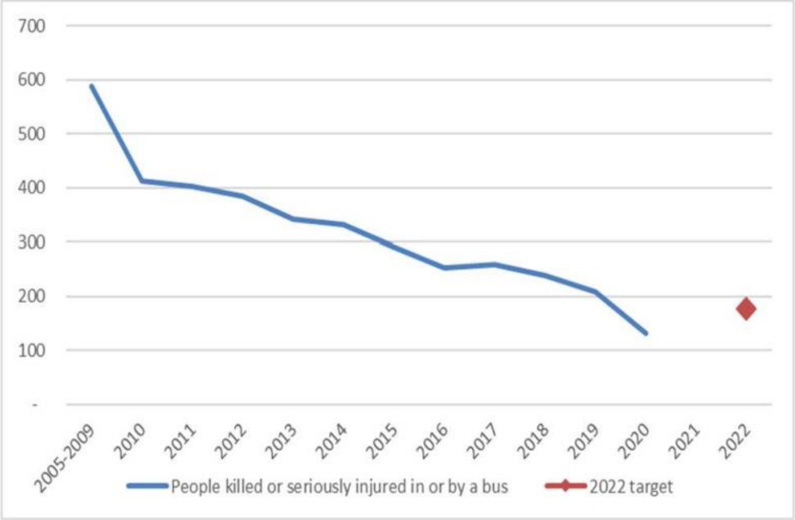
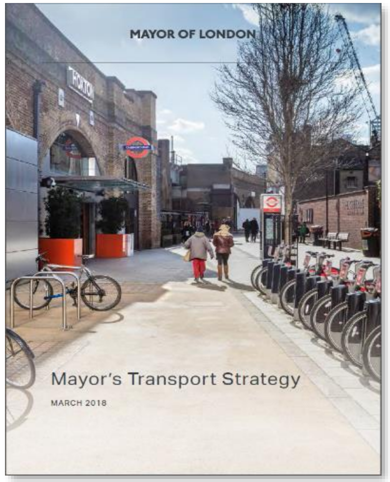
Rachel Birrell

Bus Safety Development Manager, TfL

Vision Zero

- London's **Mayor's Transport Strategy** sets out a target that no one will be killed in or by a London bus by 2030 and for no one to be killed or seriously injured on London's roads by 2041
- The number of people killed or seriously injured in or by a bus fell by 12 per cent between 2018 and 2019, to 209 people. This is 64 per cent down on the 2005-09 baseline[1]





Countdown to Vision Zero

2022
70 per cent reduction in people killed or seriously injured in or by a bus (based on 2005-09 baseline)

2030
No one killed in or by a London bus

2041
No one killed or seriously injured on London's roads

BUSES

[1]Transport for London Casualties in Greater London during 2019 – Data Release

Bus Safety Programme

The Bus Safety Programme was introduced in 2016 and focuses on 5 key Vision Zero themes to drive major safety improvements covering -

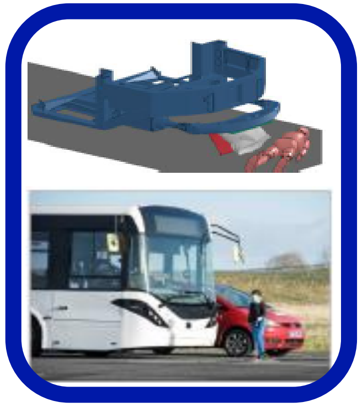
Safe Speeds

Safe Streets

Safe Behaviours

Post Collision

Safe Vehicles



Vision Zero Target:

'the number of people killed in, or by, London buses to be zero by 2030'

Bus Safety Standard

- The Bus Safety Standard was launched in 2018. It is focused on vehicle design and safety system performance using new technologies and innovations
- There are currently 25 measures required for new buses between 2019 and 2024. It is a continual programme of improvement and will carry on with new improvements every three years post 2024.

Bus Safety Standard Measures

Driver Assist

Helping the driver to avoid or mitigate the severity of incidents

- Automated Emergency Braking (AEB)
- Intelligent Speed Assistance (ISA)
- Improved Direct and Indirect Vision
- Pedal Application Error
- Runaway Bus Prevention

Partner Assist

Helping other involved road users – the collision partners – to avoid the collision

- Acoustic Conspicuity
- Visual Conspicuity

Partner Protection

Reducing severity of injuries for road users outside the bus in a collision

- Vulnerable Road User (VRU) Frontal Crashworthiness

Occupant Protection

Reducing severity of injuries for people on board the bus

- Occupant Friendly Interiors
- Slip Protection

Iain Knight

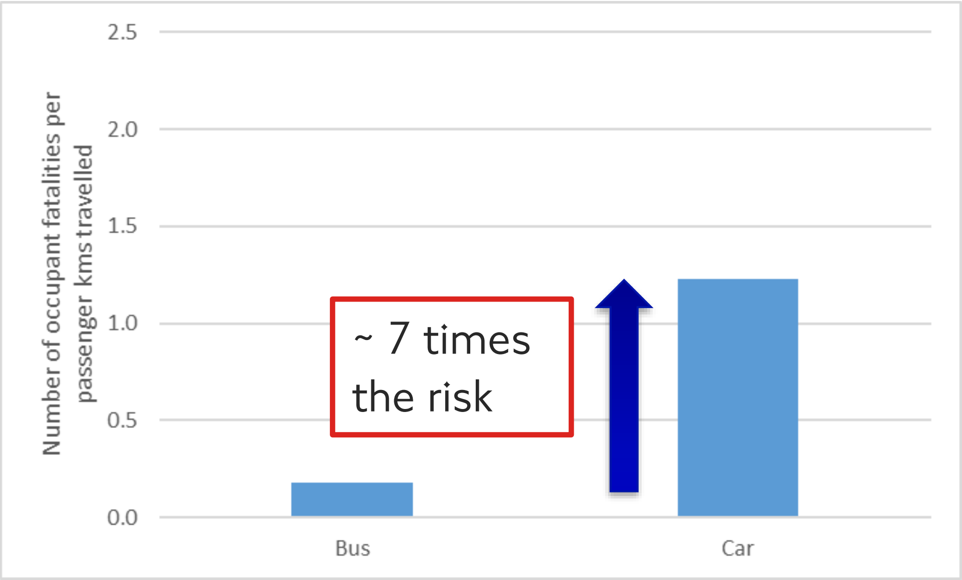
Director, Apollo Vehicle Safety

Bus Safety Standard Research Timeline

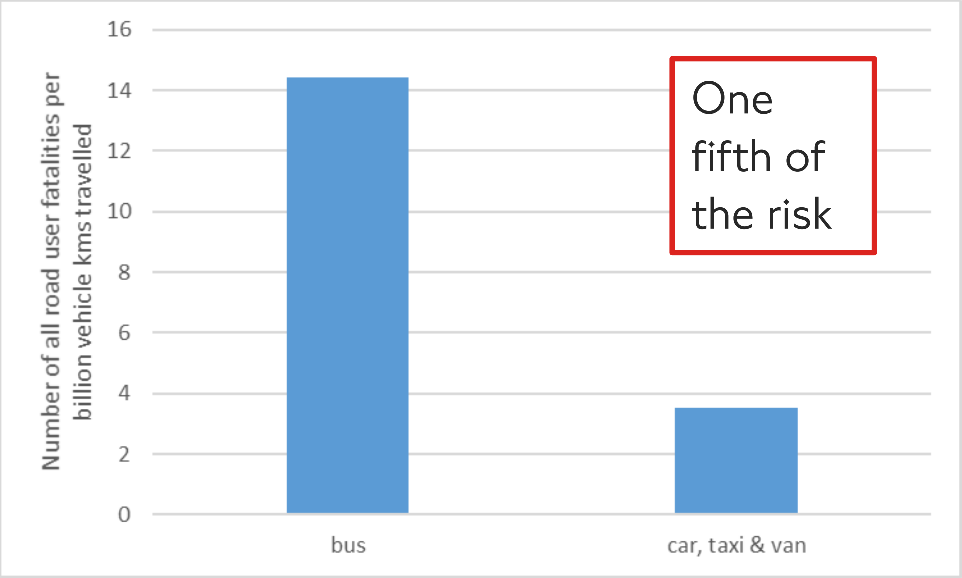
- 2016/17: Casualty analysis and countermeasure identification. http://content.tfl.gov.uk/analysis-of-bus-collisions-and-identification-of-countermeasures.pdf
- 2017/18: Bus Safety Standard Phase 1 - detailed test & evaluation of identified countermeasures. For AEB:
  - Literature review
  - Analysis of data from CCTV systems equipped with accelerometers
  - Track testing of prototype
  - Road trial of prototype
  - Development of a true/false positive risk benefit model
  - Peer Reviewed by Euro NCAP and Thatcham Research
  - https://tfl.gov.uk/cdn/static/cms/documents/advanced-emergency-braking.pdf
- 2020: Bus AEB Ethics workshop
- 2020/21: Bus Braking Data – collection of large scale data to increase robustness of initial risk benefit model
  - Naturalistic driving data – bespoke telematics data from >1million bus km, standard info from 1billion
  - Additional CCTV analyses
  - Not yet published
- Results in this presentation drawn from all 4 activities using latest data where applicable

