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A preliminary analysis of two Bus Rapid Transit accidents in Mexico City

Jaime SANTOS-REYES*, Vladimir ÁVALOS-BRAVO

SARACS Research Group, SEPI-ESIME, U.P. "Adolfo López Mateos", Edif. 5, 2o. Piso, IPN, 07738, México

Abstract

The paper presents some preliminary results of an analysis of the two BRT (Bus Rapid Transit) accidents. The case-1, relates to an accident where a BRT drives straight to a pedestrian crossing, and the case-2 involves an accident where a BRT collides with a Van. The approach has been the application of two accident analysis techniques; i.e., 'Barrier analysis' and the 'Events and causal factors". Some of the findings related to the case-1 are: a) the BRT driver's performance was "Less than adequate"; b) the 'fence' was not designed to withstand the impact of a BRT such as the one involved in the accident; c) the design layout of the station, the corridor, the pedestrian crossing, etc., was "Less than adequate". Some findings for the case-2: a) the driver of the 'V'-vehicle was in a hurry and was not familiar with the City and the BRT routes; b) the driver of the 'V'-vehicle ignored a red light; c) the emergency response were adequate and timely in assisting the injured. More research is being undertaken to complete the analysis in the light of the new evidence that has been gathered.

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Keywords: Accident analysis; Bus Rapid Transit; Mexico City

1. Introduction

The city of Curitiba, Brazil, is being credited with pioneering BRT (Bus Rapid Transit) and since then there have a number of definitions of what a BRT is; for example, the Institute for Transportation & Development Policy (ITDP) has proposed the following definition [1]:

"*a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective urban mobility through*

* Corresponding author. Tel.: +52 55 57296000x54663; fax: +52 55 57296000x54588.
E-mail address: jrsantosr@hotmail.com (J. Santos-Reyes).

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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 worldwide have implemented some form of BRT system. It is believed that such systems carry an estimated amount of 28 million passengers each weekday. At present, it is believed the BRT systems worldwide comprised 280 corridors, 4,300 km of routes, 6,700 stations, and 30,000 BRT Units [2]. A number of characteristics of BRT systems' performance and potential benefits are the following [3,4]: a) increased capacity; b) decreased travel time; c) increased reliability; d) improved accessibility; e) increased safety and security; among others. On the other hand, there has been also studies that have been reported the potential benefits of a BRT systems, such as the following [3,4]: a) increased ridership; b) improved capital cost effectiveness; c) improved operating cost efficiency; d) improved environmental quality; e) transit-supportive land development; among others. Given the performance and the benefits of these systems have helped easy mobility and environmental benefits and the needed infrastructure can be built at an relatively affordable price [5]. Some studies have shown that Metrorail systems may cost 10 times as much as BRT systems of similar length [6].

A number of approaches have been taken to study BRT systems; for example, there have been studies being conducted from an institutional perspective [7,8], a social perspective [9,10], an economic perspective [11-13], an urban planning perspective [14], a technical perspective [15,16], and an environmental perspective [11,16,17]. There has also been some publications regarding the safety of such systems; for example, a study reported in the literature argued that center-line configurations, left turns prohibitions, and signalized mid-block pedestrian crossings significantly improve safety on corridors where BRT operates [18]. Road safety improvements when a BRT system was implemented in Bogota (Colombia) have been credited with an 88% reduction in traffic fatalities on "Trans-Milenio" corridors [15,19,20]. In Istanbul (Turkey), 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[21].

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

2. Accident analysis techniques

2.1. Barrier analysis

Some of the key concepts used in barrier analysis are: 'energy', 'hazard', 'Barrier' and a 'Target'. 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 [22]. Overall, '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). [22].

2.2. Causal factors chart

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 [22]. '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 [22]. '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. [22].

3. The BRT accidents

In 2002 the Mexico City government planned a BRT (Bus Rapid Transit) corridor running across the centre of Mexico's Capital. (Hereafter the BRT unit for the two case studies will be referred to as either 'BRT' or 'Metrobus-BRT'). The first corridor of Metrobus-BRT was launched in 2005 along one of the main avenues of the city with 20 km long. It is believed the Metrobus-BRT has improved mobility by 50%, reduced accidents by 30% and encouraged a modal shift from private vehicles to public transport [23]. Based on its success, a second corridor was opened in 2008, followed by the third Line 3 which started operating in 2011 [23]. Further extensions are already planned and in construction [23]. According to the official figures by the 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. The most critical year in terms of the frequency of occurrence has been in 2011, with a total of 81 accidents. [24]. In the following subsections two of those accidents that occurred in 2011 and 2013 are described briefly.

