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EXAMINING THE EFFECT OF ROAD HORIZONTAL ALIGNMENT ON THE SPEED OF SEMI-AUTOMATED VEHICLES

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ABSTRACT

The novel semi-autonomous vehicles are becoming a reality in our roads, being a very important technological advance with promising operational and safety improvements. However, road infrastructure must be ready to host them. The technologies of these driving automation systems require certain road conditions that are not always fulfilled, causing the systems to fail. These failures generally transfer negotiation control to drivers, which may induce a crash if they were not aware of road and traffic conditions.

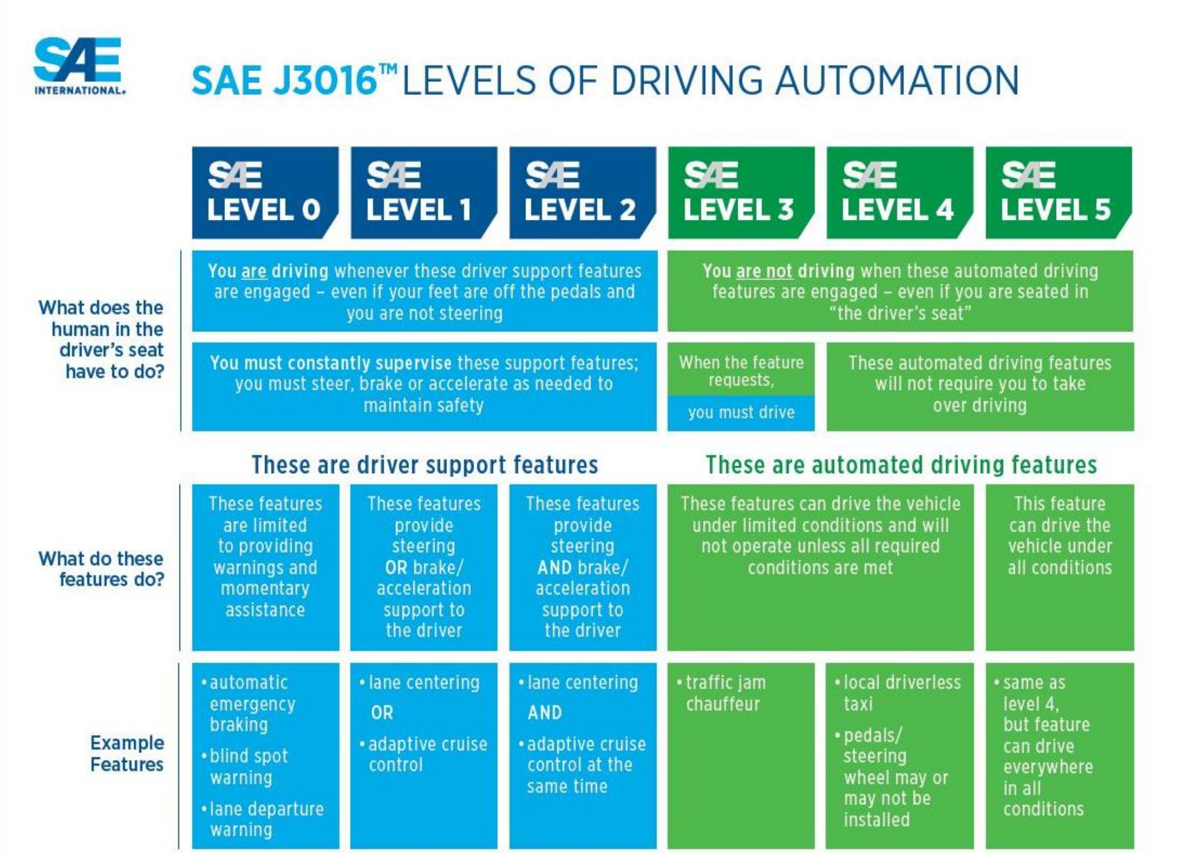
This research analyses how ready the road horizontal alignment is for existing semi-autonomous systems. A Level 2 vehicle has been tested on many different horizontal curves, finding a strong relationship between the maximum speed that the autonomous system can attain and the curve geometry. This maximum speed is proposed as a new concept (automated speed) and has been found to be lower than the design, operating and posted speeds in many cases. Another new concept – automated driving consistency – arises, as the difference between automated and operating speeds. The related inconsistencies can be addressed with the new concept of Level of Service for Automated Driving (LOSAD), which summarizes how ready a corridor is for a certain driving automation system. This parameter should be determined – further certified – for any homogeneous road segment, and later informed to drivers.

