# BRT Accidents in intersections or crossroads: A Review of Empirical Research

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## INTRODUCTION

### The Bus Rapid Transit Transport System (BRT)

The Bus Rapid Transit system (BRT) is a modern massive transportation system that allow users to move from point A to point B using a segregated way. The BRT system has become a global phenomenon in the twenty-first century due to the evidence of its capacity to implement massive transportation quickly and at low cost using the existing infrastructure, BRT projects have been implemented worldwide and many BRT systems are under construction [1-5], more specifically, the system has grown in such a way that currently about 168 cities from 39 countries around the world have adopted the system [2, 3].

There are several urban characteristics of developing cities like in Asia and in Latin America, which are different from successful cities which have implemented BRT systems, such as cities in North America, Europe and also in some cities of Latin America. Within a few considerations that must be taken into account to achieve a successful implementation of a BRT Project, is the urban sprawl caused by bad planning of the city, excessive use of private vehicles and poor quality of existing public transport too [6, 7].

It is believed that the cities that have already made the decision to invest in massive transport find BRT systems attractive for the following reasons [5]: a) Speed of implementation: time for planning and of implementation tends to be far shorter for BRT than for rail-based alternatives; b) Cost: capital costs tends to be lower than those for rail-based alternatives; and c) Network Connectivity: part of the BRT Network can operate on normal streets, and is cheaper and faster to establish links between the stations.

### Accidents

The BRT systems have some advantages as mentioned above, but also has disadvantages, i.e. A lot of accidents in the Cities where the BRT systems have been implemented causing fatalities are common and happen for many factors like the invasion of lanes, to not respect the red lights in the intersections among others. A number of approaches have been taken to study BRT systems; for example, there have been studies being conducted from different perspectives, institutional, social, economic, urban planning, technical and environmental; There has also been some publications regarding the safety of such systems [9]; A lot of traffic accidents have occurred causing fatalities (see Fig. 1).

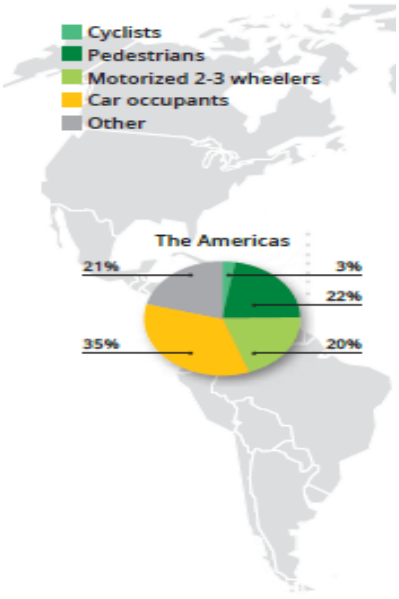


Fig. 1. Road traffic deaths by type of road user, by región in Latin America [10].

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The main cause of death in Mexican society in 2015, not related directly to diseases were the accidents, of which 3275 (38%) were traffic accidents regardless of the age of people, either as a pedestrian or as a passenger of a vehicle [8]. This means the death by traffic accidents is the 1.16% of total deaths in Mexico per year.

However, there is no evidence of studies being conducted explicitly in accident analysis related to BRT systems in intersections around the world.

This papers review aims to asses the strengths and limitations of the existing literature besides identify gaps than can be adressed by future researchs.

## The BRT system in Mexico

According to the Metrobus webpage, the central part of the development of a city is an effective public transport system. For most of the population of cities, public transport is the only mean to access employment, education and public services.

In an effort to offer people an effective mode of public transport, many cities implement expensive means, therefore, do not allow expand enough to acomplish the population needs. Metrobus is a transport system based on bus capabilities and technology, which provides urban mobility quickly and safely through the integration of a preferred infrastructure (see Table 1), rapid and frequent operations, automated payment system and excellence and quality in the service. It is a mode of Bus Rapid Transit transport (BRT) that combines stations, vehicles, services and high technology in an integrated system with a positive identity. It has several distinct components that together form an integrated system [11].

