Catalogue of Assessment Criteria for **Level 3** Autonomous Vehicles
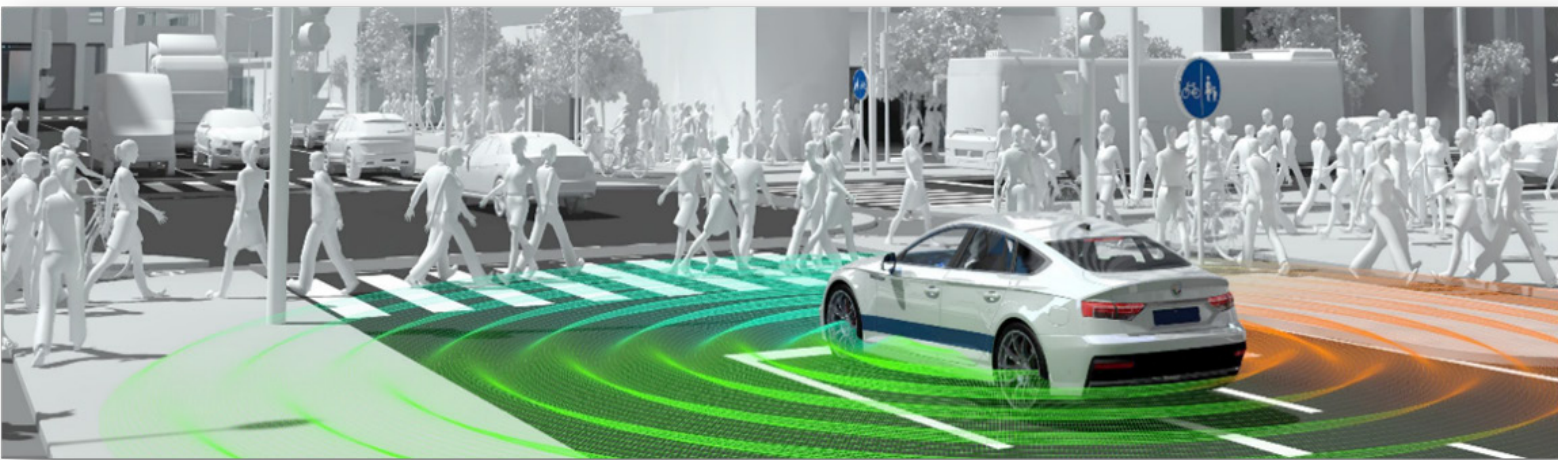
Editors:
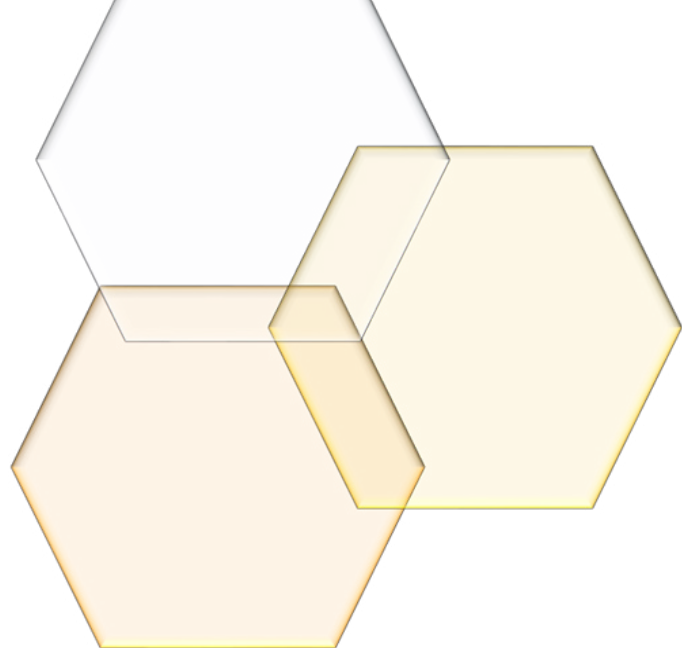Ahu Ece Hartavi
Erkan Alkan
Abhishek Shah Alias Sangani

TrustVehicle
2020

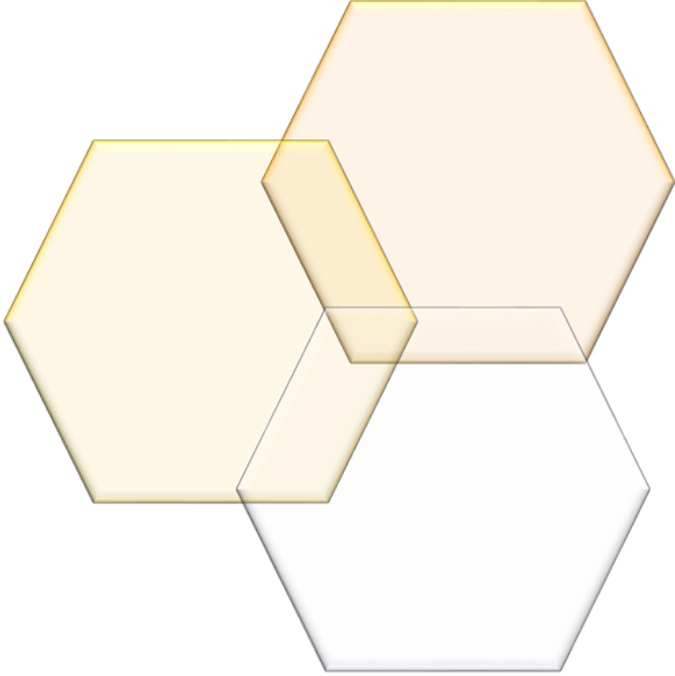TrustVehicle

Legal Disclaimer

Contents

"If you cannot measure it, you cannot **improve** it„

Lord Kelvin

TAXONOMY OF AUTOMATED DRIVING

Different levels of automation have been defined and introduced by a range of organizations. In this document classification of Society of Automotive Engineers (SAE) International Standard -J3016[1] is used, as it is the most common classification. *Figure 1* shows 6 levels of automated driving (AD) according to SAE-J3016 that shows control distribution among the human driver, and the AD system.