3.1. Case-1: A BRT unit drives straight to a pedestrian crossing

On Sunday, April 17th, 2011, a Metrobus-BRT unit stopped at 'A' station and it was intended to continue its journey to the next satiation. In order to continue with its journey, it should have turned to the right on the 'X' Av. to reach the next station (i.e. 'B' station) along 'X' avenue. However, the driver of the BRT unit lost control; i.e., the BRT unit should have turned to the right along the 'X' avenue; however, it continued straight into the pedestrian crossing (Fig. 1). As a result, the unit collided with a passenger coach coming from an adjacent road, killing three people and injured 14 in the process. Soon after, the police arrived to collect the evidence and ambulances assisted the injured; some of the injured were taken to the hospital. Fig. 2 shows some pictures of the consequences of the accident.

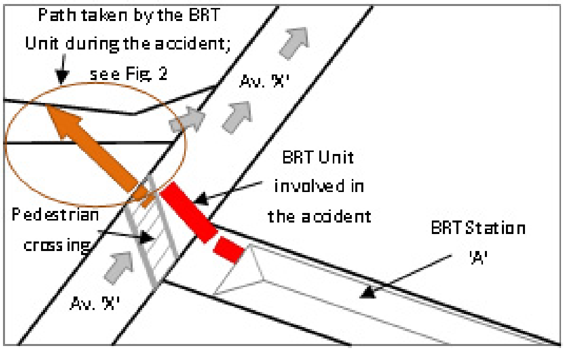

Fig. 1. A schematic representation of the Metrobus-BRT accident: Case-1.

(a) (b)

Fig. 2. Pictures of some of the consequences of the BRT accident: Case-1. [25].

3.2. Case-2: A BRT collides with a Van

On Saturday, June 29, 2013 an accident occurred at approximately 07:30 a.m; a Metrobus-BRT unit and a Ford Explorer Van (hereafter it will be referred to as "V") collided in a junction between 'X' and 'Y' Avenues (Fig. 3) [25]. It is believed that the BRT unit left 'B' station at about 07:05 am and was travelling towards 'F' station which is the last station of the Line 2, when the accident occurred. The 'V' - vehicle, on the other hand, came from the State of Mexico 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]. According to the evidence, the BRT unit 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 unit continued its journey. At this stage the BRT unit was about 20 metres away from the 'D' station (this station was next to a university campus; see Fig. 3). Meanwhile, the 'V'-driver was travelling at about 40 km/h and in a hurry. It is thought the V-driver ignored the 'Red' light and collided with the BRT unit (Figs. 3&4). It is believed the BRT driver tried to avoid further damage by driving towards the gates of the university campus (Fig. 4(b)). [25].

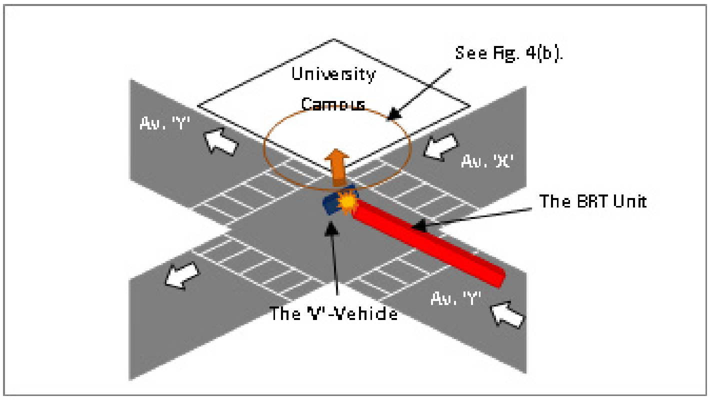

Fig. 3. A schematic representation of a BRT collision accident-Case-2.

(a) (b)

Fig. 4. Pictures of the consequences of the BRT accident-Case-2. [25]

The consequences of the accident were the following: about seventeen passengers of the BRT 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. 4). A few minutes later the emergency response teams arrived at the scene and gave medical assistance to the injured. Those who sustained severe injuries were taken to the nearest hospital. [25].

4. Analysis and discussion

In order to conduct the analysis of the two case studies described briefly in the previous section, 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].

In the subsequent sections, the results of each of the case studies is discussed.

