TRL THE FUTURE OF TRANSPORT

Study on Enhanced Truck Front End Designs (TFEDs)

Safety Benefits for Vulnerable Road Users (VRUs)

GRSG-VRU-Proxi-02

Dr Phil Martin

4th July 2017

Presentation Agenda

Presentation Agenda

- About TRL
- Research Rationale
- Research Approach
- Cost-Effectiveness of Individual Safety Measures
- Cost-Effectiveness of Clustered Safety Measures
- Primary Active Safety Measures
- Regulatory Considerations
- Conclusions

About TRL

About TRL

Vision

World leader in creating the future of transport and mobility, using evidence-based solutions and innovative thinking

320

engineers, scientists, psychologists, IT experts and statisticians

Providing world-leading research, technology and software solutions for surface transport modes and the related markets of automotive, motorsport, insurance and energy

Mission

Challenge and influence our chosen markets, driving sustained reductions (ultimately to zero) in:

- Fatalities and serious injuries
- Harmful emissions
- Barriers to inclusive mobility
- Unforeseen delays
- Cost inefficiencies

1000 clients in

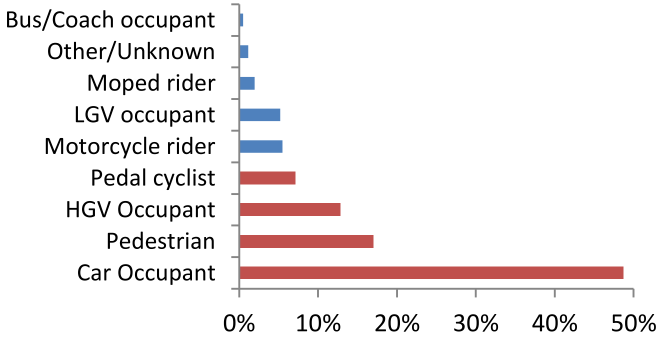
145 countries

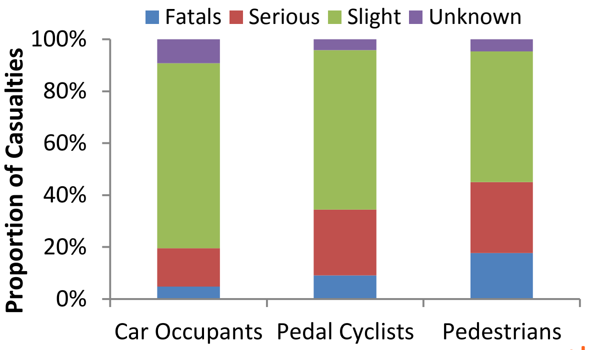
Research Rationale

Research Rationale

A European Road Safety Problem

- Over 3,850 reported road fatalities and 36,700 injuries due to HGVs (CARE database)
  - Passenger car occupants most frequently involved
  - Pedestrians/pedal cyclists next most common casualty
- Pedestrians/pedal cyclists at greater risk of more severe injuries during collisions with HGVs
  - Pedestrians have highest proportion of serious/fatal injuries
  - Car occupants have highest proportion of slight injuries





Research Rationale

The Research Context

- Current EU regulations encourage cab-over-engine HGVs
  - Maximisation of loading space within dimensions permitted by Council Directive 96/53/EC for N2/N3 vehicles
  - Sub-optimal safety performance of design per HGV-km travelled
- Directive (EU) 2015/719 provides HGV cab length derogations
  - Permits manufacturers to extend cab if new design improves the:
    - Safety of the HGV for other road users
    - Driver comfort
    - Aerodynamic efficiency of the HGV
  - HGVs designed with ***enhanced truck front-end designs (TFEDs)***
  - HGV safety to focus on better VRU detection and mitigating injuries caused to VRUs and passenger car occupants
- Holistic approach proposed for focussing on improving HGV safety
  - Cost-effective clustering of 5 safety measures to optimise benefits & costs

Research Rationale

Aims & Objectives

- Support technical requirements for Directive (EU) 2015/719
  - Specifically enhancing VRU and car occupant safety through enhanced TFEDs
- Five key objectives were outlined:
  1. A state-of-the-art review of exemplar and conceptual enhanced TFEDs
  2. A systematic review and critical appraisal of EU accidentology literature to establish target population data relevant to each safety measure
  3. A systematic review and critical appraisal of EU research literature to establish the effectiveness and costs of specific technological solutions relevant to each safety measure
  4. An analysis of safety measure clustering strategies to determine and prioritise the most cost-effective combination of safety measures
  5. An outline of the considerations for regulating the minimum performance requirements for each potential safety measure