Keywords: *Automated vehicle, driving automation system, road safety, automated speed, automated driving consistency, Level of Service for Automated Driving*

1. INTRODUCTION

Vehicle automation has reached a technological development status that has allowed to move from active safety to semi-autonomous driving systems. Semi-autonomous vehicles are already being sold by dealers, and cutting-edge technologies are also continuously being tested. While these most-advanced technologies perform on authorized itineraries or controlled areas, the semi-automated vehicles – owned by particulars – operate anywhere across the road network. Nowadays, these are not common in roads, but exponential market penetration is expected in a short-term, as more brands and models incorporate these systems.

The road to full automation is long, with vehicles depending less and less on human support to perform. A fully autonomous vehicle will indeed be able to cover an itinerary without any human intervention (just to set the destination and minimal options about the general performance of the trip). From a technological perspective, this is far from being reached, so intermediate levels between human and full automation have been proposed. The best-known classification was proposed by the Society of Automotive Engineers (SAE, 2018), which consists of six levels of automation, from Level 0 (no automation), to Level 5 (fully automated driving) (Figure 1). Levels 1 to 4 are known as partial automation (semi-autonomous driving automation systems).



SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Figure 1. Levels of driving automation according to SAE International (SAE, 2018).

Semi-autonomous vehicles present many sensors that provide information to the driving automation system. For automation level 2, the system uses this information to execute the longitudinal speed and steering tasks. However, the vehicle is considered to be human-driven, since the person is responsible for monitoring the environment and taking over control if the driving system fails (i.e. disengages). In addition, some manoeuvres (such overtaking) are not fully supported. Vehicles equipped with these systems have already hit the market.

In these vehicles, a Human-Machine Interface (HMI) is required to ask drivers to take control. Unfortunately, existing driving automation systems still present too frequent disengagements, which might be annoying for the driver. Thus, many marks and models incorporate very subtle warnings to prevent annoyance. Unfortunately, these subtle indications might be overlooked, increasing the driver response time and therefore the risk (Dogan et al., 2017; Shen and Neyens, 2017).

Automation level 3 changes the role of the driving automation system, since it will also be responsible for monitoring the environment. However, the system is not expected to be infallible, and it may also require transferring control to the driver. In this case, it is expected that the system can foresee this condition with some time to advert the driver to get aware of the environment and resume control. There are serious concerns about whether this time will be enough or not.

Level 4 systems will be able to take full control of the vehicle, including position, trajectory, speed, acceleration/deceleration, as long as the infrastructure meets some conditions (known as Operational Design Domain, ODD). They should also be able to cope with any unexpected event that could disturb their trajectory. Some of the conditions that define an ODD are: certain road characteristics; traffic; environment; accurate position of the vehicle – within the roadway and within a map –; a range of speeds; etc. Finally, Level 5 vehicles will perform without this requirement, i.e., along any road.

According to the Green Book (AASHTO, 2011), the design speed establishes a reference for several geometric features of the road. Some examples are the minimum radius, tangent length, stopping sight distance, among others. This speed must be chosen consistently to the expected speed of drivers, i.e. the operating speed, which can be defined as the speed attained by drivers when vehicles are operated under free flow conditions (TRB, 2003) (85th percentile is generally selected as representative, but operating speed actually is a range of speeds). Strictly speaking, operating speed can only be determined for existing roads. However, there is a plethora of models that can be used to estimate it, mostly based on road geometry.

In addition to design and operating speed, there are two additional speed definitions. The speed limit is established as a threshold to what is considered a safe – or comfortable – driving.

These limits are generally determined as a function of the road type and the available sight distance (Ministerio de Fomento, 2016), but these should also be compared to operating speed, to prevent large disparities (Ministerio de Fomento, 2014) that result in higher speed dispersion and might lead to higher crash rates.

Finally, the desired speed is the speed that the 85th percentile driver would like to maintain under no geometric or traffic constraints. As a virtual speed, it cannot be determined or measured but the operating speed reached at long, level tangents – if existing in a given road segment – could be used as an adequate estimation.

