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Development of safety performance index for intercity buses: An exploratory factor analysis approach

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ABSTRACT

In recent years in Malaysia, severe road crashes involving intercity buses have been increasing. With increased public concerns about intercity bus safety, effectively managing travel risk has become critical for both intercity bus operators and road safety policy makers. Intercity bus drivers are generally at a higher risk for crashes due to long hours of driving and exposure to different road conditions. Therefore, understanding and quantifying their risks and taking steps to manage them could improve intercity bus safety. The aim of this study is to establish a safety performance index for each risk domain to measure and compare intercity bus safety in terms of risk factors. The risk domains considered in this study were road environment conditions, bus driver driving behaviors and bus safety conditions. The weighted indicators were aggregated into the safety performance index for each risk domain was done using the Exploratory Factor Analysis method. The paired sample t-test was then applied to determine which safety performance indices were significantly different from each other. The results indicate that road environment conditions have contributed more to intercity bus safety risks on the east coast than on the west coast of peninsular Malaysia. The evidence presented in this study shows that different intercity bus companies showed mixed safety performance in different risk domains. Therefore, we suggest the development of targeted road safety programs for each intercity bus company to address intercity bus safety problems.

1. Introduction

Public transport provides an efficient and equitable transport alternative for the community. An increase in public transport usage leads to a decrease in private vehicle ownership and hence a reduction in gas emissions (Dirgahayani, 2013; Steg, 2003). Moreover, public transport has been found to be a safe form of transportation as compared to other transport modes (Goh et al., 2014; Chimba et al., 2010). In European Union countries, such as the United Kingdom, road crashes involving buses and coaches accounted for only .43% of total road fatalities (Nicodeme et al., 2010). Similarly, in the United States, buses accounted for only .8% of total road fatalities (Cafiso et al., 2013). However, in Malaysia, the crash rate for buses and the injury rate for bus occupants are relatively high compared to other transport modes. In 2012, the crash rate for buses was 140 for every thousand buses. This was higher than passenger cars and motorcycles crashes, which were 60 cases for every thousand passenger cars and 10 cases for every thousand motorcycles, respectively (PDRM, 2013). The fatality and injury rates for intercity buses were the highest compared to other bus types, comprising 20 fatalities and 30 injuries per thousand intercity buses.

Various risk factors contributed to motor vehicle crashes (MVC), including human, vehicle, and road environment factors. Human factors remain the major contributors to MVC. The two most common human-related risk factors significantly associated with MVC are speeding and mobile phone use while driving. Previous studies consistently indicate that the likelihood of MVC increases at higher speeds because drivers might have insufficient time to detect and respond to road hazards (Patterson et al., 2000; Aarts and Van Schagen, 2006). Consequently, this reduces vehicle maneuverability and increases the stopping distance. This is particularly acute for heavy vehicles, such as buses, because faster heavy vehicle speeds lead to a greater kinetics energy release in a road crash, thus increasing the likelihood of serious injury and fatality. Hand-held and hand-free mobile phone use while driving can seriously affect driving performance by distracting the driver's attention from the roadway (Fuse et al., 2001; RoSPA, 2002; Fitch et al., 2015). ARTSA (2015) reported that the risk of MVC increases fourfold for heavy vehicle drivers using mobile phones while driving.

Vehicle's stability and handling are important for ensuring road

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safety, and good tire condition plays a significant role by optimizing vehicle control because tires filter road disturbances, supports vehicle weight, and apply forces during acceleration and braking (Gillespie and Karamihas, 1992; Kim et al., 2015). Thus, heavy vehicle tire blowouts[1] could lead to rollover crashes[2] (Wang et al., 2015; Noggle and Palmer, 2005; McKnight and Bahouth, 2009). Solah et al. (2013) reported that, in Malaysia, tire failure is one of the common factors identified in post-crash investigations. Wearing a seatbelt was found to be effective in reducing mortality by preventing motorcar occupants from being ejected through windows (Viano and Parenteau, 2010; Mátyás, 2013), hitting hard interior elements of the vehicle (Albertsson and Falkmer, 2005), and colliding with other occupants (King and Yang, 1995; Ichikawa et al., 2002). Similar effects were also observed for bus occupants (Chang et al., 2006; Belingardi et al., 2006). However, in Malaysia, it is only mandatory for buses registered after 2008 to be equipped with passenger seatbelts. This implies that many bus occupants are often insufficiently protected in MVC.

