce the speeding rate. Speeding rate probably increased more among other drivers than among bus drivers.

The impact of the Chilean protest
During the Chilean protests (which occurred mainly between October 2019 and March 2020), the level of enforcement dropped which led to a strong in the traffic mortality in Chile (Rimbaud, 2020c). The reduction of enforcement and other factors linked to this crisis might have impacted crashes involving buses differently than crashes involving other users.

New bus lane and automatic enforcement
Between 2016 and 2021, the number of bus lanes and cameras controlling the correct us of bus lanes have greatly increased. In this period, the number kilometre of bus lane per direction increased from 200 to 304 km, at the same time the number of associated control cameras increased from 273 to 476.

The increase of number of female drivers
As mentioned in previous sections, the number of female bus drivers has increased since 2014. As women are safer drivers than men, this increase has led to a decrease in the number of pedestrian fatalities in road crashes. It is noteworthy that in 2020, the number of women drivers decreased and that year the number of fatalities in road crash involving a public transport bus has increased.

Professionalisation of bus operators
During the study period they have been improvements in the professionalisation of bus operators. For instance, one of the operators received their certification ISO 39001 in 2019 and I put in place road safety strategy (Buses Vule, 2023a). This ISO certification has also been made mandatory for operators, three years after the start of new contracts (DTPM, 2022a).

Maintenance of Transantiago buses
While there is a new maintenance procedure for the new "Red" bus, the maintenance of older buses from the Transantiago system has also improved. For those buses, the reliability index increased from 75% in January 2019 to more 95% in September 2021 (DTPM, 2022a).

Other measures have been put in place in 2022 and 2023 which might help improve public transport bus safety like:

- New buses with pedestrian or cyclist detectors (DTPM, 2022b).
- New bus drivers training, exchanging roles with cyclists (DTPM, 2022c).
- New campaign and sticker on buses to inform about blind spots (Buses Vule, 2023b).

6.4. Research limitations

While this research brought some interesting results, there are many limitations which will be discussed in this section.

Data
This research used the crash data from the Chilean police. While this database is the official source of information for road safety in Chile, it has many issues.

First of all, the injuries are recorded only up to 24 hours after the crash (48 hours since 2019 according to CONASET). It is therefore estimated that the number of fatalities is between 20 and 30 % higher. This bias in reporting is not the same for each age group, as elderlies are more likely to die from an injury than younger people.

The parameter used to control the impairment of the driver is also biased, as the police does not usually test driver for drugs after the crash, so this does not get recorded in the database.

Some values are missing for some road users. For instance, 72 out of the 1243 road fatal victims in the study area between 2017 and 2021, do not have values for their age.

Normalization of data

On top of issue with the data itself, there are some issues with the normalization of some of the parameters. Indeed, some parameters like pedestrian age, cyclist age, driver age, time range, weekend or nighttime could have been normalized to represent the difference of exposition between each alternative. For instance, most of the cyclist fatalities involving a public transport bus occurred at night, but there is less bus and bike traffic at night, so the risk is even higher.

Location

In the location part of the results, some information about the “black spots” were presented, it would be interesting to do this work for all fatalities and get more information about the crash location in order to identify patterns and correlation between the build environment and the risk of fatal crashes.

On top of that, it would also have been interesting to use information not only from the official police road crash database but also get the full report of the police investigation for fatal crashes. However, this information belongs to the justice courts and is hard to obtain.

Crash severity models

This research created two crash severity models, one for crashes involving pedestrians and one for cyclists. While the model on severity of pedestrian crashes involving public transport buses yield with interesting results, the model for cyclists was not so good. This can be explained by the lack for the data points for the fatal and severe crashes. In future research it would be advisable to extend the study period to have enough data for cyclists.

Models public transport policy evaluation

This research studied the impact of various policy changes on road safety. The model of the “Red” system roll out seems overestimate the impact of this system and should have considered other parameters (partly listed in section 6.3). Future research should try to consider more parameters.

7. Recommendations

According to Nævestad et al. (2022), public transport authorities may have direct and indirect influence on traffic safety. It is therefore very important to study how can this be done, and which measures could be put in place by public transport authorities. In this section the concept of safe system and recommendations to create a safe system road safety plan for public transport buses will be presented. The possible vision and strategy will be discussed, followed by the presentation of various measures which could have a positive impact on public transport road safety. To gather more insight, a survey was conducted with the European Metropolitan Transport Authorities (EMTA) members. Height answers from public transport authorities were received (Rimbaud, 2023).

7.1. Safe system

As the United Nations have set a global goal of a 50% reduction on traffic fatalities by 2030, the World Health Organization presented the global plan for the decade of action for road safety 2021-2030. This plan "*describes what is needed to achieve the target, and calls on governments and partners to implement an integrated safe system approach"* (WHO, 2021b*).* With this call, it seems important to use the safety system approach when implementation a road safety strategy.

Implementing an integrated safe system to road safety has many advantages. It is the most effective and efficient way to improve road safety as the Safe System approach focuses on the prevention of injuries and death rather than solely on the causes of crashes. It provides a holistic way to look at road safety and integrate the interaction between speeds, vehicles, road infrastructure and road user behaviour. It provides a framework to ensure that if one of the parts of the road transport system fails, road users will not die or suffered serious injuries (ITF, 2022).

7.2. Vision and goal

According to the International Transport Forum, the first step in adopting a Safe System is to accept this simple ethical goal: "*No human being should be killed or seriously injured as the result of a road crash*" (ITF, 2016). This is pretty easy to picture for public transport as a public service should never lead to death of citizens. In the case of public transport, a goal stating something like "no one should die in a public transport bus or for a public transport bus" could be a good start of a public transport agency road safety strategy document.

While this goal might seem unrealistic to some, it is almost a reality in some part of the world. For instance, in 2019, in the cities of Helsinki and Oslo, no pedestrians died in road crashes (The Guardian, 2020).

The inclusion of the elimination of serious injuries in the goal could be beneficial, however data about injuries are not usually at the same level as data on fatalities. Problems like reporting, or the definition of injuries could be a barrier to the evaluation and the progress of such a plan.

7.3. Strategy

In order to create an efficient strategy, its key components and pillars must be defined.

Key components

As discussed in the introduction, the Safe System approach is based on four fundamental principles (people make mistakes that can lead to crashes, the human body has a limited physical ability to tolerate strong forces, a shared responsibility exists between road users and system designer, all parts of the system must be strengthened). Those four principles should be key elements of the safe system approach. On top of them the ITF recommends adding "*Establish robust institutional governance*" as a fifth key component because of the importance of the institutional context in order to elaborate and implement efficient public policies (ITF, 2022).

Road-safety pillars

Part of the Global Plan for the Decade of Action for Road Safety 2011-2020, the WHO encourages countries to implement their road safety activity following 5 pillars: Road safety management, Safer roads and mobility, Safer vehicles, Safer road users and Post-crash response (WHO, 2011)

For the second Decade of Action for Road Safety (2021-2030), those pillars were modified to Multimodal transport & land-use planning, Safe road infrastructure, Safe vehicles, Safe road use and Post-crash response (WHO, 2021).

For its part the ITF, seeing that many national plans highlight speed as a vital area of road-safety intervention, added safe speed as separate pillar and proposed the following six road-safety pillars: Road-safety management, Safe roads, Safe vehicles, Safe speeds, Safe road-user behaviour and Post-crash care (ITF, 2022).

While most of the pillar names are similar between the different strategies, the pillar on road infrastructure usually differs. This pillar is very important, as infrastructure must supports correct user-behaviour and should be forgiving (in terms of injury mitigation). This pillar has direct impact on other pillars like safe speed and safe road user behaviour (Stigson 2009).

In the context of public transport system, two options were proposed to name this pillar:

- "Safe roads and accesses", in order to emphasize the importance of cyclist and pedestrian's accesses to public transport and the interaction between buses and vulnerable users
- "Safe roads for all", in order the emphasis on the fact, that the infrastructure is not only related to car traffic

The latter option has been chosen for this research and the proposed framework can be seen in Figure 12.

Figure 12 - Road Safety Safe System model adapted from ITF 2022

In the following sections, measures to improve public transport buses safety will be presented for each of those pillars. This list is not exhaustive and each measure needs to be evaluated in the local context.

7.4. Road Safety Management

According to the ITF (2016), road safety management structures with strong and clear mandates can be very effective to help launch the change process and ensure appropriate multi-sectoral coordination, sustained commitment and action to deliver lasting results. This is a pillar which should not be taken lightly.

Coordinate with the national road safety agency
A lead agency should be created to create a national road safety plan (WHO, 2011). The public transport authorities should lead the specific work on public transport buses. However, some measures (on road infrastructure for instance) will have an impact on all crashes, not only the one involving public transport buses. Because of that the public transport authority should coordinate its road safety actions with the national road safety agency. In the case of Santiago, DTPM should therefore coordinates its action with the CONASET.

