Accident Analysis of a Transport System: The Case of the Bus Rapid Transit System in Mexico City

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Abstract: In recent years, Mexico City has been seriously affected by the lack of efficient transport services. This is due to the excessive population growth in the City, and the lack of an efficient urban transport system has been evident. A 'Bus Rapid Transit' (BRT) system, appeared as an alternative to the problem of transport in the City. However, the system is vulnerable to accidents; it is believed that since its implementation there have been a total of 415 related accidents. When accidents occur and in particular during the rush hours, it usually brings chaos in the City. For example, a collision between a motor car and a BRT unit occurred in June 29, 2013, at the intersection of X and Y avenues. As a result of the accident, there were fifteen injured, and disruption of the vehicular traffic and took several hours to bring the traffic to normal. The paper presents some preliminary results of the analysis of the accident. The approach has been the application of accident analysis techniques such as 'Barrier analysis' and 'Events & causal factors chart'. The paper gives an account of the ongoing research project.

Keywords: Accident analysis, BRT, Mexico City, Transport.

1. INTRODUCTION

1.1. Some Characteristics of Bus Rapid Transit (BRT)

The city of Curitiba, Brazil, is being credited with pioneering BRT and its mayor at the time, Mr. Lerner, referred to the City's BRT system as a "surface metro"-a high quality bus service with similar performance of a subway but at a fraction of the cost [1]. The Institute for Transportation & Development Policy (ITDP) has defined BRT as [2]:

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

Given the acceptation of such systems more than 150 cities have implemented some form of BRT system worldwide; it is believed that such systems carry an estimated amount of 28 million passengers each weekday. At present, BRT systems worldwide comprised 280 corridors, 4,300 Km of routes, 6,700 stations, and 30,000 BRT Units [3].

Some characteristics of BRT systems' performance and potential benefits are summarized below [4,5]:

{a} Increased capacity – The maximum number of passengers carried by a critical segment of the BRT system in a period of time is a function of the size and design of the vehicles, stations, running way and the level of service.
{b} Decreased travel time – Exclusive busways have been shown to operate at an average of 30 miles per hour or more with travel time savings as high as 55 percent compared to regular bus services.
{c} Increased reliability – The use of exclusive running ways, level boarding, off-board fare collection and automated vehicle location technologies allow for greater service reliability in terms of running time, dwell time and recovery.

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{d} Improved accessibility – The design of vehicles, stations, ITS, and fare collection systems can greatly influence the accessibility of a BRT system to the mobility impaired and the general ridership as well.
{e} Increased safety and security – The combination of modern technologies, facilities, and personnel can improve the customer perception of safety and security and reduce the number of incidents.

The potential benefits of a BRT system can be characterized by the following measures [4,5]:

{a} Increased ridership – BRT systems have been shown to attract choice ridership and increase total corridor ridership. As much as one-third of BRT riders have been shown to previously use private automobiles. Corridor ridership gains of 20 percent to 96 percent have also been recorded.
{b} Improved capital cost effectiveness – BRT systems can use less costly or existing infrastructure compared to other rapid transit modes.
{c} Improved operating cost efficiency – Indicators of operating efficiency such as passengers per revenue hour, subsidy per passenger mile, and subsidy per passenger can improve when BRT service is introduced to a corridor.
{d} Improved environmental quality – By attracting choice riders and using advanced vehicles with cleaner propulsion systems and emissions controls, BRT may improve air quality, noise level and help reduce overall congestion.
{e} Transit-supportive land development – Investments in BRT infrastructure and related streetscape improvements may result in positive development effects much like other high-quality transit modes.

1.2. Global Trends

Given the above, BRT systems have gained particular interest in the so called developing countries, following the widely recognised success of similar systems in Curitiba (Brazil), Bogotá (Colombia), Mexico City (Mexico), Istanbul (Turkey), Ahmedabad (India), Lima (Peru), and Guangzhou (China). The three BRT systems that have awarded the "Golden Standard" are those at Bogota, Guangzhou and Lima Peru [6]. In order to be awarded a "Golden Standard" it needs to achieve five essential elements; i.e.: {a} Busway alignment, {b} Dedicated right-of-way, {c} Off-board fare collection, {d} Intersection treatments, {e} Platform-level boarding. [6].