Research Approach

Research Approach

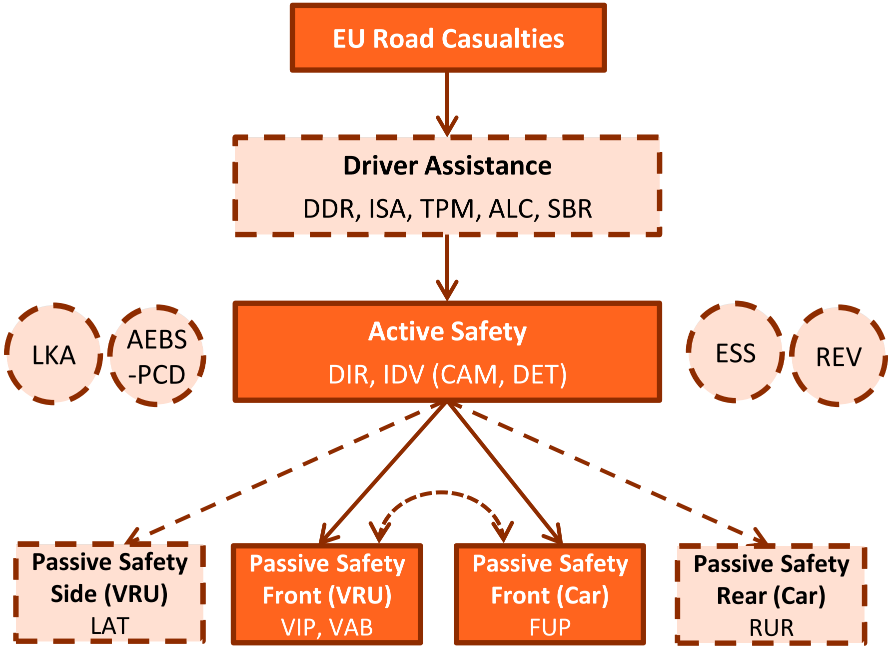
The Safety Measures

- Five safety measures proposed by the EC considered by this project:
  - Direct Vision [DIR]
    - Field of vision available to driver for directly observing/detecting the presence of “at risk” VRUs
  - Indirect Vision [IDV]
    - Field of vision available to driver via an assistive device for indirectly observing/detecting the presence of “at risk” VRUs
    - Limited to passive camera (CAM] and short-range sensor-based detection [DET] systems
  - Vulnerable Road User Impact Protection [VIP]
    - Structural components at the HGV front end that optimises VRU opponent compatibility and prevents run over events
  - Front Underrun Protection [VIP]
    - Structural components at the HGV front end that optimises passenger car opponent compatibility, prevents underrun events and ensures the occupant survival space
  - Vulnerable Road User Airbag [VAB]
    - Device that detects/predicts the occurrence of a VRU collision to trigger and deploy an external airbag
  - The potential effects of primary active safety systems also summarised

Research Approach

Safety Measure Clustering Approach

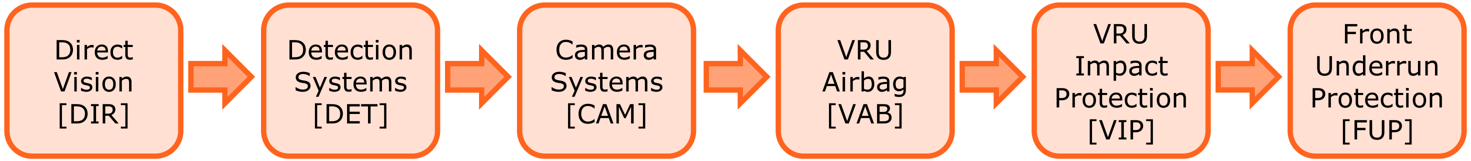
- Clustering based on GSR2 proposed approach
- Each cluster organised into three 'layers'
  - Driver assistance
    - Permanent/continuous collision prevention
  - Active safety
    - Mitigation immediately pre-collision
  - Passive safety
    - Protection during collision phase
- Interactions between five safety measures shown in dark orange boxes
  - Light orange boxes highlight additional safety measures to be reviewed by GSR2
  - Interactions expected between and within layers



Research Approach

Safety Measure Clustering Approach

- Clustering of casualty saving benefits
  - Safety measure interactions prioritised based on intervention during the collision phase
  - Clustering approach:
    - Determine initial target population
    - Estimate casualty saving benefits for highest priority safety measure in cluster
    - Remove prevented casualties from target population for second highest priority safety measure
    - Estimate casualty saving benefits for second highest priority safety measure in cluster
    - Repeat until all safety measures assessed and sum all prevented casualties
  - Approach performed for each target population (pedestrians, pedal cyclists and car occupants) and each injury severity level (fatal and serious injuries)