Table 1
Some Features of the Mexico City Metrobus Transport System [13]

| Features | Line 1 | Line 2 | Line 3 | Line 4 | Line 5 | Total |
|---|---|---|---|---|---|---|
| Lenght | 30 Km | 20 Km | 17 Km | 28 Km | 10 Km | 95 Km |
| Operations strart | June 2005 | Dec 2009 | Feb 2011 | April 2012 | Nov 2013 | - |
| Stations | 44 | 34 | 29 | 32 | 16 | 155 |
| Users/day | 480,000 | 180,000 | 140,000 | 65,000 | 55,000 | 920,000 |

During the last years in Mexico using this transport system demand has increased, counting nowadays with eighteen corridors in twelve different states, with projects of growth in some of these and projects of instauration in others more (see Fig. 2). Despite the good results that this transport system has presented in people mobility, accidents have been increasing possibly due to the lack of planning in design of the stations, as well as, null implementation of security programs that avoid accidents and recurrence of them, especially in intersections or crossroads.

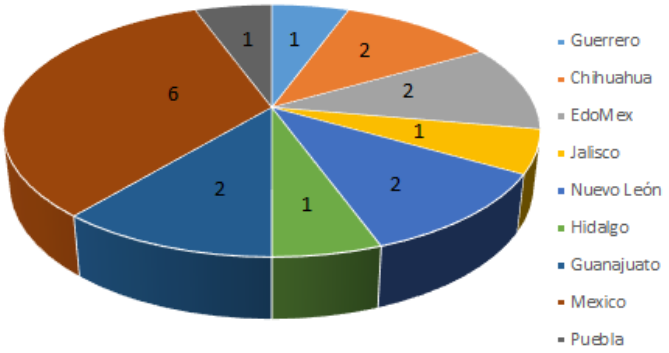


Fig. 2. BRT Corridors in Mexico [2].

The number of accidents has increased year by year, due to demand of a greater number of users and the appearance of new corridors, according to the WHO Mexico occupies the 16th place in traffic accidents [10, 12].

## BRT Accidents in Mexico City

Due to the establishment of a new infrastructure for transport citizens from one point to another in order to carry out their daily activities by confined lanes, a lot of accidents have occurred around the world, this because of the constant invasions not allowed to them, as well as, the disobedience of the traffic signals, especially in intersections or crossroads. There are worldwide records of traffic accidents involving BRT systems and Mexico is not the exception.

The most critical years in terms of accidents occurrence frequency in Mexico are the years 2015 (12.25%, 98/800), 2016 (16.12%, 129/800), 2011 and 2012 (11.51%, 92/800, each one) and 2008 (9.12%, 73/800). (Note that line 1 of Metrobus was the first to begin operations in 2005 and the results show that a total of 130 accidents occurred on Line 1 during the years 2005, 2006 and 2007; This represents a 16.25% of all accidents in the Metrobus system). On the other hand, the year where the fewer accidents recorded was 2010 with 18 (2.25%), even though they were operating lines 1 and 2 (see Fig. 3).

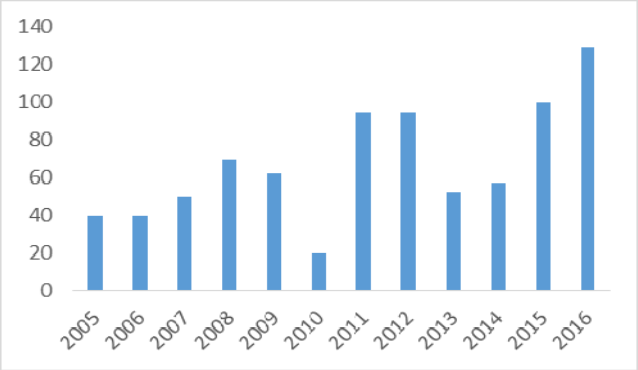


Fig. 3. Accident Occurrence per year in Mexico City Metrobus Transport System [13].