The implementation of the BRT systems in the above Capital cities, in developing countries, has shown that high performance BRT systems; this have helped easy mobility and environmental benefits and the needed infrastructure can be built at an relatively affordable price [6]. On the other hand, some studies have shown that Metrorail systems may cost 10 times as much as BRT systems of similar length [7]. Light Rail Transit can be more than four times as expensive. besides cost-savings, highly congested mega cities of the world, like Mexico City.

1.3. Research

A number of research has been conducted on BRT; for example, from a institutional perspective [8,9], a social perspective [10,11], an economic perspective [12,13,14], an urban planning perspective [15], a technical perspective [16,17], and an environmental perspective [12,17,18]. There has also been some publications regarding the safety of such systems. A study reported in the literature argued that center-line configurations, left turns prohibitions, and signalized mid-block pedestrian crossings with refuge islands significantly improve safety on corridors where BRT operates [19]. Road safety improvements when the BRT was implemented in Bogota have been credited with an 88% reduction in traffic fatalities on Trans-Milenio corridors [16,20,21]. In Istanbul, the removal of minibuses and regular bus routes and the deployment of new buses in dedicated lanes was followed by a 64% reduction in bus accidents in one year alone [22].

However, there is no evidence of studies being conducted explicitly in accident analysis of accidents related with the operation of BRT systems. The paper gives an account of the ongoing research project concerning accident analysis related to BRT systems in Mexico City.

2. THE MEXICO CITY BUS RAPID TRANSIT SYSTEM

2.1. Mexico City & Its Context

The 2013 estimated population for the city was about 8.85 million people; the Greater Mexico City population is 21.4 million people, making it the largest metropolitan area in the western hemisphere, the third largest agglomeration in the world; moreover, the population density is 6,000 inhabitants/Km^2 [23]. Mexico City is one of the busiest conurbations in the world. It is believed that about 600 new car are being registered each day, a total of 6 million cars and around 21.4 million inhabitants in the metropolitan area. The Metro underground system served for a long time as the dominating mass rapid transit system with approximately 250 Km of length and 4.5 million trips per day [23]. Over the time the city faced a rapid growth resulting in overcrowding lines and insufficient network coverage. Mexico city tried to solve the problem with investments in street infrastructure through the construction of elevated highways. However, the city realized that those measures induced more traffic congestion and the project only served a small percentage of the city's inhabitants who used passenger cars by then. For this reason the idea of implementing an efficient and cost-effective BRT system came up as the best solution for solving congestion and air pollution (Fig. 1 shows an example of the Metrobus BRT Unit). [23].

Figure 1: A Mtrobus BRT Unit in Mexico City.

Figure 2: Example of key data for the BRT-Line 3 Corridor as 10/2013. [23].

Inauguration	Length	Frequency (rush hour)	Average speed
February 2011	17 Km with 29 stops and 2 terminals	one bus every 108 sec.	17 Km/h

Daily passenger load (total)	Maximum passenger load (per hour per direction)	Average daily passenger load (per bus)	Investment costs (excl. vehicles)
140,000	5,300	220	4.4 million Euros/Km

2.2. Metrobus BRT System

In 2002 the Mexico City government planned a BRT corridor running across the centre of Mexico's Capital. Three years later the vision became reality and the first corridor of Metrobus was launched in 2005 along Insurgentes Avenue with 20 Km. Along this avenue Metrobus has improved mobility by

50%, reduced accidents by 30% and encouraged a modal shift from private vehicles to public transport. Based on its success the second corridor was inaugurated in 2008 along avenue "Eje 4 Xola", followed by the inauguration of the third corridor Line 3 in 2011 [23]. The Line 3 is the third line of the city's BRT system which started operation in 2005. Further extensions are already planned and in construction [23]. See Fig. 2.

