Development and application of a vehicle safety rating score for public transport minibuses

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Key Findings

- Minibuses transporting between nine and 15 passengers are widely used for public transport in low- and middle-income countries, yet levels of active and passive safety provided are often poor;
- A safety rating system was devised allowing relatively inexperienced personnel to quickly assess and score vehicles on a scale from zero to 50 points;
- A survey of 566 in-service minibuses in the United Arab Emirates highlighted low levels of compliance with applicable Gulf Cooperation Council (GCC) motor vehicle safety standards, with the vehicle sample scoring an average of 14.4 out of 50 (compared with an estimated score of 20 for compliance with the standard applicable at the time);
- The safety rating system was made available to the Abu Dhabi Department of Transport to set a threshold score below which vehicles could be progressively removed from service with the aim of improving the state of minibus safety within the UAE.

Abstract

Minibuses are widely used for public transport, particularly in developing countries, yet their safety levels are often poor. This study identified a simple set of active and passive safety measures and 566 minibuses in the United Arab Emirates were inspected. Most vehicles were without seat belts or head restraints and had inadequate seat attachment. Low rates of active and passive safety features were recorded. The safety rating system assigned weightings to each of the variables in the survey, based on an assessment of their approximate relative risk. Applied to the benchmarking sample, safety rating scores (out of 50) ranged from below 10 points for the least safe vehicles to around 40 points for the best. Many vehicles inspected scored below 20 points. The safety rating score provided a practical assessment of the safety of the UAE minibus vehicle fleet and could be adapted to other vehicle types. The study outcomes are helping to both justify a new minibus safety standard in the UAE aiming to significantly reduce death and serious injury among the many passengers using this service, as well as to begin the process of removing the least safe vehicles from the fleet.

Keywords

Vehicle safety, minibus, safety assessment, public transport

Introduction

This study formed one component of a longer-term program to improve the safety of minibuses in the United Arab Emirates. An earlier study by Fildes, Logan and El-Sadig (2014) outlined a proposed new safety standard for the UAE to improve the safety of these vehicles, defined in the Emirates as commercial passenger-carrying vehicles for carrying no more than 14 passengers (nine in Abu Dhabi). With the primary project goal being to undertake a benefit-cost analysis to determine the economic impact of implementing a new safety specification, it was first

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necessary to gain a more detailed understanding of the safety specification and maintenance condition of the existing fleet. To facilitate communication with the stakeholders involved, the decision was made to develop a safety rating score to quantify the outputs of the safety survey.

In the UAE at the time this project was undertaken, all motor vehicles, including minibuses, were required to comply with Gulf Cooperation Council standard, UAE.S/GSO 42:2003 (ESMA, 2003), with similar requirements to European standards of the early 21st century. Anecdotally, however, compliance with the standard often appeared poor among in-service vehicles and there were and still are currently no incentives, such as an NCAP program, to encourage consumers to purchase vehicles of better than the minimum regulatory requirements.

Method

The data collection activity was undertaken in the Emirates by local technicians who had limited vehicle safety expertise. Therefore, a set of variables was devised that satisfied three main criteria:

1. to be indicative of the overall safety level and condition of an in-service minibus;
2. to be obtained from a sample of vehicles by non-expert data collectors; and
3. to be obtained primarily through visual inspection, without the need for performance testing or complex measurements requiring specific expertise.

The parameters were grouped into two main categories (*C*): primary safety (crash avoidance) and secondary safety (crashworthiness). Each of these was assigned a relative weighting, summing to one:

Within each of the main categories, individual parameters (*R*) were chosen based on expert judgement, while satisfying the restrictions listed above. In the same way as the main category weightings summed to unity, the individual parameters selected to represent each main category were also required to total one.

$$SR_{norm} = \sum_{i=1}^{i=n} T_i \sum_{j=1}^{j=p} C_i . R_{i,j} \qquad (2)$$

where:

SR_{norm} is the weighted safety rating;
p is the number of individual parameters in category i;
$R_{i,j}$ is the weighting for parameter j within category i;
T_i is the weighting for category i
C_i is the weighting for the parent category

The weighted safety rating, between zero and one, was scaled up by a nominal factor of 50 to yield the Safety Rating Score for each vehicle.

