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Modeling of passengers' safety perception for buses on mountainous roads

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ABSTRACT

This study had developed a passenger safety perception model specifically for buses taking into consideration the various factors, namely driver characteristics, environmental conditions, and bus characteristics using Bayesian Network. The behaviour of bus driver is observed through the bus motion profile, measured in longitudinal, lateral, and vertical accelerations. The road geometry is recorded using GPS and is computed with the aid of the Google map while the perceived bus safety is rated by the passengers in the bus in real time. A total of 13 variables were derived and used in the model development. The developed Bayesian Network model shows that the type of bus and the experience of the driver on the investigated route could have an influence on passenger's perception of their safety on buses. Road geometry is an indirect influencing factor through the driver's behavior. The findings of this model are useful for the authorities to structure an effective strategy to improve the level of perceived bus safety. A high level of bus safety will definitely boost passenger usage confidence which will subsequently increase ridership.

1. Introduction

Traffic safety is a major component for national development and economic growth. The success and progress of any society strongly depends on the capability of the nation's physical infrastructure and transportation system to provide an adequate level of distributing resources and essential services to the public (Hudson et al., 1997; Deublein, 2013). A major component of the public transportation system is the buses which has been agreed by many researchers to be an effective measure to reduce the traffic congestion on roads. In Malaysia, the number of road accidents involving buses is about 1.6% of the total road accident cases over the years (Ministry of Transport, 2016). Nevertheless, the occurrence of bus accidents, especially those with a high number of fatalities usually attracts more impact on media and creates a significant impact in terms of social and economic impacts as compared to other light vehicles. Table 1 summarizes the number of bus accident cases with a high number of injuries and fatalities from year 2003 to 2017. It could be seen from the Table that the worst bus accident that happened in the nation's history was in year 2013 where 37 passengers lost their lives when the driver lost control and bus plunged into a deep ravine at Genting Sempah, Pahang (Ministry of Transport, 2014). Such severe bus accidents would, undoubtedly, tarnish the image of the bus transportation operators and impair the government effort in promoting it as a safe mode of transportation.

The occurrence of a bus accident could be attributed to three major contributing factors, namely: driver, environment and road conditions, and vehicle. The driver factor refers to the driver's behaviour (Lheureux et al., 2015; Cheng et al., 2015), attitude (Sumer, 2003) and personality (Burns and Wilde, 1995; Mallia et al., 2015), which have a close relationship to the accident rate. A careless driver, or a driver who is an altruism and excitement seeker, would have a higher risk of encountering accidents (Mallia et al., 2015). The environment and road conditions refer to the weather as well as the road geometric design and road condition. The road design and pavement condition have a significant impact on the driver's perception of road and his driving performance (Af Wahlberg, 2004; Xu et al., 2015). For instance, a bus driver might have difficulty navigating through a sharp curve or climbing a steep hill. Accident tends to happen when the driver's expectation is violated. The vehicle factor refers to the condition of the bus. This is affected by the design of the bus (single decker or double decker, high floor or low floor), age of the bus (old or new), and the maintenance of the mechanical components of the bus. A bus in tip-top condition will have lower risk of mechanical failure that leads to an accident.

The objective of this study is to develop a passenger safety perception model for buses travelling on mountainous roads taking into account various factors such as bus driver behaviour, design and characteristics of roadway, and bus characteristics. It is intended to understand how these factors could influence the perceived bus safety level. This understanding is crucial as their perceived safety could

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Table 1
The worst bus accidents in Malaysia, Year 2003–2017.