The collision problem: buses in context

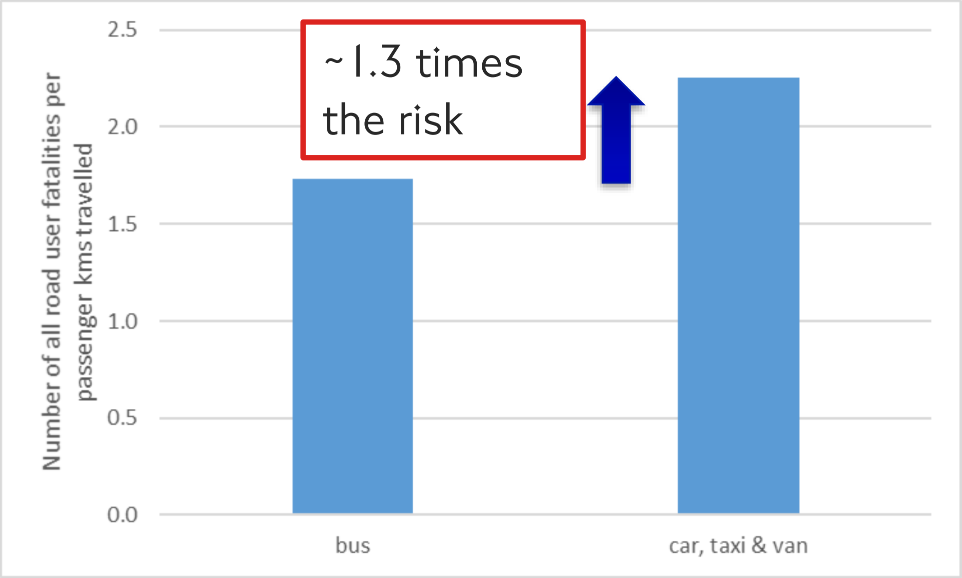
- EU bus & coach involved in c.3% of fatalities[1]. Class I/II for standees not separately identified.
- GB statistics confirm that buses are by far the safest road mode – for passengers inside the vehicle
- Less clear when fatalities from outside bus are considered
- Total fatalities per vehicle km higher than for cars & vans



Drivers & passenger fatalities per passenger km



All road user fatalities per billion vehicle kms



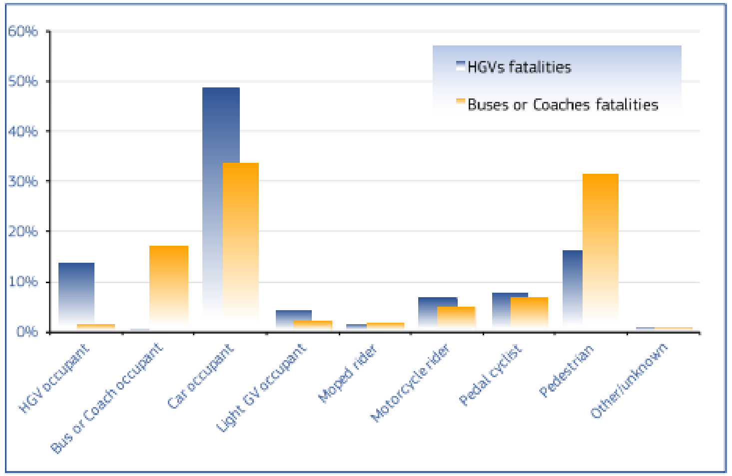
All road user fatalities per passenger km

[1]Source https://ec.europa.eu/transport/road_safety/sites/default/files/pdf/statistics/dacota/bfs20xx_hgvs.pdf
[2]Stats 19 & DfT Transport Statistics

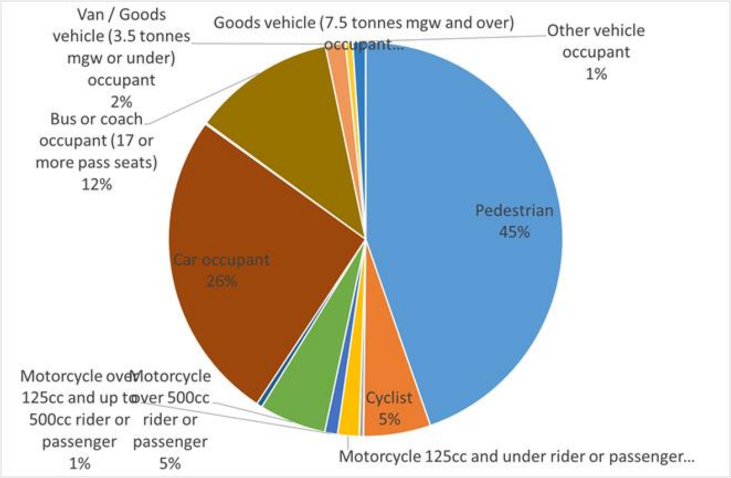
The Collision Problem: Road user types killed

- EU Pedestrian 31%, Car occupants 34%
- GB Pedestrian 45%, car occupants 26%
- London Pedestrian 64%, car occupant 16%
- Statistics are bus & coach: Balance of inter-urban coach & city bus will influence distribution
- London dominates UK bus market (20% of GB bus/coach fatalities)
- City statistics more likely to be representative of M3 class I/II

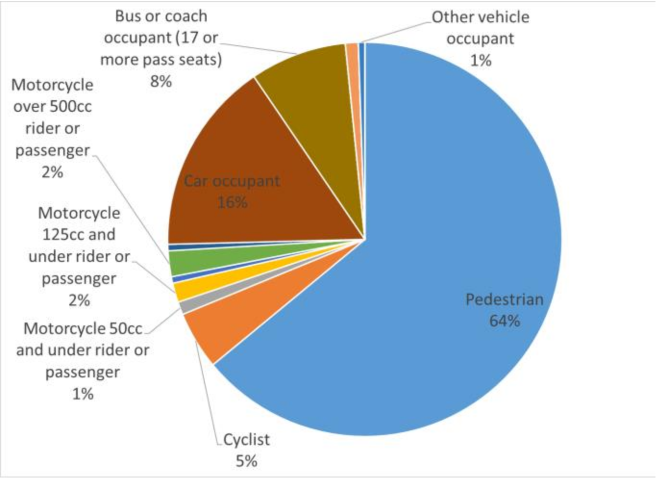
EU[1]



GB[2]



London[2]