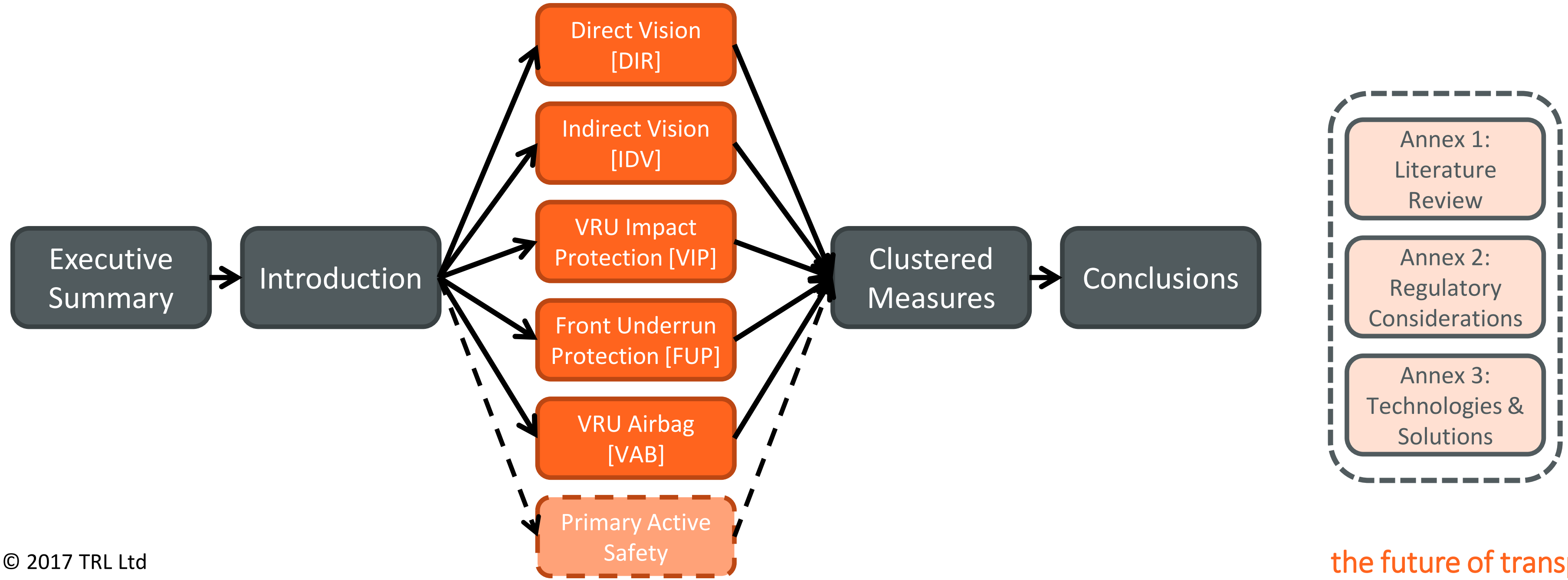
Research Approach

Safety Measure Clustering Approach

- Clustering of costs
  - Based on potential for sharing of critical components or significant amounts of design/manufacture time
  - Two cost clusters identified from 5 safety measures:
    - **Truck front-end redesign costs –** shared between direct vision, VRU impact protection and front underrun protection
    - **Sharing of camera sensor systems –** shared between camera and sensor-based detection systems
  - Assumptions for fixed costs vs. variable costs
    - Fixed costs: costs always incurred by safety measure regardless of clustering
    - Variable costs: costs that are shared between clustered safety measures through mutual use of parts/sharing of costs
    - Assumed 50% fixed costs and 50% variable costs, *stronger evidence required to underpin these cost assumptions*
  - Clustering approach:
    - For each cluster determine which safety measures can be clustered for costs
    - If no cost clusters can be established: no cost saving benefit possible
    - If cost clusters combine 2 safety measures: clustered costs are 75% of sum costs of both safety measures
    - If cost clusters combine 3 safety measures: clustered costs are 66% of sum costs of all three safety measures

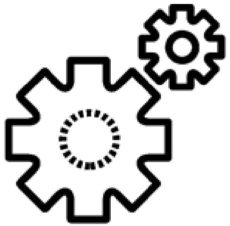
Research Approach

Reporting Structure & Outcomes



Research Approach

Summary Report Structure



Technical Considerations

- Background on Safety Measure
- Opportunities for Enhanced TFEDs
- Possible Overlaps in Benefits & Technology

Potential Effects of Regulation

- Target Population
- Estimates of Effectiveness
- Cost Implications
- Cost Effectiveness Summary
- Assessment of Evidence

Regulatory Considerations

- Regulatory Considerations

Research Approach

Cost-Effectiveness Analysis

- Evaluation of outcomes
  - Target population
  - Effectiveness
  - Costs/vehicle
  - Total fleet costs
  - Casualty reduction benefits
  - Monetised casualty benefits
  - Break-even costs/vehicle
  - Benefit-cost ratios
- Assessing the effects of differentiated market uptake
  - Rationale:
    - Manufacturers of long-haulage solutions more incentivised to apply for cab length derogations
    - May mean that a greater proportion of articulated HGVs adopting enhanced TFEDs
    - Articulated HGVs have significant differences between proportion of EU parc and involvement in collisions
  - Method:
    - Results calculated for 2 approaches for assessing the effects of different market uptake assumptions:
      - **Uniform market uptake:** enhanced TFEDs adopted uniformly across all HGV applications and vehicle types
      - **Differentiated market uptake:** enhanced TFEDs adopted only by articulated HGV types
    - Differentiated approach outcomes normalised by:
      - Proportion of articulated HGVs in EU parc (57%) – data from Eurostat/ANFAC report
      - Proportion of collisions involving articulated HGVs (~30% pedestrians/cyclists, ~50% car occupants) – estimated based on Bálint *et al*. (2014) and confirmed with Stats19 data

Cost-Effectiveness of Individual Safety Measures

Cost-Effectiveness of Individual Safety Measures

Direct Vision [DIR]

- **Target Population**
  - VRUs involved in collisions where HGV was moving off, turning to nearside and turning to offside
- **Overall Effectiveness**
  - Difference in performance between traditional cab designs and low-entry cabs (LECs)
- **Technology Costs**
  - €400-600; *stronger evidence required to underpin these costs*