Coordinate the road safety work of operators
For work related specifically related to public transport bus, according to Nævestad et al, (2022) in the case of Norway, public transport authority should act as a "*guiding star*" on road safety putting in place the following type of actions:

- Assign people dedicated to safety work in the public transport authority and the bus operators
- Establish a joint forum for traffic safety among the public transport authority and the bus operators
- Conduct risk analysis related to the interaction between buses and road environment
- Establish a system for learning among the bus operators, organized by the public transport authority
- Acting as a road safety ambassador for operators against third parties (Municipalities, road safety agency, bus suppliers, etc..)

Set realistic and long-term targets
On the institutional side, a key element is to set clear goals for fatality reductions and get useful metrics to track changes.

Promote traffic safety management initiatives
According to the WHO (2011), road safety management initiatives such as the new ISO traffic safety management standard ISO 39001, should be promoted among bus operators. This certification is mandatory for bus operator in Oslo, Norway (Rimbaud, 2023). In the case of Santiago, one of the operators already has this certification and it should become mandatory three years after the beginning of new contracts (DTPM, 2022a).

Crease a safe network structure and bus routes
The bus network structure and associated routes have an impact on road safety. The number of turns (especially left turns for countries driving on the right side of the road) has an impact on the number of crashes. Also, requirements of using large high-capacity buses in narrow streets can have a negative impact on road safety. Other requirements about punctuality and regularity might have an impact on driver stress which in turn will have an impact crash rate (Nævestad et al, 2022).

Transport for London requires operators to submit a "Route Risk Assessment" during the tender process and every two years or sooner if a route structure is changed (Rimbaud, 2023). This seems to be a good measure to identify possible risks and issues with bus routes.

7.5. Safe speeds

As mentioned in the literature, driving speed is one of the most important factors in road safety. In this section various measures to ensure safe speed for bus traffic will be presented.

Create a speeding monitoring system
In cities and regions, where the bus speed can be accurately monitored remotely, operators and public authorities should monitor and reward speed limit. In addition, it should be possible for bus users and other citizens to report speeding and give feedback on the conduction of the bus drivers by posting vehicles reference both inside and outside each public transport buses (ITF, 2019).

Transport for London is "*developing a speed compliance tool which can be used to monitor the speed of buses across our network and help in the identification of hotspot areas for which we can focus our efforts to prevent speeding*" (TfL, 2023). This is also something being done in Santiago de Chile where DTPM has just started to share a monthly speeding report with bus operators.

Implement a geofencing system
While speed monitoring mentioned above is done in a reactive way, it can also be done in proactive way. Geofencing is a method to do it. Various applications exist, some allows the creation of "safety zone", like a school zone or a hospital, where the bus will be limited (or stopped) when entering those zones. Some more advanced technology will allow remote access to the bus's engine to reduce its power and speed. This kind of technologies has been implemented in Gothenburg, Sweden or Curitiba, Brazil (Volvo buses, 2020, NY Times, 2020).

Intelligent Speed Assistance
The Intelligent Speed Assistance (ISA) is a technology build into motorized vehicles to help the driver respect the speed limits. Using GPS information and sign recognition to assess the speed limit and help the drive respect it. At the difference of geofencing, this system will not be controlled remotely or restricted to some areas.

It exists various types of ISA which can be categorize by two main attributes:

- **Switchable or mandatory:** Some versions of the ISA can be switched on and off by the user. Some other versions are built into the vehicles and cannot be switched off
- **Warning or intervening:** Some versions of the ISA only indicate the speed limit on the vehicle dashboard and send warning to the driver visually or with a sound if the driver goes above the speed limit. Some other versions directly control the speed of the vehicles and do not allow it to go over the speed limit

Since 2018, TfL installs a mandatory and intervening ISA on their buses. Their pilot project showed a reduction of the percentage of time buses spent travelling above the speed limit reduced from a range of 14.9-17.8% to 1-3.3% in 20mph zones, and from 0.5-3.3% to 0-1.1% in 30mph zones (Greenshields et al., 2016). They planned to have all buses with ISA installed by 2028.

In a pilot project made in the Netherlands, 60% of the bus drivers found driving with an ISA system more enjoyable against 10% who found it less enjoyable. 90% of the bus drivers had a positive appreciation of an ISA (van Loon and Duynstee, 2001).

In term of crash reduction, the effect depends on the type of ISA and speed limit. For fixed speed limits and a mandatory intervening ISA, the reduction of fatal crashes is of more than 35% (SWOV, 2019).

Reduce speed limits
According to the WHO (2021*), "in densely populated urban areas, there is strong evidence that even the best road and vehicle design features are unable to adequately guarantee the safety of all road users when speeds are above the known safe level of 30 km/h. For this reason, in urban areas where there is a typical, predictable mix of road users (cars, cyclists, motorcyclists, and pedestrians), a maximum speed limit of 30 km/h (20 mph) should be established, unless strong evidence exists to support higher limits".*
For these reasons, many cities around the world are reducing their speed limit to 30 km/h (or 20 mph) on some of their streets. Some cities, like Brussels, Bilbao or Helsinki have implemented city-wide 30 km/h limits (Brussels Mobility, 2022).

While this policy does not impact only public transport buses but all modes, one of the fears against is that it might increase bus travel time. It was a fear that TfL had at the beginning of the 20mph implementation in London, however the evidence in the city showed a negligible effect on journey times, for both general traffic and buses (Steer Davies Gleave, 2014). Today most of the London streets have a limit of 20mph (TfL, 2022). In a pilot project done in the City of Bristol, it was found that "*20mph (32km/h) scheme has not had any impact on bus journey time reliability*" (Bristol City Council, 2012).

In term of road safety, in Greater London, collisions involving a vulnerable road user have decreased by 36%, while collisions resulting in death or serious injury have decreased by 25% after speed limits were lowered from 30mph to 20mph (TfL newsroom, 2023). In Spain, after the reduction of the speed limit to 30 km/h on all the street with one lane, the number of pedestrian fatalities has decreased by 26% and the number of cyclists fatalities has decreased by 34% (Ministerio del interior de España, 2022).

In the specific case of this research and Santiago, lower speed limits will help reduced fatal crashes between cyclists and public transport buses which might share the same space today.

7.6. Safe vehicles

The Transport Research Laboratory (TRL) in its analysis of "bus collisions and identification of countermeasures" for Transport for London split the bus countermeasures in four categories (Vehicle, Human, Environment and other). More than 80% of the measures proposed were related to the vehicle (Edwards, A. et al., 2018). While this applied to the context of London where maybe other road safety issues have already been solved, it shows the importance of vehicle safety for public transport buses.

Improve vision standards for buses

Bus vision standards have a direct impact on the driver's ability to respond to an imminent crash based on how well the driver can see out and around the bus. The vision is separated in two categories:

- **direct vision**: what is in the driver's sightline
- **indirect vision**: concerns blind spot visibility through use of mirrors or camera systems

For direct vision, vehicles should be designed with lower cabins and larger windows to keep other road users in the driver's field of vision. In some cases, safety features such as pillars and side mirrors can create blind spots. The use of smaller mirrors or adjustments to the position of the mirrors can improve the driver's direct vision. In the future the replacement of mirrors with cameras and display system could further reduce the issue blind spots created by mirrors (Martin et al., 2018).

For indirect vision, the installation of wide-angle Class IV, V and/or VI mirrors or cameras has the potential to greatly reduce the blind spot areas surrounding the bus. In the case of London, class IV and V (Blind Spot) mirrors and camera monitor systems are estimated to be able to prevent between 42 and 69% of pedestrian and cyclist injuries (Martin et al., 2018).

Those systems help to reduce the blind spot. However, these systems do not cover the full blind spot. In addition, drivers must carefully adjust the mirrors and actively use the various mirrors and camera images (van Schagen and Goldenbeld, 2023).

Implement system for the detection of pedestrians and cyclists

To help drivers being aware of the presence of pedestrians and cyclists, some systems to detect them have been created. Those systems will alert when a pedestrian o cyclist is close to bus and is at risk of a road crash.

In the United States, crash involvement rates in lane-change crashes were 14% lower vehicles with blind spot monitoring than those without (Cicchino, 2017).

Two United Nations (UN) regulations exist on the topic:

- UN Regulation No. 151 - Blind Spot Information System for the Detection of Bicycles (UNECE, 2021)
- UN Regulation No 159 – uniform provisions concerning the approval of motor vehicles with regard to the Moving Off Information System for the Detection of Pedestrians and Cyclists (UN, 2021)

In the case of Santiago, this system has been installed on 30 buses in 2022 (DTPM, 2022).

Implement Advanced Emergency Braking system

Advanced Emergency Braking (AEB) systems are sensors which can detect the likelihood of a collision. When it identifies that a crash is imminent, and that the driver has not acted to avoid it, the system will automatically apply the brakes to help prevent the crash (or reduce its severity). This kind of systems is available for crashes with other motorized vehicles, pedestrians and cyclists (Knight et al., 2019).