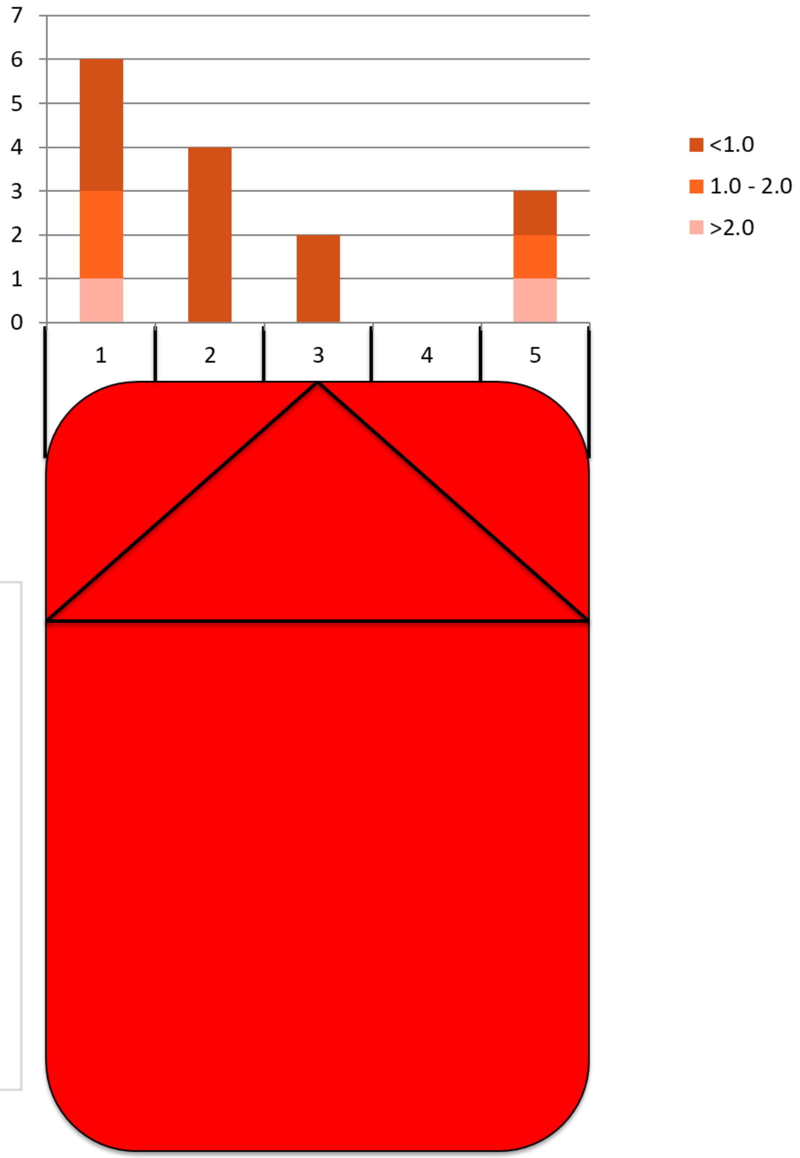


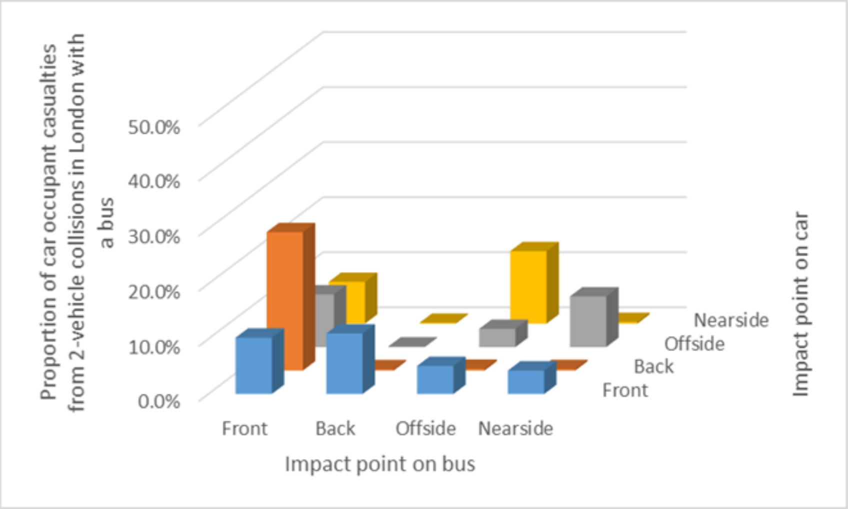
BUSES

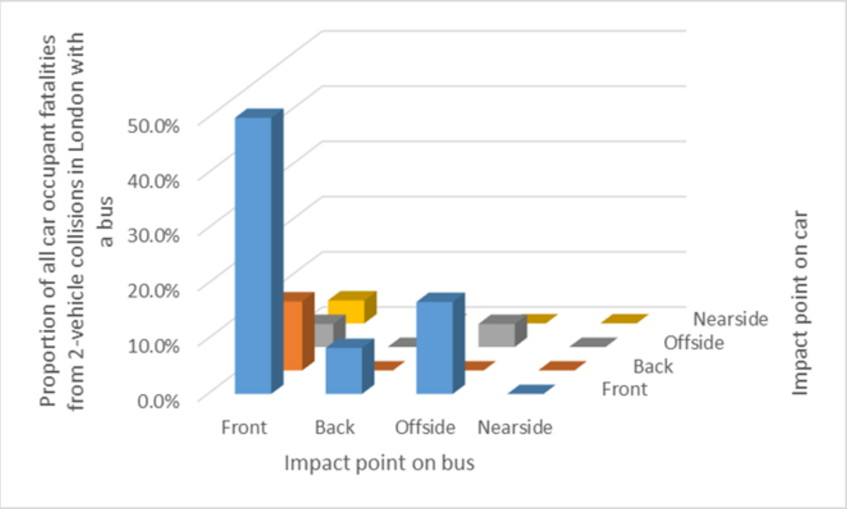
[1]Source https://ec.europa.eu/transport/road_safety/sites/default/files/pdf/statistics/dacota/bfs20xx_hgvs.pdf
[2]Stats 19 2006-2015

The Collision Problem: In-Depth Analyses

- In-depth study of 48 Police fatal collision reports London class I/II bus only (73% pedestrian).
- Analyses of CCTV data recorders from bus operators
- Available reaction time very short in most pedestrian cases, particularly characteristic of fatal collisions
- Vehicle front to rear frequent but more rarely fatal



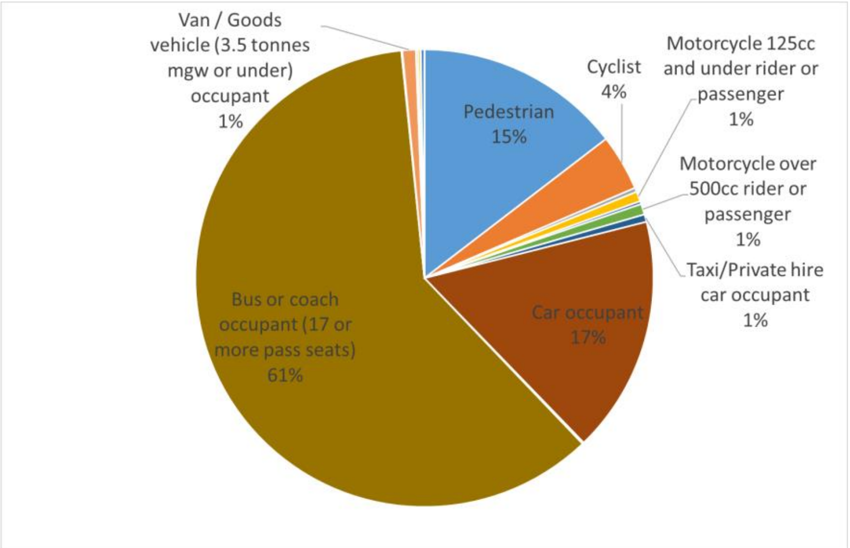


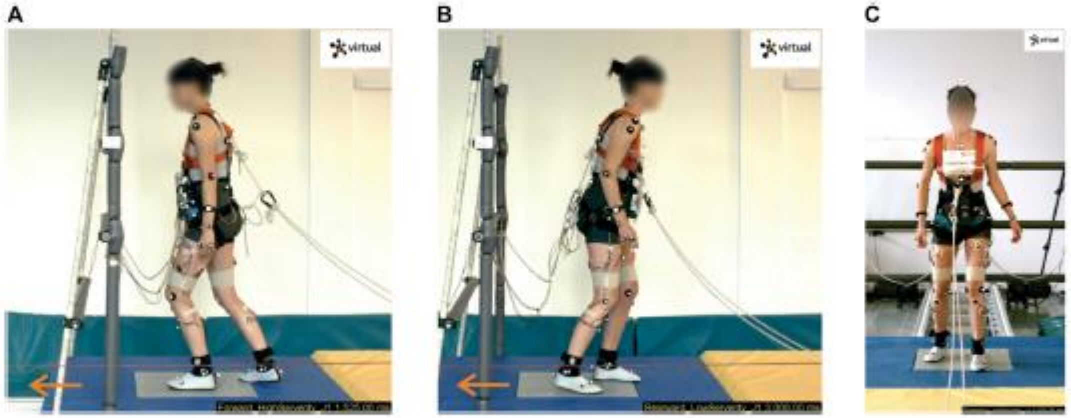


The Collision Problem: Limiting factor

- Bus Occupant injuries are frequent (61% of all casualties from GB collisions involving buses) but rarely fatal (0.1% fatal).
- Pedestrian casualties less frequent (15%) but much more commonly fatal (2.7% fatal)
- Class I/II bus occupants are unrestrained and may be standing
- More than 75% of bus occupant casualties come from incidents that did not involve an external impact
  - Braking, accelerating, cornering
  - Getting on and off, trips on steps
  - Falls due to alcohol and impairment
- Laboratory research suggests significant probability of passenger falls at c 1.5 m/s^2 acceleration

GB[1] Casualties (All severities)





Source: Krasna et al (2021) Frontiers in Bionengineering and Biotechnology

[1]Stats 19 2006-2015

Evening City Metro

Monday, 2nd June 2025

FATAL BUS BRAKE MIX-UP

By Amy Hargreaves

Tragedy struck in Islington yesterday when a 79-year old pensioner, Eileen Carterton, died of injuries suffered when the 214 bus on which she was a passenger braked suddenly, throwing her to the floor.

Tech error

The bus was fitted with the 'Advanced Emergency Braking' (AEB) system now standard across new London buses. According to driver, Ashley Andrews, 29, the system, which is meant to prevent collisions with other road users, caused the vehicle to perform an emergency braking manoeuvre for no apparent reason.

Screaming

Andrews was aghast at the incident stating "I've heard rumours of this but it has never happened to me before - I was driving along normally and suddenly the brakes slammed full on. All hell broke loose and there was screaming from the passengers."

CCTV footage from the incident shows passengers being unseated and falling as the bus lurched to a dramatic halt

CCTV image from the 214 bus as it braked wildly

Safety

A spokesperson for TfL said "Our deepest sympathies go to the family and friends of Mrs Carterton. Safety is our top priority and we are engaged in the world's most extensive programme of measures to ensure London's buses are as safe as possible. We will be conducting a full investigation into this tragic incident to learn lessons and improve our services"

No-one from the Metropolitan Police was available for comment.

