EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

In-depth intercity bus crash investigation: Case study of fire-gutted bus in Thailand

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Received 23 April 2022
Revised 28 August 2022
Accepted 5 September 2022

Abstract

This paper presents the proposed measures to prevent traffic accidents from compressed natural gas (CNG) buses. The fire-gutted bus with a CNG system was investigated in detail of component and system defects as a case study, although many single bus accidents were recorded from and caused by errant bus drivers in Thailand. Thus, several measures were proposed to encourage safer road users from bus drivers in Thailand, such as drink-not-drive, GPS-monitored speed, and the readiness of rest areas, including driver fatigue prevention. While there are many existing vehicle standards for buses from United Nations (UN) regulation and Thailand, several buses have still erupted in flames. Therefore, the proposed measures from the investigation of the fire-gutted bus and the existing vehicle regulations can be used to enhance and accelerate actions in the approval of CNG bus and periodical technical inspection for roadworthiness. Through data information from the accident investigation and proposed technical inspection, the prevention of bus accidents with CNG systems can be continuously improved and enhanced under various traffic situations. Furthermore, the results from the investigation can be useful for forensic experts to support SDG Target 3.6 in reduction of deaths from road traffic accidents.

Keywords: Fire-gutted bus, CNG system, Braking system, Periodical technical inspection, Vehicle regulation, In-depth accident investigation

1. Introduction

The United Nations (UN) officially announced 17 Sustainable Development Goals (SDGs) with 169 targets to achieve balance among three main sustainable development criteria-economic development, social responsibility, and environmental protection-by 2030. One of the SDGs directly related to road safety issues is SDG 3: 'Ensure healthy lives and promote well-being for all at all ages', particularly for Target 3.6: 'By 2030, halve the number of global deaths and injuries from road traffic accidents' [1]. This SDG and its associated target were generated to promote and encourage every country to implement appropriate policies, plans, and actions to control the current global road safety issues [2].

Based on the values of road traffic fatalities (RTFs) per 100,000 population as estimated in the Global Status Report on Road Safety 2018 [2], Thailand was ranked 9th out of 175 countries in 2016. Such road safety conditions clearly indicated that Thailand has one of the most harmful road transport systems in the world. The estimated total economic cost of such road accidents in Thailand was approximately US$14,000 billion (3% of the gross domestic product (GDP)) annually. According to RTF data in Thailand derived from three RTF database systems (the Ministry of Public Health, the Royal Thai Police, and Road Accident Victims Protection Co. Ltd.), the declining trend and magnitudes of RTFs per 100,000 population were generally compatible with those estimated by the World Health Organization (WHO; 2013, 2015, and 2018). Based on the three RTF database systems, the number of RTFs declined from 2011 (21,996 deaths) to 2021 (16,957 fatalities). However, such declining tendency, particularly amid the COVID-19 pandemic (during 2020 and 2021), was strongly influenced by various COVID-19 control actions, where an emergency decree has been announced, a legal ban on leaving residential properties between 22:00 and 04:00 was placed, and several police checkpoints were operated and strictly enforced.

Relying upon the master plan under the National Strategy (from 2018 to 2037), Thailand has set up road safety targets of 12.0, 8.0, and 5.0 RTFs per 100,000 population in 2027, 2032, and 2037, respectively [3]. To achieve such ambitious road safety targets in Thailand, various urgent actions were introduced to promptly tackle the road safety crisis in Thailand; one of the most important engineering actions was an In-depth Accident Investigation (IAI) approach. In-depth accident investigation can be used to determine the true causes of accidents scientifically. Such investigations can describe pre-crash, crash, and post-crash events, leading to the accurate identification of the factors involved in an accident [4].

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doi: 10.14456/easr.2022.68

In Thailand, the bus network connects all provinces as the main mode of transportation for road users. Most routes start or finish among three bus terminals in Bangkok. One of them is for the northern and north-eastern routes. The length of the route and the travel time vary dramatically depending on the class-named express or VIP buses. The express bus can stop during the route to pick up passengers. This bus can hold between 40 to 55 seats with or without toilets on board. The VIP bus, which has 24 to 32 seats to make passengers feel comfortable during the trip, is the fastest mode of bus transportation, with a few stops en route in the shortest time. Both bus classes can be single-or double-deck types. According to Section 103 from the Land Transport Act, a bus driver must take a rest or stop the bus at least 30 minutes after a four-hour driving period [5]. For the north-eastern route from Buengkan Province to Bangkok, the express bus normally takes at least 11 hours for travel, with the distance just under 765 kilometres [6]. This rule was enacted in 1999. Furthermore, several measures were enacted to prevent road accidents in bus transportation, such as drink-not-drive, GPS-monitored speed, the readiness of rest areas, and customer call centres for unsafe vehicles during the Songkran Festival in 2021 [7].

For a period of four years (1997-2000), single bus accidents made up more than 50% of bus accidents on highways, 82.3% by errant bus drivers and 71.9% by exceeding the speed limit [8]. Under this circumstance, the human factor consequently became the main contributor to the bus accidents of Thailand. Based on the bus accidents database of Department of Land Transport (DLT) of Thailand [9], the number of bus accidents dramatically increased from 237 (in 2015) to 305 (in 2016). From 2017 to 2018, these numbers were relatively stable at 298 and 297, respectively. However, these numbers considerably decreased from 226 (in 2019) to 119 (in 2020). One of the key contributing factors to the bus accidents reductions was the implementation of the effective countermeasures such as the drink-not-drive policy, the installation of the GPS-tracking system for buses to monitor the driving behaviours of the bus drivers such as bus real-time operating speeds, travelled distances and stopped locations. However, after 2019, one of the main factors causing bus accidents reductions was the government measures to deal with the outbreak of the COVID-19 [10]. Some examples of such measures included an announced emergency decree, a legal ban on leaving residential properties and the implementation of several effective police checkpoints. Furthermore, the Department of Land Transport (DLT) enacted uniform provisions concerning the approval of buses regarding the strength of their superstructure in Thailand in 2020 [11]. This enaction is based on Vehicle Regulation No. 66 of the Economic Commission for Europe of the UN (UN/ECE). The approval process can be achieved through residual space within passenger compartments while and after the bus is subjected to the impact force using the rollover test [12].