LEVEL 0

No Automation

"Human driver controls all aspects of driving"

LEVEL 1

Driver Assistance

"Human driver controls all aspects of driving"

LEVEL 2

Partial Automation

"Driver assistance system undertakes steering and acceleration / deceleration using info. About the driving environment, human driver performing all other tasks"

LEVEL 3

Conditional Automation

"Automatic driving systems undertake all the aspects of the dynamic driving task *with the expectations that the human driver will respond appropriately to a request to intervene*"

LEVEL 4

High Automation

"Automatic driving systems undertakes all the aspects of the dynamic driving task, *even if a human driver does not respond appropriately to a request to intervene*"

LEVEL 5

Full Automation

"Automatic driving systems undertakes all the aspects of the dynamic driving task in all roadway and environmental conditions"
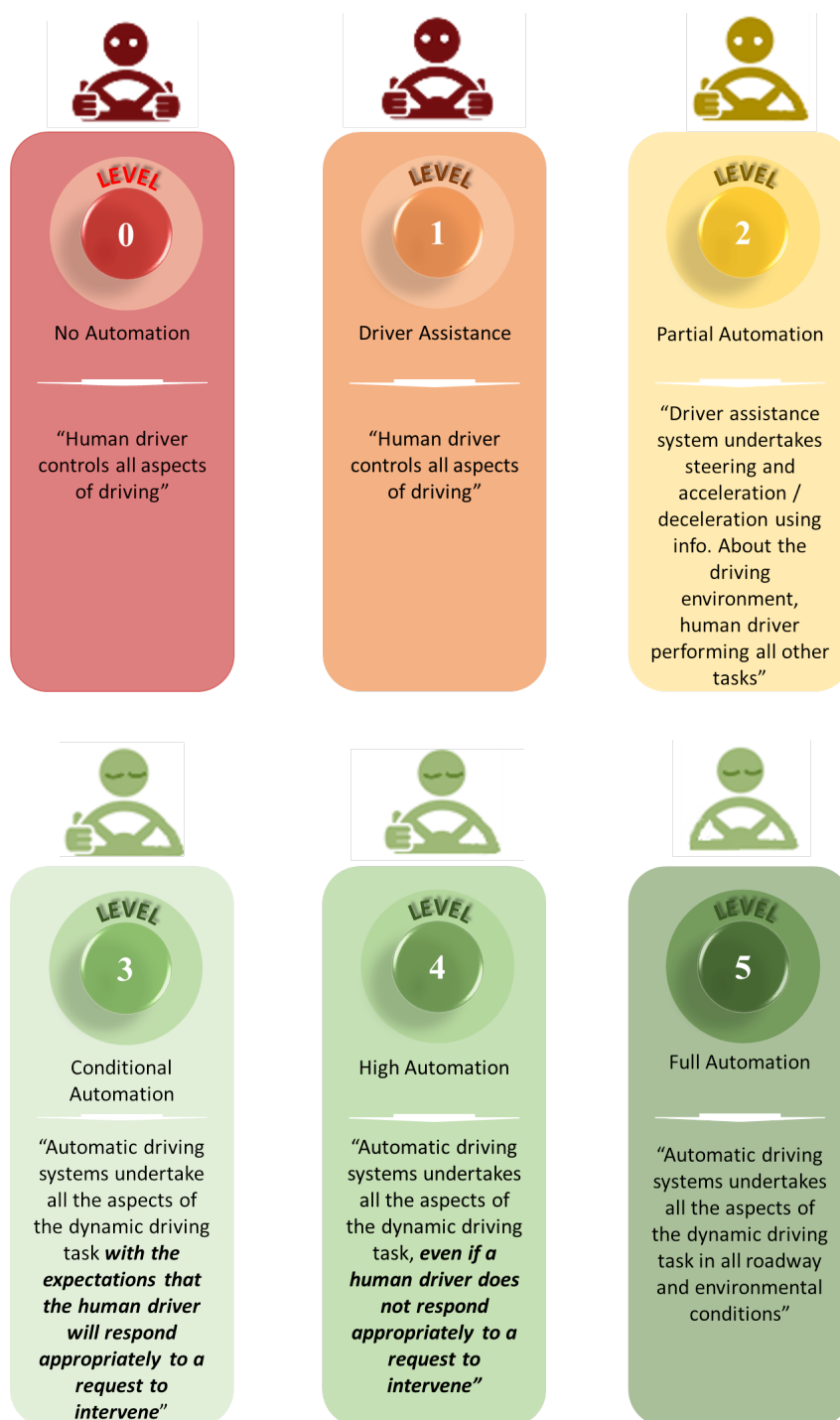
Figure 1: *SAE Levels of automation*

[1]SAE International Standard J3016

FORECAST OF AUTOMATED DRIVING MARKET TREND & ROAD MAP

The market growth for SAE Level 3 (L3) and Level 4 (L4) automated vehicles is forecasted to reach from **~€40 billion** in 2025 to **~€74 billion** in 2035[2]. Estimated annual market value for autonomous systems in transport just for the UK market alone is expected to reach **€82 billion**[3].

These numbers show the significant potential of the AD industry. To date, **impressive demonstrations** have been presented not only by the European but also by global market leaders (Figure 2[4]). Today, most of the demonstrations have been carried out in **controlled and well-defined environments**.

With the current technology, SAE level 3 functions can already offer solutions to many of today's grand societal challenges, including the increase of traffic safety and passenger comfort. Technologically, the development of these functions is understood, as confirmed by the millions of test km of automated cars on public roads.