Outcome	Uniform	Differentiated
Casualty Benefits	**KSI:** Peds. 244-517, Cycl. 0-121	**KSI:** Peds. 73-155, Cycl. 0-36
Break Even Costs	€338-579	€176-302
Benefit-Cost Ratio	**0.56-1.45**	**0.29-0.76**

Cost-Effectiveness of Individual Safety Measures

Indirect Vision [IDV]: Cameras [CAM]

- **Target Population**
  - 360°: VRUs involved in collisions where HGV was moving off, turning to nearside/offside and sideswipe
  - Blind-Spot: VRUs involved in collisions where HGV was moving off and turning to nearside
- **Overall Effectiveness**
  - Estimates based upon range of driver reaction factors
- **Technology Costs**
  - 360° Camera: €264-565; Blind-Spot Camera: €151-188

Outcome	Uniform	Differentiated
Casualty Benefits	**360° KSI:** Peds. 60-224, Cycl. 55-223 **Blind-Spot KSI:** Peds. 10-92, Cycl. 10-97	**360° KSI:** Peds. 18-67, Cycl. 16-67 **Blind-Spot KSI:** Peds. 16-41, Cycl. 15-38
Break Even Costs	**360°:** €158-408 **Blind-Spot:** €26-183	**360°:** €82-213 **Blind-Spot:** €14-96
Benefit-Cost Ratio	**360°:** 0.28-1.55 **Blind-Spot:** 0.14-1.22	**360°:** 0.15-0.81 **Blind-Spot:** 0.07-0.63

Cost-Effectiveness of Individual Safety Measures

Indirect Vision [IDV]: Detection Systems [DET]

- **Target Population**
  - 360°: VRUs involved in collisions where HGV was moving off, turning to nearside/offside and sideswipe
  - Blind-Spot: VRUs involved in collisions where HGV was moving off and turning to nearside
- **Overall Effectiveness**
  - Estimates based upon range of driver reaction and sensor activation factors
- **Technology Costs**
  - 360° Detection System: €264-565; Blind-Spot Detection System: €392-573

Outcome	Uniform	Differentiated
Casualty Benefits	**360° KSI:** Peds. 130-241, Cycl. 131-214 **Blind-Spot KSI:** Peds. 107-164, Cycl. 94-157	**360° KSI:** Peds. 39-73, Cycl. 33-64 **Blind-Spot KSI:** Peds. 32-49, Cycl. 28-47
Break Even Costs	**360°:** €364-486 **Blind-Spot:** €302-363	**360°:** €190-254 **Blind-Spot:** €157-190
Benefit-Cost Ratio	**360°:** 0.64-1.24 **Blind-Spot:** 1.40-2.47	**360°:** 0.33-0.65 **Blind-Spot:** 0.73-1.29

Cost-Effectiveness of Individual Safety Measures

Vulnerable Road User Impact Protection [VIP]

- **Target Population**
  - VRUs involved in collisions with the front-end of HGVs
- **Overall Effectiveness**
  - Difference in performance between non-regulated TFEDs and TFEDs regulated to the best-in-class (1.0 m) and mid-range (0.5 m) levels of performance for front-end impact protection for VRUs
- **Technology Costs**
  - €400-600; *stronger evidence required to underpin these costs*

Outcome	Uniform	Differentiated
Casualty Benefits	**BIC KSI:** Peds. 347-529, Cycl. 149-226 **Mid KSI:** Peds. 214-353, Cycl. 92-152	**BIC KSI:** Peds. 104-158, Cycl. 45-68 **Mid KSI:** Peds. 65-106, Cycl. 28-45
Break Even Costs	**BIC:** €657-947 **Mid:** €406-631	**BIC:** €343-495 **Mid:** €212-330
Benefit-Cost Ratio	**BIC:** 1.10-2.37 **Mid:** 0.68-1.58	**BIC:** 0.57-1.24 **Mid:** 0.35-0.82

Cost-Effectiveness of Individual Safety Measures

Front Underrun Protection [FUP]

- **Target Population**
  - Passenger car occupants involved in head-on collisions with HGVs
- **Overall Effectiveness**
  - Difference in performance between non-regulated TFEDs and TFEDs regulated to the best-in-class (0.8 m) and mid-range (0.4 m) levels of performance for front underrun protection
- **Technology Costs**
  - €220-350

Outcome	Uniform	Differentiated
Casualty Benefits	**BIC KSI:** 738-1643 **Mid KSI:** 589-1463	**BIC KSI:** 372-828 **Mid KSI:** 297-737
Break Even Costs	**BIC:** €405-966 **Mid:** €295-762	**BIC:** €355-848 **Mid:** €259-669
Benefit-Cost Ratio	**BIC:** 1.16-4.39 **Mid:** 0.84-3.47	**BIC:** 1.01-3.85 **Mid:** 0.43-1.67