In comparisons of the bus accidents status in Thailand and Malaysia as shown in Figure 1, the bus operations in Thailand were safer than those in Malaysia in terms of both the number of bus accidents and the number of bus accidents per 100,000 population.

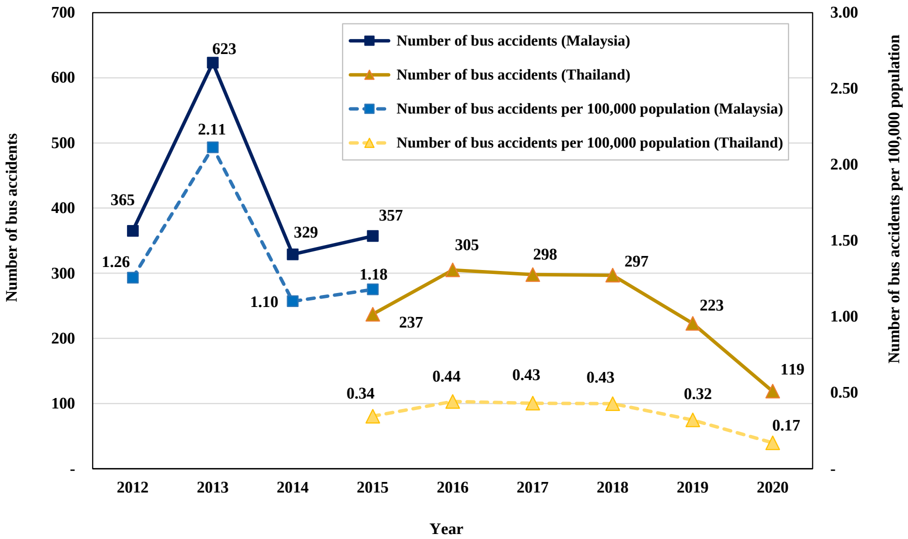

Figure 1 Comparisons of the bus accidents status between Thailand and Malaysia

However, several Thai bus accidents involved eruption into flames. For example, a double-deck bus accident caused 20 people to die in early 2018 in Tak Province [13]. In April 2021, there were five fatalities and 12 injuries from a bus fire with a compressed natural gas (CNG) system on the route to the north-eastern province [14]. After preliminary investigation, the DLT recalled 48 double-deck buses for technical inspections of braking and CNG systems within 30 days [15]. However, no further evidence was found to improve technical bus standards for fire prevention and increase the awareness of bus users in Thailand.

2. Vehicle regulations

The braking system in a vehicle is crucial to prevent vehicle collision. The effectiveness of such a system should be evaluated from the actual running conditions of the vehicle. Based on the approval of the bus with regard to braking performance, the DLT in Thailand requires braking performance based on the stopping distance and the mean fully developed deceleration [16]. The stopping distance should be measured from the initial speed of the vehicle at 80 kilometres per hour. While the force applied to foot control is not more than 70 dekanewtons (daN), the stopping distance in metres should be less than $0.15v + v^2/130$, where v = test speed in kilometres per hour. The mean fully developed deceleration should not be less than 5 metres per second squared. These requirements of braking performance are similar to United Nations Regulation No. 13 of vehicle category N1 under the Type-0 test with the engine disconnected when the temperature measured on the disc or drum brake is below 100 degrees Celsius [17]. However, bus approval from the DLT in Thailand excludes the Type-I test (fade test) with continuous braking and the Type-II test (downhill behaviour test), which are mandatory in Vehicle Regulation No. R13. For the periodic technical inspection and characteristics of braking systems, a minimum of

50% braking force for each axle weight and a maximum of 25% deviation of braking force on each wheel in the same axle must be assessed, as mentioned in Vehicle Regulation No. R13 and by the DLT. However, there are additional requirements in Vehicle Regulation No. R13, such as the wear condition of the friction linings in the drums and discs, adhesive utilisation for each axle, wheel lock sequences, etc.

A tire-pressure monitoring system (TPMS) is used to avoid traffic accidents from the extreme under-inflation of tires. This can lead to the overheating, excessive flexing, and sudden destruction of the tire sidewall or tread separation [18]. During the late 1990s and 2000, a lot of customers complained about tread separation from vehicles in the United States [19]. This caused the National Highway Traffic Safety Administration (NHTSA) to investigate 59 million tires over the last ten years. The main purpose set to identify and correct safety-related defects in vehicles. Consequently, the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act for U.S. federal law increased consumer safety through the implementation of a warning system of under-inflated tires in new motor vehicles in 2000 [20]. Therefore, the NHTSA from the DLT established the Federal Motor Vehicle Safety Standards (FMVSS) regarding the TPMS, controls, and displays as a final rule in 2005 [21]. The TPMS was also set as a mandatory item in Vehicle Regulation No. R141 [22].