The values for individual weightings were chosen to reflect their relative importance among their respective category. For practical reasons, this process was achieved by reaching expert consensus among the research team, based on multiple decades of road safety research experience, since amassing sufficient research evidence to objectively compare the relative benefits of different safety features was beyond the scope of the study, even if such evidence was available.

Results

Parameter selection – primary safety

Three safety features were selected for inclusion in the crash avoidance category, as shown in Table 1.

A pseudo-static stability factor was based on static stability factor (SSF), defined by the US National Highway Traffic Safety Administration in NHTSA (2000). SSF, being based on vehicle track width and the height of the centre of gravity (CofG).

$$\text{SSF} = \frac{T}{2H} \qquad (3)$$

where:

SSF is the Static Stability Factor;
T is the track width of the vehicle;
H is the measured height of the centre of gravity;

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If the entire mass of the vehicle were concentrated into a point, the CofG location represents the height this point. CofG is normally determined using a tilt table test, in which the tethered vehicle is tilted sideways from the horizontal until the wheels on one side begin to leave the ground at which point the tilt angle is measured. SSF thus represents a measure of propensity to rollover. Since it was impossible to determine this experimentally, the height of the CofG was determined for this vehicle type by the engineering approximation of the vertical distance from the ground to the base of the driver seat at the seat back pivot.

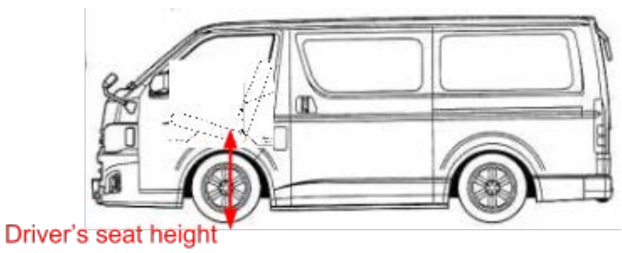

Figure 1. Height measurement for pseudo static stability factor

The parameter values for ESC and ABS were set to one when fitted; zero when not fitted. Pseudo-SSF values ranged between zero for pseudo-SSF of 0.6 or lower to one for 0.9 and higher, with the endpoints chosen to represent the range of vehicles surveyed in the study and the likely rollover risk. In between the endpoints linear interpolation was used to determine the value assigned.

Table 1. Primary safety features assessed, with relative weightings

Safety feature/characteristic	Weighting
Electronic stability control (ESC)	0.60
Pseudo-static stability factor	0.35
Antilock braking system (ABS)	0.05
Total	1.00

Parameter selection – secondary safety

Secondary safety parameters were selected to reflect the prioritisation of minibus passengers in the current UAE environment. Crashworthiness rating (CWR) was derived from Newstead, Watson and Cameron (2013), which statistically evaluates crashworthiness based on real-world secondary safety performance from 24 years of police-reported crash data across Australia and New Zealand. The method by Newstead et al relies on a statistically valid sample being available, therefore in the case of vehicles in the study without crashworthiness ratings, engineering judgement was used on the basis of approximate mechanical equivalence (such as Chinese brands based on previous models of Japanese vehicles) or through comparisons of NCAP ratings where available. The parameter values for CWR were on a scale from a CWR of 2.0 representing a zero score, to a score of one for a CWR of 5.0, linearly interpolated between the two endpoints and assigned values of zero or one for scores lower than 2.0 or higher than 5.0 respectively. This parameter was assigned a third of the overall secondary safety weighting.