Evening City Metro

Monday, 2nd June 2025

ELLIE, 2, "VICTIM OF COMPROMISE"

By Amy Hargreaves

Scene of the crash near Alexandra Palace

Tragedy struck near Alexandra Palace yesterday when 5-year old child, Ellie Carterton, died of injuries suffered when she stepped off the kerb chasing a ball and was hit by the 184 bus.

Tech error

The bus was fitted with the 'Advanced Emergency Braking' (AEB) system now standard across new London buses. According to driver, Ashley Andrews, 29, the system, which is meant to prevent collisions with other road users, did not brake hard enough to avoid the child.

Shock

Andrews was aghast at the incident stating "I was just checking my mirrors and the child came out of nowhere. The bus braked automatically before I could react but didn't seem to do enough. I stood on the brakes as soon as I could but it was already too late."

Safety

A spokesperson for TfL said "Our deepest sympathies go to the family of Ellie Carterton. Safety is our top priority and we are engaged in the world's most extensive programme of measures to ensure London's buses are as safe as possible."

Tuning

Experts cast doubt on the cause of the crash. An independent crash investigator said "Bus passengers are the only vehicle occupants that are allowed not to wear seatbelts and even stand without holding on. The AEB has been deliberately de-tuned for passenger comfort, which compromises pedestrian safety and ultimately contributed to this tragic loss of life."

Advanced Emergency Braking (AEB): Areas of investigation

		Does the system activate?	
		Yes	No
Will a collision happen without AEB intervention?	Yes	True Positive (TP)	False Negative (FN)
	No	False Positive (FP)	True Negative (TN)

AEB activates when required

- Benefit of collision avoidance or mitigation
- Cannot brake harder than the best human driver
- Drivers don't always max brakes
- Risk to bus occupants from heavier braking in some cases

AEB activates when NOT required

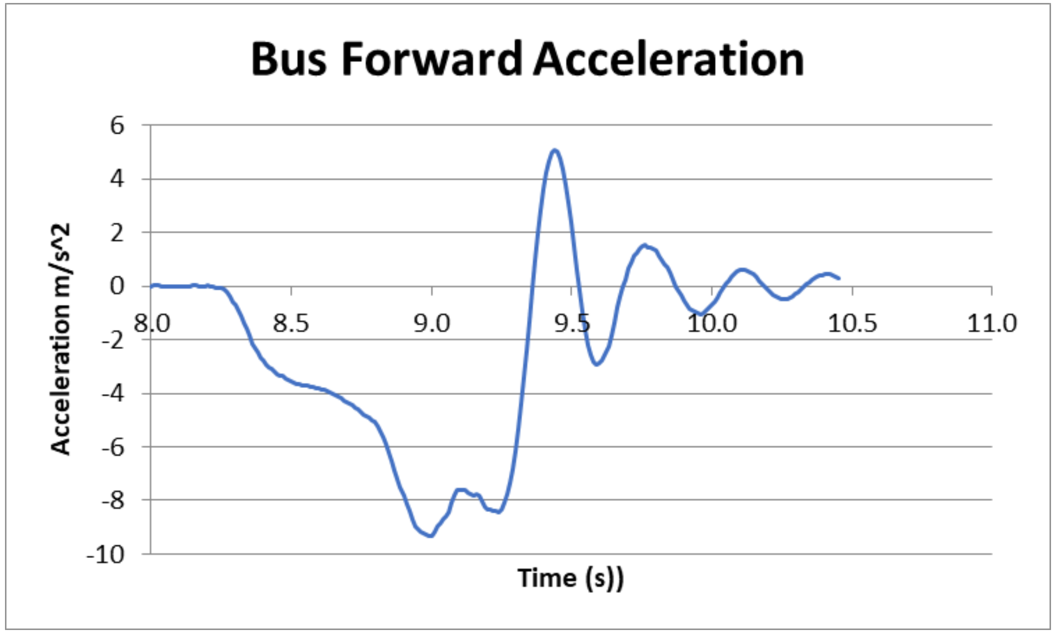
- Risk to bus occupants from braking

AEB does not activate

- No casualty savings
- No additional risk to bus occupants
- As if AEB not fitted
- Driver always in charge so remains liable for shortcomings

AEB: True Positive Benefit

- Prototype bus supplied by a UK manufacturer working with a major tier 1 ADAS supplier
- Tested to adapted Euro NCAP protocols, measurements via OXTS IMU
- Only small set of results published due to confidentiality
- Acceleration trace shown is a typical example of the response in an urgent pedestrian test



AEB: True Positive Benefit

- In-Depth collision data (Fatals/CCTV)
- Case by case review and reconstruction of actual driver applied response
- Recalculation of collision speed if AEB was present
  - Based on track test results
- Results applied to STATS19 for London

• Avoidance

Daytime – Adult Nearside 75%

AEB: True Positive Benefit

- In-Depth collision data (Fatals/CCTV)
- Case by case review and reconstruction of actual driver applied response
- Recalculation of collision speed if AEB was present
  - Based on track test results
- Results applied to STATS19 for London
- Estimate up to 25% pedestrian fatality reduction

- Mitigate

Daytime – Adult Nearside 25%

AEB: True Positive Risk

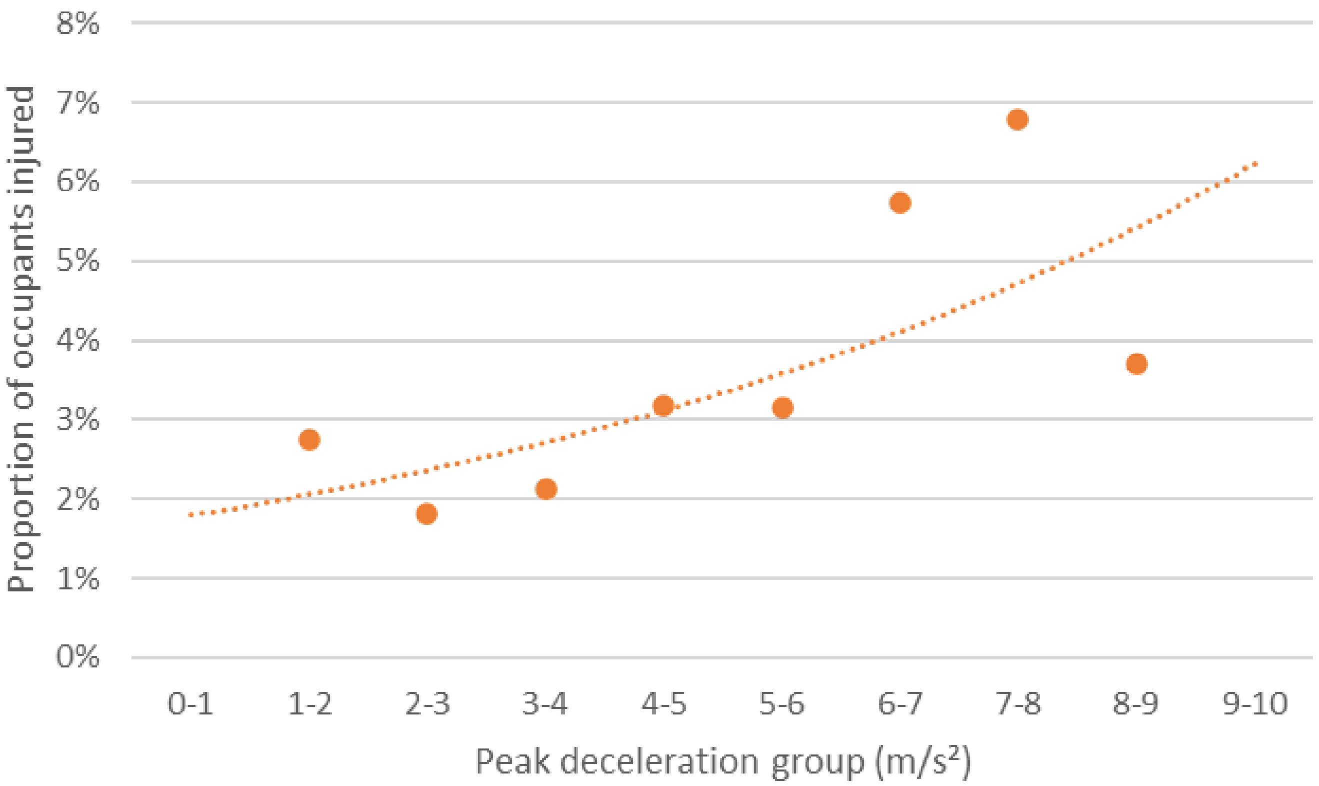
% passengers on board injured in braking incidents (on-board CCTV)

Actual driver deceleration observed in collisions (on-board CCTV)

Estimate change in deceleration due to AEB

Assume all collisions had average occupancy (19)