Automated vehicles should provide natural speeds and speed transitions, based on the limitations mentioned above. There have been many efforts in coming up with Intelligent Speed Adaptation Systems (ISAs) that consider these aspects. Gámez Serna et al. (2017) proposed a Dynamic Speed Adaptation (DSA) algorithm, which takes the speed limit of curves and corrects the operating speed – if necessary – considering a detailed analysis of their geometry. This is especially useful for sharp curves. Other systems (Aguiléra et al, 2005) consider accelerations as a surrogate measure to tire-pavement friction, warning the driver if a certain threshold is exceeded.

New and oncoming capacities of semi-automated vehicles must be in hand with road infrastructure. Most road features are designed based on a speed threshold that is considered safe and/or comfortable for human manoeuvring capabilities, perception-reaction time and interpretation ability. Not only do these parameters differ between humans and driving automation systems, but these vary in time and across models. Technological development plays a critical role here: most advanced systems will likely enhance human performance, but many existing systems are far from that goal.

Driving automation systems which are not able to adapt to existing conditions would a) perform at lower speeds than other users, or b) experience disengagements. Either the case, the system would be uncomfortable and/or unsafe, so drivers would presumably be willing to disconnect it. In the end, this would delay the effective deployment of most advanced driving automation systems.

2. OBJECTIVES

The main goal of this research is to analyse how the road horizontal alignment affects the performance of semi-autonomous vehicles, looking at which circumstances cause a semi-autonomous driving automation system to disengage. These conditions will be compared to design standards, setting clear goals for the development of disengagement-free driving automation systems. The main hypothesis is that there is a speed-geometric relationship that could explain many disengagement events. Hence, operating and design speeds will be considered in this analysis.

3. METHODOLOGY

A semi-autonomous vehicle was driven at different speeds along a road network, covering a wide range of horizontal curves, looking for the conditions that caused the driving automation system to disengage.

3.1. Vehicle

The vehicle used in this research was a BMW 520d of 2017, equipped with the "Driving Assistant Plus" package. This is a Level 2 semi-autonomous system, composed of an Active Cruise Control (ACC) and a Lane Keeping Assistant (LKA). Upon selection of the cruise speed by the driver and both systems activated, the driving automation system takes control of the longitudinal and lateral negotiation, keeping the vehicle within the lane thanks to the detection of the centre and edge road markings by means of two video cameras located behind the interior rear-view mirror. The vehicle sensors also provide information about the proximity of other vehicles. This information is used to take adequate decisions depending on traffic conditions.

This being a Level 2 system, the driver must supervise its performance as well as traffic conditions at all time. To prevent driver distraction, the vehicle checks whether the driver is in contact to the steering wheel, warning them if it is released more than a few seconds.

The LKA system informs about its performance with a colour code on the dashboard. A green mark is displayed when the LKA system is enabled and working properly (i.e., tracking road markings and correcting trajectory if needed). If the system is unable to track road markings or process the information (not being able to correct the vehicle trajectory, if needed), it turns orange. Finally, the mark is grey if the system is disabled by the driver. The shift from green to orange will be used as surrogate measure to determine where the system disengages. To track this condition, the vehicle was equipped with a Garmin Virb Elite video camera, which records in HD with GPS geolocation. The camera was placed beside the driver's head to simultaneously record the road, the map, the dashboard, the position of the hands on the steering wheel and the driver's voice (Figure 2).

Figure 2. Travel recording with HD video camera (left) and screenshot (right).

3.2. Horizontal curves

The vehicle performed along 178 horizontal curves several times, covering more than 2000 km of freeways, multilane highways and two-lane rural highways at the Valencian region (Eastern Spain, Figure 3). This number considers two curves if a curve has been covered in both directions. This decision was taken due to the different factors that might trigger disengagements and are not identical for both directions.

All data collection was performed between May and July 2017, extending to a total of 150 hours. No remarkable differences were observed between the first and the last hours of recording.