Experience with observations of the minibus fleet strongly indicated poor seat belt fitment rates, despite the fact that it is a legal requirement. Furthermore, while many vehicles observed had seat belts fitted in the rear compartment, they were often unavailable to passengers by being tucked under the seat, folded or knotted or otherwise made inaccessible. The scores assigned for rear seat belt fitment by position were: zero for no belt or an inaccessible belt, 0.5 for a two-point belt and 1.0 for a three-point belt. The final score was the average of all rear seating positions, since seat belt availability frequently varied between seats.

Three parameters assessing airbag fitment provided 28% of the secondary safety assessment in total, covering frontal airbags and side or curtain airbags in either or both of the front or rear passenger compartments, with a score of one awarded for fitment of each.

Headrest fitment was evaluated by awarding one point for a seating position with a headrest (either integrated or adjustable) and zero points for a seat without any support above shoulder level. The final value for this parameter was the average of the values for all of the rear seating positions.

The final two parameters were average inter seat spacing and passenger ‘knee room’ (also referred to as ‘foot room’), as shown in Figure 2. Inter seat spacing influences the possibility of passenger to passenger contact during a crash event, particularly when restrained by two-point, lap belts only. The knee room parameter, while correlated with inter-seat spacing, is primarily related to comfort and accessibility but could also influence the risk of lower limb injuries in a frontal impact. Inter seat spacing was scored zero points for 60 cm and below, one point for 90

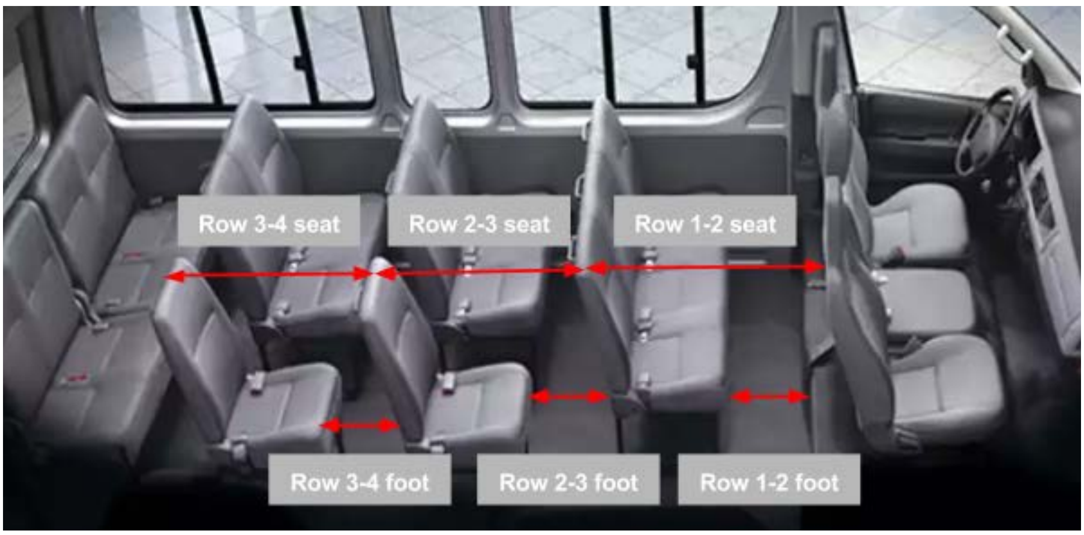

Figure 2. Key for seat-to-seat and knee-room measurements

Table 2. Secondary safety features assessed, with relative weightings

Safety feature/characteristic	Weighting
CWR (Crashworthiness rating)	0.33
Rear seatbelt fitment (average of all seating positions)	0.33
Front airbag fitment	0.10
Side/curtain airbag fitment (front compartment)	0.09
Side/curtain airbag fitment (rear compartment)	0.09
Rear head restraint fitment (average of all seating positions)	0.04
Average seat-seat spacing (cm)	0.015
Average knee room (cm)	0.005
Total	1.00

cm and above and interpolated linearly in between these two end points. The lower limit was derived from the Economic Commission for Europe (ECE) standard R107 Rev 6 Annex 4 (ECE, 2014) and the upper limit based on the torso height of a 50th percentile male (McBride, 2011). The average of the scores for all passenger rows was used to determine the final score. Similarly, knee/foot spacing scores were consistent with ECE (2014), but with allowances made to reflect the current requirements of UAE GSO.S 42 and for consistency with the maximum inter-seat spacing value used. Consequently, the assigned parameter values ranged from 20 cm (zero) to 40 cm (one point), with interpolations in between.