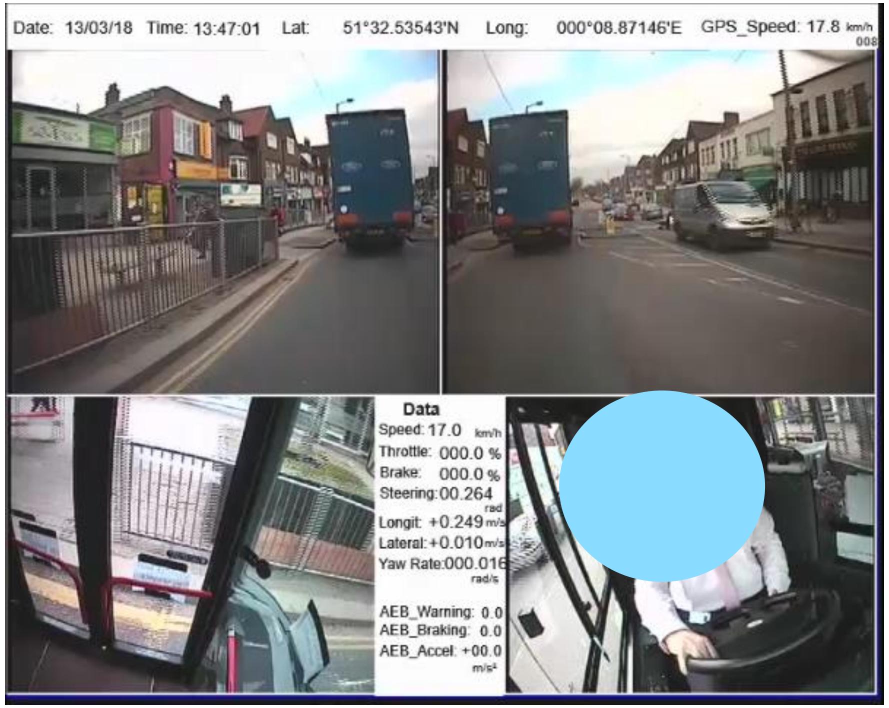
Estimate additional number injured due to harder braking by AEB



Group	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Number of Cases	0	29	45	48	38	36	41	41	21	2

AEB: Characterising false positives

- Prototype bus had not yet been tuned to eliminate false positives
- 400km road trial on real London bus routes, with real drivers but not in service
- AEB activation made available via CAN but not connected to brakes
- Identified characteristics to inform development of false positive tests – **frequency of false positive not representative of developed system**



AEB: Modelling false positive risk

N° braking events/km (Naturalistic driving)

London bus vehicle km (490million bus km/yr)

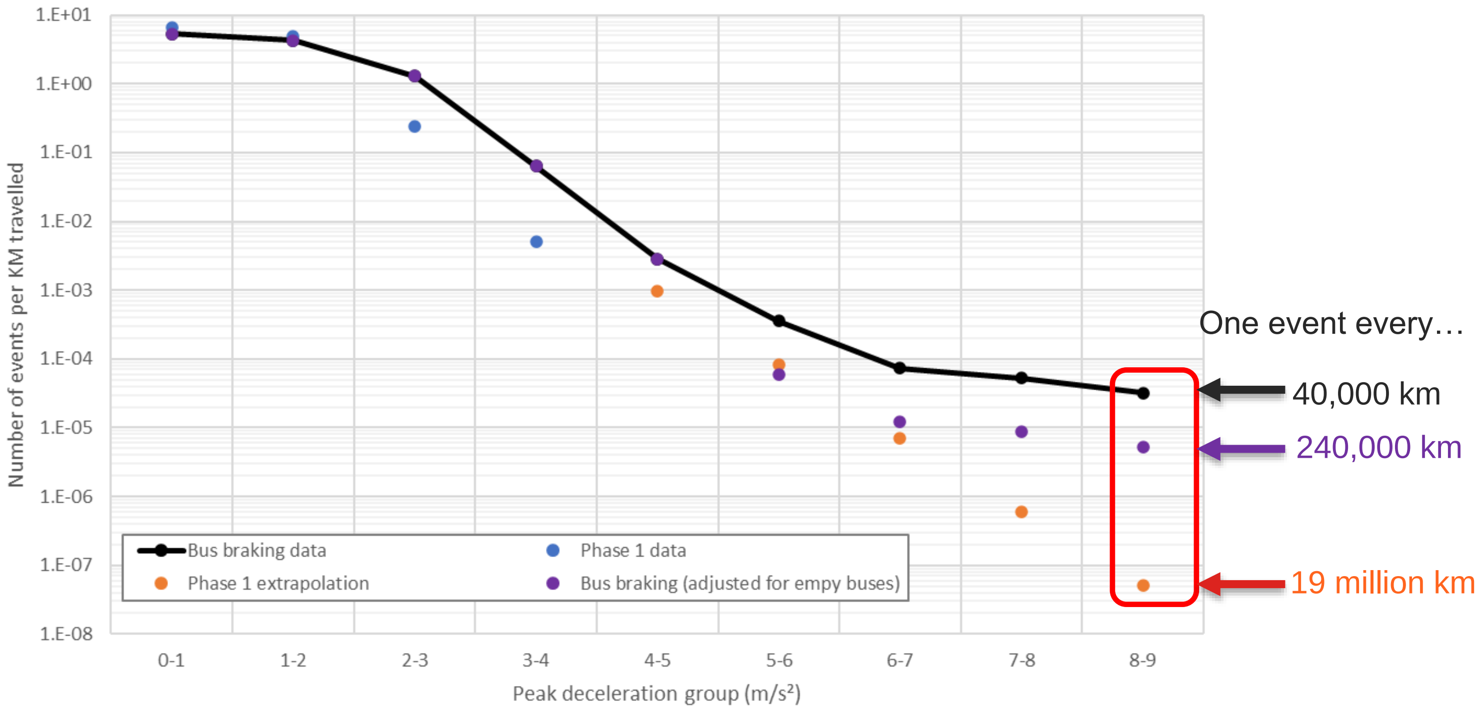
Brake events/yr by decel

% passenger falls by decel (on-board CCTV)

N° passenger falls per brake application by decel

Distribution of AEB false positive by decel (road trial)

London bus casualties per year from AEB False Positive



- 2018 phase 1 data (orange) extrapolated from 400km road trial – 2021 study shows not valid
- Black line from 1m+ bus km in real service
- Braking of 1-2 m/s^2 happen around 4 times per km (> 1billion events/year). If fall risk were as high as lab studies suggest, total fall numbers would be huge
- Reviewing sample of real heavy brake activations showed high proportion occurred with empty bus – analyses proceeded on basis of excluding these (purple)

AEB: Modelling false positive risk

N° braking events/km (Naturalistic driving)

London bus vehicle km (490million bus km/yr)

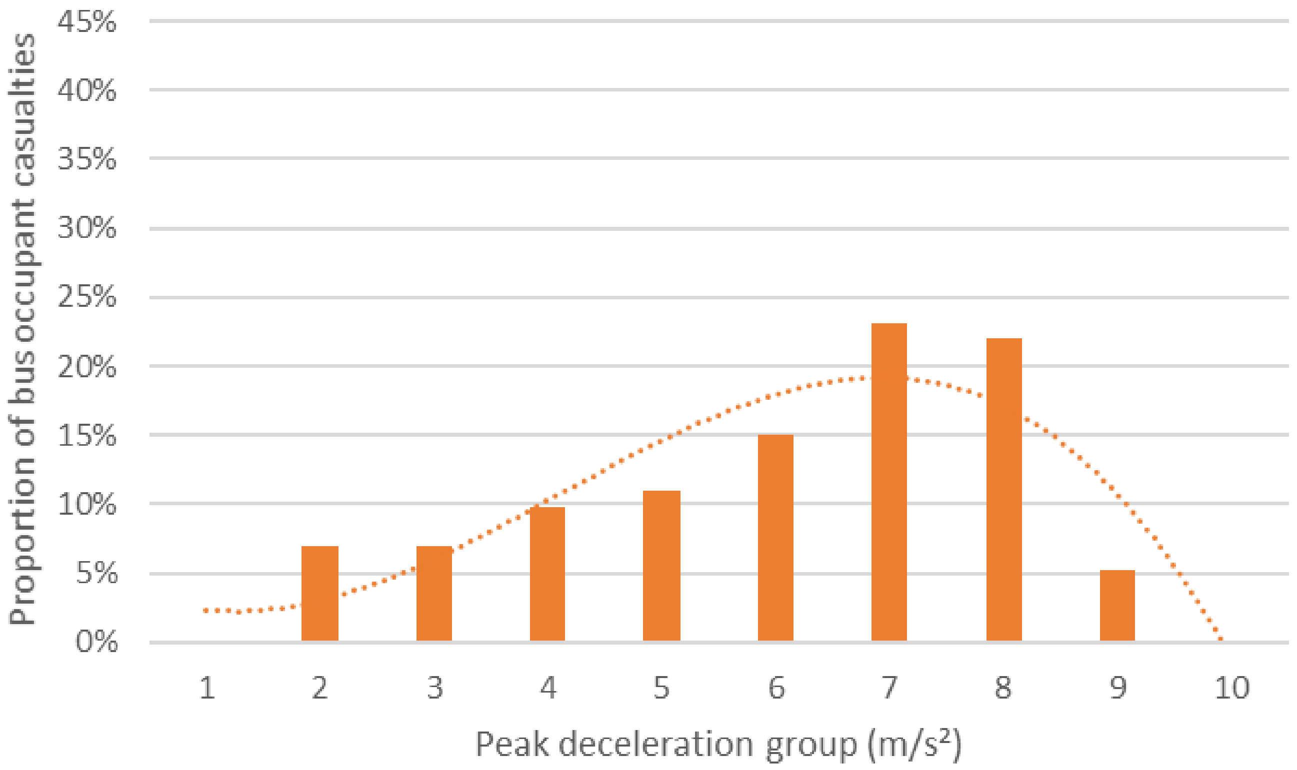
Brake events/yr by decel

% passenger falls by decel (on-board CCTV)