According to Rosen (2013), AEB systems can reduce pedestrian fatalities by 48%, pedestrian severe injuries by 42%, cyclist fatalities by 55% and cyclist severe injuries by 33%.

Improve Vulnerable Road User (VRU) Frontal Crashworthiness

The design of the front end of buses can be improved in order to prevent crashes and to reduce their severity for pedestrians and cyclists. According to Martin et al. (2020), in the case of London, the following measures can have a positive impact on avoiding pedestrian and cyclist injuries:

- Enhancing geometric requirements (to reduce energy transfer and run-over)
- Replacing class II mirrors by cameras (to avoid crashes involving those mirrors)
- Repositioning of the windscreen wipers
- Using energy absorbing structures
- Deployable run-over airbags

Make bus interior "occupant friendly"

While the majority of the fatal and serious injuries in road crashes involving a public transport bus occurred outside of the bus, there still casualties occurring inside the bus. In the case of Santiago, 9 of the 242 fatalities involving a public transport bus occurred between 2017 and 2021 were bus occupants. In order to prevent that kind of fatalities or serious injuries, the interior of the buses must be "occupant friendly".

In the case of London, Edwards, M., et al. (2018) proposed two levels of bus interior improvements (Level 2 being an extension of level 1). Both levels shown a return on investment. While those change are highly specific to bus used in the local context they include:

- Improve restraint for standing and seated passengers
- Remove general hazards for standing and seated passengers
- Provide additional protection for rear-facing seats which have potential hazard behind like hard structure

Implement driver distraction warning systems

Distracted driving is likely to be more common among professional drivers. Bus drivers may need to interact with passengers while driving (van Schagen and Goldenbeld, 2023). This is why the European Union has made mandatory advanced driver distraction warning systems from July 2024. This system monitors driver eye movements and warns drivers when distracted (European Commission, 2023). This kind of system could be beneficial for road safety in many local contexts.

System to be made mandatory in the European Union in 2024

It is noteworthy that in 2019, the European Parliament adopted a regulation to introduce the mandatory implementation of several vehicle measures to improve road safety. Some of those measure apply to all vehicles, and some are specific to buses and trucks. Seven will become compulsory for all new buses from July 2024 (European Commission, 2022):

- For all road vehicles
    - Intelligent speed assistance
    - Reversing detection with camera or sensors
    - Attention warning in case of driver drowsiness

    - Emergency stop signal
    - Cybersecurity measures
- For buses and trucks
    - Detection and warnings to prevent collisions with pedestrians or cyclists.
    - Tyre pressure monitoring system, reporting tyre pressure loss in real time.

7.7. Safe road user behaviours

The behaviour of road users is a very important factor for road safety. It is especially true for the road users driving heavier vehicles which can have a greater impact, like buses.

Create a driver monitoring system

Before trying influence professional drivers' behaviour, it must be documented. One way of doing so is through driving outcomes, such as crashes. Road crashes are rare events, at the individual level and they might not adequately represent the behaviour of one particular driver. However, at aggregate level, they are useful in monitoring the performance of a bus operator over time or comparing the performance of different bus companies (ITF, 2019). On top of road crashes, other safety metrics are essential, and they can be separated in two groups:

- **Qualitative**: using data from bus user or other road users' feedback, like risky behaviour or driving style
- **Quantitative**: using data from speeding or other road traffic rule violation

For instance, the public transport of the city of Budapest, Hungary, BKK (Budapesti Közlekedési Központ Zrt) has a threshold of the number of crashes allowed per contract and per year. The bus operator can be sanction if they provoke more crashes that this threshold. For its part, TfL uses the number of crashes as part of a Safety Performance Index (SPI), which is produced periodically for each bus operating company, and for London bus operations as a whole. TfL recommends not to sanction operator to avoid the operator hiding some safety issues and to be able build a safety culture based on trust. Also, driver quality monitoring and engineering quality monitoring are already elements of the tender evaluation process in London (Rimbaud, 2023).

Provide drivers training

According to the Elvebakk et al. (2020), in the case of Norway, mandatory periodic trainings for professional drivers have positive impact on road safety. Drivers report that they have acquired new knowledge and more importantly, that they changed their driving practices.

In Europe, professional Heavy Good Vehicles (HGV) and bus drivers must accomplish basic training and every five years, a periodic refresher course (EU, 2022).

In Greater London, drivers receive a "Vision Zero bus driver training course", which includes hazard perception, better understanding of the risks to pedestrians, cyclists, motorcyclists and passengers as well as ways of preventing driver fatigue (TfL, 2019). In Santiago, some drivers were trained exchanging roles with cyclists (DTPM, 2022).

Reduce driver stress and promote a safety culture

There is a relationship between time pressure, level of stress, driving style and crash involvement. According to Nævestad et al. (2019); there are differences aggressive violations in traffic between countries because of different national road safety cultures. However, those differences are less important than work related variables and so, a positive organizational safety culture may reduce aggressive violations on the roads and reduce road crashes.

In the same way, a good safety culture reduces the perceived time pressure and stress. also, drivers who have an immediate manager who often talks about avoiding fines report higher level of stress (Nævestad et al., 2022).

Finally, to reduce crashes, public transport authorities should try to encourage good working conduction and encourage operators create a safety culture in their organisation.

Promote women drivers

This research indicates that female bus drivers in Santiago de Chile are 62.8% less likely to be involved in pedestrian fatal crash. A similar tendency was found in the city of Bogota. Additionally, according to BID (2019), in Santiago, female drivers have a better relationship with bus users compared to men, women are kinder, empathetic, calm, greet passengers properly and they know how to cope well in conflictive situations, without escalating problems. This is something which should be evaluated in the local context but incentivizing more female drivers could be beneficial for road safety.

7.8. Safe roads for all

Separate buses from other road users

According to van Schagen and Goldenbeld (2023), spatial separation of buses from other users, especially unprotected users like pedestrians and cyclists, is a very effective safety measure. Due to great difference in mass between buses and most other road users, crashes involving public transport buses generally result in very serious injuries or death. Examples of measure to separation of bus from other road users are:

- dedicated bus lanes
- dedicated bicycle/pedestrian facilities with conflict-free traffic lights

Create dedicated bus infrastructure

Bus rapid transit and bus priority systems have become an attractive solution to urban mobility needs in recent years because of their relatively low capital costs and short construction times compared to trains or metros. On top of increasing commercial bus speed, this system offers safety benefits (Duduta et al., 2015).

In Seoul, South Korea, the creation of a Bus Rapid Transit increased transit ridership by more than 20% while reducing total bus crashes by 26% and bus casualties by 11% (Lim et al., 2006). Similar effects have been observed in Bogotá with a reduction of 52% in the number of fatalities after the creation of a BRT corridor in Avenida Caracas (Duduta et al. 2013). In the case of Albuquerque, United States, fatal and serious injury collisions decreased by 64.9% after the implementation of a BRT system (Bia and Ferenchak, 2022).

Create dedicated cyclist/pedestrian facilities with conflict-free intersections
To protect pedestrians and cyclists from the bus traffic, an efficient way is to create a specific network. A safe and continuous cycling network is necessary to avoid crashes between buses and cyclists. This applies also to pedestrians who should be able to have their own space.

Also, conflict-free intersections should be put in place to avoid fatalities at intersection and especially for turning vehicles. Specific intersection treatments must be put in place to reduce conflicts. While the desire solution highly depends on the local context, some of the following measures could be investigated:

- **Banning left turn:** to remove high risk manoeuvre
- **Arrow traffic signals**: to remove phases when turning motorized vehicles and pedestrians have both a green light
- **Leading Pedestrian Intervals:** to give pedestrian a head start at traffic lights to improve pedestrian safety
- **Leading Cyclists Intervals**: to give cyclists a head start at traffic lights to improve pedestrian safety
- **Curb Radius Reduction:** to reduce turning speed

It is noteworthy that in the case of Santiago, a large proportion of pedestrians are killed by turning buses and at intersections.

Pedestrian facilities and access to public transport will be discussed further in the next section.

Provide safe access to public transport
For a public transport system to bring road safety benefits, it must be designed to be safely accessible to pedestrians. Indeed, most journeys on public transport begin and end with walking (ITF, 2016). This is particularity true for Latin America, where a big proportion of pedestrian are killed by bus or truck which suggest that the accessibility and safety of the area close the public transport station should be carefully studied (ITF, 2017).

According to Duduta et al. (2015), on most public transport systems major transfer stations are the locations with the highest number of crashes. This does not necessarily mean that transfer stations and terminals have a higher crash rate, but this high number might be explained by high volumes of vehicles (including buses) and pedestrians. However, because of those high vehicle and pedestrian flows, any safety problem at a major transfer station can result in very large number of crashes and injuries. It is therefore vital to review the walking and cycling access to the main public transport stations.

A study carried out in the city of New York, United States, established a correlation between the number of bus stops close to a metro station and number crashes involving pedestrian and bicycle crashes. It was also found that additional bike lanes could reduce crashes involving cyclists (Ashraf et al, 2022).