Year	Type of Bus	Reported accident scenario	Type of road	Casualty
2003	Express bus; School bus	Head on collision	Rural arterial road	14 deaths (24 injuries)
2006	Express bus	Bus overturned and crashed into ditch	Expressway	11 deaths (35 injuries)
2006	Double deck express bus	Bus overturned on road	Rural arterial road	3 deaths
2007	Express bus	Bus skidded into ravine	Expressway	6 deaths (20 injuries)
	Express bus	Bus lost control and crashed into a ditch	Expressway	22 deaths
2008	Express bus	Bus overturned	Expressway	2 deaths (7 injuries)
	Express bus	Bus skidded	Highway	2 deaths (41 injuries)
	Express bus	Bus overturned	Expressway	10 deaths (19 injuries)
2009	Double deck express bus	Bus skidded and crashed into a road divider as the driver dozed-off	Expressway	10 deaths (3 injuries)
2010	Express bus	Bus crashed into the rear of a car and rammed into the opposite road	Expressway	12 deaths (45 injuries)
	Express bus	Bus skidded and overturned	Rural arterial road	7 deaths (39 injuries)
	Express bus	Bus driver was speeding and lost control when going down the hill	Rural arterial road	27 deaths
2012	Express bus	Bus overturned	Rural highway	2 deaths (20 injuries)
	Express bus	Bus hit toll plaza and overturned	Expressway	3 deaths (3 injuries)
2013	Express bus	Bus rammed into roadside stalled vehicle	Expressway	2 deaths (5 injuries)
	Express bus	Bus crashed into road divider	Expressway	3 deaths (1 injury)
	Stage bus	Bus lost control and plunged into a deep ravine	Rural highway	37 deaths (16 injuries)
2014	Express bus	Bus lost control and overturned	Expressway	3 deaths (10 injuries)
	Double deck express bus	Bus driver lost control and plugged into the 10-metre deep ravine	Expressway	1 death (39 injuries)
2015	Express bus	Bus rammed into a road divider and fell into a drain	Expressway	20 injuries
	Express bus	Bus lost control, skidded and plunged into ravine	Rural arterial road	4 injuries
2016	Express bus	Driver tried to avoid a tyre that rolled from the opposite lane. The driver lost control and hit the divider	Expressway	2 deaths (36 injuries)
	Express bus	Bus skidded and plunged off a cliff	Rural arterial road	14 deaths (16 injuries)
2017	Express bus	Bus skidded and crashed	Expressway	2 deaths (1 injury)
	Express bus	Rear-end collision with another bus	Expressway	8 deaths (32 injuries)
	Express bus	Bus hit the road divider and turned on its side, crossing over to the opposite of the road	Expressway	27 injuries

influence their willingness to use bus transportation.

This study is different from the existing studies as it adopts a variation of naturalistic driving study (NDS) (National Highway Traffic safety Administration (NHTSA, 2015) approach in data collection which allows for a "close-to-real" driving behaviour to be observed. The driver's behaviour and performance are observed through the bus dynamics (in terms of lateral, longitudinal, and vertical accelerations) and speed which are measured by the accelerometer and GPS set-up in the bus by a group of research assistants who ride on the bus. The lateral acceleration represents the movement of the bus in X-axis (left-right), while the longitudinal acceleration represents the bus movement in Y-axis (front-back) and the vertical acceleration shows the bus motion in Z-axis (up-down). Xu et al. (2015) and Spacek (2005) had shown that the driver's ability to cope with the road design (i.e. curve and speed) could be observed from their acceleration behavior and speed. The passengers on board are asked to rate the bus driver's performance during the journey in terms of their perceived comfort level which is then used to compute the potential accident risk.

The Bayesian Network Modelling (BNM) is adopted to construct the model based on the data collected. BNM is chosen because it has the following advantages as compared to the statistical and econometric analysis adopted in most of the existing studies, namely- (i) its ability to model the complex relationship among the contributing factors to an accident, i.e. the driver's behaviour, road and environment, and vehicle; (ii) no prior assumption on the data distribution is required; (iii) its ability to accommodate for uncertainty, i.e. the occurrence of an accident, modelled by probability theory. It could be observed that the proposed methodology can overcome the limitations of past studies to some extent. It could predict the occurrence of an accident by detecting the bus driver's behaviour (measured in terms of bus dynamic), and their interaction with the road environment. In fact, this probability could be computed in real time if an on-line bus dynamic profile is fed into the proposed model. This facilitates the development of a real time driver warning system to remind drivers of their risky behaviour.

This paper is divided into 5 sections. Section 1 provides the background and the objectives of the study. Section 2 presents an overview of the existing studies. The accident contributing factors and the analysis methodologies are reviewed. The limitations of the existing studies are highlighted. Section 3 highlights the methodology adopted to accomplish the study. This includes data collection, cleaning, coding, and modelling with Bayesian Network. Section 4 presents the Bayesian Network Model constructed and the detailed explanation of the model. Besides, the model implication and its practical implementation especially in traffic safety policy maker are also discussed. Lastly, the conclusion of the study is presented in Section 5.

2. Review of past studies

This section presents the literature review of past related studies on traffic accident modelling. The contributing factors of an accident and their modelling approaches are discussed in detail. Besides, the application of the Bayesian Network in traffic accident modelling is highlighted as well.

2.1. Traffic accident modeling studies

Three major contributing factors to an accident are; driver, environment, and vehicle. The questionnaire survey study approach (Cho et al., 2009; Lheureux et al., 2015; Cheng et al., 2015) is mostly adopted to investigate the accident risk incited by the drivers' behaviour and their personality. The stated preference survey (Machado et al., 2014; Iraguen and Ortuzar, 2004; Rizzi and Ortuzar, 2006) and structured self-evaluation survey (Lheureux et al., 2015; Mallia et al., 2015) are usually adopted. Drivers are interviewed and are asked to answer the questionnaire. Some studies (Kaplan and Prato, 2012) reviewed the crash database to find the relationship of accident frequency and