4.1. Case-1: A BRT drives straight to the pedestrian crossing

Table 1 shows a summary of the Barrier analysis that was conducted for the case study. It can be seen many deficiencies that have been identified. For example, the "Braking of the BRT unit" has been considered as a 'barrier' in the analysis. However, when conducting the analysis and with the available information, it has been found that they were operational at the time of the accident; i.e. "not applicable". But then the question arises as, if they were operational, why they were not applied and stop the BRT unit? Effectively, if applied the accident could have been avoided. In a similar way, "Drive's competence" was considered as a 'barrier' in the analysis. According to the information being obtained on the accident, it may be argued that the driver could not control the unit. When assessing "how did the barrier affect the outcome?" Then, it may argue that has the driver processed the information being received, his reaction time could have avoided the accident. The analysis of the other 'barriers' identified, in this preliminary study, have been analysed in a similar way.

Table 1. Barrier analysis of the BRT accident: Case-1.

What are the Barriers?	How did the barrier perform?	Why did the barrier failed?	How did the barrier affect the accident?
Braking of the BRT unit	Not applicable	Apparently, the driver did not apply the brakes. (According to mechanical test conducted on the unit, the brakes were operational at the time)	If applied the BRT unit could have stopped and avoided the fatalities and the injured.
Pedestrian 'fence' between Av "X" & the pedestrian crossing	Failed	There was a pedestrian 'wall' between the Av. "X" and the pedestrian crossing; however, it was overthrown by the BRT unit.	If strong enough it could have avoided the fatalities as a consequence of the accident.
Maneuvering ability of the BRT driver	Failed	According to reports on the accident; shortly after departing the station, the BRT unit started abruptly and at an accelerated pace. The driver failed to maneuver the unit.	If maneuver correctly, the accident could have been avoided.
Driver's competence	Failed	The driver actions were less than adequate; e.g., he failed to stop the BRT unit.	If the driver was knowledgeable enough on how to operate the BRT unit, the accident could have been avoided
Other mechanical components of the BRT unit (e.g. transmission and accessories, etc.)	Not applicable	According to the reports on the accident, all the mechanical components (apart of the brakes) were operational at the time.	It did not contribute directly to the accident.

Once a Barrier analysis was completed, it was decided to apply the 'Events and causal factors' technique for further analysis. The preliminary results of the accident by applying the technique with the availability of the evidence so far is shown in Fig. 5. Overall, the chart shows the sequence of 'events' leading to the accident and the 'conditions' affecting these. Fig. 5 also shows five 'primary' event sequences prior to the accident; for example, the first 'primary' event intends to illustrate the event when the BRT unit arrived at the 'A' station; apparently, at this stage everything was working; i.e., the brakes of the BRT unit was operational and the driver did not report anything unusual. It also 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 driver (e.g. three years experience). This is crucial in accident investigation because it helps to identified possible deficiencies or contributing causal factors to the accident. Similarly, the fourth and the fifth 'primary' events are shown with their associated 'conditions'.

It is interesting to note that two relevant aspects of these 'conditions'; i.e., those associated with a) the design layout of the BRT station, pedestrian crossing, and the surrounding infrastructure where the accident occurred; and b) the 'competence' of the BRT driver. It is well known that accidents such as the present case are not the result of a unique cause but they are systemic [26]. It can also be argued that at least three elements are involved in accidents such as in the present case; i.e., the human element, the BRT element, and the design layout of the streets, avenues, etc. According to research being conducted on the subject, the design of streets, avenues, motorways, etc., should consider the driver's attributes (i.e., the human element) in order to minimize the drivers decisions (i.e., human error) [27-30]. It is believed that the number of crashes increase in the number of decisions required of the driver [28]. In the present case, it can be argued that those that lost their lives in the accident were not aware of the danger by walking in the area [30]. Given this, the following question arises: was the BRT station, corridors, such as the present case, considered the pedestrian element? This requires further analysis.

In a similar vein, the driver performance of the accident has been assessed as "Less than adequate". Again, research has shown that, in principle, when street, avenue, motorway, etc., are designed to be compatible with the drivers' capabilities and limitations, their performance is aided; however, when a design is not compatible with the drivers' capabilities, the probability for driver errors increase, and as a consequence crashes may occur [29,30]. Given this, the following question arises: was the BRT drivers' capabilities and limitations considered when the infrastructure was built? This requires further analysis.

4.2. Case-2: A BRT collides with a Van

Similarly, the analysis of the accident for the case-2, has been conducted on a similar way. Some of the key events of the causal & events flow chart is shown in Fig. 6. It can be seen that there have been 'primary' and 'secondary' events for the case study. In general, the 'primary' event has been considered for the case of the BRT unit involved in the accident. On the other hand, the 'secondary' event has been considered for the 'V' involved in the collision. As with the previous case, the 'primary' and 'secondary' events have been associated 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. 6 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' may have contributed to convince himself that it was safe to just ignore the 'RED' light.