Several road environmental factors affect heavy vehicle safety, such as gradient, the number of lanes, road shoulders and travel time. It is expected that the road crash likelihood increases at at-grade sections that have a high number of heavy vehicles. Heavy vehicles may have braking deficiency on the descending gradients (Sétra, 2007), and they travel at lower speeds than lighter vehicles on the ascending gradients. Consequently, this would increase risky overtaking manoeuvers made by other vehicles (FHWA, 2014; Hosseinpour et al., 2014, Bar-Gera and Shinar, 2005). As sight distance decreases, drivers may not have sufficient reaction time to avoid a collision with an on-coming vehicle and thus causes a head-on crash (Hosseinpour et al., 2014). Similarly, head-on crashes also commonly occur on two-lane roads (Gårder, 2006; Farah, 2013). A wider roadway paved shoulder provides adequate space for a bus stopping in an emergency situation and also prevents buses from hitting roadside objects. This is consistent with the estimation that widening the road shoulder by 1 m in each direction decreases head-on crashes by .4% (Hosseinpour et al., 2014). Previous published studies consistently indicate that driving during nighttime is associated with a higher crash risk due to fatigue and visibility restriction (Massie and Campbell, 1993; Lin and Fearn, 2003; Keall et al., 2005; Tay et al., 2008). This is particularly acute for intercity bus drivers because they are involved in long hours of driving.

In recent years in Malaysia, severe road crashes involving intercity buses have been increasing. With increased public concerns about intercity bus safety, effectively managing travel risk has become critical for both intercity bus operators and road safety policy makers. Intercity bus drivers are generally at a higher risk for crashes due to long hours of driving and exposure to different road conditions. Therefore, understanding and quantifying their risks and taking steps to manage them could improve intercity bus safety. However, testing intercity bus safety levels through a complete set of road crash risk indicators is difficult to quantify and interpret. In order to avoid this difficulty, it has been recommended that the analysis of intercity bus safety could be tackled by aggregating a multidimensional set of indicators in each risk domain into a safety performance index (SPI) for each risk domain by giving different weighted importance to different indicators. The risk factors considered in this study were road environment conditions, bus driver driving behaviors and bus safety conditions. Given this background, the aim of this study is to establish a SPI to measure and compare intercity bus safety in terms of risk factors. This index can be used as a safety benchmark for cross intercity bus company comparisons. Moreover, it can also be used to give various stakeholders, such as policy makers and intercity bus operators, a better understanding of how risk factors affect intercity bus safety and thus identifying potential countermeasures to improve intercity bus safety.

2. Research method

In this section, we present the methodology adopted in this study. First, the independent risk indicators were chosen in accordance with their analytical uniformity, measurability and relevance to the analyzed phenomenon. For each variable used to determine the risk indicator, the recognition of a related dataset, the imputation of missing data, the assessment of inherent errors and the normalization of the variable were needed. Normalization transforms the indicators into the same unit. After normalization, the weighted indicators were aggregated into the SPI for each risk domain was done using the Exploratory Factor Analysis (EFA) method. The paired sample t-test was then applied to determine which safety performance indices were significantly different from each other.

2.1. Sample

A two-stage sampling method was used to choose sample intercity buses. In the first stage, a simple random sampling technique was used to select 30 out of 86 intercity bus companies in Malaysia. The sample was weighted in terms of bus routes and travel time to match the profile of the overall target intercity bus companies. Out of 30 selected intercity bus companies, 4 intercity bus companies that mainly operating on the east coast of peninsular Malaysia where the road conditions are generally poor and not well developed were compared to bus companies driving on roads on the west coast. At the second stage of sampling, 30% of the total number of buses were randomly selected from each selected intercity bus company. There is no significant variance in the types of buses both within an intercity bus company and across companies.

2.2. Data collection

Three risk domains for intercity buses were identified in this study, which includes bus safety conditions, road environment conditions, and bus driver driving behaviors. The identification was based on the local context and understanding of intercity bus safety problems in Malaysia. The Malaysian Institute of Road Safety Research study indicated that intercity bus driver's inappropriate driving behavior is one of the main contributing factors to MVC (2016). These include using mobile phone while driving, driving under the influence of alcohol and drug, red-light running and speeding. Moreover, in Malaysia, there is no age limit for intercity buses and it is only mandatory for buses registered after 2008 to be equipped with passenger seatbelts. Therefore, the intercity bus safety conditions are not satisfactory. As indicated earlier, the road conditions in the east coast are generally poor and not well developed compared to road on the west coast of peninsular Malaysia. This indicates that road environment conditions have contributed more risk to intercity buses mainly operating on the east coast of peninsular Malaysia.

Enumerators travelled with buses to observe and collect intercity bus safety-related information. Data for bus driver driving behaviors were collected mainly through naturalistic observation. This approach not only provides an opportunity to gain an in-depth understanding of bus driver driving behaviors but also may avoid the possible biases of self-report measures (Eby, 2012). The mobile global positioning system tracker[3] was used to record bus running speed throughout the journey, and the maximum running speed[4] was chosen to indicate bus driver recklessness in driving. The average of maximum bus running speed

[1] Bareket et al. (2000) showed that tire blowout is the most common tire failure on heavy vehicles.

[2] The heavy vehicle has a higher gravity center, which can cause a rollover (Solmaz et al., 2008).

[3] The global positioning system equipment has a resolution of 10m and data was collected during daytime and nighttime.

[4] The maximum running speed was chosen because higher speed would increase the risk of crash and fatality.