To increase fire safety in the bus, the burning behaviour of the material used in its interior components is significant for vehicle standards. Based on United Nations Regulation No. 118, one of the specific requirements of such material covers a burning rate of less than 100 millimetres per minute in the horizontal and vertical directions [23]. In addition, materials above the seat cushion and in the roof should pass another test to determine the flaming drop of the material from the melting behaviour. This test is also applied to insulation materials installed in the engine compartment. Such insulation materials for the engine compartment should be additionally tested for the capability of such materials to repel fuel or lubricant through a special apparatus. This apparatus can identify the increase in the weight of fuel or lubricant in the test sample. However, the requirement of the burning rate in the horizontal and vertical directions is only adopted by the DLT. This requirement can be applied for curtain and seat materials in newly registered buses or changed vehicle bodies after 1 January 2022. For the floor and encapsulated materials of the bus structure, the burning rate can be tested after 1 January 2023 [24].

In the CNG system, with minimal standard requirements from United Nations Regulation No. 110 [25], there are 15 components: the container(s), the pressure indicator, the pressure relief device (PRD, temperature triggered), the automatic cylinder valve, the manual valve, the pressure regulator, the gas flow adjustment, the excess flow limiting device, the gas supply device, the filling unit, the flexible fuel line, the rigid fuel line, the electronic control unit, the fittings, and the gas-tight housing. Furthermore, the CNG system may include the following components: the non-return valve or check valve, the pressure relief valve, the CNG filter, the pressure and/or temperature sensor, the fuel selection system and electronic system, the PRD pressure triggered, and the fuel rail. Most of them should have technical specifications for safety measures. One significant part is the CNG container(s), which should pass maximum pressures and the number of filling cycles for use with periodic requalification. The CNG container(s) should be mounted in the vehicle excluding the area of the engine compartment. Each mounted CNG container in the vehicle categories of M2 and N2 can be subjected to the acceleration of 10 g and 5 g (g = 9.81 meters per second squared) in the longitudinal and horizontal driving directions, respectively. Therefore, United Nations Regulation No. 110 covers the Thai standard requirements and installation for a CNG vehicle [26]. Standard CNG installation and guidelines including test methods from Thai Industrial Standards Institute (TISI) No. 2333-2550 can be also accepted [27].

Based on the 1997 agreement on the periodical technical inspection of wheeled vehicles [28], testing facilities and equipment are used to ensure and evaluate minimum technical and safety requirements. These facilities and equipment should be periodically calibrated and verified for correct measurements. To independently conduct such examination without conflicts of interest, inspectors should be verified for the appropriate knowledge, experience, and skills with theoretical and practical elements. For passenger vehicles using CNG above 3,500 kilogrammes, technical inspections should be yearly conducted within one year after registration [29]. Visual inspections for insecure components with the immediate risk of detachment, gas leakage, or fire are mainly used for ventilation housing, ventilation pipes, and the gas filling system. However, the leak-detecting device is only used for leakage inside the engine, passenger, and luggage compartments under engine running conditions with gas and switched off. Furthermore, vehicle inspection for roadworthiness using facilities and equipment should be examined yearly, such as braking, steering, visibility, lighting, axles, wheels, tires, and suspension [30]. Although the DLT did not sign the 1997 agreement for periodic technical standards, the visual inspection and test measurements for roadworthy vehicles are conducted, especially in braking, steering, etc. For the yearly inspection of CNG buses, both virtual inspection and test measurements are only conducted by DLT-authorised inspectors in Thailand [31].

It can be concluded that vehicle safety items for the CNG bus are mainly taken into consideration except for the TPMS in Thailand, as shown in Table 1. However, each item of vehicle safety may have a different level of requirement from the international vehicle standard. Although many regulations for vehicles equipped with CNG were implemented and applied, many measures were proposed from the accident investigation of fire-gutted buses in France and Germany [32]. These measures consist of fire prevention from engine compartments, the periodic maintenance of fire detection, fire suppression, and fire propagation control.

Table 1 Requirement of vehicle safety items between international homologation and Thai standards

Vehicle safety items	International vehicle standard	Thai vehicle standard
Brake system	Required	Required
TPMS	Required	Not required
Vehicle fire safety	Required	Required
CNG system	Required	Required
Roadworthiness	Required	Required

3. Case presentation and methodology

In 2021, at around midnight during the Songkran festival of Thailand, a CNG double-deck bus was running en route from the Buengkan province to Bangkok along the divided four-lanes highway (two lanes in each direction) and burst into flames after CNG refilling. As illustrated in Figure 2 and based on the limited direct interviews with some victims, at the beginning of this single-vehicle accident, a rear-left tire burst and then the flames started at the rear parts of bus, where the engine compartment was located (point 1). Then, the driver tried to stop the bus for the occupants to safely escape from the fire. However, the explosion of the CNG tank immediately occurred after the bus was temporarily stopped (point 2) located approximately 300 meters further from the beginning of the incident. Subsequently, the bus moved slowly backward for about 100 meters (from point 2) and finally ceased (point 3). At this point, the entire bus was ablaze. In addition, the fire-gutted bus was officially approved for the recent (less than one month) vehicle inspection prior to the incident. This detrimental accident caused 5 fatalities and 12 injuries, while the total number of a driver and all passengers were 33.