It is important to mention that the metrobus line where the greatest number of accidents have occurred is line 1 which corresponds to the greatest number of transported users and these are presented in the greater risk intersections or crossroads of all the lines (see Fig. 4).

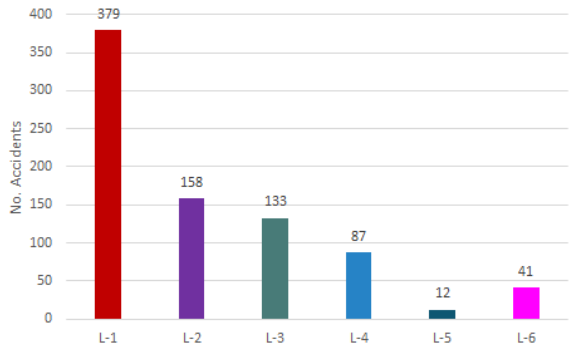


Fig. 4. Accidents distribution per line in Mexico City Metrobus lines [13].

## METHODOLOGY

### Method

In this paper a methodology based on the scientific method is proposed, once the problem is defined, it means, the constant accidents that occur in BRT systems around the world, It is necessary proceed to collect and organize the information and then the issued solution proposals by the scientific community (if already exist), use the bests as a reference to go deeper into the topic and then take action to control the root cause.

The methodology is divided in only three phases, which have a specific goal, the first phase is to find a trustworthy data source that have information of this problem around the world (see Fig. 5), the next phase is to select the most precise search criteria in order to debug not necessary information and finally, to obtain expected results. These three phases are called 1) Data Source, 2) Study Classification Criteria and 3) Specific Data Obtaining.

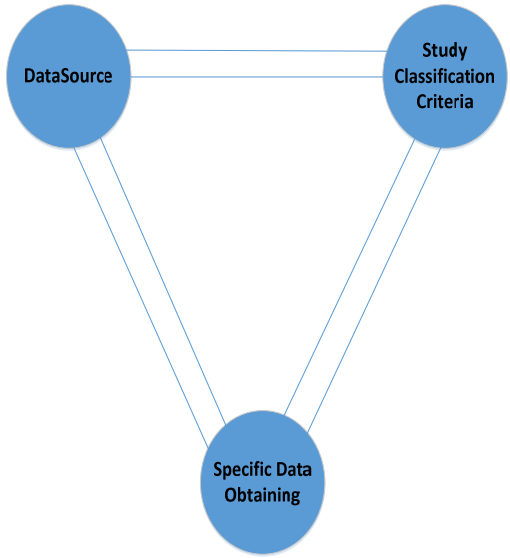


Fig. 5. Research Methodology Proposal.

In order to carry out an exhaustive literature concerning the BRT systems in the world, as well as accidents and the way in which these affect the urban mobility, It is important thus, to define the approach in which these studies have been carried out. It should be mentioned that before attempting to conceptualize and locate in a systems theory approach the BRT systems accidents, it is necessary to consider that a greater part of the BRT systems accidents in Mexico City occurs in the intersections or crossroads, Either due to vehicular and pedestrian influx, Metrobus units run overs or collisions or some of these.

In order to begin the search that let us know the literature about BRT systems accidents in intersections, It is necessary to define the keywords in Spanish and English, with a combination of some of these, in addition to a singular search for every keyword, try to find related articles in the datasource.