2.3. Metrobus BRT and Some Statistics

It is believe the Metrobus now serves 755,000 passengers per day on 95 Km in total. In february 2011 the third corridor of Metrobus between the stations Tenayuca and Etipia was inagurated and is encompassing 17 km. For the third corridor 54 new BRT buses with low emission have been contributing significantly to the reduction of CO_2 emissions of 100,000 tons/year. [24].

Figure 3: Accidents related to collisions between Metrobus-BRT Units with motorcars.

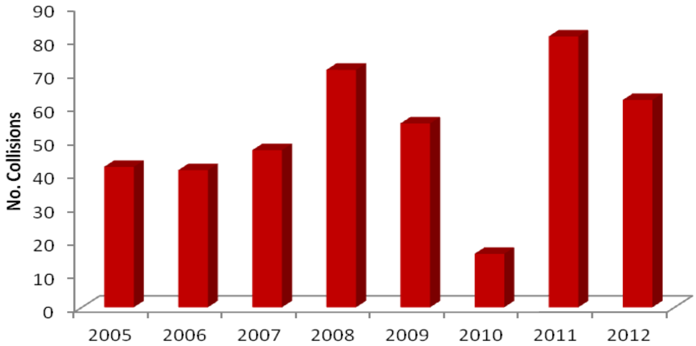


Fig. 3 illustrates the frequency of the accidents associated with collisions between BRT units with motorcars. According to the official figures by the Metrobus-BRT system operator, there has been a total of 415 accidents from 2005 to 2012. According to these figures, there has been 51.8 accidents per year. By looking at Fig. 3, 16 collision related accidents were registered in the year 2011 whereas the most critical year has been 2011 with a total of 81 accidents. It can be argued that collision related accidents are in fact increasing. [24,25].

3. BARRIER ANALYSIS AND EVENTS & CAUSAL FACTORS TECHNIQUES

The primary purpose of any accident investigation is to help line management prevent recurrence of accidents by identifying all of an accident's causal factors [26,27]. Modern accident investigation theory indicates that generally the root causes of accidents are found in management system failures, not in the most directly related causal factor(s) in terms of time, location, and place. Generally, the higher the level in the management and oversight chain at which a root cause is found, the broader the scope of the activities that the root cause can affect. [26,27].

There are a number of accident techniques available to determine an accident's causal factors; for example: {a} Events and causal factors charting and analysis; {b} Barrier analysis; {c} Change analysis; {d} Root cause analysis; and others. [26].

In what follows a very brief description of {a} and {b}is given; i.e. these two analytical tools have been employed so far in the analysis of an accident of the BRT system. (See section 4).

3.1. Barrier Analysis

In general, Barrier analysis is based on the premise that hazards are associated with all accidents. 'Barriers' are developed and integrated into a system or work process to protect personnel and equipment from hazards. That is, for an accident to occur, there must be: {a} A 'hazard' (e.g. electrical cable), which comes into contact with {b} A 'target' (e.g. a person or worker), because {c} 'Barriers' or controls failed (e.g. personal protective equipment and unknown hazards). [26].

A hazard may be regarded as the potential for an unwanted 'energy' flow to result in an accident or other adverse consequence. 'Energy' flow is the transfer of energy from its source to another destination; energy could be, for example, kinetic, biological, acoustical, chemical, electrical, mechanical, potential, electromagnetic, thermal, or radiation. [26].