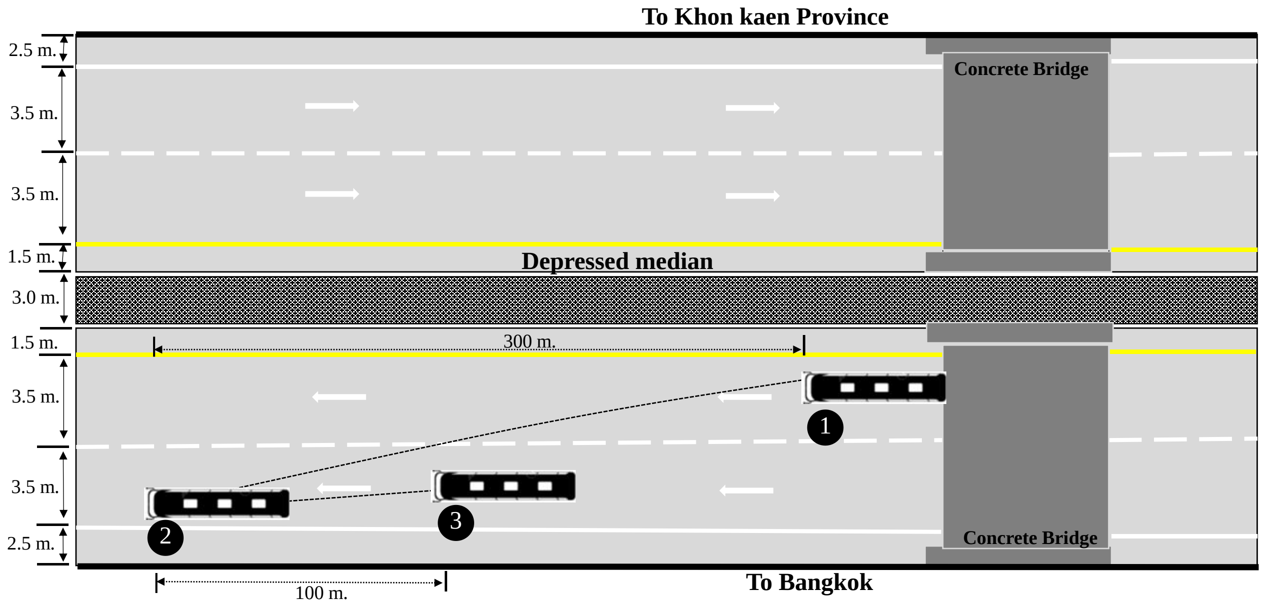

Figure 2 The bus accident scene diagram

Since the case in this investigation has not been settled yet, the source of general information cannot be disclosed. The detailed investigation is based on evidence from the fire-gutted bus. The pictures in this case were drawn and revealed only in terms of specific defective parts. Typically, there are three main contributing factors involved in the road accidents. These three factors include the human factor (fatigue drivers, drunk drivers, unhealthy driver, etc) [33], the road and the environment factor (eg the unsafe road surface conditions, poor road (horizontal and/or vertical) alignments, etc) [34] and the vehicle factor (eg braking system failure, unsafe installation of the power system, etc). In this case study, an In-depth Crash Investiga
tion (ICI) unit was assigned to undertake an in-depth accident investigation at the accident scene. As a result, the human and road and environment factors revealed minimal contribution to this bus accident [35]. Therefore, the objective of this in-depth accident investigation is to identify the vehicle-contributed risks of road accidents based on the case study of the fire-gutted bus in Thailand. The results can be useful for forensic experts in dealing with CNG bus and truck accidents. Furthermore, the evident based information from this fire-gutted bus can be beneficial to local researchers and manufacturers in enhancing the automotive components and systems for both performance and safety under the driving conditions.

To investigate vehicle-contributed risks for the case of the fire-gutted bus, several procedures should be applied, as shown in Figure 3. Firstly, global and national vehicle standards for the bus should be explored, such as braking performance, tire pressure monitoring, burning behaviour, CNG installation, and periodical inspection. Secondly, a comparison between bus and related national standards should be conducted in terms of evidence based on the side effects of vehicle parts and their functions. Risk factors based on the vehicle structure and typical collisions are also assessed. Furthermore, the gap between approved buses on the road and the current requirements of safety measures can be determined. This can be used to strengthen the discipline of approval procedures by using locally visual or engineering methods during periodical inspection for accident prevention. Finally, improvement and measures based on engineering points of view are proposed to enhance accident prevention. Engineering tools and inspection methods are also suggested in this research.

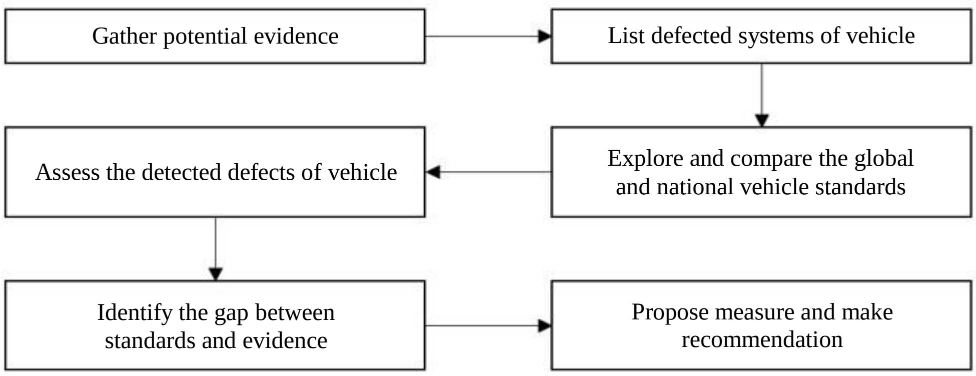

Figure 3 Research methodology.