Cost-Effectiveness of Individual Safety Measures

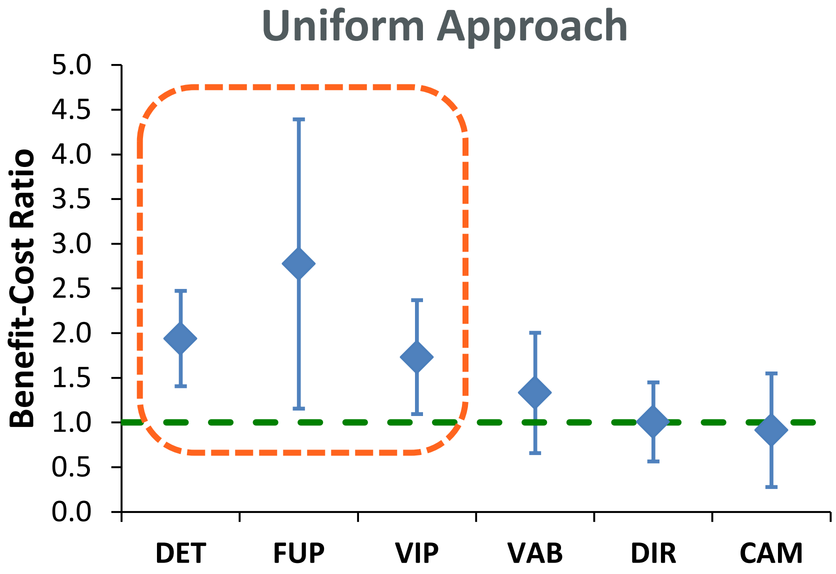
Vulnerable Road User Airbag [VAB]

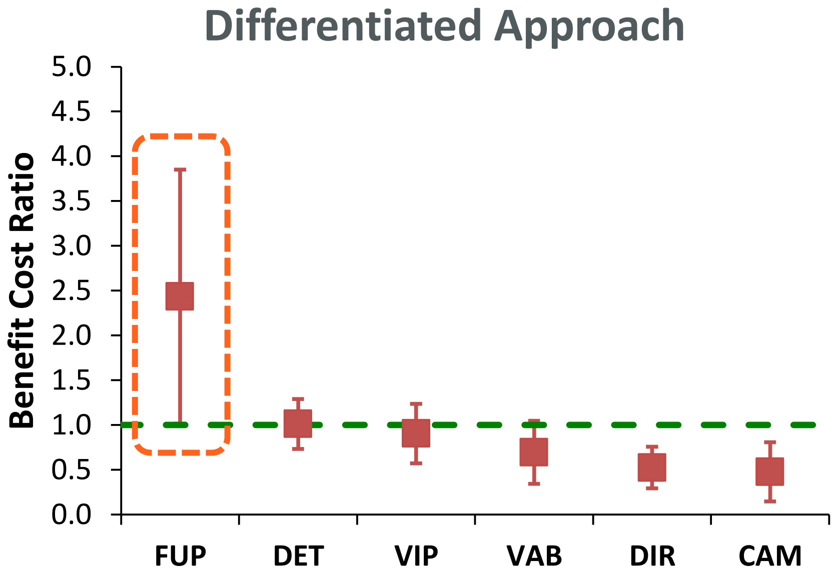
- **Target Population**
  - VRUs involved in collisions with the front-end of HGVs
- **Overall Effectiveness**
  - Combination of effectiveness values from GSR2 HED measure and estimated coverage factors, assumed 400 mm of head travel before impact
- **Technology Costs**
  - €170-340; *double the cost proposed in GSR2*

Outcome	Uniform	Differentiated
Casualty Benefits	**KSI:** Peds. 123-189, Cycl. 38-79	**KSI:** Peds. 37-56, Cycl. 11-23
Break Even Costs	€224-340	€117-178
Benefit-Cost Ratio	**0.66-2.00**	**0.34-1.05**