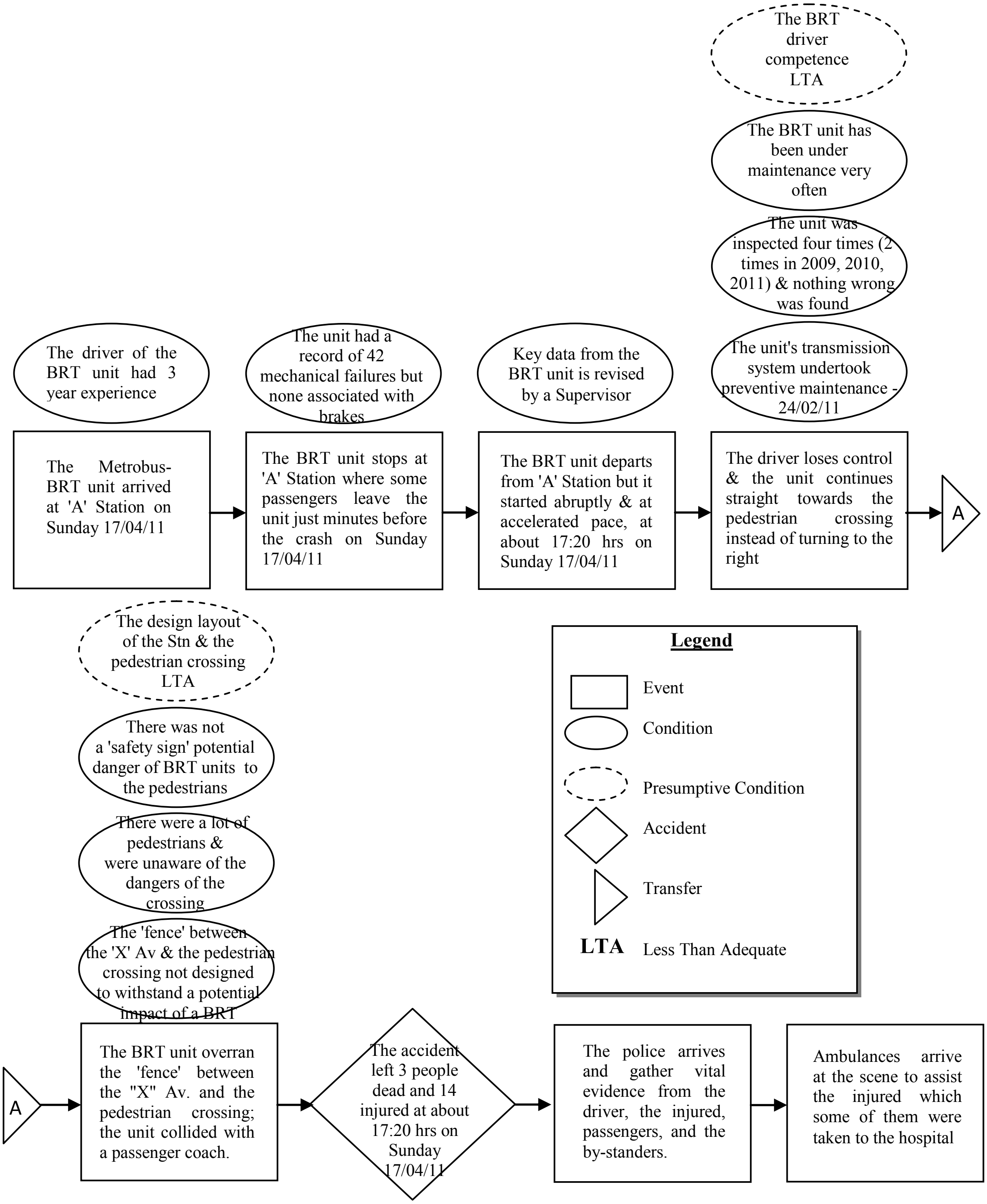

Fig. 5. A preliminary analysis of a BRT accident: Case-1.