For transfers, the main safety issue to be considered is pedestrian safety. It was shown that people are considerably safer when they are in the bus or on the station platform than when they are walking to the station. Therefore, the safest types of transfers are those where the passengers never leave the station platform (Duduta et al 2015).

According to NACTO (2016b), a public transport trip is “door-to-door” and not “stop-to-stop”. A fully connected, safe and comfortable pedestrian network are indispensable to have a good public transport network. Safe pedestrian crossings should be provided at all public transport stops, including at mid-block. For mid-block stops, if the distance to the nearest intersection is too high, controlled mid-block crossings must be provided for pedestrian safety.

Finally, incomplete intersections that require pedestrians to cross multiple times to continue in a straight line should be avoided. They are a source of pedestrian delay and can increase pedestrian crash rates.

7.9. Safe post-crash care

Post-crash care is an important part of road safety. In this section actions which could be done straight after the crash or at a later stage will be presented.

Implement automatic Emergency alerting from bus
It exists systems for vehicles to automatically alert emergency services in case of a crash. In Europe, all new car models must be equipped with this kind of systems. Vehicles involved in a serious crash, will contact the nearest emergency-response network (Your Europe, 2023).

Investigate road crashes
According to Nævestad et al. (2022), a system to investigate and learn from crashes should be put in place for bus transport. The information gathered by bus operators, public transport authorities but also other stakeholders like municipalities or road authorities should be shared to increase the possible positive safety impacts.

In the case of Santiago, four pedestrian fatalities occurred in the same location (blackspot P3) between 2017-2021, however the infrastructure issues are still present. A similar case happened in 2023, when a woman got killed by a turning bus in the same intersection where 10 years earlier the same situation happened (Cooperativa, 2011, 2023, Gómez, 2023). It is not acceptable that safety issues stay in place for years and a system to learn from road crashes should be put in place.

TfL closely monitors the number of collisions involving buses, whether they are damage only or result in injury, and require operators to share their investigation findings and learnings about the most serious crashes (Rimbaud, 2023).

7.10. Recommendations summary

All recommendations presented in this research need to be evaluated in the local context. Their feasibility, benefits and the entities involved might differ. In the case of Santiago, for each measure, the list of possible stakeholders is available in Table 14.

Table 14 - Public transport bus safety recommendations summary

Pillar	Measure	Possible involved stakeholders in Santiago
Road Safety Management	Coordinate the road safety work of operators	DTPM, bus operators
	Set realistic and long-term targets	DTPM, CONASET
	Promote traffic safety management initiatives	DTPM
	Crease a safe network structure and bus routes	DTPM, bus operators
Safe speeds	Create a speeding monitoring system	DTPM, bus operators
	Implement a geofencing system	DTPM, bus operators, bus suppliers
	Intelligent Speed Assistance	DTPM, bus operators, bus suppliers
	Reduce speed limits	Transport Ministry, Regional Government, DTPM, CONASET, municipalities
Safe vehicles	Improve vision standards for buses	DTPM, bus operators, bus suppliers
	Implement system for the detection of pedestrians and cyclists	DTPM, bus operators, bus suppliers
	Implement Advanced Emergency Braking system	DTPM, bus operators, bus suppliers
	Improve Vulnerable Road User (VRU) Frontal Crashworthiness	DTPM, bus operators, bus suppliers
	Make bus interior occupant friendly	DTPM, bus operators, bus suppliers

	Implement driver distraction warning systems	DTPM, bus operators, bus suppliers
Safe road user behaviours	Create a driver monitoring system	DTPM, bus operators
	Provide driver training	DTPM, bus operators
	Reduce driver stress and promote a safety culture	DTPM, bus operators
	Promote women drivers	DTPM, bus operators
Safe roads for all	Separate buses from other road users: • Create dedicated bus infrastructure • Create dedicated bicycle/pedestrian facilities with conflict-free traffic intersections	Transport Ministry, Regional Government, DTPM, CONASET, municipalities
	Provide safe access to public transport	Transport Ministry, Regional Government, DTPM, CONASET, municipalities
Safe post-crash care	Implement automatic Emergency alerting from bus	DTPM, bus operators
	Investigate road crashes	DTPM, bus operators, CONASET

In the case of Santiago, as there is a specific tender for the supply of the bus fleet and the new standard “Red” already seems to have positive impact on road safety, it seems important to study the addition of bus standard improvements in the next tenders.

8. Conclusion and future research

This research examines the severity of the road crashes involving public transport buses in Santiago de Chile from 2017 to 2021, particularly crashes involving pedestrians and cyclists. The study reveals that public transport buses have a significant impact on road safety in Santiago de Chile, they are involved in 26.2% of the pedestrian fatalities; 26.9% of the cyclist fatalities and 19.5% of all traffic fatalities. Pedestrians represent the majority (55.8%) of the fatalities in road crashes involving public transport buses.

For crashes between pedestrians and public transport buses, elderly and male pedestrians are more likely to be involved in a fatal crash. Those crashes are more likely to be fatal at night, at an intersection or with a bus turning or restarting. So, it is important to create safety policies to reduce the likelihood and severity of crashes involving turning buses.

Female bus drivers are less likely to be involved in a fatal pedestrian crash. This is aligned with other studies on the subject and should push Santiago public transport authority to pursue their work to promote female bus drivers.

For crashes between cyclist and public transport buses, female cyclists are less likely to be involving in a severe crash. Those crashes are more likely to be fatal at night. The models for cyclist injury severity in road crashes involving buses had only two significant variables because of a low number of cyclists fatal and severe injuries.

This research also evaluates the impact of the implementation of an integrated public transport system "Transantiago" in Santiago between 2005 and 2007. This policy significantly reduced the number of fatalities in road crashes involving buses. It also decreased the proportion of fatal road crashes involving public transport buses. Before the implementation of this system (2002-2004), the proportion of fatalities in crashes involving public transport was similar to the proportion of other cities in Chile (Greater Concepción, Greater Valparaiso) in recent years (2017-2021). At road safety level, the implementation of an integrated public transport system in Santiago had a positive effect and shows potential benefits for other Chilean cities.

A city comparison revealed that a bus safety front runner city like Greater London has a bus system 7.5 times safer than Santiago, while the overall city road safety is 3 times safer (in term of road traffic fatalities per capita). This indicates that investing into the road safety of bus systems can bring results. It also shows the necessity for Santiago and other cities in Chile to improve the road safety of their public transport system.

During the 2017-2021 period, there has been a significant reduction in the number of fatalities in road crashes involving public transport buses, while there was no similar reduction for crashes involving other road users. This research created a model to explain this reduction accounting for the number of kilometres travelled by public transport buses, the average speed of buses and the number of the new bus from the new "Red Metropolitana de Movilidad" bus system. This model fits the data well however it seems to overestimate the effect of the new bus fleet. Other factors like the impact of the 2019 Chilean protest, the impact of the COVID-19 pandemic, new bus lanes with automatic enforcement, the increase of the number of female drivers, the professionalisation of bus operators and the improvement of the maintenance of Transantiago buses are some of the factors which may have also contributed to this decrease.

Finally, a safe system framework and a list of recommendations were provided to help public transport authorities improve the safety of their bus system. In the case of Santiago, one especially interesting area of improvement would be the safety standards of buses. Indeed, the new “Red” bus fleet seems to already have positive impacts on road safety, and there exists a separate tender for the supply of the bus fleet.

It is hoped that those information and recommendations will help public authorities make public transport safer in Santiago and in the rest of Chile.

In future research, it would be important to study the impact of other parameters like bus maintenance or bus lanes on road crashes involving buses. It would also be interesting to look at the 2022 data which would be less impacted by the mobility restrictions put in place for the COVID-19 pandemic. The severity model for cyclist injuries in bus-related crashes had only two significant parameters because of a lack of data, it would be interesting to perform another study about this kind of crashes with a longer time period. Then, the possible impacts and safety benefits of an integrated public transport buses system should be evaluated in other Chilean cities. Finally, it would be beneficial to perform an impact analysis of all the recommendations provided in this research in the case of Santiago.