4. Results and discussion: Case study of fire-gutted bus

After extinguishing the hazardous fire on the CNG double-deck bus, a flat-bed truck and mobile crane were used to move it to the police station. The details of the vehicle body in this case study are shown in Figure 4. To investigate the active safety components in detail, our researchers with technicians were allowed to disassemble the key components in the wheels for the brake system. The components and installation of the CNG system are also explored together with the engine compartment for the enhancement of safety measures. The influence of the explosion on the vehicle structure was investigated.

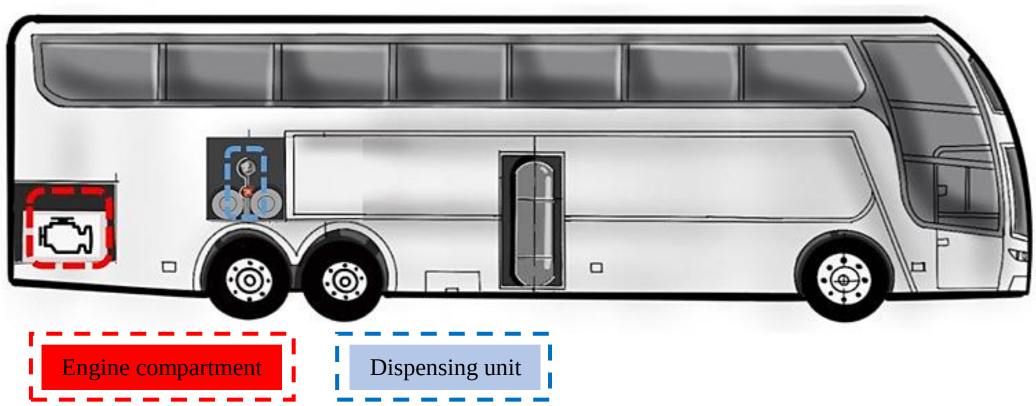

Figure 4 Vehicle body of the CNG bus for the case study.

4.1 Braking system

As shown in Figure 5, there were three axles in the fire-gutted bus, with only one remaining tire in the front axle. Each wheel for each axle was dissembled together with the drum brake. The evidence revealed that the bus had two different types of braking systems. The air-over-hydraulic brake system was used in the front- and middle-axle wheels, as shown in Figures 5(a) and 5(b), respectively. Alternatively, the rear-axle wheels were controlled by the air braking system, as shown in Figure 6. However, different types of braking systems in terms of different components and characteristics can be accepted in United Nations Regulation No. 13 if the vehicle can pass braking performance tests such as Type-0 (cold brake test), Type-I, (fade test), Type-II (downhill behaviour test), Type-III (fade test for vehicles of category O4), and Type-IIA (endurance braking performance test).

(a) (b)

Figure 5 Air-over-hydraulic system: (a) front-axle wheel; (b) middle-axle wheel.

Figure 6 Air brake system in the rear axle wheel.

Figure 7 Small cracks on the drum brake surface at the front-axle wheel.

As shown in Figure 7, small cracks on the surface of the drum can be found in the front wheel of the bus, which passed the brake test as part of the periodical inspection from the DLT. The wear debris of the brake pads is shown in Figure 5 (a). These can be interpreted as conditions of strength loss in the drum brake and pad materials. The crack developments are related to thermal stress between excessively high temperature at the rubbing surface and low temperature at the surface gradient during the brake application [36]. During the cooling period, the temperature gradient at the drum brake can be reversed, resulting in the cyclic loading and thermal fatigue of the material. The high surface temperature of the brake pads also involves the wear debris and the mechanism of the brake pad [37]. Furthermore, a large vehicle mass that dominates large kinetic energy under high speed should be considered as high thermal loading in the vehicle brake system. The research work in the evaluation of different material compositions from aftermarket brake pads showed different wear characteristics [38]. For these reasons, the development of surface cracks in the drum brake and wear debris in the fire-gutted bus reveal the poor performance of the brake system together with the selection of pad materials under vehicle usage conditions. Therefore, there are many research topics in both material and design to enhance the brake performance based on these results under various driving conditions.

In addition, the remaining tire (approximately two years old) in the front wheel bus showed high wear at both edges of tire-pavement contact, as shown in Figure 8. Tire wear can reflect the non-uniform distribution of tire–pavement contact stress that is related to tire pressure [39]. For tire wear in a vehicle, there are many impact parameters, such as low tire pressure, high ambient temperature, high-speed driving, and increases in the sprung mass and side slip angle [40]. Poor tire wear with degradation phenomena can cause unstable vehicle performance because tread removal affects thermal and frictional tire characteristics [41]. However, tire pressure has a major influence on vehicle instability given the rapid change of tire properties under pressure loss [42]. Therefore, applicable technologies such as electronic stability control (ESC) and the TPMS are essential to avoid vehicle instability. However, the performance of such technology is necessary to be evaluated under various driving and usage conditions.

Consequently, the DLT in Thailand should enhance the brake test protocol for new bus registration. The protocol should cover the Type-I test (fade test) with continuous braking and the Type-II test (downhill behaviour test), which are mandatory in Vehicle Regulation No. R13. To avoid tire explosions in public buses and poor vehicle dynamic performances, the TPMS should also be set as a mandatory item in vehicle regulation.

Figure 8 Tire condition of the front wheel of the bus.

4.2 CNG System

In the fire-gutted bus, the CNG containers did not burst because the PRD in each container operated functionally. Some horizontal containers can be located close to the engine compartment given heat protection for preventing higher surrounding temperatures than specific values from the containers' manufacturers, as mentioned in TISI No. 2333-2550 [27]. Furthermore, a CNG dispensing unit that was not one of the 15 standard components from United Nations Regulation No. 110 was found near the CNG filling unit, as shown in Figure 9.