3.1. Events and Causal Factors Chart

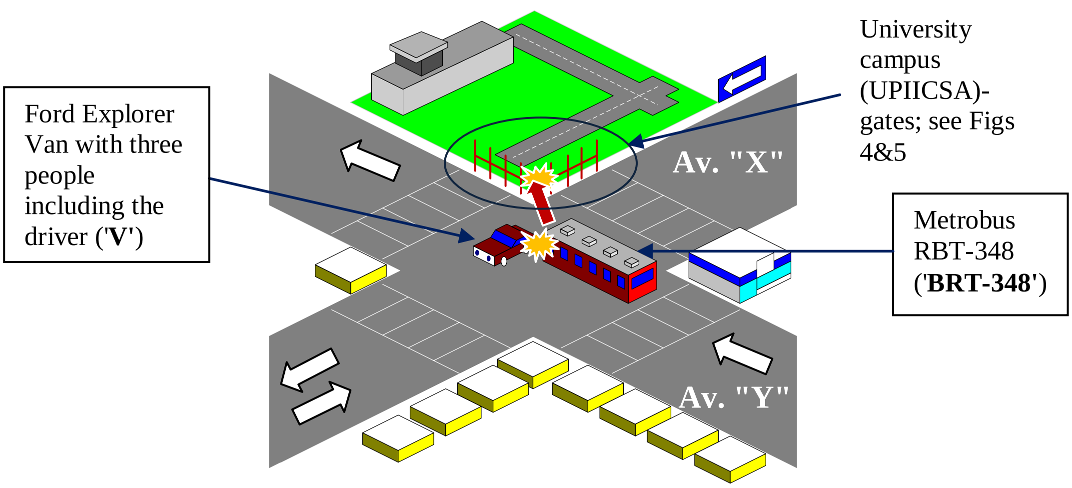
Overall, Events and causal factors charting is useful in identifying the multiple causes and graphically depicting the triggering conditions and events necessary and sufficient for an accident to occur [26]. Events and causal factors charting is a graphical display of the accident's chronology and is used primarily for compiling and organizing evidence to portray the sequence of the accident's events. It is a continuous process performed throughout the investigation [26]. Events and causal factors analysis is the application of analysis to determine causal factors by identifying significant events and conditions that led to the accident. As the results of other analytical techniques (e.g., change analysis and barrier analysis) are completed, they are incorporated into the events and causal factors chart. After the chart is fully developed, the analysis is performed to identify causal factors. [26].

4. THE ANALYSIS

4.1. The Accident

On Saturday, June 29, 2013 an accident occurred at approximately 07:30 hrs; a Metrobus BRT-348 (hereafter it will be referred to as "BRT-348") and a Ford Explorer Van (hereafter it will be referred to as "V") collided in a junction between 'X' and 'Y' Avenues (Fig. 4) [25]. It is believed that the BRT-348 left "Tepalcates" station at about 07:05 am and was travelling towards the "Etiopia" station which is the last station of the Line 2 when the accident occurred. The 'V' - vehicle, on the other hand, came from the Mexico State to the Capital City to do some shopping and it was travelling along the 'X' Avenue and it is thought the 'V'-driver was in a hurry. [25].

Figure 4: The collision between the BRT-348 and the 'V'-vehicle. [25].



According to the evidence, the BRT-348 was travelling at about 50 Km/h just before the junction between "X" and "Y" Avenues when the traffic light was showing "Green", the BRT-348 continued its journey; at this stage the BRT-348 unit was about 20 metres away from the "UPIICSA" station (The Station was given the same name as the University campus which is just next to it; see Fig. 4). Meanwhile, the 'V'-driver was travelling at 40 Km/h and in a hurry; the driver was skipping other vehicles in front of him when the traffic light showed "Red". It is thought the V-driver ignored the 'Red' light and continued towards the "Y" Avenue when collided with the BRT-348 unit (Figs. 4 and 5-left). It is believed the BRT-348 driver tried to avoid further damage by driving towards the gates of the University (Fig. 5-right); however, a student who was waiting on the sidewalk to go through the crosswalk to the Station (i.e., "UPIICSA") was hit by the BRT-348 Unit. [25].

The consequences of the accident were the following: about seventeen passengers of the BRT-348 unit were injured; the three people including the V-driver were severely injured; and a student was injured as a result of the accident (Fig. 6). A few minutes later the emergency response teams arrived at the scene and gave medical assistance to the injured (Fig. 6). Those who sustained severe injuries were taken to the nearest hospital. [25].

Figure 5: The 'V'-vehicle (left) and the BRT-348 (right) after the accident.

Figure 6: The consequences of the collision.

4.2. The Analysis

In order to conduct the analysis of the collision between the BRT-348 and the V-vehicle, an exhaustive literature review was conducted in order to collect data about the accident. Given the fact that there is no information available, most of the data of the present case study has been gathered by consulting newspapers sites, interviews with the key players involved in the running of the system. [25].