Cost-Effectiveness of Individual Safety Measures

Comparison of Individual Safety Measures

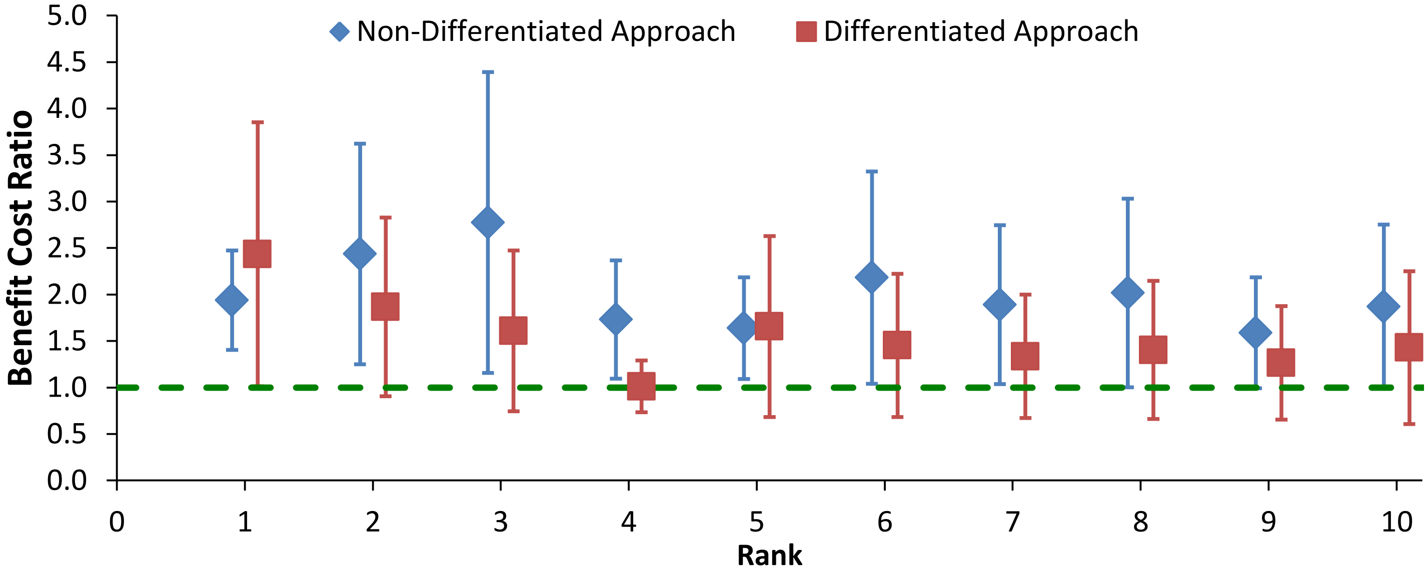




Cost-Effectiveness of Clustered Safety Measures

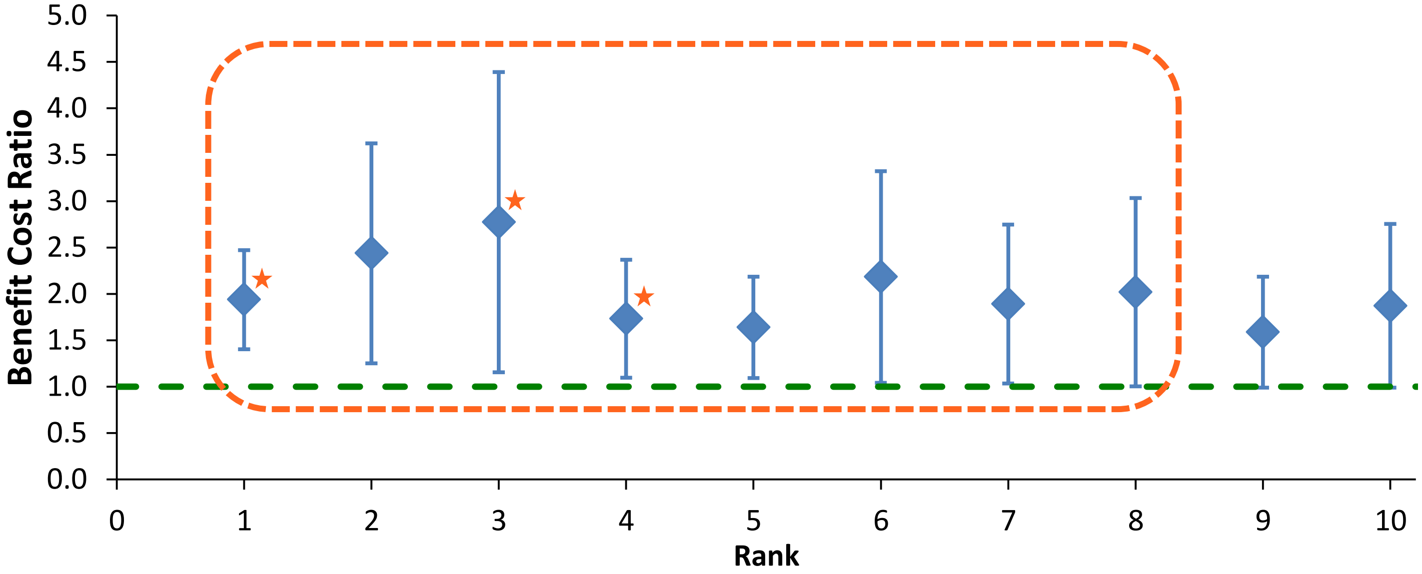
Cost-Effectiveness of Clustered Safety Measures