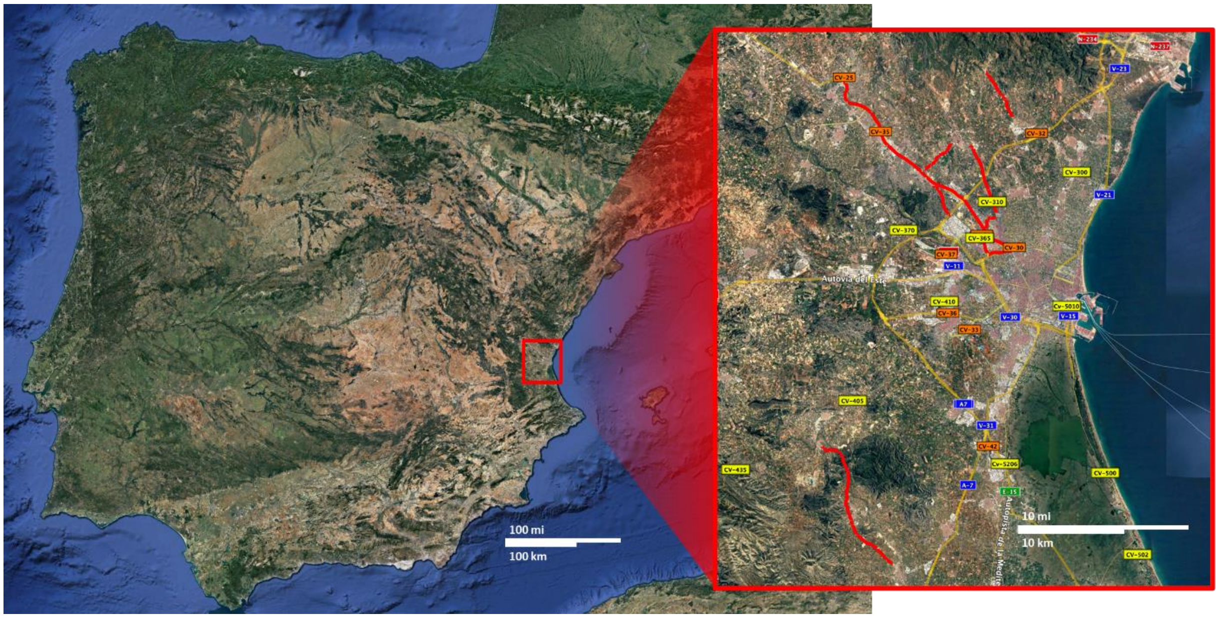


Figure 3. Data collection map (roads that where covered are shown in red).

The geometry of all curves was recreated using specific software developed by the Highway Engineering Research Group (Camacho-Torregrosa et al., 2015). This methodology, based on the analysis of the heading direction instead of the curvature, allows a very accurate determination of the different geometric features that may compose an alignment. This is especially useful not only for determining the radii and parameters of curves and spirals, but also to detect compound curves that might be overlooked with other recreation techniques.

The following variables were determined for every curve. Figure 4 shows the speed limit (left) and the radii (right) distributions of all curves:

- Road and station.
- Radius (m) (see Figure 4 for radius distribution).
- Deflection Angle (gon) (100 gon = 90º).
- Length (m).
- Curvature Change Rate (gon/km).