**DataSource** Two electronic online databases were used to identify the articles related to BRT accidents in intersections or crossroads; i.e. the "WEB OF SCIENCE" AND "SCOPUS". The following keywords were used: "Cruces Viales", "Intersecciones", "Cruceros", "Intersections", "Crossroads", "BRT", "BRT AND Accidents" "BRT AND Accidents AND in AND Intersections". The extensive literature search was conducted from August to November 2016. The review only includes articles from year 2004 to the present, since the assigned parameter in SCOPUS and WEB OF SCIENCE database search engine is the date when these kind of systems were

installed, considering the Mexico City Metrobus predecessor was the City of Leon Optibus established in 2003.

**Study Classification Criteria** The articles are peer reviewed and also those that appear in international journals with impact factor (JCR). The research is based on the obtaining of empirical data related in general to the public, and only applies to the accidents where the BRT system units are involved, this information can be qualitative and quantitative.

The proposed keywords are: Cruceros, BRT, Accidentes, and synonyms in Spanish, Cruces Viales, Intersecciones, Metrobus, Sistema de Transporte Masivo and Transporte besides Incidente, Colision and Choque. The keywords to look for in English are: Crossroads, Intersection, Transport, Massive Transport, Incident, Crash and Collision.
Once the keywords were defined, the search in Spanish will be made, it is important considering that results will be fewer because English is the global communication language over the world.

**Specific Data Obtaining** The amount of articles found in both databases was 1,438 in SCOPUS and 0 in the WEB Of SCIENCE. 69.55% of this titles (of a total of 1,000 articles) were eliminated due to the fact that they did not match with the classification criteria mentioned above. For example the word "Cruces Viales" deployed zero results (0) in the search engine of SCOPUS and the search engine of WEB OF SCIENCE, the word "Cruce Vial" deployed zero results (0) in the search engine of SCOPUS and the search engine of WEB OF SCIENCE, the word "Interseccion" deployed fifteen results (15) in the SCOPUS search engine and zero results (0) in the WEB OF SCIENCE search engine, but none of these results match with the classification criteria. The "BRT" keyword deployed 438 results, but just 24.96% (359 articles) were found in the time period in which BRT systems were installed in Mexico, 0.48% (7 titles) of this result were related to the keywords "BRT" and "accident".

After this search, a new one was made using the keyword "BRT AND accidents" word criteria, and the amount of articles in both databases was 36 in SCOPUS and 0 in the web of science, from these papers only 66.66% (24 articles) are for the engineering subject area, only 25% (6 articles) used the keyword BRT as not a Bus Rapid Transit acronym, 12.5% (3 articles) used the keyword BRT as Break Reaction Time acronym, 54.16% (13 articles) are study cases for the Bus Rapid Transit systems and 12.5% (3 articles) of them were repeated in the search.

RESULTS AND DISCUSSION

The most relevant information of the paper titled "Prioritizing Highway Safety Manual's crash prediction variables using boosted regression trees" [14] are: Aims to determine the impact of each independent variable in the HSM on crash predictions with the help of Boost Regression Trees (BRT).
The key findings of this paper are: The keyword BRT is used to describe the Bus Rapid Transit and can be misunderstood with Boosted Regression Tree which first letters are the same, the word accident makes direct reference to crashes, but it does not present a BRT accidents approach.
Keywords: Accidents Traffic, Bayes Theorem, Boosted Regression Trees, Calibration, Calibration Factor.

The most relevant information of the paper titled "Accident prediction models for bus rapid transit systems: generalized linear models compared with a neural network" [15] are: The research sought to model traffic accidents in the Bus Rapid Transit (BRT) in Bogota Colombia for each station using 35 variables. After a selection process of generalized linear models and a neural network model, they were used to compare the results and the neural network model had better predictability indicators, finally a scenario analysis was developed.
The key findings of this paper are: The keyword BRT describes the Colombia BRT system but makes no reference to accidents, only makes reference to variables traffic variables such as proximity to at-grade vehicular intersections, bus flow and number of accesses, but it does not present a BRT accident analysis approach.
Keywords: Accidents Prediction Model, Accidents, Bins, BRT systems, Bus transportation.