However, demonstrating the **trustworthiness**, **reliability**, **safety**, **robustness** as well as **weather independence** of the technology, has been still a key challenge, and is today the main roadblock for product homologation, certification, end-user acceptance, and thus commercialisation.
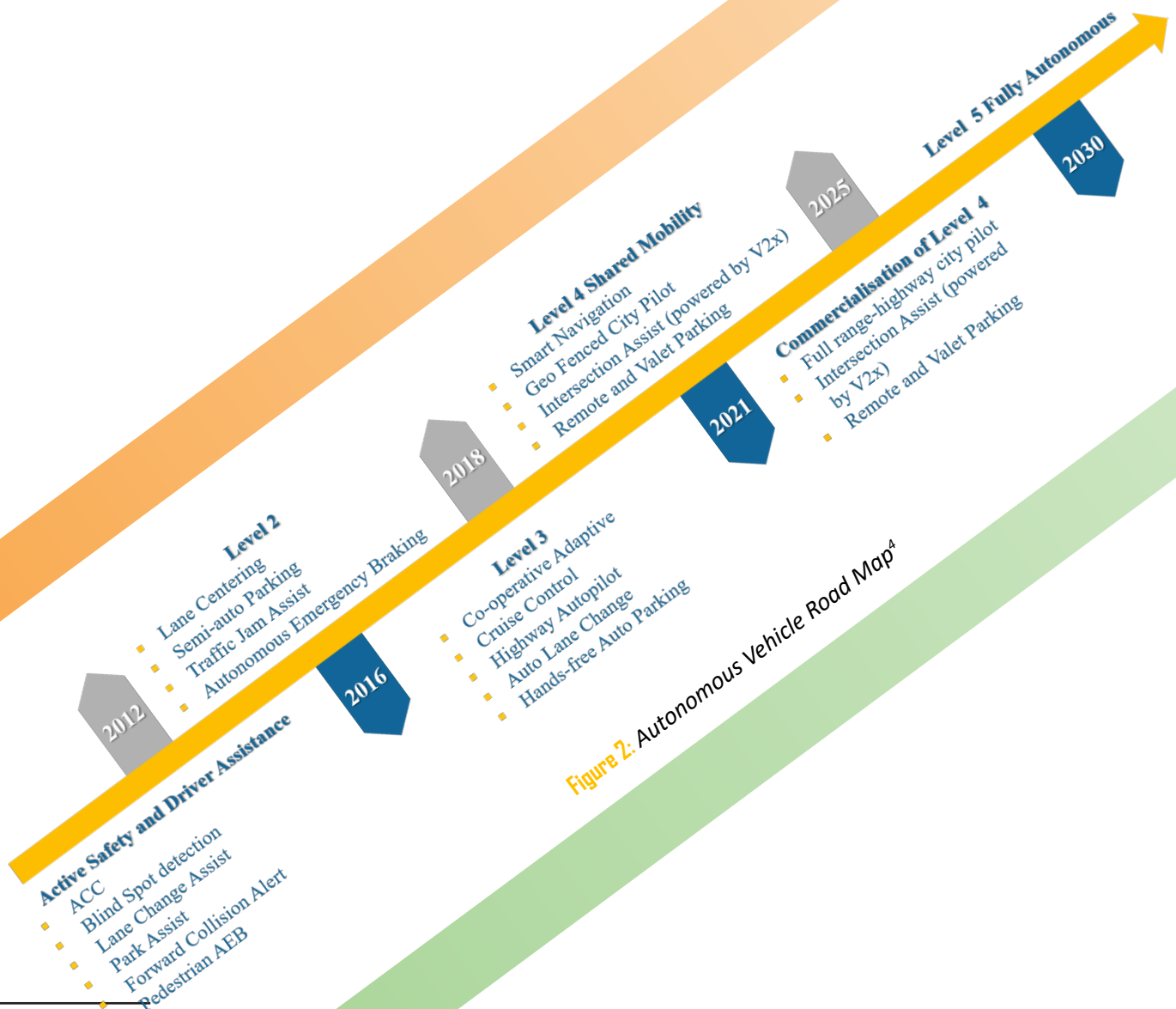

Level 2
- Lane Centering
- Semi-auto Parking
- Traffic Jam Assist
- Autonomous Emergency Braking

Level 3
- Co-operative Adaptive Cruise Control
- Highway Autopilot
- Auto Lane Change
- Hands-free Auto Parking

Level 4 Shared Mobility
- Smart Navigation
- Geo Fenced City Pilot
- Intersection Assist (powered by V2x)
- Remote and Valet Parking

Commercialisation of Level 4
- Full range-highway city pilot
- Intersection Assist (powered by V2x)
- Remote and Valet Parking

Active Safety and Driver Assistance
- ACC
- Blind Spot detection
- Lane Change Assist
- Park Assist
- Forward Collision Alert
- Pedestrian AEB

2012 · 2016 · 2018 · 2021 · 2025 · 2030 · Level 5 Fully Autonomous

Figure 2: Autonomous Vehicle Road Map[4]

[2]https://www.consultancy.uk/news/2065/bcg-autonomous-car-market-to-hit-42-billion-by-2025

[3]http://www.prnewswire.com/news-releases/world-unmanned-ground-vehicle-market-to-see-30-cagr-to-2019-501689211.html

[4]https://info.microsoft.com/rs/157-GQE-382/images/K24A-2018%20Frost%20%26%20Sullivan%20-%20Global%20Autonomous%20Driving%20Outlook.pdf

GETTING THE MEASURES RIGHT

Measurement is at the heart of any engineering and scientific discipline as it helps to support the regulatory framework. However, the automotive industry also needs to refine the definition of the, for the L3AD to ensure more timely and accurate insights into the future. The streamlining of these definitions will allow for better decision making and thus prevent the generation of unwanted results due to a priori processing of findings.

The information presented in this document is provided by the Trust-Vehicle consortium as a result of 32 surveys conducted in two rounds, among the 231 experts from 7 countries in Europe. The pool of metrics for the first round were based on the literature and expert's knowledge[7,8].

An accelerated Delphi (a-Delphi) approach is taken in the analysis of the questionnaires (Dalkey and Helmer, 1963)[5]. Two rounds of intensive questionnaires, with 16 surveys in each round, were conducted to obtain the most reliable consensus of a group of experts in 4 different categories. Categories were defined according to vehicle class by a series of intensive questionnaires (Williamson, 2002)[6]. The model's performance was superior to a naïve prediction, which proves their validity.