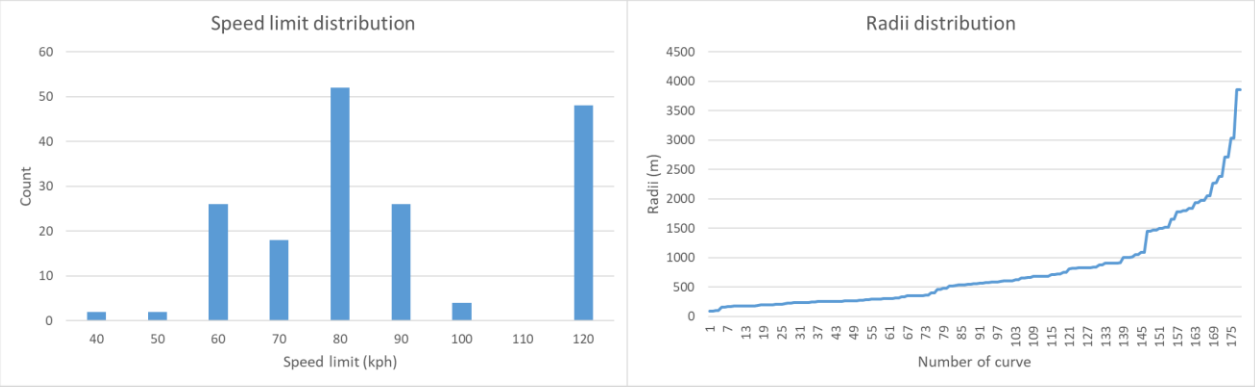


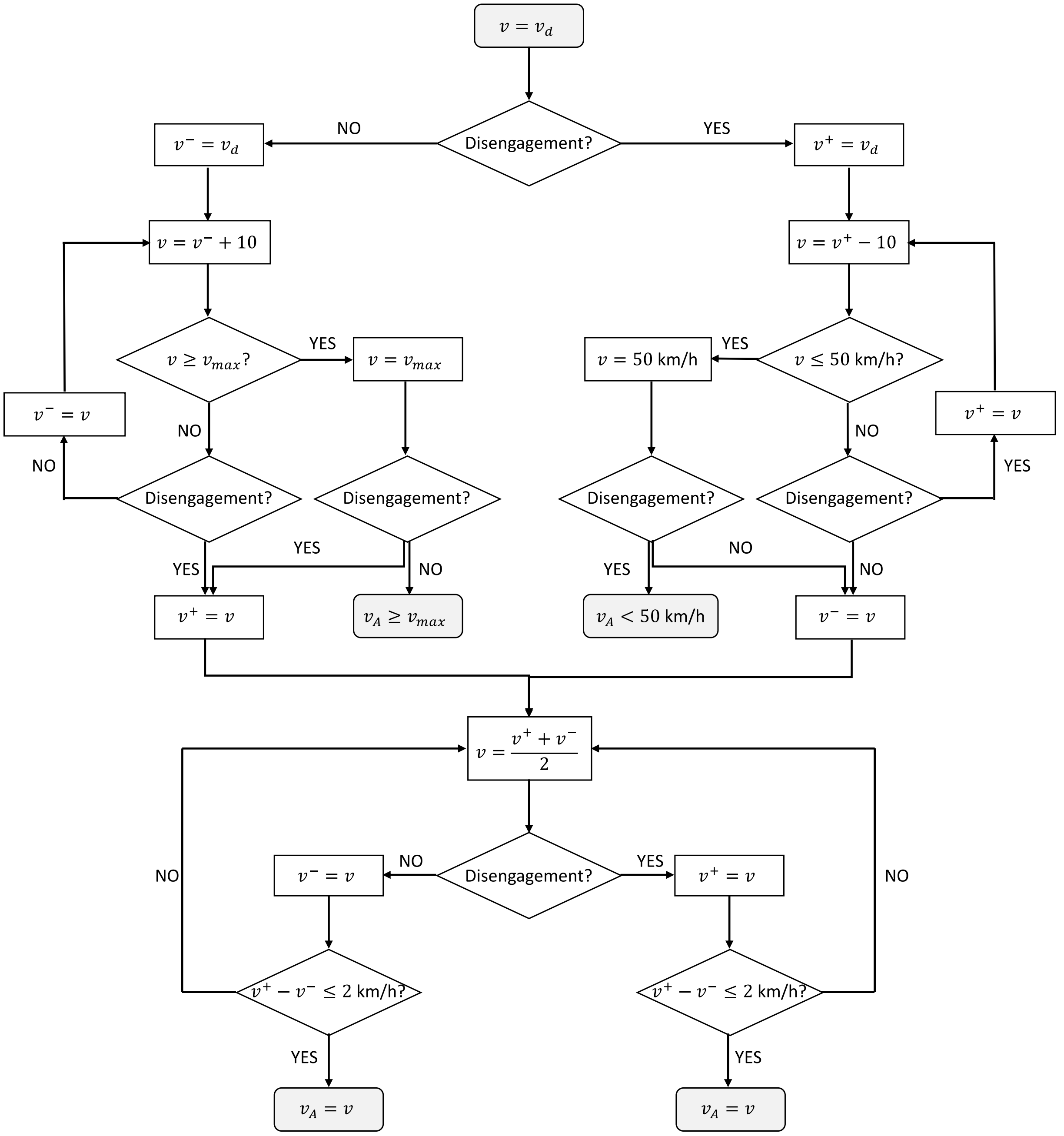
Figure 4. Speed limit and radii distribution of all curves involved in the experiments.