Table 1: Barrier analysis summary.

What are the Barriers?	How did the Barrier perform?	Why did the Barrier fail?	How did the Barrier affect the accident?
Maintain adequate speed restriction prior to a BRT station	Failed	BRT-348 was travelling at 55 Km/h which should have been less than that and could have stopped.	BRT-348 driver not adhering to speed restrictions prior to a station.
Braking of BRT-348	Not applicable.	No time to apply brakes before collision.	Not applicable (brakes not used)
Maneuvering ability (BRT-348 driver)	Not applicable	BRT-348 swerve to right and impact on the wall of a university facility.	BRT-348 driver was able to stop the unit.
V (Ford Explorer Van) stop at Red light	Failed.	V-driver drove past the Red light.	Collision with the BRT-348 unit.
V-driver knowledge of the City and the BRT routes	Failed.	V-driver was not familiar with the city and the BRT routes.	Collision with the BRT-348 unit.

Figure 7: Stage 1 of the analysis.

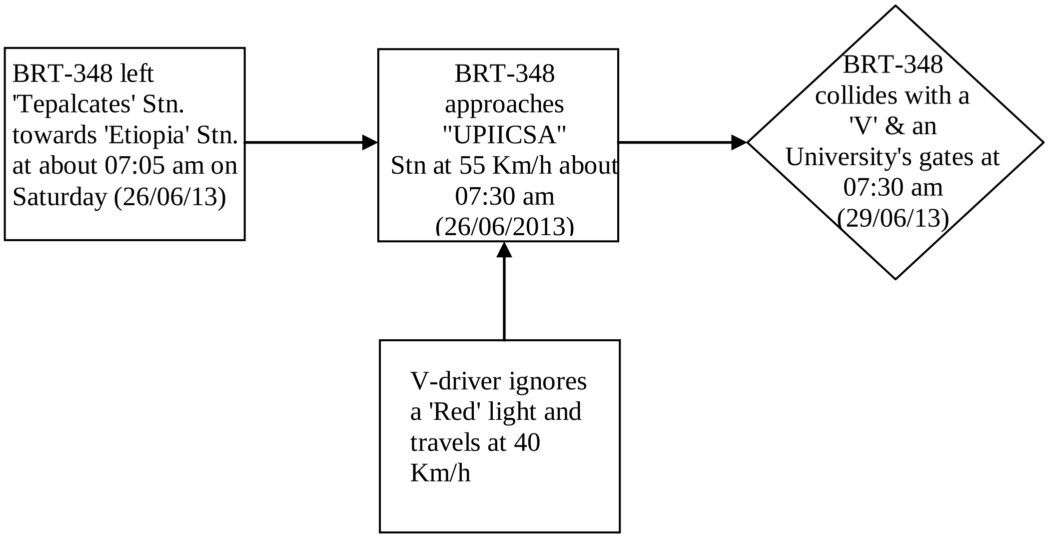


Table 1 shows a summary of the Barrier analysis that was conducted for the case study. It can be seen many deficiencies of both the BRT-348 and the V-vehicle drivers. For example, the "V-driver knowledge of the City and the BRT-routes" Barrier failed because the V-driver was from Mexico State (Not to be confused with Mexico City) and was not familiar with the City, in the first place, and let alone the BRT routes.

Once a Barrier analysis was completed, it was decided to apply the 'Events and causal factors chart' technique for further analysis. As described in the previous section, the accident analysis technique helps, among other things, to illustrate the sequence of events leading to an accident.

Figure 8: Events and causal factors chart for the case study.