Assoc. Prof. Ahu Ece Hartavi KARCI
Scientific Coordinator of the TRUSTVEHICLE

[5]Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. Management Science, 9, 458- 467. doi:10.1287/mnsc.9.3.458

[6]Williamson, Kirsty. (2002). Research Methods for Students, Academics and Professionals: Information Management and Systems. Inf. Res.. 8.

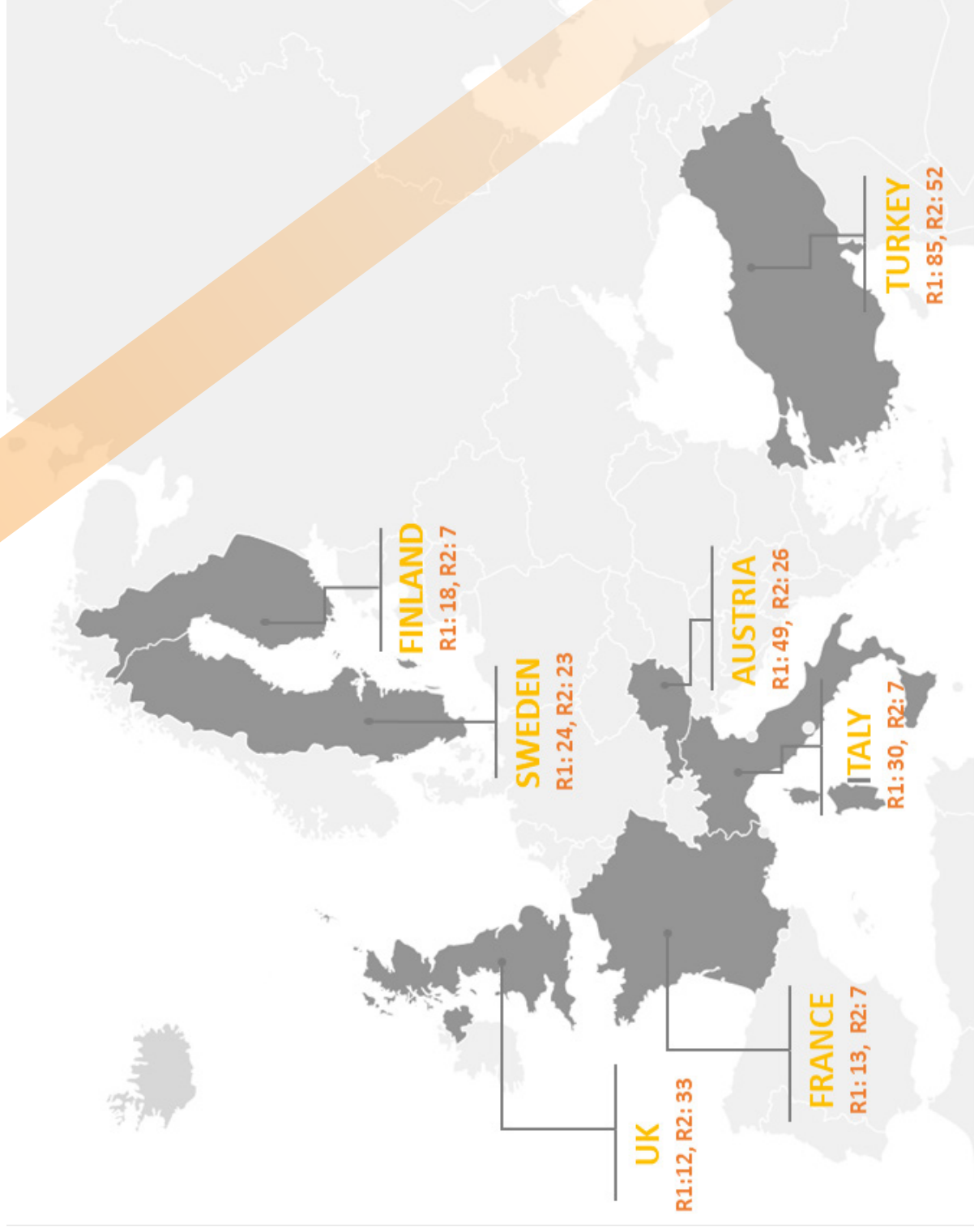[7]Survey on KPI for Automated Driving - ERTICO Newsroom' (ERTICO Newsroom, 2019) <https://erticonetwork.com/participate-survey-kpi-automated-driving/>

[8]Connected Automated Driving | Europe's Self-Driving Transport' (Connected Automated Driving Europe, 2019) <https://connectedautomateddriving.eu/> accessed 8 June 2019

1 Identify & Invite Experts

7 Identification of KPI*s*

2 KPI*s* Collection

6 Final Review

3 R(1): KPI Ranking

5 R(2): KPI Ranking

4 Analysis & Review

Accelerated Delphi Technique

TURKEY
R1: 85, R2: 52

FINLAND
R1: 18, R2: 7

SWEDEN
R1: 24, R2: 23

AUSTRIA
R1: 49, R2: 26

ITALY
R1: 30, R2: 7

UK
R1:12, R2: 33

FRANCE
R1: 13, R2: 7

Expert Numbers R2: Round II

Expert Numbers R1: Round I

NON-TECHNICAL KPIs

"The Changing Face of Public Transportation in Finland: Level 3 Autonomous Electric Bus…"

To test which KPIs will survive, mean scores and consensus level were calculated for each item. The KPIs which had a mean score of 7.5 or were ranked above 8 by a minimum of 60% of experts were then selected.

DRIVER EXPECTATIONS KPIs

Mean scores and consensus levels were analysed for each vehicle separately. The analysis revealed that 6 KPIs for Passenger Vehicle, 3 for Light Commercial Vehicle, 4 for Bus, and 3 for Truck accessed the edge of significance which was defined as a priori (a mean score of 7.5 or ranked above 8 by 60% of experts).

In the analysis for **passenger vehicles** - experts evaluated safety M =7.94, CL = 68.50 and trust M=7.68, CL =67.40 as the most important KPIs.