3.3. Experimental process

For every curve, the speed that the driving automation system was able to reach without disengaging was obtained as described in Figure 5. The driver performed a few passes throughout every curve at different speeds, starting from the inferred design speed of the curve and performing successive steps diverging in 10 km/h. Finally, the range is narrowed down to find this speed with an accuracy of 2 km/h. Some additional passes were required to confirm the disengagement status at some iterations, as well as to confirm the final speed. On average, more than 10 passes through every curve were needed to determine it.

To detect whether a certain speed caused disengagement or not, the LKA indication on the dashboard was examined, as explained above. It is important to highlight that the system presents LKA technology, i.e., the driver was always negotiating the vehicle position and no additional risks than normal driving were assumed. The driver was the same across all experiments, since they did not introduce additional variability. In order to control the target speed for every run, the Active Cruise Control (ACC) was set in advance.

The speed found with this experiment therefore represents the maximum speed that can be handled by this driving automation system. This is a new speed concept: the **Automated Speed ($\boldsymbol{v_A}$)**.



v_d: Design speed of the curve.

v_{max}: Maximum speed at which the experiment can be performed without compromising safety.

v: Speed at which the observation is performed.

v^+: Minimum speed that – at a certain iteration – has proven to disengage the vehicle *(internal parameter, it may vary through iterations)*.

v^-: Maximum speed that – at a certain iteration – has proven to not disengage the vehicle *(internal parameter, it may vary through iterations)*.

v_A: Automated speed.

Figure 5. Flowchart of the experiment to find the maximum speed attained by the driving automation system without disengaging.

4. RESULTS

Figure 6 presents the observed automated speed compared to the curve radius. Some aspects were not controlled in the experimentation process, such as the presence of pavement irregularities, cross-section variations, presence of road marking gaps (their type was recorded, but homogeneity could not be ensured), lighting conditions, etc. These aspects, in addition to the vertical alignment, might also cause disengagements. Since the objective of this research was to identify how the horizontal alignment affected the driving automation system, all disengagements clearly triggered by non-horizontal-related factors were removed from the analysis. These events are depicted with crosses in Figure 6, highlighting two types:

- Curves showing a disengagement event probably triggered by overlap with sharp vertical curves and presence of on/off ramps. These crosses have a non-null v_A value.
- Curves for which the system was already disengaged before entering them due to other factor, so it was impossible to determine the effect of the isolated horizontal curve. These events are shown as $v_A = 0$.

Finally, the total amount of valid automated speed values was 132.