Normally, the CNG dispensing unit is used for quickly filling all the CNG containers, especially in large vehicles, for long-distance trips in Thailand. The output of rigid fuel lines from the CNG dispensing unit can be connected to all the CNG containers as a parallel circuit. Without the CNG dispensing unit, all the CNG containers can be connected as a serial circuit, which take longer to be filled. Although the DLT-authorised inspector performs yearly CNG leakage tests through both virtual inspection and measurement, the CNG dispensing unit and the blocked tube, including the related connectors, can be loosened from vibration under operation, as shown in Figure 10. Therefore, the CNG dispensing unit should be one of the required components to be tested for external leaks under 1.5 times working pressure between 3 MPa and up to 26 MPa, as mentioned in United Nations Regulation No. 110. In addition, all the CNG components should be tested for two-hour vibration resistance at 17 Hz with an amplitude of 1.5 millimetres in each direction [25]. However, there are still some questions whether such testing conditions are suitable for road and usage conditions in Thailand or not. Therefore, robustness and durability are necessary to be conducted in the field test for safety assessment.

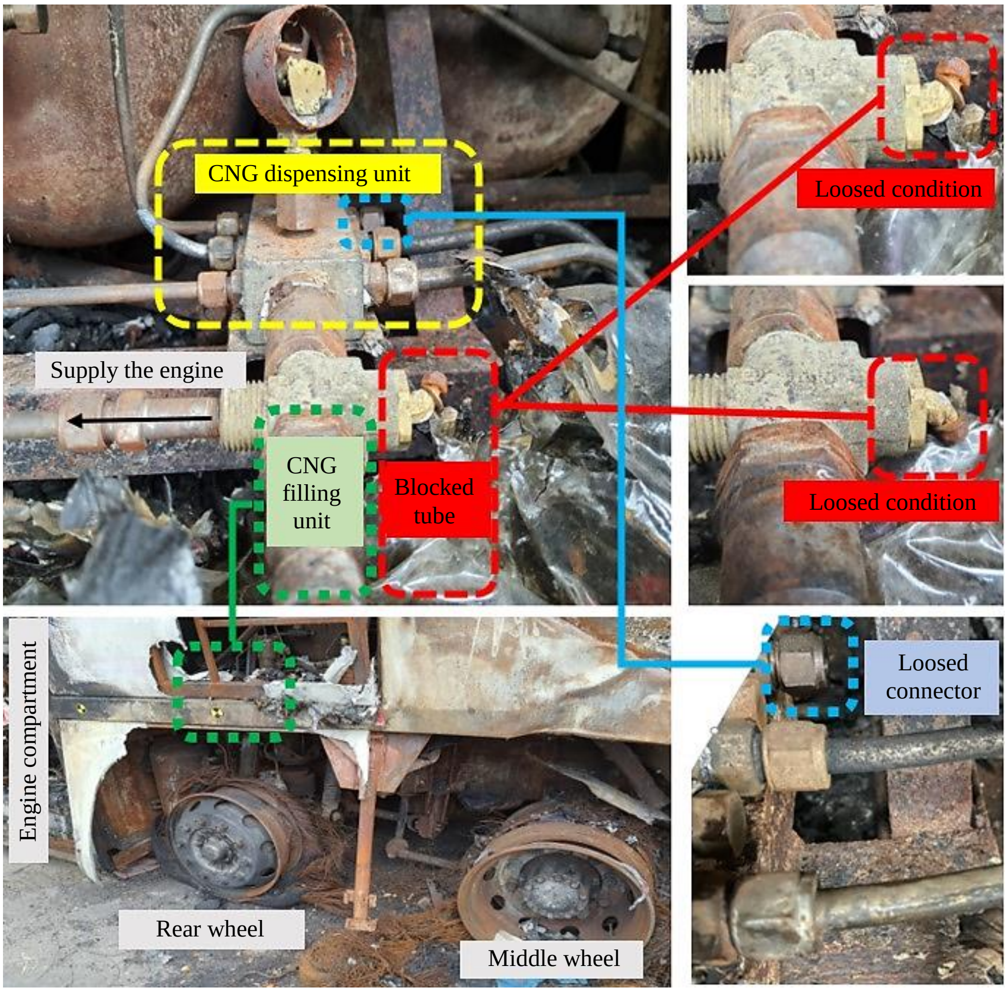

Figure 9 Locations of the CNG dispensing and filling units in the fire-gutted bus.

As shown in Figure 10, the broken metal sheets of the wheel well were bent downwards to the middle wheel on the right side of the vehicle. This occurred at the same axle on the left side of the vehicle, as shown in Figure 11. Such a bent wheel well might have occurred from the gas leak explosion at the loosened connector and the blocked tube near the CNG dispensing unit. Furthermore, the rigid fuel line for the vertical CNG container was located near the outer body, as shown in Figure 12. According to United Nations Regulation No. 110 and Thai CNG standards, the rigid fuel line should be secured without vibration stress and be fitted with protective material. Although the fire-gutted bus was approved for the installation of a rigid fuel line, it could not protect the gas leakage from the side impact at low-speed collision. In addition, the structure frame that mounted the CNG containers had an unwelded gap during installation, as shown in Figure 13. If this bus was subjected to frontal or side collisions, the mounting structure for the CNG containers could have been easily dislocated.