References

World Health Organization (WHO), 2018, Global Status Report on Road Safety, https://www.who.int/publications/i/item/9789241565684

World Health Organization (WHO), 2017, Managing Speed, https://www.who.int/publications/i/item/managing-speed

UITP, 2020, Safe and Sustainable Cities with Public Transport, https://www.uitp.org/news/safe-and-sustainable-cities-with-public-transport/

APTA, 2016, The Hidden Transportation Safety Solution: Public Transportation, https://www.apta.com/wp-content/uploads/Resources/resources/reportsandpublications/Documents/APTA-Hidden-Traffic-Safety-Solution-Public-Transportation.pdf

ITF (2016), Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System, OECD Publishing, Paris, https://doi.org/10.1787/9789282108055-en

Société de l'assurance automobile du Québec(SAAQ), 2022, Visibility around heavy vehicles, https://saaq.gouv.qc.ca/en/road-safety/behaviours/blind-spots/visibility-around-heavy-vehicles

NACTO, 2016a, Transit Street Design Guide - Turn Radii, https://nacto.org/publication/transit-street-design-guide/intersections/transit-route-turns/turn-radii/

Axel Rimbaud, 2022, La necesidad de aumentar los estándares de seguridad de los buses de la Red Metropolitana de Movilidad, https://www.contraexceso.org/seguridad-de-los-buses-en-santiago

Matts-Åke Belin, 2021, The Swedish Vision Zero—An Advanced Safety Culture Phenomenon, https://link.springer.com/chapter/10.1007/978-981-16-1115-5_1

Fred Wegman, 2021, Sustainable Safety: The Dutch Example of a Safe System Approach

ITF, 2022, The Safe System Approach in Action, Research Report, OECD Publishing, Paris

CONASET, 2023, Observatorio de Seguridad Vial, https://www.conaset.cl/programa/observatorio-datos-estadistica/

World Health Organization, 2020, Global Health Estimates: Life expectancy and leading causes of death and disability, https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-leading-causes-of-death

Francisco Fresard, Paula Iglesias, Stefan Berg, 2017, Seguridad vial de usuarios vulnerables en Chile: un problema urgente, https://repositorio.uc.cl/handle/11534/45730

Axel Rimbaud, 2020a, Siniestros de Tránsito Chile 2010-2019, https://www.contraexceso.org/siniestros-transito-chile-2010-2019

DTPM, 2018, Historia del Sistema, https://www.dtpm.cl/index.php/homepage/historia-del-sistema

Cooperativa, 2007, Transantiago: Una historia de retrasos y críticas, https://www.cooperativa.cl/noticias/pais/transportes/transantiago/transantiago-una-historia-de-retrasos-y-criticas/2007-01-14/125925.html

Juan Carlos Muñoz, Marco Batarce, Dario Hidalgo, 2014, Transantiago, five years after its launch, https://www.sciencedirect.com/science/article/abs/pii/S0739885914000821

DTPM, 2013, Directorio de Transporte Público Metropolitano, https://www.dtpm.cl/index.php/homepage/directorio-de-transporte-publico

SLOCAT, 2021, Transport and Climate Change Global Status Report, https://tcc-gsr.com/wp-content/uploads/2021/06/Slocat-Global-Status-Report-2nd-edition.pdf

RED, 2019, Presidente Piñera presentó "Red" la identidad que definirá el nuevo transporte público de las principales ciudades del país, https://www.red.cl/red-comunica/noticias/presidente-pinera-presento-red-la-identidad-que-definira-el-nuevo-transporte-publico-de-las-principales-ciudades-del-pais/

RED, 2021, Se suscriben contratos para la fabricación de más de 2 mil buses https://www.red.cl/red-comunica/noticias/se-suscriben-contratos-para-la-fabricacion-de-mas-de-2-mil-buses/

DTPM, 2022a, Informe de Gestión 2021, https://www.dtpm.cl/index.php/documentos/informes-de-gestion

Paola Tapia Salas, 2023, Contexto, Marco Legal y Desafíos del Transporte Público en el Gran Santiago, https://www.dtpm.cl/archivos/presentaciones/PRESENTACIoN%20CCCEE%201.pdf

bnamericas, 2019, Metro de Santiago: 80 estaciones dañadas o destruidas durante protestas, https://www.bnamericas.com/es/noticias/metro-de-santiago-80-estaciones-danadas-o-destruidas-durante-protestas

24 horas, 2021, 125 buses quemados en Santiago en menos de dos años, https://www.24horas.cl/nacional/125-buses-quemados-en-santiago-en-menos-de-dos-anos-4846316

Ministry of Transportation and Communications Chile (MTT), 2020, Balance de la operación del transporte público e impacto en la seguridad vial por emergencia del COVID19 http://www.mtt.gov.cl/archivos/24883

Ministry of Social Development Chile (MDSF), 2020, Elige Vivir Sano y Conaset lanzaron guía con recomendaciones para el uso seguro de la bicicleta y otros ciclos durante la pandemia, https://www.desarrollosocialyfamilia.gob.cl/noticias/elige-vivir-sano-y-conaset-lanzaron-guia-con-recomendaciones-para-el-uso-seguro-de-la-bicicleta-y-ot

Revolución Ciclista, 2021, Declaración alerta blanca, https://revolucionciclista.cl/assets/images/da_blanca_2021/declaracion-alerta-blanca3.pdf

Cooperativa, 2022, El 65% de buses del Transantiago excedió el límite de velocidad la última semana, https://www.cooperativa.cl/noticias/pais/transportes/transantiago/el-65-de-buses-del-transantiago-excedio-el-limite-de-velocidad-la/2022-02-05/105711.html

DTPM, 2022b, DTPM realiza inédita jornada de trabajo con organizaciones vinculadas con la movilidad para elaborar el primer Plan de Convivencia Vial, https://www.dtpm.cl/index.php/homepage/noticias/763-dtpm-realiza-inedita-jornada-de-trabajo-con-organizaciones-de-ciclistas-y-victimas-de-accidentes-para-elaborar-el-primer-plan-de-convivencia-vial

WHO, 2021a, SDG Target 3.6 Halve the number of global deaths and injuries from road traffic accidents, https://www.who.int/data/gho/data/themes/topics/sdg-target-3_6-road-traffic-injuries

Sustainable Development Goals (SDG), 2023, Indicator 11.2.1

Scopus, 2023, TITLE-ABS-KEY ((pedestrians OR pedestrian OR cyclists OR cyclist) AND (bus OR buses OR public AND transport) AND (crashes OR crash OR accident OR accidents)) https://www.scopus.com/term/analyzer.uri?sid=72384588516997f73fbde2ab14e66f61&origin=resultslist&src=s&s=TITLE-ABS-KEY%28%28pedestrians+OR+pedestrian+OR+cyclists+OR+cyclist%29+AND+%28bus+OR+buses+OR+Public+Transport%29+AND+%28crashes+OR+crash+OR+accident+OR+accidents%29%29&sort=plf-f&sdt=b&sot=b&sl=152&count=430&analyzeResults=Analyze+results&txGid=1dabd73bede906ac9c8b3f9010cf063b

Wei Yan, Soames Job, 2021, Road crashes affect women and men differently—here's why https://blogs.worldbank.org/endpovertyinsouthasia/road-crashes-affect-women-and-men-differently-heres-why

NHTSA, 2013, Injury Vulnerability and Effectiveness of Occupant Protection Technologies for Older Occupants and Women, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811766

Ahmad Aiash and Francesc Robusté, 2022, Traffic accident severity analysis in Barcelona using a binary probit and CHAID tree

Guangnan Zhang, Kelvin K.W. Yau, Xun Zhang, 2014, Analyzing fault and severity in pedestrian–motor vehicle accidents in China

Dongkwan Lee, Jean-Michel Guldmann and Burkhard von Rabenau, 2023, Impact of Driver's Age and Gender,

Marina Moscoso, José Segundo López, Valentina Montoya Robledo, Lina Marcela Quiñones Sánchez, Laura Daniela Gómez, Natalia Lleras, Claudia Adriazola-Steil, Juliana Vega, 2020, Las Mujeres Y El Transporte En Bogotá: Las Cuentas, https://www.despacio.org/portfolio/las-mujeres-y-el-transporte-en-bogota-las-cuentas/

Banco Interamericano de Desarrollo (BID), 2019, Inclusión laboral femenina en labores de conducción del sistema de transporte público de Santiago, https://publications.iadb.org/es/inclusion-laboral-femenina-en-labores-de-conduccion-del-sistema-de-transporte-publico-de-santiago

Vic roads, 2017, Victoria's Graduated Licensing System, https://www.vicroads.vic.gov.au/safety-and-road-rules/driver-safety/young-and-new-drivers/victorias-graduated-licensing-system

Birgitta Thorslund, Niklas Strand, 2016, Vision measurability and its impact on safe driving – a literature review, DOI: https://doi.org/10.5384/SJOVS.vol9i1p1

Adebola Olowosegun , Nathaniel Babajide, Adeyemi Akintola, Grigorios Fountas, Achille Fonzone, 2022, Analysis of pedestrian accident injury-severities at road junctions and crossings using an advanced random parameter modelling framework: The case of Scotland

Akerstedt, T., S. Folkard and C. Portin (2004) Predictions from the three process model of alertness. Aviat Space Environ Med 2004; 75(3, Suppl.):A75–83

Carina Fors, Sven-Olof Lundkvist, 2009, Night-time traffic in urban areas A literature review on road user aspects, https://journals.sagepub.com/doi/epub/10.1177/14604086221148954

Naved A. Siddiqui, Xuehao Chu, and Martin Guttenplan, 2006, Crossing Locations, Light Conditions, and Pedestrian Injury Severity, https://journals.sagepub.com/doi/10.1177/0361198106198200118