The most relevant information of the paper titled "Joint impacts of bus rapid transit urban form on vehicle ownership: New evidence form a quasi-longitudinal analysis in Bogotá Colombia" [16] are: The paper improves the knowledge of BRT's potential as an alternative to vehicle ownership, because the results indicate that the Transmilenio main trunk system is significantly and negatively associated with vehicle ownership for higher wealth households. The research contributes a methodology for joint analysis of urban transit form and transit availability on vehicle ownership.

The key findings of this paper are: The keyword makes reference on Colombia Transmilenio BRT system, but makes no reference to accidents because it does not present a BRT accident analysis approach.
Keywords: Bogota, BRT, Bus transportation, Collision Avoidance, Cost effectiveness.

The most relevant information of the paper titled "Evaluating improvements in bus rapid transit in Mexico City. How feasible is it to improve a consolidated system?" [17] are: cost of implementation, level of complexity and administrative process as the criteria used to determine the

level of complexity of a BRT system in Mexico City, with help of a simulation tool named EMBARQ the results were found, requiring infrastructure investment than operational modifications produce improvements in the BRT system.
The key findings of this paper are: The Mexico City BRT system is studied from different perspectives, but no accident analysis approach has been made to them, so the obtained results only can improve a 10% of all the components of a BRT system, because one of the variables to improve is the accidents in the BRT corridors and there is no information about this analysis.
Keywords: Administrative process, BRT systems, Bus transportation, Costs, Decision making.

The most relevant information of the paper titled "Accident analysis of bus rapid transit units in Mexico City" [4] are: This paper presents some preliminary results of the analysis of an accident that involved two BRT Units, a Vehicle transporting gas LPG, and a Minibus. The accident left over 15 injured and caused heavy disruption of vehicular traffic in Mexico City. The approach has been the application of the 'Events & causal factors chart' and the 'Barrier **a**nalysis' technique.
The key findings of this paper are: The approach applied are two accident analysis techniques, both of them allow the user to do a probabilistic analysis with qualitative variables considering an accident in the Mexico City BRT system as an undesirable event. The immediate causes are part of the BRT system such as users, infrastructure, red lights, highways and avenues, traffic flow, among others.
This approach considers how a BRT system disruption caused by an accident affects urban mobility too.
Keywords: Accident analysis, Accident prevention, Accidents, Mexico City, BRT.

The most relevant information on the paper titled "Accident analysis of a transport system: the case of the bus rapid transit system in Mexico City" [18] are: The BRT system installed in Mexico City is an efficient urban transport system, but is vulnerable. Although is an alternative solution to the lack of transport services, at least 425 accidents happened generating traffic disruption, two study cases are analysed, The approach has been the application of the 'Events & causal factors chart' and the 'Barrier **a**nalysis' technique.
The key findings of this paper are: The approach applied are two accident analysis techniques, both of them allow the user to do a probabilistic analysis with qualitative variables considering an accident in the Mexico City BRT system as an undesirable event. The immediate causes are part of the BRT system such as users, infrastructure, red lights, highways and avenues, bad deign on the intersections and bad design on the turnovers of the buses, among others.
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Keywords: Accident analysis, Accident prevention, Accidents, Mexico City, BRT.

The most relevant information on the paper titled "The performance of the accessibility to BRT stop: A case study on Transpadang Metrobus" [19] are: This study focuses on the accessibility of the BRT stops in Padang City, comparing different users' perception from multiple variables in order to determine which of them have increased and which have decreased.
The key findings of this paper are: One of the variables is the protection from traffic accidents, but it is just a reference to the infrastructure and it is not related to the way the accidents happen near to the BRT station or facilities. The study is the result of the users' perception trough a poll that mentions the variables and not their development.
Keywords: Access distance, Accessibility, BRT, Bus transportation, Collision Avoidance, Cost effectiveness.