To prevent the risks of CNG and rigid fuel installation, an experimental method should be used for the assessment instead of the calculation method as required by United Nations Regulation No. 110 and Thai regulations. Furthermore, monitoring and directing DLT-authorised inspectors should be enhanced because each inspector can have a different attitude for the visual assessment of defects (the visual inspection method is described in detail).

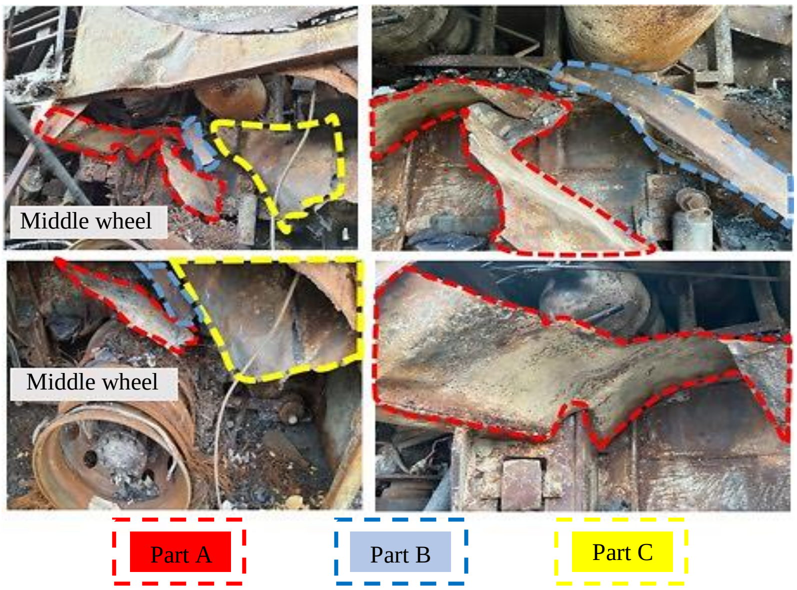

Figure 10 Broken metal sheets of wheel well above middle wheel at right side of vehicle.

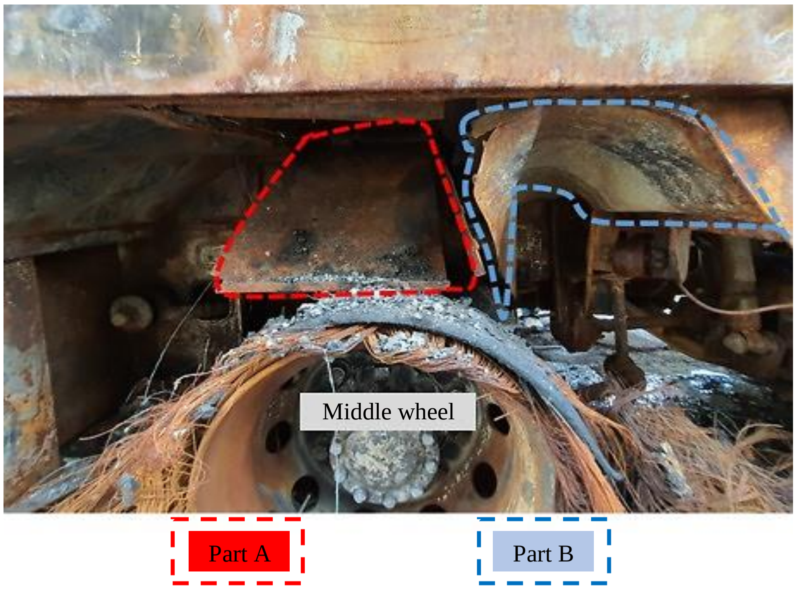

Figure 11 Downwards deformation of wheel well at left side of vehicle.

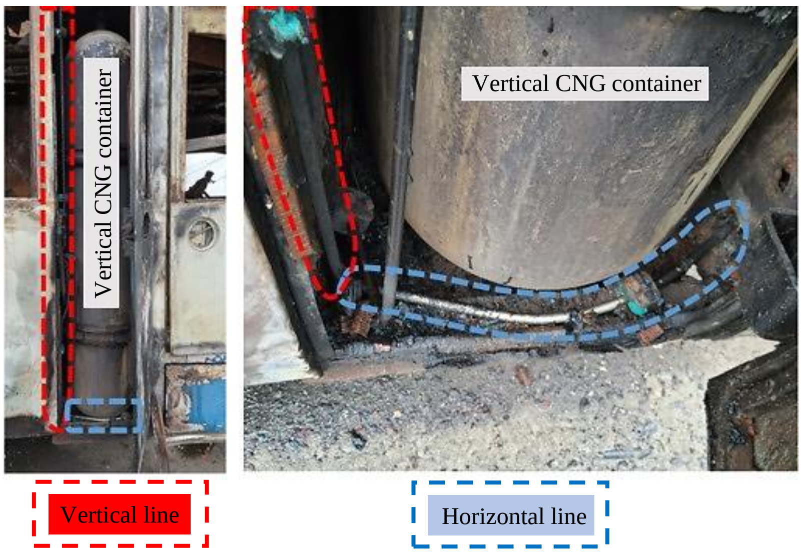

Figure 12 Location of rigid fuel line for vertical CNG container at right side of vehicle.