N° passenger falls per brake application by decel

Distribution of AEB false positive by decel (road trial)

London bus casualties per year from AEB False Positive



- Only a small proportion of bus occupant falls under braking occur at the low levels of deceleration simulated in lab studies. Most involve higher peak deceleration

AEB: Modelling false positive risk

N° braking events/km (Naturalistic driving)

London bus vehicle km (490million bus km/yr)

↓

Brake events/yr by decel

% passenger falls by decel (on-board CCTV)

↓

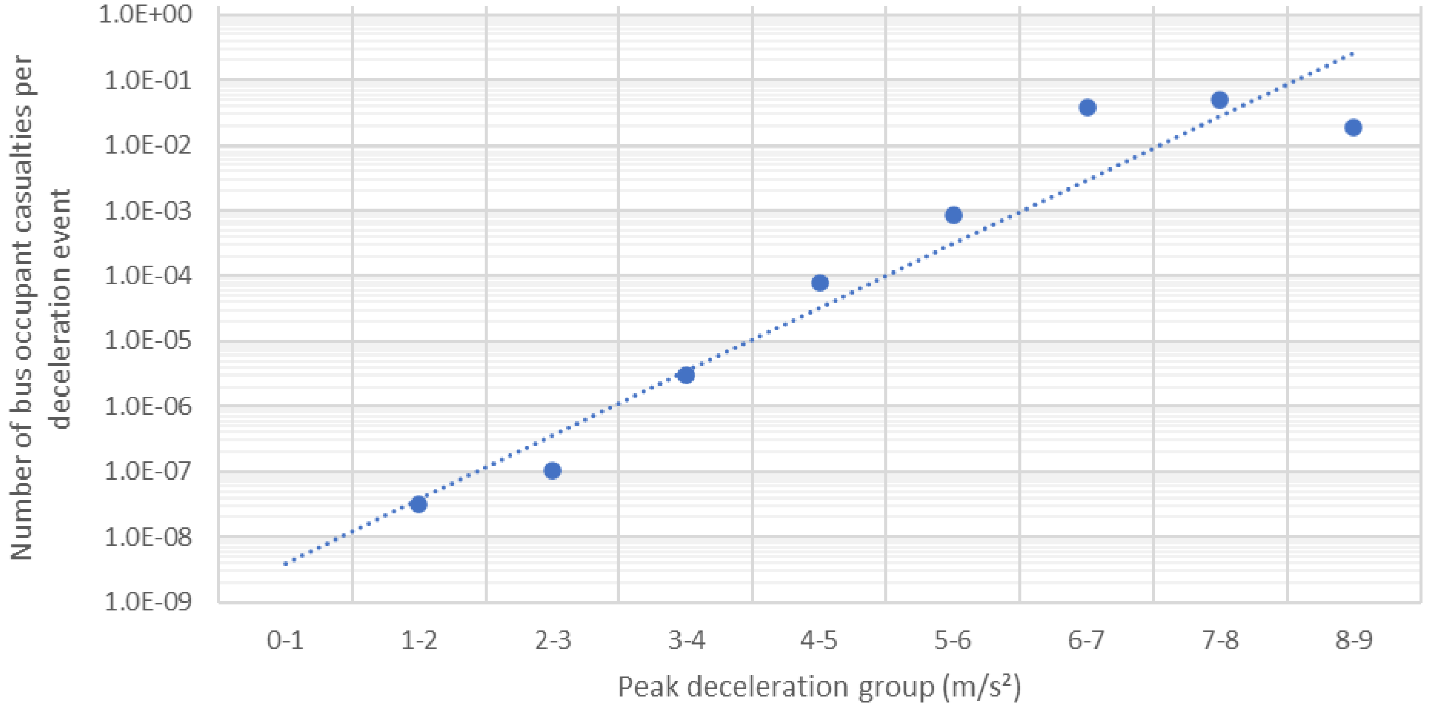
N° passenger falls per brake application by decel

Distribution of AEB false positive by decel (road trial)

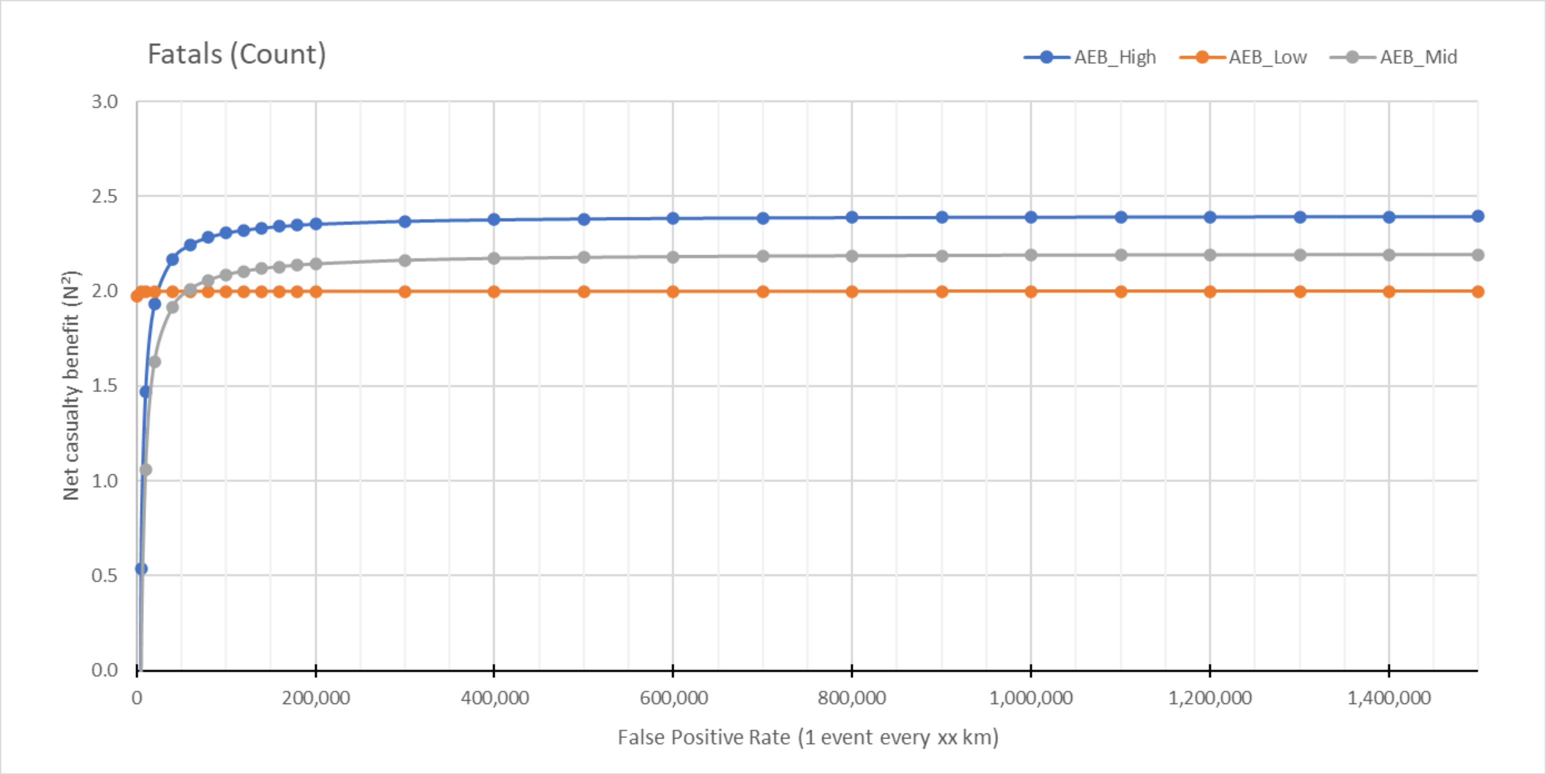
↓

London bus casualties per year from AEB False Positive

- Emergency Braking (6 m/s^2+ peak decel) calculated to produce 1 bus passenger casualty (0.1% fatal) once every 20 to 50 events
- **Note Log scale**: casualties per check brake (1-2 m/s^2) once every 31 million events