The most relevant information on the paper titled "A simulation study of the effects of alcohol on driving performance in Chinese population. Accident analysis and prevention" [20] are: Driving under the influence of alcohol (DUA) is a significant factor contributing to road traffic crashes, injuries and fatalities. Studies on the effects of alcohol on driving performance in China are rare, and a series of simulated tests were performed evaluating standard deviation (SD) on speed and lane
The key findings of this paper are: The keyword BRT is used to identify the Break Reaction Time and not the Bus Rapid Transit, even evaluating driver's performance the study was not applied to BRT units' operators and only determine abuse in consuming alcohol as a factor of crash accidents.
Keywords: Automobile drivers, Automobile simulators, Braking, Braking performance, Chinese population.

The most relevant information on the paper titled "Evaluating health impact from a bus rapid transit system implementation in India case study of Indure, Medhya Predesh" [21] are: This study mentions that sustainable transportation affects public health directly in three ways, trough reduced pollution emissions, increased physical activity and reduced road accidents showing results that recommend that public health aspects should be considered in transport policy. Estimated benefits of the implementation in the city of Indore in the Indian state of Madhya Pradesh were considered too.
The key findings of this paper are: The information of improvement trough corridors and how they benefit the people are evident, but no accident studies related to BRT systems were applied, it is true that using BRT systems help to reduce crash accidents but BRT systems generate crash accidents too and they are unavoidable yet.

Keywords: Air pollution exposure, BRT systems, Bus transportation, Business-as-usual, Crashworthiness.

The most relevant information on the paper titled "A research of pedestrian evacuation simulation for BRT station based on fine grid method" [22] are: Making BRT stations a centralized area with high density of passengers for public transport it is necessary to consider accidents such as serious crowds, panic, trample may occur. In order to avoid this scenarios an evacuation model for BRT station is proposed to provide guidance and advice for evacuation.
The key findings of this paper are: This study case consider overcrowding as a possible accident however no accident analysis related directly with a BRT system is proposed.
Keywords: BRT, Bus station, Evacuation, Find grid, Simulation.

The most relevant information on the paper titled "A framework for bus rapid transit reform & redesign: Case study Kolkata" [23] are: This paper makes reference to the service of the BRT system in Kolkata, this due the quality of bus service demand and supply mismatch, rash driving and overtaking between buses resulting in an increasing number of accidents. The proposal is an urgent need to reform and redesign the existing BRT system through an appropriate framework development identifying possible BRT corridors, BRT routes, detail planning for individual BRT and planning of new BRT services
The key findings of this paper are: Despite the paper propose a reform and redesign of the BRT system in Kolkata due to some factors like overtaking between buses that produces accidents, the framework development does not consider an accident analysis applied to decrease them because the BRT systems are not part of road infrastructure.
Keywords: Accident, BRT, Bus transit service, Bus transportation, Buses.

The most relevant information on the paper titled "Bus rapid transit (BRT) parallel system based on ACP approach" [24] are: This paper aims to apply an Artificial systems, Computational experiments, Parallel execution (ACP) approach to operate, control and monitor real-time passengers flow at stations in order to provide short-term prediction to timely arrange transportation management and relieve congestion to improve the management of the accidents in Guangzhou, Zhongshan Avenue.
The key findings of this paper are: This approach consider the application of an ACP system to improve the way the BRT system works, but management of BRT system is not the only stage of an accident evaluation, it is necessary to do a real-time accident analysis using this tool.
Keywords: ACP approach, BRT, Civil Defense, Disaster.

The most relevant information on the paper titled "Implementation on the Bus Rapid Transit (BRT) system in Colombia" [25] are: Summarization the main aspects associated with the implementation of the BRT systems in some of the most populated cities in Colombia. Benefits like improved operation conditions, administrative organization of two public transportation, reduction in environmental pollution, support of economic development and improvement in safety. Despite the positive results, additional aspects to improve the Colombian BRT system are identified
The key findings of this paper are: The BRT systems implemented in Colombia does not present an accident analysis as a main aspect, however it is, also mentions an improvement in safety, but no results of the crash accidents between units and cars were evaluated.
Keywords: Accident prevention, Administrative organization, Advanced technology, Bituminous materials, BRT system.