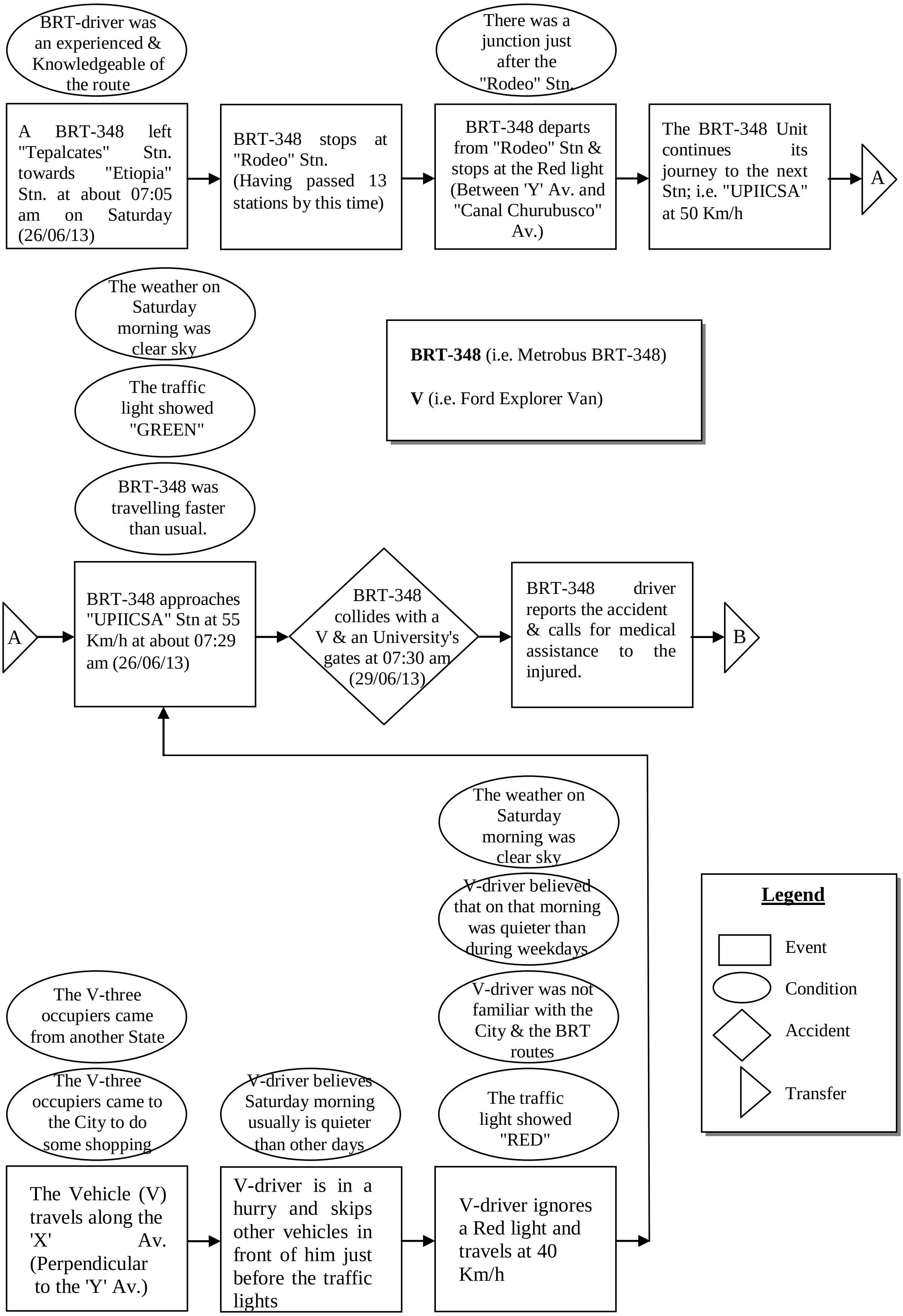
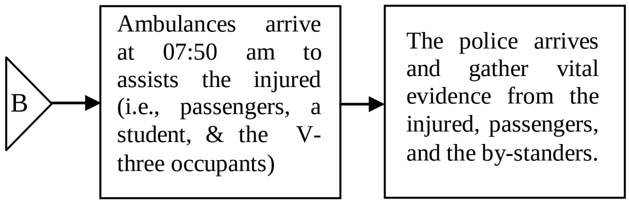


Figure 8: Continued.



Moreover, it helps to direct the progression of additional data collection and analysis by identifying information gaps. For example, Fig. 7 shows the first stage of the construction of the chart with the limited data obtained at the time. Essentially, it illustrates how data may become available during an accident investigation, and how a chart would first be constructed and subsequently updated and expanded, as shown in Fig. 8.