Driver Expectations KPIs for Passenger Vehicle	M	CL
Safety	7,94	68,50
Trust	7,68	67,40
Reliability	7,65	68,50
Controllability	7,40	60,00
Availability of L3AD within limited traffic scenarios	7,34	61,00
Availability of L3AD during harsh weather conditions	7,13	61,10

7.94
M

68.50
CL
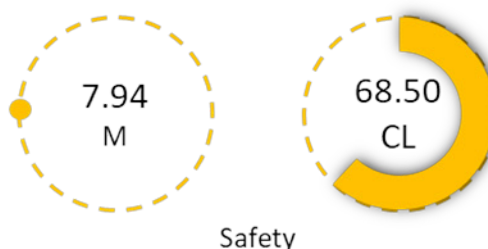
Safety

In the analysis for **light commercial vehicle/van** - experts evaluated safety M=7.78, CL = 70.50 and reliability M=7.71, CL =68.40 as most important KPIs.

Driver Expectations KPIs for Light Commercial Vehicle	M	CL
Safety	7,78	70,50
Reliability	7,71	68,40
Trust	7,41	65,30

7.78
M

70.50
CL
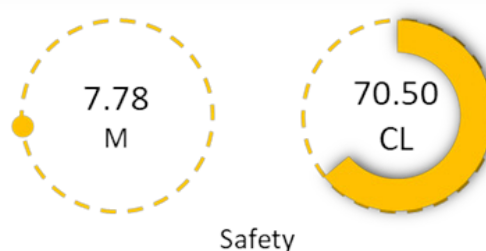
Safety

DRIVER EXPECTATIONS KPIs...

In the analysis for **buses** - experts evaluated safety M=7.84, CL = 69.40 and reliability M=7.79, CL = 71.60 as most important KPIs.

Driver Expectations KPIs for Bus	M	CL
Safety	7,84	69,40
Reliability	7,79	71,60
Trust	7,56	65,20
Reduction of driver fatigue and alertness in AD mode	7,36	60,10

7.84
M

69.40
CL
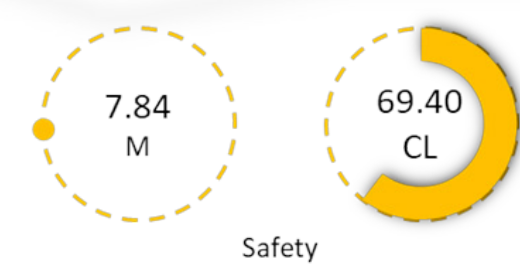
Safety

Analysis for **Truck** showed that experts evaluated Trust M=7.38, CL=63.20 and safety M=7.65, CL = 65.20 as most important KPIs among those for truck.

Driver Expectations KPIs for Truck	M	CL
Trust	7,38	63,20
Safety	7,65	65,20
Reliability	7,55	65,30