It should be noted that some subtle, more complex effects were neglected: for example, the use of a two-point belt with low seat-to-seat spacings could result in increased neck or spinal trauma compared with non-use of seat belts. On balance, the judgement was made that seatbelt fitment should be encouraged, regardless of the type.

The list of parameters included in the safety rating score was compared qualitatively with the safety-related clauses of UAE.S/GSO 42 and good correlation found between the two, except for the three clauses pertaining to windscreen and windows, speedometer accuracy and tyre specification. Electronic Stability Control was assessed, but is not yet mandatory for minibuses in the Gulf region (ESMA, 2016).

Main criteria weighting and general comments

The two categories (primary safety and secondary safety) were combined by assigning weightings of 0.3 and 0.7 respectively, aligning with the relative priorities of each in the Middle Eastern context.

A star rating score was calculated for a selection of vehicles representing a wide range of safety levels in order to ensure that the scores awarded were commensurate with a subjective assessment of individual vehicles and gave good discrimination between poorer and better performing vehicles.

While the rating system was targeted at discriminating vehicles based on their fundamental specification, in practice the secondary safety component of the score reflected vehicle operating condition to an extent, given that—in particular—a sizeable proportion of vehicles were not fitted with seat belts in accordance with the standard.

Study data collectors rated several vehicles under supervision of the study team to ensure accuracy and consistency before data collection began.

Typical minibus safety rating scores

The study sample was dominated by variants of the Toyota Hiace, which makes up a significant proportion of the minibus fleet in the Emirates. Also present were examples of the Nissan Urvan and its newer replacement, the NV350. The remaining general use minibuses comprised Mitsubishi, Mazda and Chinese-built Foton vehicles. Also included were a sample of Mercedes-Benz Vito vehicles dedicated by the Abu Dhabi government to transporting airline passengers between Abu Dhabi city and the airport. These were commissioned between 2013 and 2014.

Scores for a selection of the vehicles included in the study are provided in Table 3 below. The mean safety score (out of a maximum of 50) for the entire sample was 14.4, with a standard deviation of 8.2.

Mean safety rating scores clearly differentiate between the less safe and more safe vehicles. The spread between the minimum and maximum scores results from variations in rear seat passenger belt fitment, seat spacing and vehicle

Table 3. Benchmarking study safety rating scores.

		Safety score (0-50)		
Vehicle	**No.**	**Min**	**Mean**	**Max**
Toyota Hiace, 1996-2004	79	6.8	7.6	12.9
Toyota Hiace, 2005-2014 (narrower track)	392	9.7	13.6	23.2
Toyota Hiace, 2005-2014 (wider track)	10	13.1	18.3	24.0
Nissan Urvan, 2001-2012	13	6.5	9.1	13.0
Mercedes-Benz Vito, 2013-2014	35	40.9	40.9	40.9

condition. The wider track Toyota Hiace has not only a 200 mm wider track, but is often a higher specification model with three-point seat belts and head rests, unless modified by the owner. The Mercedes-Benz vehicles were all well-maintained and did not appear to have been modified.