The preliminary results of the accident with the availability of data so far is shown in Fig. 8. Overall the chart shows the sequence of events leading to the collision and the 'conditions' affecting these events. Fig. 8 also shows five 'primary' event sequences prior to the collision; for example, the first primary event shows the time the BRT-348 left the starting point of its journey; i.e. the "Tepalcates" station. Moreover, it can be seen the 'conditions' that are associated with the primary events; for example, the 'condition' for the first primary event is associated with the experience of the BRT-348 driver and his knowledge of the BRT routes. This is crucial in accident investigation because it helps to identified possible deficiencies or contributing causal factors to the accident. Similarly, the third and the fifth primary events are shown with their associated 'conditions'. It is interesting to note that the condition "BRT-348 was travelling a little faster than usual" prior to the collision; i.e., the driver may have brake or avoided the collision if he had travelled slower than that on the day of the accident (the velocity o the BRT units during week days is much slower than at weekends). However, this should be analyzed further.

Fig. 8 also shows the 'secondary' event sequences prior to the collision; i.e. those associated with the 'V'-vehicle. Three 'secondary' events and their associated 'conditions' are shown in the figure. For example, the event "The vehicle 'V' travels along the 'X' avenue" is associated with two 'conditions'. Similarly, the third secondary event prior to the collision is associated with four 'conditions'. This section of the chart illustrates the circumstances that contributed to the collision; for example, the 'condition' "V-driver believed that on that morning (Saturday) was quieter than during week days"; this 'condition' made him to convince himself that it was safe to just ignore the 'RED' light.

The chart also shows the events that took place after the collision (i.e., the 'Accident' in the chart shown in Fig. 8). In this case, there were two events and are associated with the emergency response to the injured and the arriving of the police to gathering the evidence of the accident. The events were considered in order to assess whether the injured were assisted in time and efficiently.

5. CONCLUSION

The paper has presented some preliminary results of an analysis of an accident that involved a 'V'-vehicle and the BRT-348. The approach has been the application of two accident analysis techniques; i.e., 'Barrier analysis' and the 'Events and causal factors chart'. The tools may be enough to the analysis of accidents such as the one considered in the paper. However, other approaches can be applied in order to 'validate' the results presented here.

The most relevant causal factors identified in the analysis are summarized as follows:

1. The driver of the 'V'-vehicle was not familiar with the City and the BRT-routes.
2. The driver of the 'V'-vehicle was in a hurry.
3. The driver of the 'V'-vehicle ignored a red light. (This may be regarded as the root cause of the accident).
4. The BRT-348 Units was travelling at a velocity higher than that required prior to a Station.
5. Given the BRT-348 Unit's velocity, the driver could have injured/killed more people including students when he drove towards the University's gates.
6. The emergency response were adequate and timely in assisting the injured.