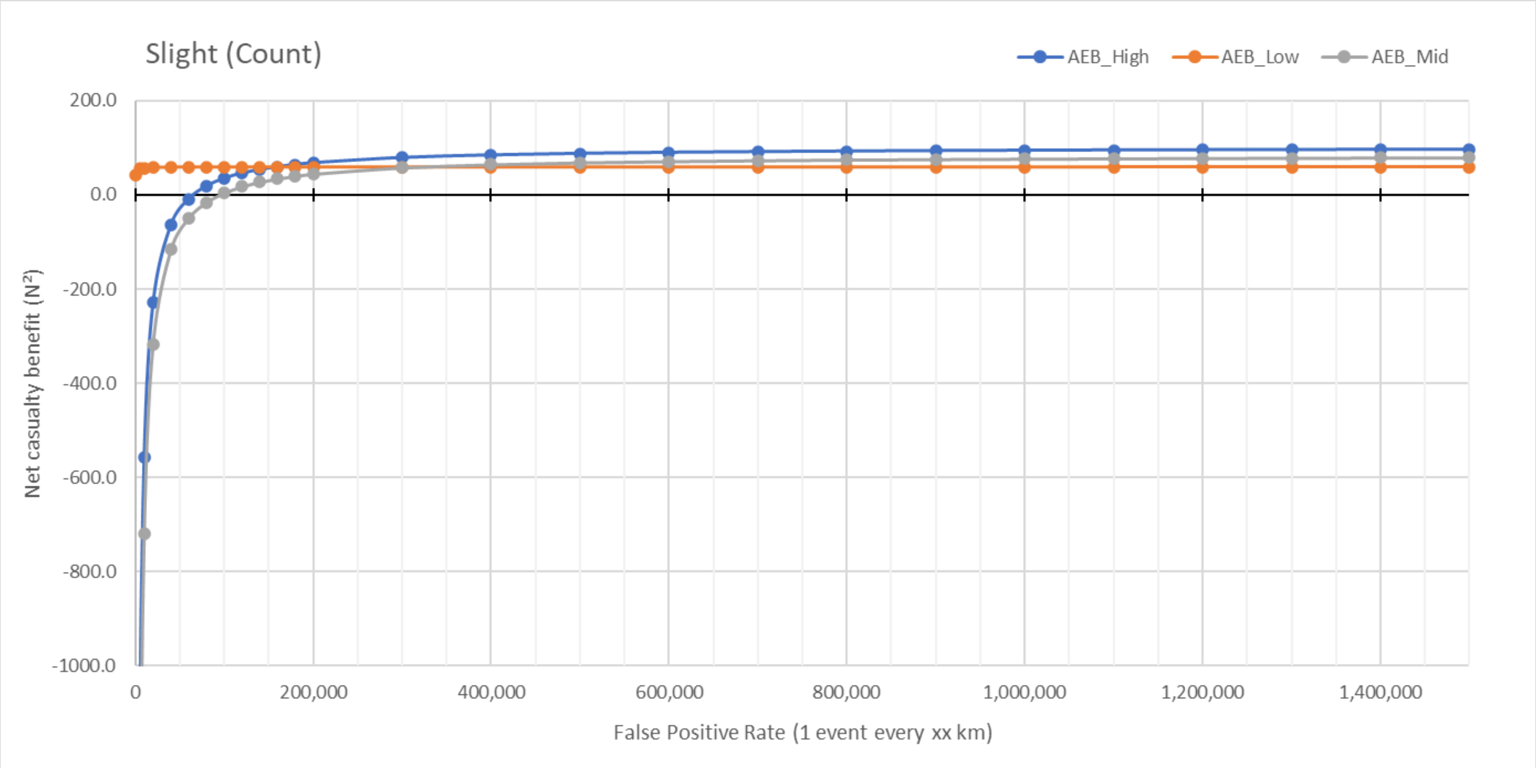


AEB: Net result of risk analysis



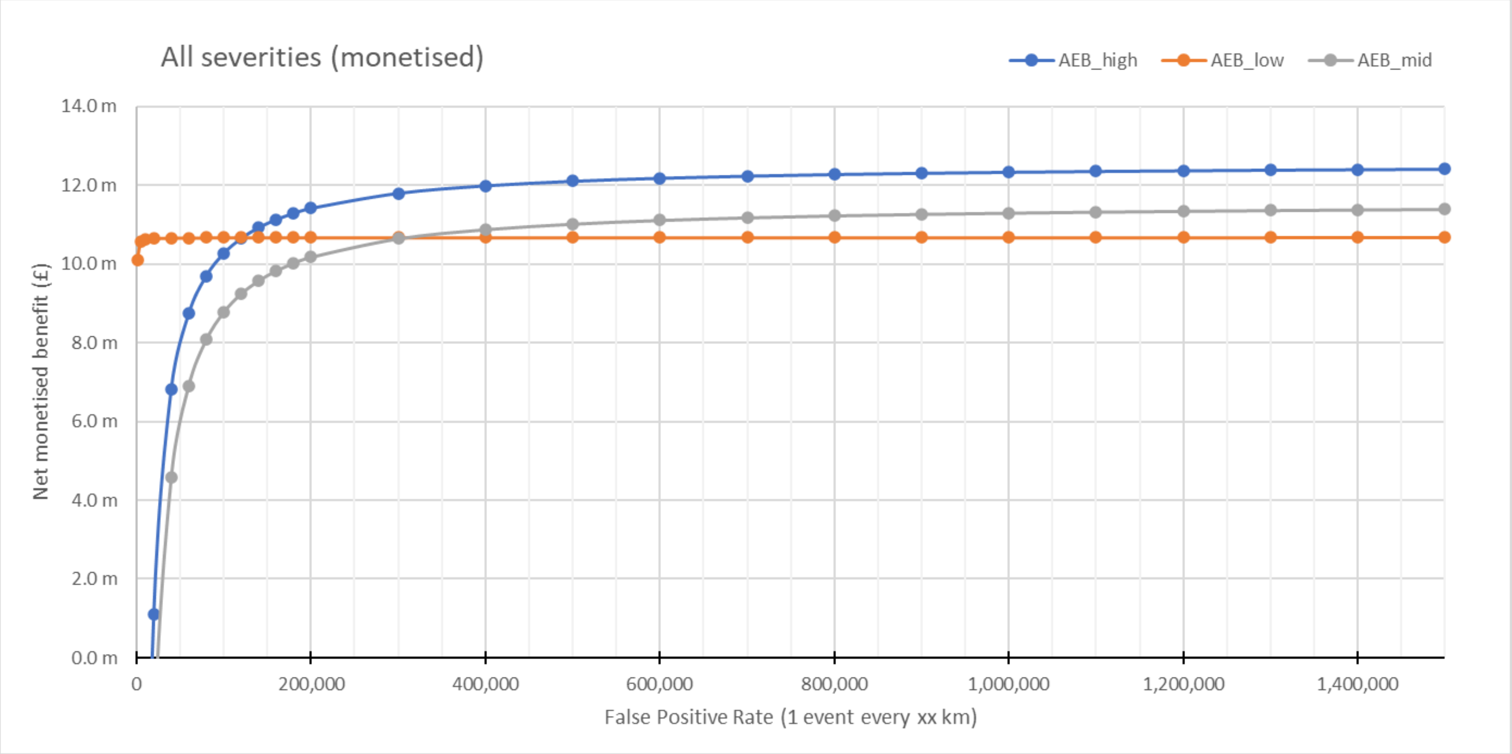
- AEB High based on prototype (max braking). Mid capped to 7 m/s^2, low to 5 m/s^2
- Based on consideration of fatalities only, net benefit almost always positive regardless of false positive rate
- Max braking the best strategy at false positive rates better than one every 20,000 bus km
- Prototype manufacturer expected to be able to offer false positive rate better than one every 600,000km