Discussion

The safety rating method devised for this study showed good discrimination between vehicle types, reflecting variations in base vehicle design and specification, as well as vehicle fitout and in-service condition. While the inspections of a number of vehicles in this study were undertaken at the government-operated inspection stations in conjunction with their mandatory annual check, the majority were conducted at a central bus station and considerable variation was observed between individual vehicles. Several issues were observed, with the following being of particular note:

- Although two-point seat belts on all rear seating positions are mandatory, a large proportion of vehicles either had no belts fitted, the belts were rolled up or fed between the seat back and squab such that they would be unavailable to passengers;
- In the emirate of Abu Dhabi there is a requirement for minibuses to seat no more than nine occupants in total, compared with the 14-15 seats normally fitted to the most common vehicle, the Toyota Hiace. Consequently, it is necessary for operators to remove one or more of the standard bench seats and refit different seat assemblies to reconfigure the vehicle. It seemed likely that this process is not always carried out with due diligence, since third row seats in many vehicles were inadequately secured or not equipped with seat belts.
- Fitment of frontal airbags for front seat passengers and, in many cases, drivers also was inconsistent, even allowing for vehicle age. This may be an indication of problems with the import approval process.

A safety rating score of around 20 correlated with a vehicle that would be compliant with the current UAE.S/GSO 42:2003. By way of comparison, the study proposed two hypothetical alternative vehicles that would constitute a practical improvement over the existing fleet, using the predominant Toyota Hiace as a case study:

- Improvement #1: a safety retrofit program to existing narrow track Toyota Hiace vehicles, currently averaging 13.0 points. A hypothetical maximum safety rating score of 27.5 points could be achieved by retrofitting existing vehicles of 2005 and newer with high-back seats with headrests, three-point seat belts and relocating the seats to provide a minimum of 870 mm inter-seat spacing. This configuration reflects the seat type and layout of Toyota Hiaces available in many international markets, albeit in a narrower track form.
- Improvement #2: a replacement Toyota Hiace, based on the 2015 Australian market Hiace Commuter minibus with wide track chassis, fitted with high-back seats, head restraints, and 3-point seat belts as standard equipment, along with Electronic Stability Control (ESC), Anti-lock Brakes (ABS), and Electronic Stability Control (ESC). With fitment of driver and passenger frontal impact airbags, in good condition and with all safety features currently available to all passengers, this would give a Safety Rating of 38.

One limitation of this study is the lack of research evidence to support the relative weightings (and therefore relative risk of crash involvement or serious injury outcome given a crash) between individual safety features and characteristics. However, the values selected, while not necessarily objectively measuring relative risk, certainly provide a strong indication of the relative importance of each to minibus passengers in the Emirati minibus fleet as it stands. Similarly, the relative weightings between primary and secondary safety along with maintenance and condition could be varied to suit the priorities and current safety standards of other jurisdictions. In Australia, for example, a higher weight might be assigned to crash avoidance, acknowledging that vehicle crashworthiness is perhaps of a generally better standard and perhaps more uniform between vehicles. Consequently, disparity among the fleet regarding primary safety features would be better quantified with more emphasis on this category. Future work could focus on developing a more objective basis for determining intra- and inter-category weightings.

Additional study limitations included the use of a proxy for static stability factor (SSF) rather than a test-derived value, and the necessity of assuming crashworthiness equivalence for vehicles sold into the Middle Eastern market with those tested in other countries.

Furthermore, in order to apply this method to other jurisdictions, the individual parameters should be selected and weighted to reflect the current fleet standard and desired vehicle safety outcomes, with the goal of encouraging ongoing improvements to vehicle safety policy.

Conclusions

This study set out to develop a safety rating score able to be relatively easily determined from a combination of publicly available information and a visual inspection undertaken by non-expert personnel. The schema has the advantage of being transparent and objective, with the weights of individual safety features and characteristics as well as the overall categories highlighting their individual contributions. Because of this, individual weightings can be adjusted to reflect the priorities in other jurisdictions.

Applied to a real-world sample, vehicles scored from below 10 points out of a maximum of 50 up to almost 41 points for the better equipped and maintained minibuses.

The safety rating score was made available to the Abu Dhabi Department of Transport to set a threshold score below which vehicles will be progressively phased out of service, with a benefit-cost study indicating the societal benefits of this program aimed at significantly improving the state of minibus safety in the United Arab Emirates.

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