The most relevant information on the paper titled "Bus Rapid Transit systems in Latin America and Asia results and difficulties in 11 cities" [26] are: This paper summarizes performance information regarding bus system improvements in 11 cities of Latin America (Mexico among others) and Asia affirming most of the problems were solved in the initial months after implementation.
The key finding of this paper is: There is no enough evidence of a safety improvement through the years in Mexico City BRT system.
Keywords: BRT, BRT systems, Bus systems, Buses, Capital Investments.

The most relevant information on the paper titled "Preliminary evaluation of metro Orange line bus rapid transit project" [27] are: A comparison between three transport system in the United States, Metro Orange Line of Los Angeles a BRT system, Gold Line Light Rail a transport system and Metro Rapid with limited BRT features, Orange line bus have presented collisions between buses and private cars primarily because private cars were running red lights.
The key finding of this paper is: Another comparison between the three transport systems is necessary, besides and accident assessment.
Keywords: Accident Prevention, BRT, Bus Transportation, Collision Avoidance, Cost Effectiveness.

The most relevant information on the paper titled "An evaluation on a lane support system for bus rapid transit on narrow shoulders and the relation to bus driver mental workload" [28] are: dedicated bus shoulders is a key method used for implementing BRT in areas that do not have space for additional infrastructure. The study considered the potential role of a prototype lane support system to support vehicle control within the narrow shoulder measuring speed, position control relevant to mobility. The bus drivers did not stressor in the BRT environment, but the use of the shoulder during high density traffic conditions improved mobility.

The key findings of this paper are: there is no evidence that lane support system reduced bus driver workload while operating in the narrow shoulder and there is no evidence that a BRT accident was simulated to help improve the bus drivers' development.
Keywords: Accidents, Traffic, Adult, Anticipation, Article, Automobile Driving.

The most relevant information on the paper titled "A preliminary analysis of two bus rapid transit accidents in Mexico city" [29] are: This paper presents some preliminary results of the analysis of an accident that involved two BRT Units, a Vehicle that was impacted by a BRT unit and dumped a school fence hitting a pedestrian. The accident left over 10 injured and caused heavy disruption of vehicular traffic, the second one was a BRT unit who invaded a pedestrian crossing and ran over three pedestrian and injured 15 more in Mexico City. The approach has been the application of the 'Events & causal factors chart' and the 'Barrier **a**nalysis' technique.
The key findings of this paper are: The approach applied are two accident analysis techniques, both of them allow the user to do a probabilistic analysis with qualitative variables considering an accident in the Mexico City BRT system as an undesirable event. The immediate causes are part of the BRT system such as users, infrastructure, red lights, highways and avenues, bad deign on the intersections and bad design on the turnovers of the buses, among others.
This approach considers how a BRT system disruption caused by an accident affects urban mobility too.
Keywords: Accident analysis, Accident prevention, Accidents, Mexico City, BRT.

From all the papers reviewed above, only three of them used an accident analysis as a methodological approach in order to determine the causal factors that lead to an undesirable event. This papers were wrote by Mexican authors in spite of the most research about BRT has been made by people in the USA.

The results show that research on BRT systems has increased in recent years, with the participation of various countries (see Fig. 6), however, research in BRT systems accident analysis has not been made in other countries besides Mexico.