Fanny Malin, Ilkka Norros, Satu Innamaa, 2019, Accident risk of road and weather conditions on different road types, https://www.sciencedirect.com/science/article/pii/S0001457518308455

Xiaoqi Zhai, Helai Huang, N.N. Sze, Ziqi Song, Kai Kwong Hon, 2019, Diagnostic analysis of the effects of weather condition on pedestrian crash severity, https://www.sciencedirect.com/science/article/pii/S0001457518308650

Axel Rimbaud, 2020b, Lluvia y velocidad, https://www.contraexceso.org/lluvia-y-velocidad

Adebola Olowosegun, Nathaniel Babajide, Adeyemi Akintola, Grigorios Fountas, Achille Fonzone, 2022, Analysis of pedestrian accident injury-severities at road junctions and crossings using an advanced random parameter modelling framework: The case of Scotland

Deo Chimba, Thobias Sando, Valerian Kwigizile, 2010, Effect of bus size and operation to crash occurrences, https://www.sciencedirect.com/science/article/pii/S000145751000182X

Shrinivas, C Bastien, H Davies, A Daneshkhah, J Hardwicke, 2023, Parameters influencing pedestrian injury and severity – A systematic review and meta-analysis, https://www.sciencedirect.com/science/article/pii/S2666691X22000562

Venkataraman Shankar and Fred Mannering, 1996, An Exploratory Multinomial Logit Analysis of Single-Vehicle Motorcycle Accident Severity

Kristen Hubbert and Mehrnaz Doustmohammadi, 2019, Multinomial Logit Analysis of Injury Severity in Crashes Involving Emotional Drivers

Ana M Novoa, Katherine Pérez, Elena Santamariña-Rubio, and Carme Borrella, 2011, Effect on road traffic injuries of criminalizing road traffic offences: a time–series study, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3099552/

Katherine Pérez, Elena Santamariña-Rubio, Josep Ferrando, Maria José López and Llorenç Badiella, 2023, Effectiveness of a Road Traffic Injury Prevention Intervention in Reducing Pedestrian Injuries, Barcelona, Spain, 2002–2019, https://ajph.aphapublications.org/doi/full/10.2105/AJPH.2022.307216

Frank Gross, 2021, Exposure: A Critical Factor in Risk Analysis, https://www.sciencedirect.com/science/article/pii/B978008102671710137X

Eduardo Martínez-Gabaldón, Ildefonso Méndez Martínez and Jorge Eduardo Martínez-Pérez, 2020, Estimating the impact of the Penalty Point System on road fatalities in Spain, https://www.sciencedirect.com/science/article/pii/S0967070X18307091

Rune Elvik, Anna Vadeby, Tove Hels, Ingrid van Schagen, 2019, Updated estimates of the relationship between speed and road safety at the aggregate and individual levels

Göran Nilsson, 2004, Traffic Safety Dimensions and the Power Model to Describe the Effect of Speed on Safety

Rune Elvik, 2012b, A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims https://www.sciencedirect.com/science/article/pii/S0001457512002667

Instituto Nacional de Estadísticas Chile (INE), 2017, Estimación de población 2019 - INE estimaciones y proyecciones de población 1992-2050 base 2017,

R documentation, 2023, sunriset method, https://www.rdocumentation.org/packages/maptools/versions/0.6-3/topics/sunriset-methods

CONASET, 2022, Portal de Información Geoespacial, https://mapas-conaset.opendata.arcgis.com/

Elvik, R., 2012b, A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims https://www.sciencedirect.com/science/article/pii/S0001457512002667

Axel Rimbaud, 2019, Implementación del Narcotest, https://www.contraexceso.org/implementacion-del-narcotest

DTPM, 2012, Informe de Gestión 2011 https://www.dtpm.cl/index.php/documentos/informes-de-gestion

Observatory of Mobility and Road Safety of the City of Buenos Aires, OMSV, 2022, Informes estadísticos de seguridad vial, https://buenosaires.gob.ar/jefaturadegabinete/movilidad/informes-estadisticos-de-seguridad-vial

Secretaria de Movilidad de Bogotá, 2022, Anuario de Siniestralidad Vial de Bogotá 2021, https://datos.movilidadbogota.gov.co/documents/movilidadbogota::anuario-de-siniestralidad-vial-de-bogota-2021/explore

Nicolae Duduta, Claudia Adriazola-Steil and Dario Hidalgo, 2013, Saving Lives with Sustainable Transport: Traffic Safety Impacts of Sustainable Transport Policies, https://www.wri.org/research/saving-lives-sustainable-transport

TfL, 2022, bus action plan, https://content.tfl.gov.uk/bus-action-plan.pdf

TfL, 2023, Casualties in Greater London during 2022, https://content.tfl.gov.uk/casualties-in-greater-london-2022.pdf

Federal Highway Administration (FHWA), 2022, Leading Pedestrian Interval, https://highways.dot.gov/safety/proven-safety-countermeasures/leading-pedestrian-interval

Federal Highway Administration (FHWA), 2021, Curb Radius Reduction, https://safety.fhwa.dot.gov/saferjourney1/library/countermeasures/09.htm

Rodrigo Mora, Ricardo Truffell and Gabriel Oyarzún, 2021, Equity and accessibility of cycling infrastructure: An analysis of Santiago de Chile

DTPM, 2023, En un 25% aumentaron las conductoras de buses de Red Movilidad en 2022, https://www.dtpm.cl/index.php/homepage/noticias/890-en-un-25-aumentaron-las-conductoras-de-buses-de-red-movilidad-en-2022

DTPR, 2020, Implementación Sistema de Buses Estándar RED en Punta Arenas, http://www.dtpr.gob.cl/pe/punta_arenas/ascendal/inicio

Emol, 2021, Muertes asociadas a exceso de velocidad en zonas urbanas subieron un 39% en 2020 influido por menor flujo vehicular, https://www.emol.com/noticias/Nacional/2021/02/25/1013210/Siniestros-viales-1400-muertes-2020.html

Axel Rimbaud, 2020c, Mortalidad y fiscalización en el tránsito, https://www.contraexceso.org/mortalidad-fiscalizacion-transito

Buses vule, 2023a, Seguridad vial, https://busesvule.cl/seguridad-vial/

DTPM, 2022b, Presentan primeros 30 buses eléctricos con sensores para evitar puntos ciegos: en 450 mil kilómetros no han tenido siniestros con modos vulnerables https://www.dtpm.cl/index.php/homepage/noticias/791-presentan-primeros-30-buses-electricos-con-sensores-para-evitar-puntos-ciegos-en-450-mil-kilometros-no-han-tenido-siniestros-con-modos-vulnerables

DTPM, 2022c, DTPM apoya trabajo colaborativo conductores de buses y ciclistas para potenciar la convivencia vial, https://www.dtpm.cl/index.php/homepage/noticias/735-dtpm-apoya-trabajo-colaborativo-conductores-de-buses-y-ciclistas-para-potenciar-la-convivencia-vial

Buses Vule, 2023b, Vule, DTPM, Conaset y empresas operadoras del transporte público lanzan campaña de puntos ciegos en buses RED https://busesvule.cl/noticia/vule-dtpm-conaset-y-empresas-operadoras-del-transporte-publico-lanzan-campana-de-puntos-ciegos-en-buses-red/

Tor-Olav Nævestad, Rune Elvik, Vibeke Milch, Katrine Karlsen, Ross Phillips, 2022, Traffic safety in bus transport: An analysis of Norway's largest transit authority's contract requirements to bus companies, https://www.sciencedirect.com/science/article/pii/S1369847822001541

WHO, 2021b, Global Plan For the decade of action for road safety 2021-2030, https://cdn.who.int/media/docs/default-source/documents/health-topics/road-traffic-injuries/global-plan-for-road-safety.pdf?sfvrsn=65cf34c8_35&download=true

The Guardian, 2020, How Helsinki and Oslo cut pedestrian deaths to zero https://www.theguardian.com/world/2020/mar/16/how-helsinki-and-oslo-cut-pedestrian-deaths-to-zero

WHO, 2011, Global Plan for the Decade of Action for Road Safety 2011-2020, https://www.who.int/publications/m/item/global-plan-for-the-decade-of-action-for-road-safety-2011-2020

Helena Stigson, 2009, A safe road transport system - factors influencing injury outcome for car occupants

ITF, 2019, New Directions for Data-Driven Transport Safety, https://www.itf-oecd.org/new-directions-data-driven-transport-safety-0

TfL, 2019, Bus safety, https://tfl.gov.uk/corporate/safety-and-security/road-safety/bus-safety

Volvo buses, 2020, Brazil: Connected safety technology cuts accident rates by 50%, https://www.volvobuses.com/en/news/2020/jan/connected-safety-technology-cuts-accident-rates-by-50.html

NY Times, 2020, Can Controlling Vehicles Make Streets Safer and More Climate Friendly?, https://www.nytimes.com/2022/03/28/world/europe/geofencing-sweden.html