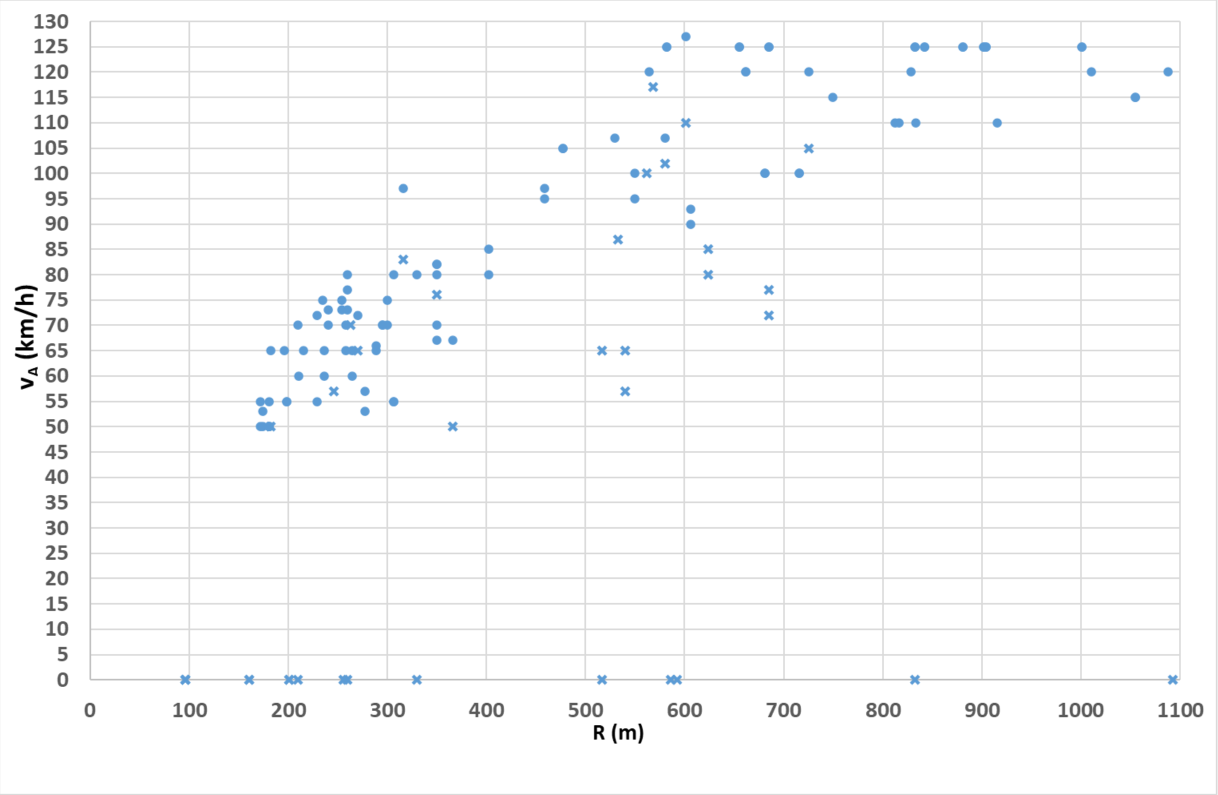


Figure 6. Results of the experiments.

After the data collection process, it was clear that speed had a strong relationship to disengagements. The automated speed seems to be clearly connected to curve radius, although some dispersion can be observed due to other factors. In addition, the system performance could not be tested for speeds much higher than the speed limit. On the other hand, the LKA did not operate for curves sharper than 170 m (even for speeds lower than 50 km/h), indicating a possible strong technological limitation of this LKA system.

The automated speed (*AS*) can also be expressed as a function of the Curvature Change Rate (CCR, expressed in gon/km). This relationship presents a hyperbolic shape, with a horizontal asymptote for $v_A \rightarrow 50$ km/h (Figure 7).