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References

[1] R. Cervero. *"The transit metropolis: a global inquiry".* Washington, D.C.: Island Press. (1998). USA.
[2] L. Wright and W. Hook. *"Bus rapid transit planning guide."* New York: Institute of Transportation & Develoment. (2007). USA.
[3] BRTDATA.ORG. Accessed July 24---25, (2013).
[4] R. Diaz, et al. *"Characteristics of Bus Rapid Transit for Decision-Making."* Published by the U.S. Federal Transit Administration, (2004), USA.
[5] A. Cain, G. Darido, J. Flynn and C. Thole. *"BRT Update: An Overview of Bus Rapid Transit in the United States."* Mass Transit magazine, May (2007). USA.
[6] R. Cervero. *"Bus rapid transit (BRT): An efficient and competitive mode of public transport."* Working paper 2013-01. Institute of urban and Regional Development. University of California. (2013). USA.
[7] H. Suzuki, R. Cervero and K. Luchi. *"Transforming cities with transit: transit and land-use integration for sustainable urban development."* Washington, D.C: World Bank. (2013), USA.
[8] F. Lámbarry Vilchis, L.A. Rivas Tovar and M.P. Peña Cruz. *"Planeación de los sistemas BRT y consensos entre transportistas y autoridades de gobierno durante su implementación: el caso de Metrobús y Mexibús [Planning of BRT systems and consensus between transport contractors and government's authorities during their implementation: the case of Metrobús and Mexibús]*. Administración y Desarrollo 39(54), pp. 133-150. (Mexico).
[9] R.V. Ponnaluri. *"Sustainable Bus Rapid Transit initiatives in India: The role of decisive leadership and strong institutions."* Transport Policy 18, pp. 269-275. (2011).
[10] E. Cahill Delmelle and I. Casas. *"Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia".* Transport Policy 20, 36-46. (2012).
[11] Z. Lin and J. Wu. *"Summary of the application effect of Bus Rapid Transit at Beijing south-centre corridor of China."* J Transpn Sys Eng & IT 7(4), 137-142. (2007).
[12] R. Cervero and C.D. Kang. *"Bus Rapid Transit impacts on land uses and land values in Seoul, Korea."* Transport Policy 18, pp. 102-116. (2011).
[13] D.A. Hensher and T.F. Golob. *"Bus rapid transit systems: a comparative assessment."* Transportation 35, 501-518. (2008).
[14] L.A. Lindau, *et al. "Alternative financing for Bus Rapid Transit (BRT): The case of Porto Alegre, Brazil."* Research in Transportation Economics 22, 54-60. (2008).
[15] A. Ardila-Gómez. *"Transit planning in Curitiba and Bogotá. Roles in interaction, risk and change."* Ph.D. Thesis, Massachusetts Institute of Technology. (2004), USA.

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

[17] S.B. Nugoro, A. Fujiwara and J. Zhang. *"The influence of BRT on the ambient PM10 concentration at roadside sites of Trans Jakarta Corridors."* Procedia Environmental Sciences 2, 914-924. (2010).

[18] H. Wöhrnschimmel. *et al. "The impact of a Bus Rapid Transit system on commuter's exposure to Benzene, CO, PM2.5 and PM10 in Mexico City".* Atmospheric Environment 42, 8194-8203. (2008).

[19] N. Duda, C. Adriazola-Steli, D. Hidalgo, L. Lindau and P. Santos. *"The relationship between safety, capacity and operating speed on bus rapid transit".* paper presented at the 13th World Conference on Transportation research, Rio de Janeiro, (2003). Brazil.

[20] D. Hidalgo and T. Yepes. *"Are bus rapid transit systems effective in poverty reduction? Economist intelligent Unit. 2010. Liveanomics: urban liveability and economic growth."* (2005). Colombia.

[21] J. Echeveryy, A. Ibañex, A. Myoa and J. Hilllón. *"The economics of Transmilenio: a mass transit system for Bogota."* Economia. Spring. (2005), USA.

[22] Yazici, M., Levinson, H., Ilicalli, M., Camkasen, N., Kamga, C. 2013. A bus rapid transit line case study: Istanbul's Metrobus System. Journal of Public Transportation, vol. 16, No. 1 pp. 153-177.

[23] Mercedes-Benz. *"BRT in Mexico City, Mexico: Metrobus linea 3 Corridor-An example of a successful BRT solution in one of the biggest Cities in the worldwide."* (2013).

[24] Metrobús. Accessed at: http://www.metrobus.df.gob.mx/beneficios.html. (2013).

[25] V. Avalos-Bravo. *"Reporte de tesis Doctoral."* Departamento de Ingeniería de Sistemas, SEPI-ESIME, IPN, (2014), Mexico.

[26] C.W. Johnson. *"Reasons for the failure of incident reporting in the healthcare and rail industries."* In F. Redmill and T. Anderson, editors, Components of system Safety: Proceedings of the 10th Safety-Critical Systems Symposium, pp. 31-60, Berlin, (2002), Germany.

[27] J. Santos-Reyes and A.N. Beard. A systemic analysis of the Edge-Hill railway accident, *Accident Analysis and Prevention*, vol. 41, No. 6, pp. 1133-1144. (2009).