7.38
M

63.20
CL
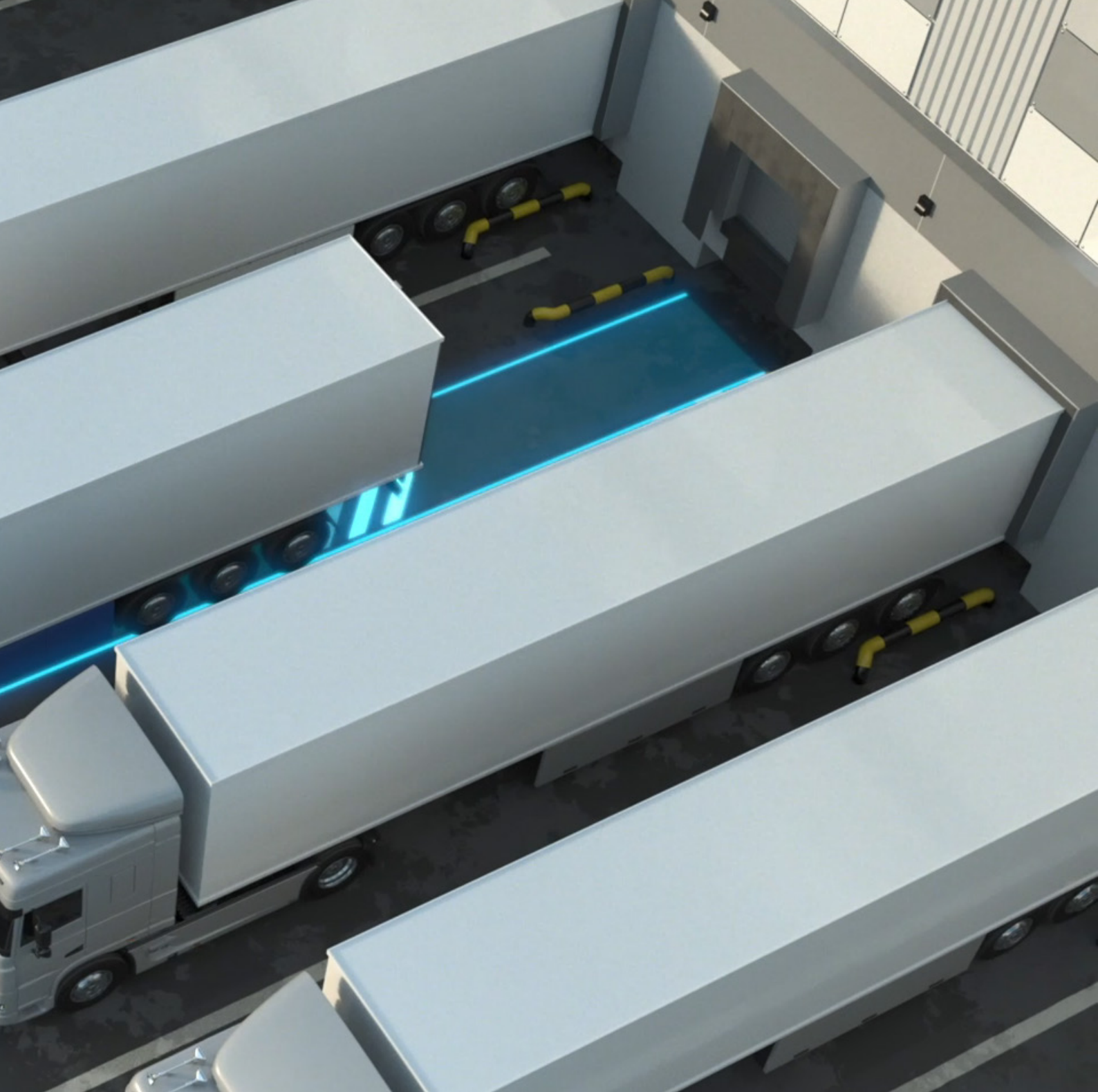
Trust

TRUSTVEHICLE
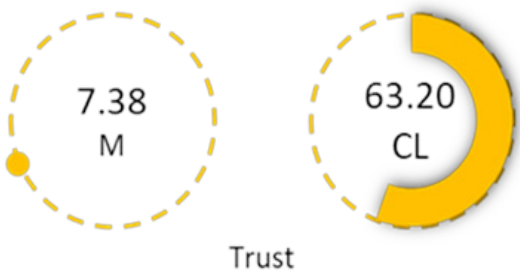
Level 3
Autonomous Reverse Parking Truck and Trailer...
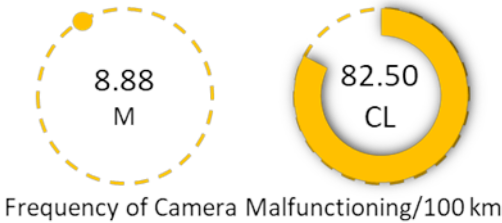
TRUSTVEHICLE

TECHNICAL
KPI_s

CAMERAS KPIs

Mean score and consensus level analysis revealed that 4 out of the 10 Camera KPIs access the edge of significance which was defined as a priori (a mean score of 8 and ranked above 8 by 75% of experts).

Camera KPI	M	CL
Frequency of camera malfunctioning /100 km	8,88	82,50
Camera environmental light robustness	8,68	85,00
Camera accuracy	8,25	77,50
Camera weather condition robustness	8,25	72,50

8.88
M

82.50
CL

Frequency of Camera Malfunctioning/100 km

SENSORS KPIs

Mean score and consensus level analysis revealed that 5 out of the 10 Sensor KPIs access the edge of significance which was defined as a priori (a mean score of 8 and ranked above 8 by 75% of experts).

Sensor KPI	M	CL
Frequency of sensor malfunctioning / 100 km	8,85	85,00
Sensor eye safety	8,75	77,50
Sensor accuracy	8,73	87,50
Sensor robustness	8,73	82,50
Sensor weather condition robustness	8,40	77,50

8.85
M

85.00
CL

Frequency of sensor malfunctioning /100 km

"The Autonomous Trucks are a Reality Today &
Arriving Soon to the Urban Areas After High-
ways..."

HUMAN MACHINE INTERFACE KPIs

Mean scores and consensus levels were analysed for each vehicle separately. Analysis revealed that 6 KPIs for Passenger Vehicle, 7 for Light Commercial Vehicle, 7 for Bus, and 10 for Truck accessed the edge of significance which was defined as a priori (a mean score of 8 and ranked above 8 by 75% of experts).
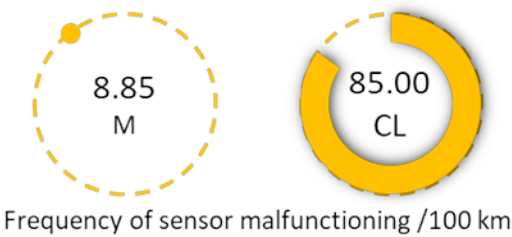
Analysis has shown that experts reached a consensus on 6 of the KPIs for passenger vehicle to be eligible for the final list. Among those 'Hand over request understanding' had the biggest mean score M=9.09, CL = 95.40

HMI KPIs Passenger Vehicle	M	CL
Hand over request understanding	9,09	95,40
Indication of the current mode	8,95	86,30
Deactivation in AD mode	8,45	81,80
Intuitiveness of HMI	8,23	77,20
Frequency of error	8,23	72,70
Time left prior to L3AD not available	8,23	81,80

9.09
M

95.40
CL

Take Over Request Understanding

Analysis revealed that experts reached a consensus on 7 of the KPIs for light commercial vehicle/van to be eligible for the final list. Among those 'Hand over request understanding' has the biggest mean score M=9.14 CL=95.50.

| HMI KPIs for Light Commercial Vehicle/Van	M	CL
Hand over request understanding	9,14	95,50
Indication of the current mode	9,00	91,00
Audible warning of deactivation of AD mode	8,59	86,40
Time delay of HMI	8,41	77,30
Information in case of deactivation in AD mode	8,41	86,40
Visual warning of deactivation of L3AD	8,27	81,80
Indication of L3AD availability	8,00	77,30

9.14
M

95.50
CL

Take Over Request Understanding

HUMAN MACHINE INTERFACE KPIs...

Analysis showed that experts reached a consensus on 7 of the KPIs for bus to be eligible for second round. Among those 'Hand over request understanding' has the biggest mean score M=9.23, CL=100.00.

HMI KPIs for Bus	M	CL
Hand over request understanding	9,18	100,00
Indication of the current mode	9,05	90,90
Frequency of error	8,59	86,40
Audible warning of deactivation of L3AD	8,59	77,30
Driver stress level in AD mode	8,45	81,80
Visual warning of deactivation of L3AD	8,45	81,80
Information in case of deactivation in L3AD mode	8,45	81,80
Time delay of HMI	8,32	81,80
Indication of L3AD availability	8,27	81,80
Efficiency of use	8,18	77,30

9.18
Median
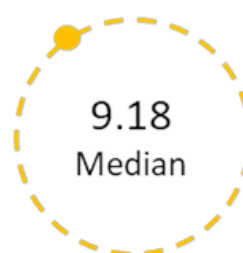
100.0
CL

Take Over Request Understanding

Analysis revealed that experts reached a consensus on 10 of the KPIs for truck to be eligible for second round. Among those 'Hand over request understanding' has the biggest mean score M=9.23, and CL = 100.00.