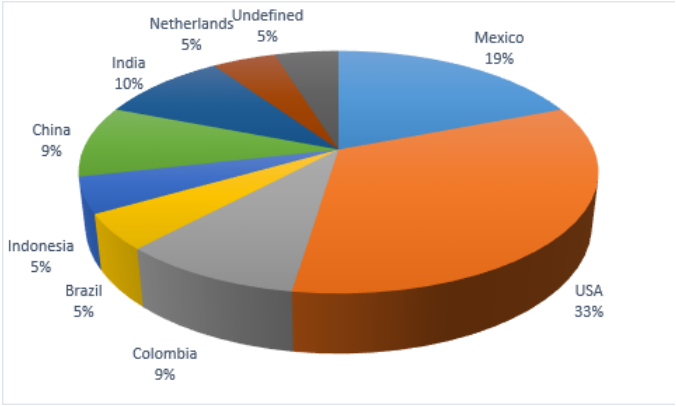


Fig. 6. BRT Studies by country

## CONCLUSION

Despite the fact that BRT systems have been installed around the world, and there have been reports of traffic accidents between road vehicles and BRT units, there is no specific literature related to the accidents analysis and the way in which affect urban mobility. There are many countries that have done research on BRT systems but no research on the accidents that occur in BRT systems and the delays that it generates in urban mobility have been made. Currently a large number of specialized journals only a few contain articles that refer to these types of problems and are not explicit enough to propose improvements.

19 studies have been published from 2006, the date when BRT systems were installed in Mexico City, however the BRT systems and its accidents have been happening since late 70's. These 19 studies have been published in 10 journals (see Fig. 7), the leading journal regarding BRT systems is Transportation Research Record and the journals regarding BRT accidents have been Procedia engineering, PSAM 12 proceedings and ESREL 2015 proceedings.

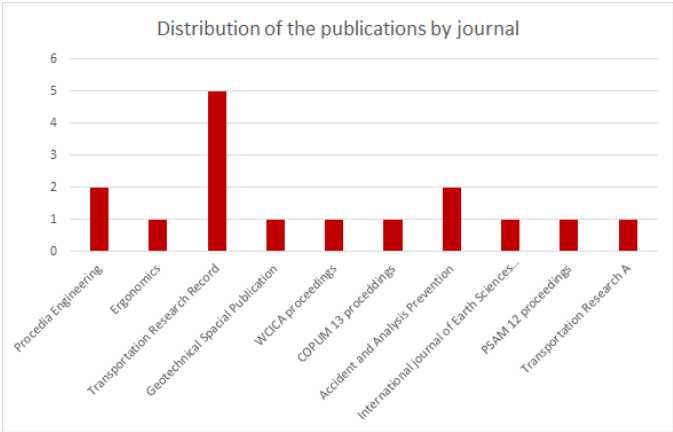


Fig. 7. Distribution of the publications by journal

The result shows the need to carry out more prevention and sound approach studies of accidents in this type of system, using statistical analysis and be more explicit when presenting results too.

## FUTURE RESEARCH AGENDA PROPOSAL

To be able to understand the perception that people have about the accidents that occur in the BRT systems, in addition to the way it affects urban mobility and how to prevent them, it is important to create new directives for study in this area, in addition to improving those proposals reviewed previously. Some of the results derived from this review were discussed above.

{a} Future research should be directed towards a more theoretical sound approach to BRT accidents. BRT systems around the world are increasing day by day and it is necessary to warrantee reliability on every BRT system. More information related to BRT accidents may be useful to prevent and avoid future accident scenarios.

{b} There is a need to be explicit with the information, it is important when presenting i.e. the information related to BRT systems is qualitative rather than quantitative. It becomes difficult to compare different studies, as a result, it is necessary to propose well established information criteria that may help to obtain hard data to study.

{c} There is a need to conduct more accident analysis studies to understand the way different factors around the BRT systems and within cause issues. These studies could improve the BRT development. The knowledge of these factors could help to improve the BRT service.

{d} More information about the accident analysis should consider the way the urban mobility is affected after a collision, because the trajectory is blocked due the presence of the emergency response vehicles. And the waste of time the user experience besides the loss of advantages the system offers.

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