AEB: Net result of risk analysis



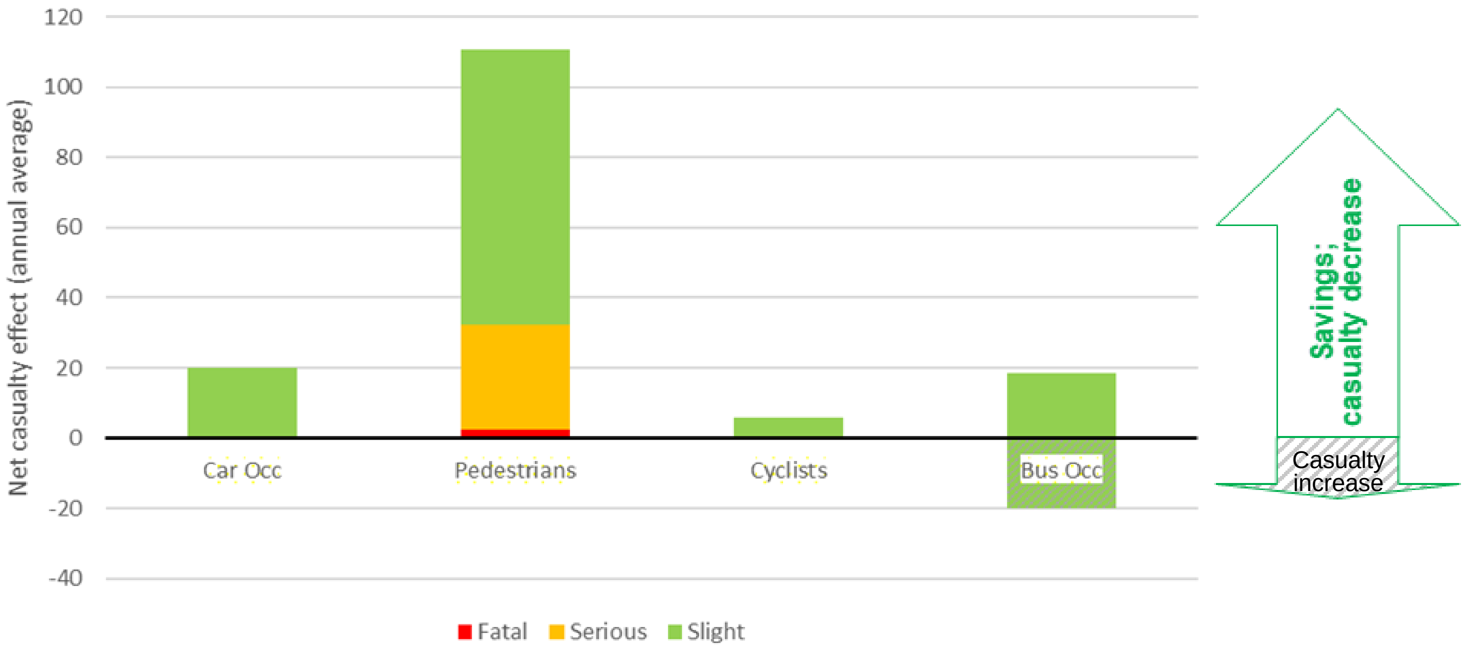
- Note: Negative benefit = disbenefit or increased risk
- Based on consideration of slight injuries only, then net adverse effects are possible for higher decel systems at false positive rates worse than around one every 60,000 to 100,000 bus km
- Capping to 5 m/s^2 max braking is a better strategy when false positives are frequent but not when they are rare

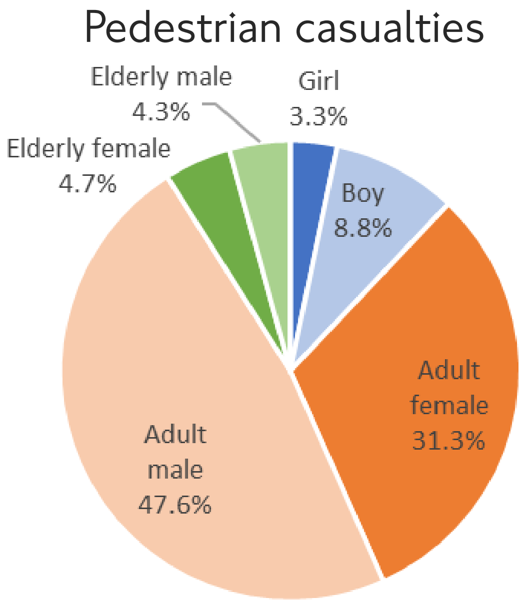
AEB: Net result of risk analysis

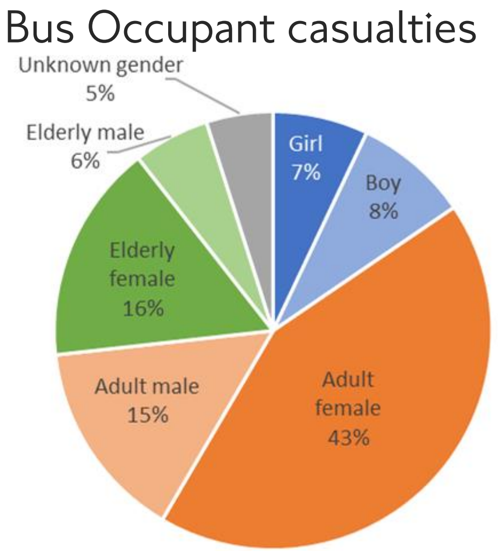


- Monetised (all severities) is (fatal numbers*casualty prevention value of fatal)+(serious numbers*casualty value) etc.
- Always a positive financial saving at false positive rates better than one every 20,000 bus km
- Max braking the best strategy at false positive rates better than one every 140,000 bus km

AEB: Analysis by road user group





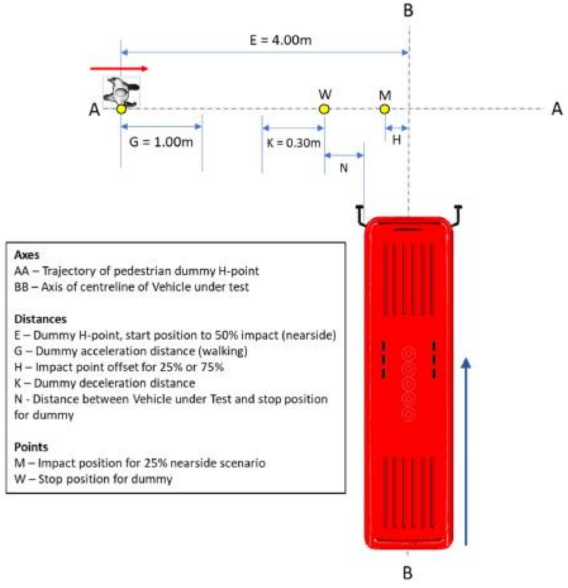


- Bus occupants benefit from avoiding collision with vehicles but suffer disbenefit in collision with VRUs
- Strong net benefit masks some disbenefit to bus occupants
    - Shifts risks from severe to minor but also from young adult male to elderly and female

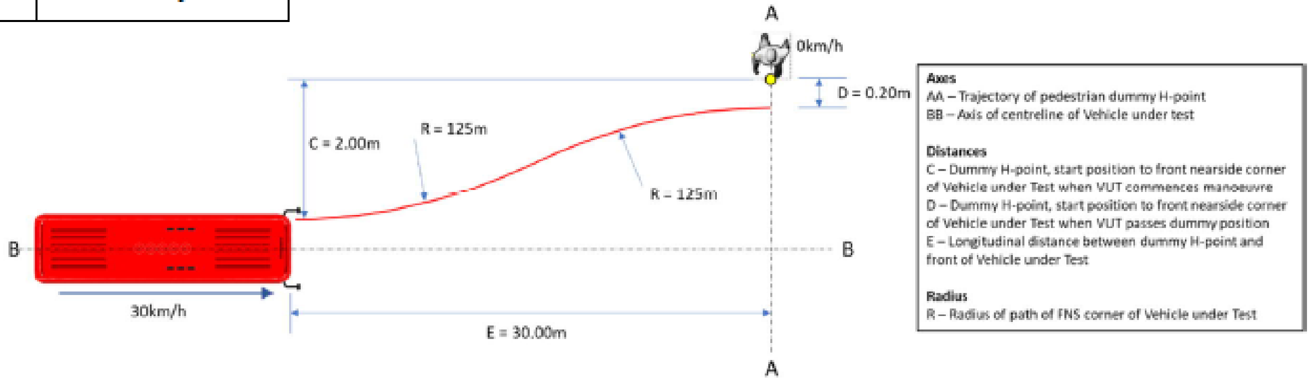
AEB: Test procedure

- Test procedure has been developed based on adaptation of Euro NCAP protocols (continuous rating not minimum standard) accounting for different collision patterns & system limits to car
  - Bus front to rear, stationary target (no moving test) 10- 50 km/h
  - Bus to Pedestrian Crossing

	Test Scenario			
	BPFA-50	BPNA-25	BPNA-75	BPNC-50
VUT speed (V_{TEST_VUT})	20 – 45 km/h			
TT speed (V_{TEST_TT})	8 km/h	5 km/h		
Impact location (VUT)	50%	25%	75%	50%
Lighting conditions	Day	Day & Night		Day



  - Bus to bicyclist longitudinal
  - False Positives
    - Aborted Crossing (rating not pass fail)
    - Bus stop test (pass fail test)



Conclusions

- Original R131 group correct to conclude benefit uncertain for AEB V2V on class I/II buses
- Pedestrians commonly killed or seriously injured in collisions involving city buses, addition of pedestrian functionality transforms the benefit (predicted 25% fatality reduction)
- Strong net benefit now predicted regardless of system characteristics or choice of casualty measure **IF** systems suffer fewer false positives than one every 140,000 bus km
- Worse false positive rates can be considered (possibly as often as one in 20,000 bus km) if the focus is on severe injury or if system deceleration is limited but both approaches may have ethics considerations
- No test information on actual false positive rate achievable in practice. A tier one supplier involved in the work expected to perform better than one in 600,000
- Class I/II true positive requirements could be added to existing draft text very easily
- Consideration may be needed as to whether false positive tests in draft regulation covers the city bus risks identified in the research but, if not, draft test protocol does exist.