HMI KPIs for Truck	M	CL
Hand over request understanding	9,23	100,00
Indication of the current mode	9,05	90,90
Frequency of error	8,59	86,40
Driver stress level in AD mode	8,50	81,80
Visual warning of deactivation of L3AD	8,50	81,80
Information in case of deactivation in AD mode	8,50	81,80
Audible warning of deactivation of L3AD	8,41	77,30

9.23
M

100.0
CL
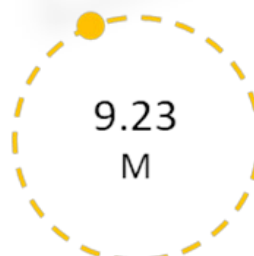
Take Over Request Understanding

TRUSTVEHICLE

"The New Face of Personal Mobility:
Self Driving Vehicles..."

VEHICLE OPERATIONS KPIs

Mean scores and consensus levels were analysed for each vehicle separately. Analysis revealed that 6 KPIs for Passenger Vehicle, 3 for Light Commercial Vehicle, 6 for Bus, and 6 for Truck accessed the edge of significance which was defined as a priori (a mean score of 8 and ranked above 8 by 75% of experts).

Analysis showed that experts reached a consensus on 6 of the KPIs for passenger vehicle to be eligible for the final list. Among those 'System reaction time during emergency braking' had the biggest mean score M=8.82, CL=87.80.

Vehicle Operation KPIs for Passenger Vehicle	M	CL
System reaction time during emergency braking	8,82	87,80
Number of accidents in AD mode per 100 M km	8,82	81,80
Malfunctioning of AD functions (number of events per 100 km)	8,70	81,80
Number of traffic violations in AD mode per 1000 km	8,58	78,80
Number of conflicts encountered where TTC is less than a predetermined threshold	8,55	84,90
Number of instances where the situation is not correctly handled in AD mode per 1000 km	8,45	81,80

8.82
M

87.50
CL

System Reaction Time During Emergency Braking

Analysis revealed that experts reached a consensus on 3 of the KPIs for light commercial vehicle/van to be eligible for the final list. Among those 'Number of accidents in AD mode per 100 million km' has the biggest mean score M=8.79, CL = 81.80.

Vehicle Operation KPIs for LCV	M	CL
Number of accidents in AD mode per 100 million km	8,79	81,80
Number of traffic violations in AD / 1000 km	8,73	78,80
System reaction time during emergency braking	8,64	81,80

8.79
M

81.80
CL
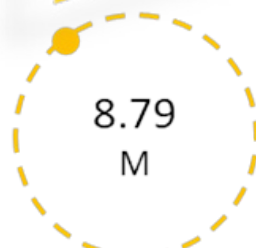
Number of Acidents in AD Mode/ 100 million km

VEHICLE OPERATIONS KPIs...

Analysis showed that experts reached a consensus on 7 of the KPIs for bus to be eligible for the final list. Among those 'Number of accidents in AD mode per 100 million km' has the biggest mean score M=8.88, and CL=84.80.

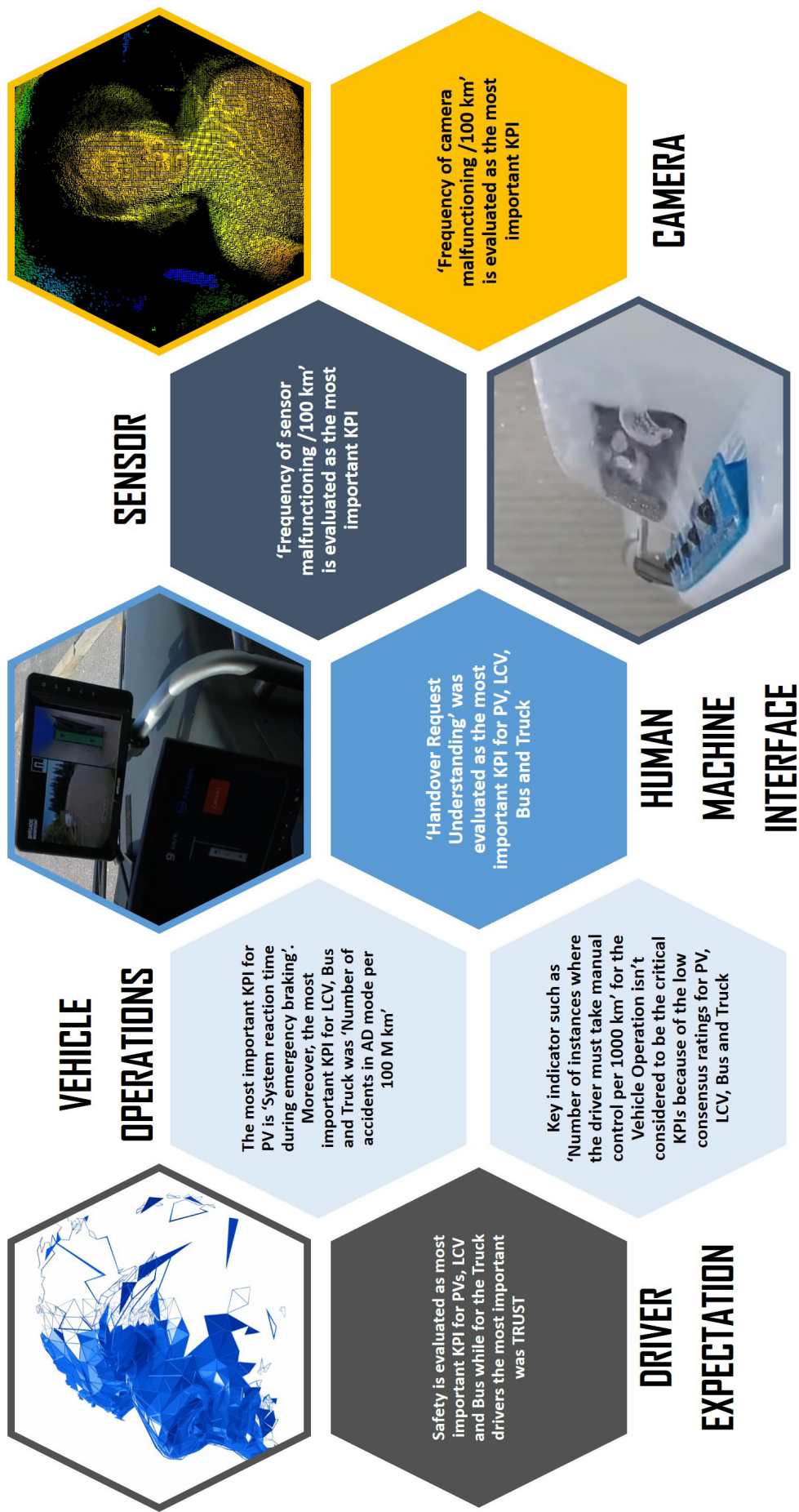| Vehicle Operations KPIs for Bus	M	CL
Number of accidents in AD mode per 100 million km	8,88	84,80
Number of traffic violations in AD mode per 1000 km	8,85	84,90
System reaction time during emergency braking	8,76	90,90
Malfunctioning of AD functions (number of events per 100 km)	8,70	78,80
Number of conflicts encountered where TTC is less than a predetermined threshold	8,67	81,80
Number of instances where the situation is not correctly handled by vehicle in AD mode per 1000 km	8,42	78,90
Number of emergency stops per 1000 km	8,06	69,60