Comparison of Clustered Safety Measures



Cost-Effectiveness of Clustered Safety Measures

Comparison of Clustered Safety Measures: Uniform Approach



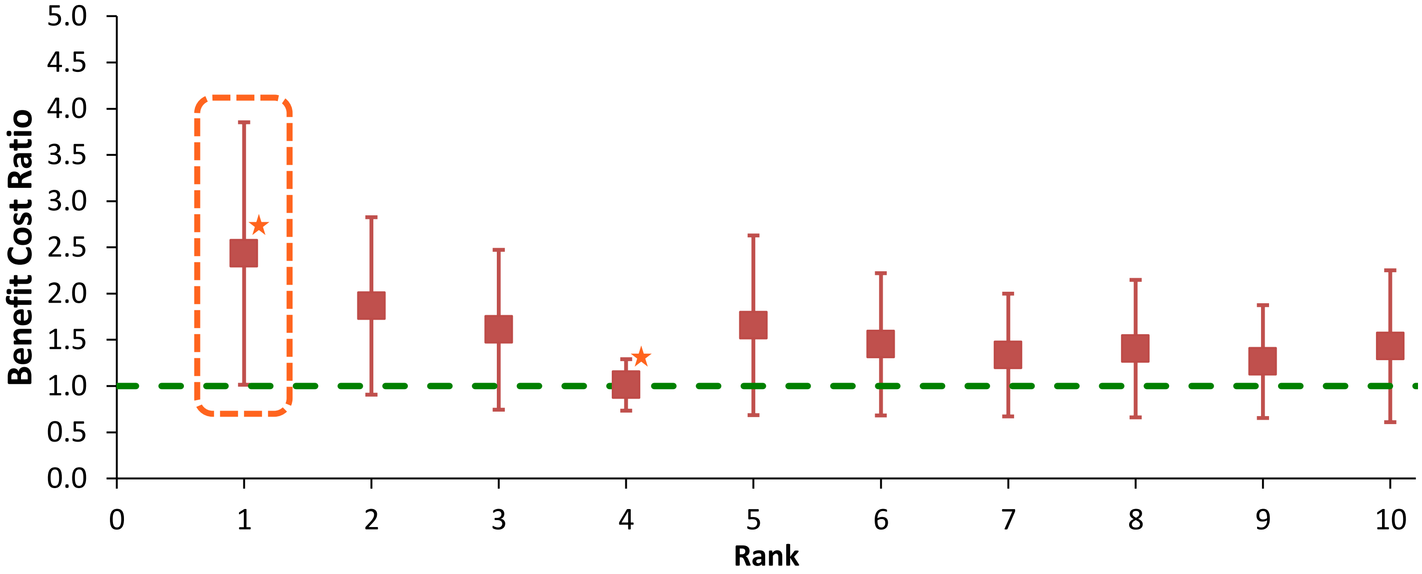
Cost-Effectiveness of Clustered Safety Measures

Comparison of Clustered Safety Measures: Uniform Approach

Rank	DIR	CAM	DET	VIP	FUP	VAB	Benefit-Cost Ratio
1			✓				1.40-2.47
2			✓		✓		1.25-3.62
3					✓		1.16-4.39
4				✓			1.10-2.37
5			✓	✓			1.09-2.19
6	✓				✓		1.04-3.32
7			✓	✓	✓		1.04-2.75
8			✓		✓	✓	1.00-3.03
9	✓		✓		✓		0.99-2.75
10	✓			✓			0.99-2.19

Cost-Effectiveness of Clustered Safety Measures

Comparison of Clustered Safety Measures: Differentiated Approach



Cost-Effectiveness of Clustered Safety Measures

Comparison of Clustered Safety Measures: Differentiated Approach

Rank	DIR	CAM	DET	VIP	FUP	VAB	Benefit-Cost Ratio
1					✓		1.01-3.85
2			✓		✓		0.91-2.83
3	✓				✓		0.75-2.47
4			✓				0.73-1.29
5					✓	✓	0.68-2.63
6			✓		✓	✓	0.68-2.22
7	✓		✓		✓		0.67-2.00
8				✓	✓		0.66-2.15
9	✓			✓	✓		0.65-1.88
10		✓	✓		✓		0.61-2.25

Primary Active Safety Measures

Primary Active Safety Measures

Overview of Potential Effects

- VRUs in crossing collisions
  - Autonomous Emergency Braking systems with pedestrian and cyclist functionality [AEB-PC]
    - May not be appropriate for all pedestrian/cyclist crossing collision, although a significant number still in scope
    - 1/3 collisions at speeds <40 km/h, 1/2 collisions impact nearside/offside corners of HGV, increased brake build up times
  - AEB-PC can compliment VIP/VAB safety measures for mitigating crossing collision injuries
- VRUs in close proximity manoeuvres
  - Turn Assist Systems [TAS] and low-speed AEBS-PC
    - TAS used to assist braking during low-speed turning manoeuvres (procedures under development by BASt/TfL)
    - Low-speed AEBS-PC used to assist braking during low-speed moving-off manoeuvres (<10 km/h)
  - TAS/low-speed AEBS-PC share target populations with DIR/CAM/DET, so could be more cost-effective
- Car/HGV occupants
  - Emergency Lane Keeping Assist [LKA] systems
    - May avoid/mitigate majority of head-on and run-off-road collisions caused by lane incursions
  - LKA systems share target populations with FUP safety measures

Regulatory Considerations

Regulatory Considerations

Direct Vision [DIR]

Relevant Regulations/Standards/Protocols

- HGV Direct Vision Standard (DVS) testing & assessment protocols
- Regulation 46: Indirect Vision

Potential Issues with Requirements

- HGV Direct Vision Standard
  - Curved face would result in areas around cab that wouldn't be regulated
  - No agreed minimum performance criteria (at time of drafting)
- Regulation 46
  - Curved face would result in areas around cab that wouldn't be regulated
  - Minimum requirements for area of direct visibility inappropriate as HGV will obstruct

Potential Updates to Requirements

- Adopt DVS approach – minimum % of zone (rating score) to be visible – encourages innovation
- Specify direct vision assessment zones to start 300 mm from outer profile of HGV

Regulatory Considerations

Indirect Vision [IDV]: Camera Systems [CAM]

Relevant Regulations/Standards/Protocols

- Regulation 46: Indirect Vision
- HGV Direct Vision Standard (DVS) testing & assessment protocols

Potential Issues with Requirements

- Regulation 46
  - Curved face would result in areas around cab that wouldn't be regulated
- HGV Direct Vision Standard
  - Could be integrated such that direct and indirect vision requirements addressed by same regulation
  - Current DVS assessment zones do not align with Regulation 46 zones