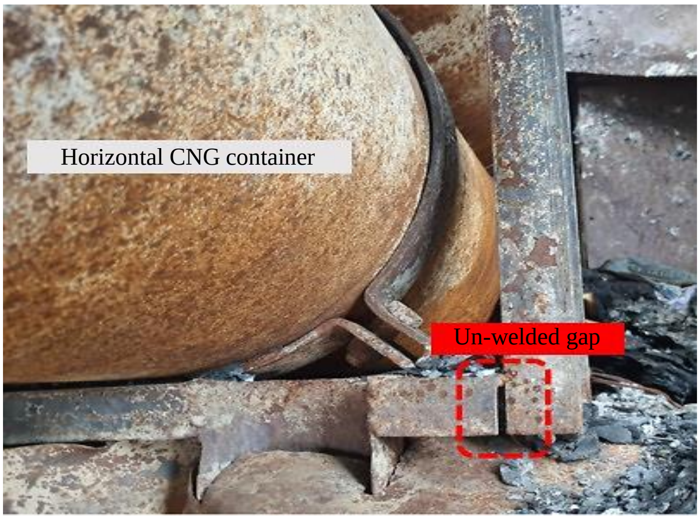

Figure 13 Poor mounting structure of CNG container near dispensing unit.

4.3 Proposed measures for bus safety

From the case study of the fire-gutted bus, two proposed measures should be considered-the approval of the bus and the periodical technical inspection for roadworthiness by the government authority or authorized agencies by the DLT. Either one of them can control quality of the bus safety. In the first measure, type approval for the active safety and CNG systems of the buses should be taken into consideration. This includes full test protocols for continuous braking and downhill behaviour tests, as mentioned in United Nations Regulation No. 13. ESC and TPMS technologies should also be equipped for the prevention of vehicle instability and tire explosion.

To avoid gas leakage, the dispensing unit should be set up as a standard component with technical requirements and testing procedures. For the mounting structure of the CNG containers and the passage of the rigid fuel line, the experiment-based evaluation should be conducted under loading directions to simulate vehicle collisions. In France and Germany, the CNG container is typically located in the roof of the bus, while the engine compartment is located close to the rear axle [32]. This can help to avoid the risk of high temperature from the engine compartment, where the most fires occur in vehicles (65.1% of total accidents) [43]. Therefore, the CNG container in the bus should not be installed close to the engine compartment, even with heat protection, as mentioned in the TISI. Furthermore, the DLT should encourage bus manufacturers in Thailand to change fire protection materials for curtains, seats, and interior surfaces as soon as possible before the date of enforcement.

In the second measure, the periodical technical inspection for roadworthiness should be focused to control and monitor qualified inspectors. Visual inspection can be subjective in terms of quality assessment. Therefore, testing facilities and devices should be used, and the inspection procedure should be recorded as much as possible. These can be used to evaluate the level of function, component lifetime value, and personal performances, including the enhancement of their criteria. Areas of such technical inspection and measurement should be related to components and systems of active safety and CNG based on data from vehicle manufacturers and accident investigation. Therefore, standard vehicle regulations can be updated to prevent traffic accidents from CNG buses in Thailand. The proposed measures and actions for CNG buses are summarised in Table 2. DLT and Ministry of Transport must strongly support the approval of laws to effectively regulate and enforce the two proposed measures in practice. Similar law approval procedures applicable to the vehicle inspection laws for annually renewing the vehicle registration is highly recommended.

Table 2 Proposed measures and actions for CNG buses

Proposed measures	Actions
Type approval of CNG bus	• Enhance testing procedures in the brake and CNG systems • Encourage the usage of advanced technologies such as ESC and TPMS for active safety • Improve the standards of the CNG dispensing unit • Avoid the risk of CNG container installation, position, and mounting structure • Allocate the passage of the rigid fuel line to avoid gas leakage from different types of vehicle collision • Encourage the usage of fire protection materials before the date of enforcement
Periodical technical inspection for roadworthiness	• Control and monitor qualifications for DLT-authorised inspectors • Utilise facilities and devices for quantity instead of quality assessment • Enhance the criteria and technical inspections based on data from vehicle manufactures, updated standard regulations, and accident investigation

5. Conclusions

The fire-gutted CNG bus in this research can be used to identify areas of improvement, even with existing requirements based on international and Thai vehicle standards. Given the small cracks on the surface of the brake drum at the front-axle wheel, the full testing procedures of evaluation in the vehicle braking system should be enhanced to meet related standards from UN regulations. To avoid high tire wear and vehicle instability, the TPMS should be mandatory for public transportation vehicles in Thailand. In the CNG system, the dispensing unit should be set as a standard component for the vehicle (more than one CNG container installed). Thus, internal and external gas leaks can be tested in the early stage of type approval. The CNG containers should be located far from the engine compartment, where the most fires are found according to research work in accident investigation. The installation and passage of the rigid fuel line should be considered to avoid different types of vehicle collision. For periodical technical inspection, DLT-authorised inspectors should be controlled and monitored through testing procedures from vehicle regulations. The data from records in periodical technical inspection and accident investigation can be used to prevent traffic accidents from CNG buses in Thailand. Furthermore, the proposed measures can certainly support SDG Target 3.6 to halve global deaths from road traffic accidents by 2030.

6. Acknowledgements

The authors would like to express their sincere gratitude to Dr. Wittaya Chadbunchachai (WHO Collaborating Centre for Injury Prevention and Safety Promotion, Khon Kaen Hospital, Thailand), who supported and arranged the investigation, as well as Mr. Wiroon Yotmeeboon, Mr. Warunvit Auttha, and Mr. Natthapoj Faiboun, who helped support the investigation of the buses in the field survey. The authors are also grateful to King Mongkut's University of Technology (North Bangkok), the Rajamangala University of Technology (Phra Nakhon), and the Sustainable Infrastructure Research and Development Center (SIRDC) (Khon Kaen University). This study was supported by a research grant from the Army Research and Development Office and the Ministry of Higher Education, Science, Research, and Innovation.

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