8.88
M

84.80
CL

Number of Accidents in AD Mode/ 100 M km

KEY FINDINGS

SENSOR

'Frequency of sensor malfunctioning /100 km' is evaluated as the most important KPI

CAMERA

'Frequency of camera malfunctioning /100 km' is evaluated as the most important KPI

HUMAN MACHINE INTERFACE

'Handover Request Understanding' was evaluated as the most important KPI for PV, LCV, Bus and Truck

VEHICLE OPERATIONS

The most important KPI for PV is 'System reaction time during emergency braking'. Moreover, the most important KPI for LCV, Bus and Truck was 'Number of accidents in AD mode per 100 M km'

Key indicator such as 'Number of instances where the driver must take manual control per 1000 km' for the Vehicle Operation isn't considered to be the critical KPIs because of the low consensus ratings for PV, LCV, Bus and Truck

DRIVER EXPECTATION

Safety is evaluated as most important KPI for PVs, LCV and Bus while for the Truck drivers the most important was TRUST

TRUSTVEHICLE

ACRONYMS

AD	Automated Driving
α-Delphi	Accelerated Delphi
CL	Consensus Level
ERTRAC	European Road Transport Research Advisory Council
HMI	Human Machine Interface
KPI	Key Performance Indicator
L3AD	Level 3 Automated Driving
LCV	Light Commercial Vehicle
M	Median
OEM	Original Equipment Manufacturer
PV	Passenger Vehicle
SAE	Society of Automotive Engineers
SD	Standard Deviation
TTC	Time-to-Collision
VO	Vehicle Operations

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LIMITATIONS

There are some potential limitations to the interpretation of this study. Firstly, in the first round, coverage bias may occur considering uneven representation of countries, some countries are represented by more experts then others. Secondly, second round was limited by gender distribution as experts were predominantly males. Finally, surveys were conducted in English which might cause a language barrier across non-native English-speaking countries.

This study was accepted by the University of Surrey Ethics Committee's requirements and the experts were informed of the study purposes and of data confidentiality through an informed consent form.

REFERENCES

1. SAE International standard J3016:Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. (Copyright © 2014 SAE International)

2. "BCG: Autonomous car market to hit 42 billion by 2025," Consultancy.uk (2015). Available: https://www.consultancy.uk/news/2065/bcg-autonomous-car-market-to-hit-42-billion-by-2025.

3. "World Unmanned Ground Vehicle Market to see 30% CAGR to 2019," CISION PR Newswire, (2015). Available: https://www.prnewswire.com/news-releases/world-unmanned-ground-vehicle-market-to-see-30-cagr-to-2019-501689211.html.

4. "Global Autonomous Driving Market Outlook, 2018," Global Automotive & Transportation Research Team at Frost & Sullivan, 2018.

5. Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. Management Science, 9, 458- 467. doi:10.1287/mnsc.9.3.458

6. Williamson, Kirsty. (2002). Research Methods for Students, Academics and Professionals: Information Management and Systems. Inf. Res. 8.

7. Survey on KPI for Automated Driving - ERTICO Newsroom' (ERTICO Newsroom, 2019) <https://erticonetwork.com/participate-survey-kpi-automated-driving/>

8. Connected Automated Driving Europe. (2019). Connected Automated Driving | Europe's Self-Driving Transport. [online] Available at: https://connectedautomateddriving.eu/ [Accessed 6 Nov. 2019].

9. Rispoli F and others, 'Synergies for Trains and Cars Automation in The Era of Virtual Networking' (2018) 08 Journal of Transportation Technologies

10. Lima, T. de M., Aguiar, P. M., & Storpirtis, S. (2018). Development and validation of key performance indicators for medication management services provided for outpatients. Research In Social & Administrative Pharmacy: RSAP.

11. Ogbeifun, E., Mbohwa, C., & Pretorius, J. H. C. (2016). Developing Key Performance Indicators using the Delphi technique. Journal of the Environment, 10(1).

12. Sanli, E., Ennis, K. A., Brown, R., & Carnahan, H. (2018). The Development and Validation of Key Performance Indicators for Two Tasks Related to Marine Emergency Duties Training. International Journal of Training Research, 16(2), 145–154.

13. Underwood, S.E., Chen, D., & Ervin, R.D. (1991). Future of intelligent vehicle-highway Systems: A delphi forecast of markets and social technological determinants. Transportation Research Record No: 1305, 291-304

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