Potential Updates to Requirements

- Adopt combined DVS/R46 approach – minimum % of zone (rating score) around whole HGV
- Specify all assessment zones to start 300 mm from outer profile of HGV

Regulatory Considerations

Indirect Vision [IDV]: Detection Systems [DET]

Relevant Regulations/Standards/Protocols

- Turn Assist System (GRSG-109-19) testing & assessment protocols
- HGV Blind Spot Safety System (TfL) testing & assessment protocols

Potential Issues with Requirements

- Both testing & assessment protocols unreleased
- Both relevant to AEBS, but DET could use these protocols up to the braking requirements
- Expected that these will account for nearside turn collisions only (not moving off)

Potential Updates to Requirements

- Could update requirements to assist in moving off collisions
- Requirements for warning systems should be determined, but can possibly be taken from Regulation 130 (LDWS)

Regulatory Considerations

Vulnerable Road User Impact Protection [VIP]

Relevant Regulations/Standards/Protocols

- Heavy Vehicles Aggressivity Index (HVAI) testing & assessment protocols (APROSYS)
- Regulation 127: Pedestrian Safety

Potential Issues with Requirements

- Heavy Vehicles Aggressivity Index
  - Curved and inclined HGV faces likely to require different testing procedures
  - Different impact angles in real world during nearside turn collisions
  - Underrun testing locations will require redefining
- Regulation 127
  - Currently relevant to M1/N1 vehicles, test equipment and assessment criteria may be transferrable
  - Legform testing protocols may be adopted and adapted

Potential Updates to Requirements

- Adopt HVAI approach considering WADs for inclined faces, impact angles and legform tests

Regulatory Considerations

Front Underrun Protection [FUP]

Relevant Regulations/Standards/Protocols

- Regulation 93: Front Underrun Protection
- Regulation 29: Cab strength

Potential Issues with Requirements

- Regulation 93
  - Curved face would require updated testing procedures
  - Quasi-static testing only – not very relevant to high-energy absorbing FUPs
- Regulation 29
  - Current method assumes front pillar location at front of vehicle and no inclined face

Potential Updates to Requirements

- Regulation 93: Include MPDB tests for eaFUPs at a range of speeds dependent upon extension
- Regulation 29: Front pillar test may need to be adapted to account for different pillar locations

Regulatory Considerations

Vulnerable Road User Airbag [VAB]

Relevant Regulations/Standards/Protocols

- Heavy Vehicles Aggressivity Index (HVAI) testing & assessment protocols (APROSYS)
- Regulation 127: Pedestrian Safety

Potential Issues with Requirements

- Heavy Vehicles Aggressivity Index
  - Curved and inclined HGV faces likely to require different testing procedures
  - Different impact angles in real world during nearside turn collisions
  - Key difference from VIP measure: more stringent thresholds need defining for particular locations
- Regulation 127
  - Current relevant to M1 vehicles, test equipment and assessment criteria may be transferrable

Potential Updates to Requirements

- Adopt HVAI approach considering WADs for inclined faces, impact angles and legform tests
- Incorporate more stringent assessment thresholds for certain key protection zones (edges)

Conclusions

Conclusions

Conclusions

1. **First study to evaluate the cost-effectiveness of a range of clustered safety measures**
   - Six key safety measures investigated resulting in 63 unique safety measure clusters
   - Combined costs and benefits of each safety measure cluster calculated to estimate cost-effectiveness
   - Safety measures ranked in order of cost-effectiveness, with the top-ten safety measure clusters presented
2. **Market adoption of selected safety cluster critical in maximising cost-effectiveness**
   - Differentiated market adoption of safety measure clusters consistently less cost-effective than uniform market adoption across all HGV types
   - 8 cost-effective clusters for uniform adoption vs. 1 cost-effective cluster for differentiated adoption
3. **All reviewed safety measures can adapt existing regulations/protocols to base future safety requirements for Directive (EU) 2015/719**
   - HGV Direct Vision Standard; Regulation 46; Turn Assist System/HGV Blind Spot Safety System; Heavy Vehicles Aggressivity Index; Regulation 127; Regulation 93; Regulation 29.

Conclusions

Gaps in Available Evidence Base

1. **Target Population**
   - Based on collision scenarios involving traditional cab-over-engine HGV designs only – unknown if target populations will change with enhanced TFEDs
2. **Technology effectiveness**
   - Limited empirical evidence linking technology effectiveness to collisions avoided/injuries mitigated
   - Assumptions made using best available evidence about sensor activation rates, driver detection/reaction rates and the extent of coverage
3. **Costs**
   - Cost differentials between regulated/unregulated enhanced TFEDs unknown – important to get right
   - Fixed/variable cost assumptions made when clustering technologies
4. **Cost-effectiveness**
   - Limited information on composition of EU parc and EU HGV collision rates wrt HGV application/type
   - Further depth required for benefit-cost analysis

Questions?

Dr Phil Martin
Senior Researcher

pmartin@trl.co.uk
+44 [0]1344 770 326 | +44 [0]7771 604891
TRL | Crowthorne House | Nine Mile Ride | Wokingham
Berkshire | RG40 3GA | United Kingdom