Greenshields S, Ball S, Barlow T, 2016, Intelligent Speed Assistance on London Buses, TRL https://content.tfl.gov.uk/intelligent-speed-assistance-on-london-buses.pdf

Alex van Loon and Lies Duynstee; 2001, Intelligent Speed Adaptation (ISA): A Successful Test in the Netherlands http://homes.plan.aau.dk/agerholm/ISA%20litteratur/Intelligent%20Speed%20Adaptation%20(ISA).%20A%20Successful%20Test%20in%20the%20Netherlands.pdf

SWOV, 2019, Intelligent transport and advanced driver assistance systems (ITS and ADAS). SWOV fact sheet, April 2019. SWOV, The Hague. https://swov.nl/en/fact/its-what-intelligent-speed-adaptation-isa-and-what-effects-does-it-have-road-safety

Brussels Mobility, 2022, Other 30 Cities, https://city30.brussels/other-30-cities

Steer Davies Gleave, 2014, Research into the impacts of 20mph speed limits and zones, https://www.roadsafetyknowledgecentre.org.uk/downloads/20mph-reportv1.0-FINAL.pdf

TfL, 2022, London digital speed limit map, https://content.tfl.gov.uk/london-digital-speed-limit-map.pdf

Bristol City Council, 2012, 20MPH SPEED LIMIT PILOT AREAS, https://www.bristol20mph.co.uk/wp-content/uploads/2016/06/20mph-Monitoring-Report-pilot-areas-2012.pdf

TfL newsroom, 2023, TfL Press Release - New data shows significant improvements in road safety in London since introduction of 20mph speed limits, https://tfl-newsroom.prgloo.com/news/tfl-press-release-new-data-showssignificantimprovements-in-road-safety-in-london-since-introduction-of20mphspeed-limits

Ministerio del Interior de España, 2022, Balance de Seguridad Vial 2021, https://www.interior.gob.es/opencms/es/detalle/articulo/Descienden-un-20-los-fallecidos-por-siniestro-de-trafico-en-las-ciudades/

Alix Edwards, Adam Barrow, Siobhan O'Connell, Varun Krishnamurthy, Rahul Khatry, Nicola Hylands, Mike McCarthy, Shaun Helman and Iain Knight, 2018, Analysis of bus collisions and identification of countermeasures. Published Project Report PPR819. Wokingham, Berkshire, TRL, https://content.tfl.gov.uk/analysis-of-bus-collisions-and-identification-of-countermeasures.pdf

Phil Martin, Martin Dodd, Iain Knight, Emily Castiaux, Robert Hunt, and Alix Edwards, 2018, The Transport for London Bus Safety Standard: Direct Vision, Indirect Vision and Detection of Vulnerable Road Users, TRL, https://www.trl.co.uk/Uploads/TRL/Documents/PPR985-Bus-Safety-Standard---Vision-v1-1.pdf

Ingrid van Schagen and Charles Goldenbeld, 2023, Road Safety Thematic Report – Professional drivers of trucks and buses, European Road Safety Observatory, https://road-safety.transport.ec.europa.eu/system/files/2023-03/Road_Safety_Thematic_Report_Professional_drivers_trucks_and_buses_2023.pdf

Jessica B. Cicchino, 2017,Effects of blind spot monitoring systems on police-reported lane-change crashes, https://doi.org/10.1080/15389588.2018.1476973

UNECE, 2021, UN Regulation No. 151 - Blind Spot Information System for the Detection of Bicycles; https://unece.org/transport/documents/2021/08/standards/un-regulation-no-151-blind-spot-information-system-detection

UE, 2021, UN Regulation No 159 – uniform provisions concerning the approval of motor vehicles with regard to the Moving Off Information System for the Detection of Pedestrians and Cyclists, https://op.europa.eu/en/publication-detail/-/publication/471f2e44-bcf4-11eb-8aca-01aa75ed71a1

Iain Knight, Martin Dodd, Alix Edwards, Mervyn Edwards, Phil Martin and Mike McCarthy, 2019, The Transport for London Bus Safety Standard: Advanced Emergency Braking (AEB) - Evaluation of Safety Measure, TRL, https://content.tfl.gov.uk/advanced-emergency-braking.pdf

Erik Rosén, 2013, Autonomous Emergency Braking for Vulnerable Road Users, https://www.researchgate.net/publication/288125228_Autonomous_emergency_braking_for_vulnerable_road_users

Phil Martin, Ianto Guy, Jolyon Carroll, Jack Radcliffe, Robert Hunt, Martin Dodd, Iain Knight, Alix Edwards, Mike McCarthy, 2020, The Transport for London Bus Safety Standard: Vulnerable Road User (VRU) Frontal Crashworthiness Evaluation of Safety Measure, TRL, https://content.tfl.gov.uk/bus-safety-standard-vru-front-crashworthiness.pdf

Mervyn Edwards, Josh Appleby, Krishnan Venkateswaran, Brian Robinson, Alix Edwards, Phil Martin and Mike McCarthy, 2018, The Transport for London (TfL) Bus Safety Standard: Occupant Friendly Interiors, TRL, https://content.tfl.gov.uk/occupant-friendly-interiors.pdf

European Commission, 2023, Road safety – advanced driver distraction warning systemhttps://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13740-Road-safety-advanced-driver-distraction-warning-systems_en

European Commission, 2022, New rules to improve road safety and enable fully driverless vehicles in the EU, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_4312

Axel Rimbaud, 2023, Road safety in bus operations – results of a survey of the European Metropolitan Transport Authorities (EMTA) circulated May 2023, Private Communication

Beate Elvebakk, Tor-Olav Nævestad, Leif Christian Lahn, 2020, Mandatory periodic training for professional drivers: A Norwegian study of implementation and effects, https://www.sciencedirect.com/science/article/pii/S1369847820304101?via%3Dihub

EU, 2022, Directive (EU) 2022/2561 of the European Parliament and of the Council of 14 December 2022 on the initial qualification and periodic training of drivers of certain road vehicles for the carriage of goods or passengers (codification) (Text with EEA relevance)

Tor-Olav Nævestad, Ross O. Phillip, Alexandra Laiou, Torkel Bjørnskau and George Yannis, 2019, Safety culture among bus drivers in Norway and Greece

Esther Marie Bia and Nicholas N. Ferenchak, 2022, Impact of Bus Rapid Transit Construction and Infrastructure on Traffic Safety: A Case Study From Albuquerque, New Mexico, https://doi.org/10.1177/03611981221085532

ITF, 2017, Benchmarking de la seguridad vial en América Latina

Md Tanvir Ashraf, Kakan Dey, Dimitra Pyrialakou, 2022, Investigation of pedestrian and bicyclist safety in public transportation systems, https://www.sciencedirect.com/science/article/abs/pii/S2214140522002018

Nicolae Duduta, Claudia Adriazola-Steil, Dario Hidalgo, Toni Lindau, Vineet John and Carsten Wass, 2015, Traffic Safety on Bus Priority Systems https://wrirosscities.org/research/publication/traffic-safety-bus-priority-systems

NACTO, 2016b, Pedestrian Access & Networks, https://nacto.org/publication/transit-street-design-guide/transit-system-strategies/network-strategies/pedestrian-access-networks/

Your Europe, 2023, eCall 112-based emergency assistance from your vehicle, https://europa.eu/youreurope/citizens/travel/security-and-emergencies/emergency-assistance-vehicles-ecall/index_en.htm

Cooperativa, 2011, Mujer falleció tras ser atropellada por bus del Transantiago en Alameda, https://cooperativa.cl/noticias/pais/policial/accidentes-de-transito/mujer-fallecio-tras-ser-atropellada-por-bus-del-transantiago-en-alameda/2011-05-02/221818.html

Cooperativa, 2023, Mujer murió atropellada por micro que desvió su recorrido por manifestaciones en la Alameda, https://cooperativa.cl/noticias/pais/policial/accidentes-de-transito/mujer-murio-atropellada-por-micro-que-desvio-su-recorrido-por/2023-06-09/172902.html

María José Gómez, 2023, Nataniel Cox: el peligro de los cruces peatonales no autorizados en plena Alameda , La Tercera, https://www.latercera.com/tendencias/noticia/nataniel-cox-el-peligro-de-los-cruces-peatonales-no-autorizados-en-plena-alameda/QGAQMXD2TBHIBKGZKH23V7F2G4/

Annexes

Annex 1 - Comparison between pedestrian fatalities with or without any public bus in (2017-2021)