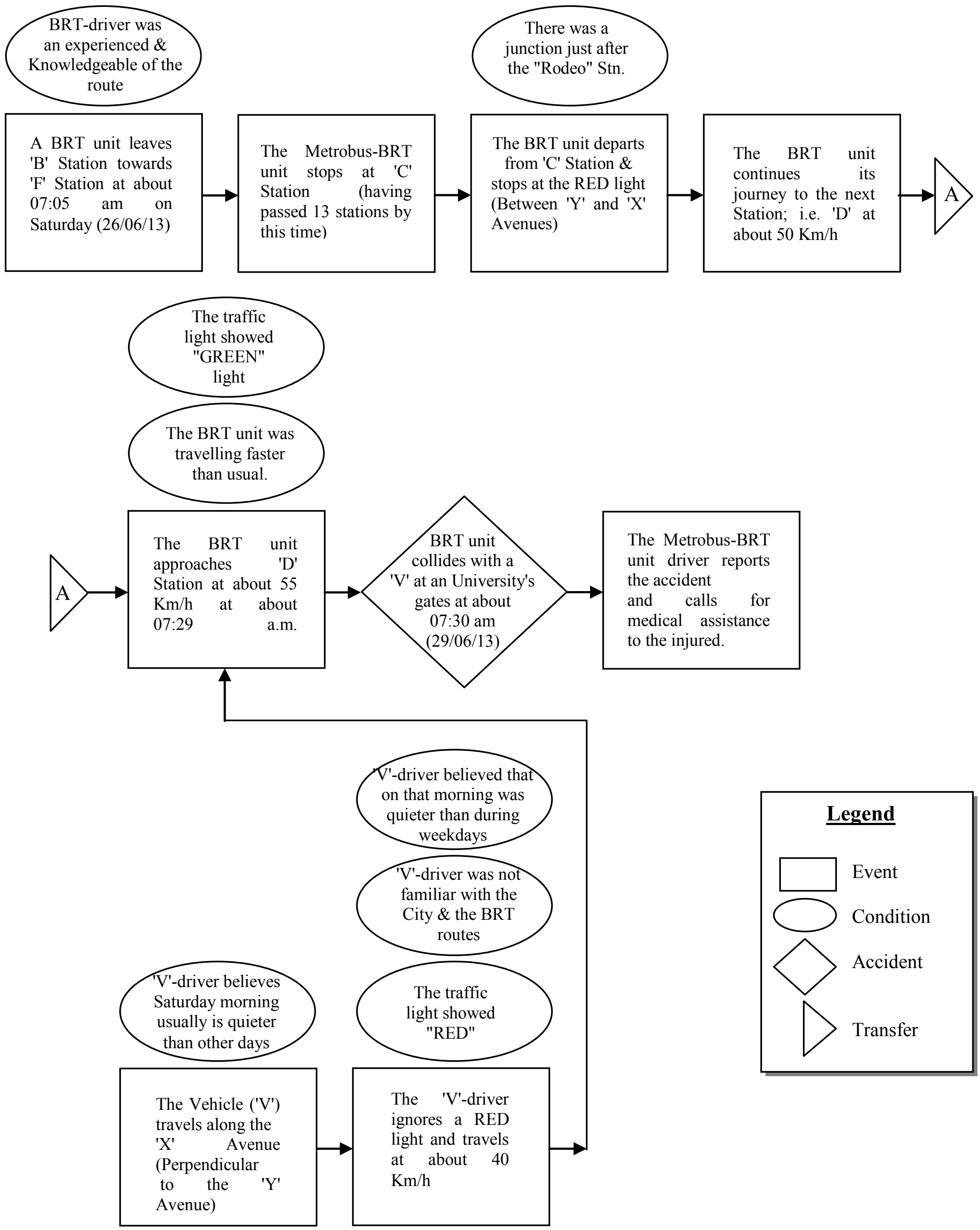

Fig. 6. A preliminary analysis of a BRT accident: Case-2.

5. Conclusion

The paper has presented some preliminary results of an analysis of the two BRT accidents considered for the analysis. The approach has been the application of two accident analysis techniques; i.e., 'Barrier analysis' and the 'Events and causal factors". The analysis shows that the tools may be sufficient to the analysis of BRT related accidents. However, other approaches can be applied in order to 'validate' the results presented here. Some key findings for each case are the following:

a) Case-1: A BRT drives straight to the pedestrian crossing.

- The BRT driver's performance was "Less than adequate"; it is believed he has three years experience, however, he failed to maneuver the unit.
- The 'fence' was not designed to withstand the impact of a BRT such as the one involved in the accident.
- The design layout of the station, the corridor, the pedestrian crossing, etc., was "Less than adequate". (see above).

b) Case-2: A BRT collides with a Van.

- The driver of the 'V'-vehicle was in a hurry and was not familiar with the City and the BRT routes.
- The driver of the 'V'-vehicle ignored a red light. (This may be regarded as the root cause of the accident).
- The emergency response were adequate and timely in assisting the injured.
- As with the case-1, the layout of the BRT infrastructure should consider the capabilities and the limitations of drivers.

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