	Cyclist fatalities with public transport bus not involved (N=76)	Cyclist fatalities with public transport bus involved (N=28)	Total pedestrian fatalities (N=104)	p value
Gender				0.065
Male	66 (86.8%)	20 (71.4%)	86 (82.7%)	
Female	10 (13.2%)	8 (28.6%)	18 (17.3%)	
Age Range				0.100
Unknown	3	1	4	
10 to 17 years	2 (2.7%)	2 (7.4%)	4 (4.0%)	
18 to 29 years	13 (17.8%)	9 (33.3%)	22 (22.0%)	
30 to 44 years	16 (21.9%)	6 (22.2%)	22 (22.0%)	
45 to 64 years	24 (32.9%)	9 (33.3%)	33 (33.0%)	
65 years and above	18 (24.7%)	1 (3.7%)	19 (19.0%)	
is Weekend?				0.854
Weekday	53 (69.7%)	19 (67.9%)	72 (69.2%)	
Weekend	23 (30.3%)	9 (32.1%)	32 (30.8%)	
Weather Condition				0.164
Bad condition	5 (6.6%)	0 (0.0%)	5 (4.8%)	
Good condition	71 (93.4%)	28 (100.0%)	99 (95.2%)	
Day or Night?				0.575
Night	36 (47.4%)	15 (53.6%)	51 (49.0%)	
Day	40 (52.6%)	13 (46.4%)	53 (51.0%)	
Crash Time Range				0.128
00:00 - 07:59	21 (27.6%)	4 (14.3%)	25 (24.0%)	
08:00 - 09:59	9 (11.8%)	0 (0.0%)	9 (8.7%)	
10:00 - 17:59	22 (28.9%)	10 (35.7%)	32 (30.8%)	
18:00 - 19:59	9 (11.8%)	6 (21.4%)	15 (14.4%)	
20:00 - 23:59	15 (19.7%)	8 (28.6%)	23 (22.1%)	
Is Junction?				0.845
Junction	39 (51.3%)	16 (57.1%)	55 (52.9%)	
Not Junction	33 (43.4%)	11 (39.3%)	44 (42.3%)	
Others	4 (5.3%)	1 (3.6%)	5 (4.8%)	
Number of Lanes				0.883
1	1 (1.3%)	0 (0.0%)	1 (1.0%)	
2	30 (39.5%)	11 (39.3%)	41 (39.4%)	
3	4 (5.3%)	1 (3.6%)	5 (4.8%)	
4	30 (39.5%)	10 (35.7%)	40 (38.5%)	
5 or more	11 (14.5%)	6 (21.4%)	17 (16.3%)	
Road direction				0.720
Two-way	38 (50.0%)	12 (42.9%)	50 (48.1%)	
Two-way with central separation	24 (31.6%)	9 (32.1%)	33 (31.7%)	
One-way	14 (18.4%)	7 (25.0%)	21 (20.2%)	
Driver Gender				0.341
Unknown	7	0	7	
Female	2 (2.9%)	2 (7.1%)	4 (4.1%)	
Male	67 (97.1%)	26 (92.9%)	93 (95.9%)	

	Cyclist fatalities with public transport bus not involved (N=76)	Cyclist fatalities with public transport bus involved (N=28)	Total pedestrian fatalities (N=104)	p value
Driver Age Range				0.061
Unknown	19	1	20	
18 to 29 years	16 (28.1%)	1 (3.7%)	17 (20.2%)	
30 to 44 years	15 (26.3%)	8 (29.6%)	23 (27.4%)	
45 to 64 years	22 (38.6%)	14 (51.9%)	36 (42.9%)	
65 years and above	4 (7.0%)	4 (14.8%)	8 (9.5%)	
Driver Is Chilean?				0.055
Unknown	38	5	43	
Foreigner	38 (100.0%)	23 (100.0%)	61 (100.0%)	
Driver Is Impaired?				0.055
Unknown	38	5	43	
Not impaired	38 (100.0%)	23 (100.0%)	61 (100.0%)	
Driver manoeuvre				0.179
Driving straight	38 (50.0%)	20 (71.4%)	58 (55.8%)	
Emergency braking	1 (1.3%)	0 (0.0%)	1 (1.0%)	
Other Manoeuvre	5 (6.6%)	4 (14.3%)	9 (8.7%)	
Restarting	1 (1.3%)	0 (0.0%)	1 (1.0%)	
Turning left	2 (2.6%)	1 (3.6%)	3 (2.9%)	
Turning right	9 (11.8%)	1 (3.6%)	10 (9.6%)	
Unknown	20 (26.3%)	2 (7.1%)	22 (21.2%)	

Annex 2 - Comparison between crashes between public buses and pedestrians and between public buses and cyclists in Santiago (2017-2021)

	Cyclist fatalities (N=28)	Pedestrian fatalities (N=135)	Total (N=163)	p value
Gender				0.900
Male	20 (71.4%)	98 (72.6%)	118 (72.4%)	
Female	8 (28.6%)	37 (27.4%)	45 (27.6%)	
Age Range				0.011
Unknown	1	5	6	
0 to 9 years	0 (0.0%)	2 (1.5%)	2 (1.3%)	
10 to 17 years	2 (7.4%)	3 (2.3%)	5 (3.2%)	
18 to 29 years	9 (33.3%)	15 (11.5%)	24 (15.3%)	
30 to 44 years	6 (22.2%)	26 (20.0%)	32 (20.4%)	
45 to 64 years	9 (33.3%)	48 (36.9%)	57 (36.3%)	
65 years and above	1 (3.7%)	36 (27.7%)	37 (23.6%)	
is Weekend?				0.159
Weekday	19 (67.9%)	108 (80.0%)	127 (77.9%)	
Weekend	9 (32.1%)	27 (20.0%)	36 (22.1%)	
Weather Condition				0.160
Bad condition	0 (0.0%)	9 (6.7%)	9 (5.5%)	
Good condition	28 (100.0%)	126 (93.3%)	154 (94.5%)	
Day or Night?				0.240
Night	15 (53.6%)	56 (41.5%)	71 (43.6%)	
Day	13 (46.4%)	79 (58.5%)	92 (56.4%)	
Crash Time Range				0.118
00:00 - 07:59	4 (14.3%)	22 (16.3%)	26 (16.0%)	
08:00 - 09:59	0 (0.0%)	15 (11.1%)	15 (9.2%)	
10:00 - 17:59	10 (35.7%)	54 (40.0%)	64 (39.3%)	
18:00 - 19:59	6 (21.4%)	11 (8.1%)	17 (10.4%)	

	Cyclist fatalities (N=28)	Pedestrian fatalities (N=135)	Total (N=163)	p value
20:00 - 23:59	8 (28.6%)	33 (24.4%)	41 (25.2%)	
Is Junction?				0.383
Junction	16 (57.1%)	70 (51.9%)	86 (52.8%)	
Not Junction	11 (39.3%)	48 (35.6%)	59 (36.2%)	
Others	1 (3.6%)	17 (12.6%)	18 (11.0%)	
Number of Lanes				0.790
1	0 (0.0%)	4 (3.0%)	4 (2.5%)	
2	11 (39.3%)	43 (31.9%)	54 (33.1%)	
3	1 (3.6%)	3 (2.2%)	4 (2.5%)	
4	10 (35.7%)	58 (43.0%)	68 (41.7%)	
5 or more	6 (21.4%)	27 (20.0%)	33 (20.2%)	
Road direction				0.671
Two-way	12 (42.9%)	65 (48.1%)	77 (47.2%)	
Two-way with central separation	9 (32.1%)	46 (34.1%)	55 (33.7%)	
One-way	7 (25.0%)	24 (17.8%)	31 (19.0%)	
Driver Gender				0.172
Unknown	0	1	1	
Female	2 (7.1%)	3 (2.2%)	5 (3.1%)	
Male	26 (92.9%)	131 (97.8%)	157 (96.9%)	
Driver Age Range				0.789
Unknown	1	2	3	
18 to 29 years	1 (3.7%)	4 (3.0%)	5 (3.1%)	
30 to 44 years	8 (29.6%)	31 (23.3%)	39 (24.4%)	
45 to 64 years	14 (51.9%)	83 (62.4%)	97 (60.6%)	
65 years and above	4 (14.8%)	15 (11.3%)	19 (11.9%)	
Driver Is Chilean?				0.341
Unknown	5	4	9	
Chilean	23 (100.0%)	126 (96.2%)	149 (96.8%)	
Foreigner	0 (0.0%)	5 (3.8%)	5 (3.2%)	
Driver Is Impaired?				0.674
Unknown	5	4	9	
Impaired	0 (0.0%)	1 (0.8%)	1 (0.6%)	
Not impaired	23 (100.0%)	130 (99.2%)	153 (99.4%)	
Driver manoeuvre				0.016
Driving straight	20 (71.4%)	64 (47.4%)	84 (51.5%)	
Emergency braking	0 (0.0%)	9 (6.7%)	9 (5.5%)	
Other Manoeuvre	4 (14.3%)	6 (4.4%)	10 (6.1%)	
Restarting	0 (0.0%)	15 (11.1%)	15 (9.2%)	
Turning left	1 (3.6%)	15 (11.1%)	16 (9.8%)	
Turning right	1 (3.6%)	21 (15.6%)	22 (13.5%)	
Unknown	2 (7.1%)	5 (3.7%)	7 (4.3%)	