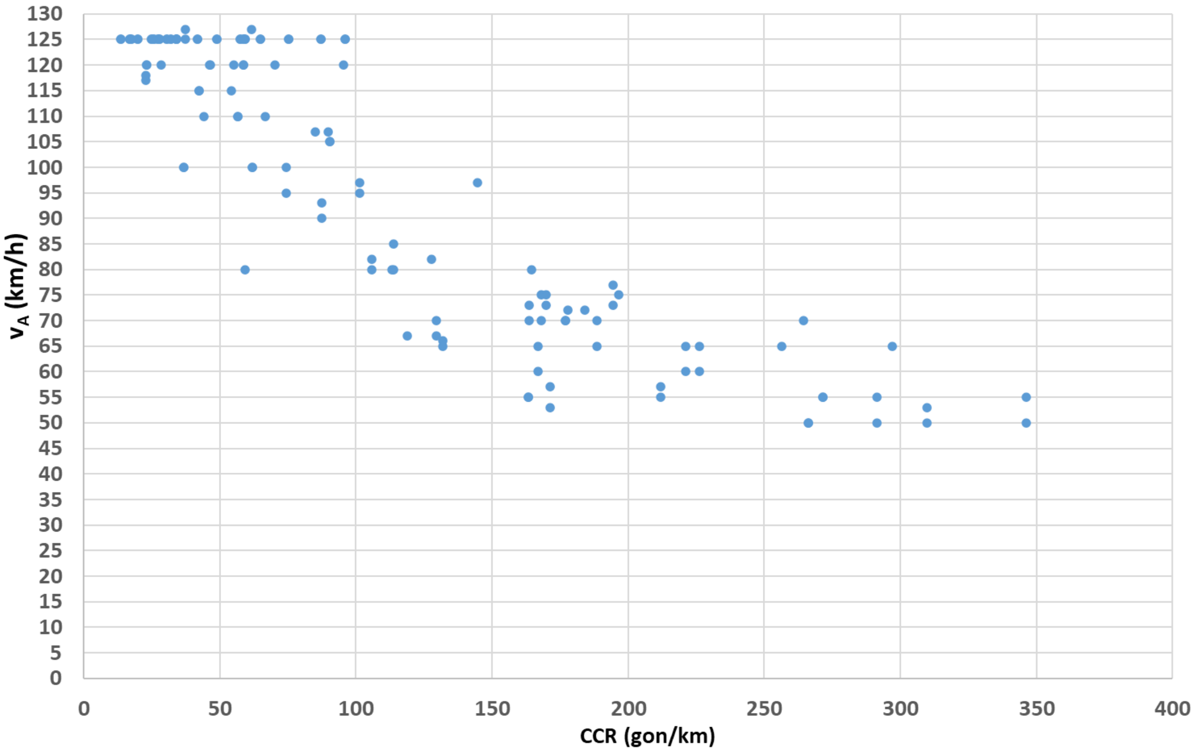


Figure 7. Automated Speed based on the curve CCR.

5. ANALYSIS

Automated Speed can be related to radius and CCR via two models, as follows:

- As a function of the radius ($R^2 = 84.42\%$):

$$v_A = \begin{cases} 16.36 + 0.2299 \cdot R - 0.0001274 \cdot R^2 & \text{if } R \leq 901.7 \text{ m} \\ 120 & \text{if } R > 901.7 \text{ m} \end{cases}$$

- As a function of CCR ($R^2 = 85.01\%$):

$$v_A = \begin{cases} 140.45 - 0.541 \cdot CCR + 0.000831 \cdot CCR^2 & \text{if } CCR \leq 325.3 \text{ gon/km} \\ 52.5 & \text{if } CCR > 325.3 \text{ gon/km} \end{cases}$$

Where v_A is the automated speed (km/h), R is the radius of the horizontal curve (m), and CCR is the Curvature Change Rate (gon/km).

Figure 8 represents both models, compared to the collected data.

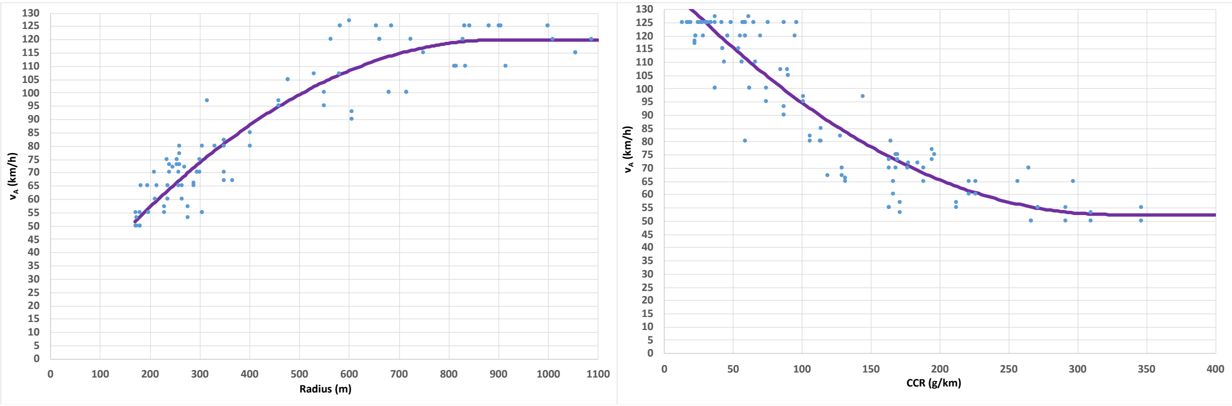


Figure 8. Automated speed as a function of curve radius (left) and curve CCR (right).

It is important to highlight that these correlations have been performed to all disengagements clearly related to horizontal geometry – although other aspects might partially affect, too. This is why all disengagements clearly triggered by non-horizontal factors were removed first. In the future, all factors involved in the disengagement event should be studied.

6. DISCUSSION

Automated Speed has been introduced as a new concept, indicating the maximum speed that can be managed by a certain driving automation system.

Due to the implications of this definition, it is important to compare it to other speed concepts, namely design speed, operating speed and speed limit. Since the analysis was carried out in Spain, Spanish standards (Ministerio de Fomento, 2016) will be used as reference. Figure 9 compares the Automated Speed to the design speed (as a function of curve radius), and the operating speed (85th percentile obtained with the model calibrated for Spanish two-lane rural roads (Pérez-Zuriaga et al., 2010)).

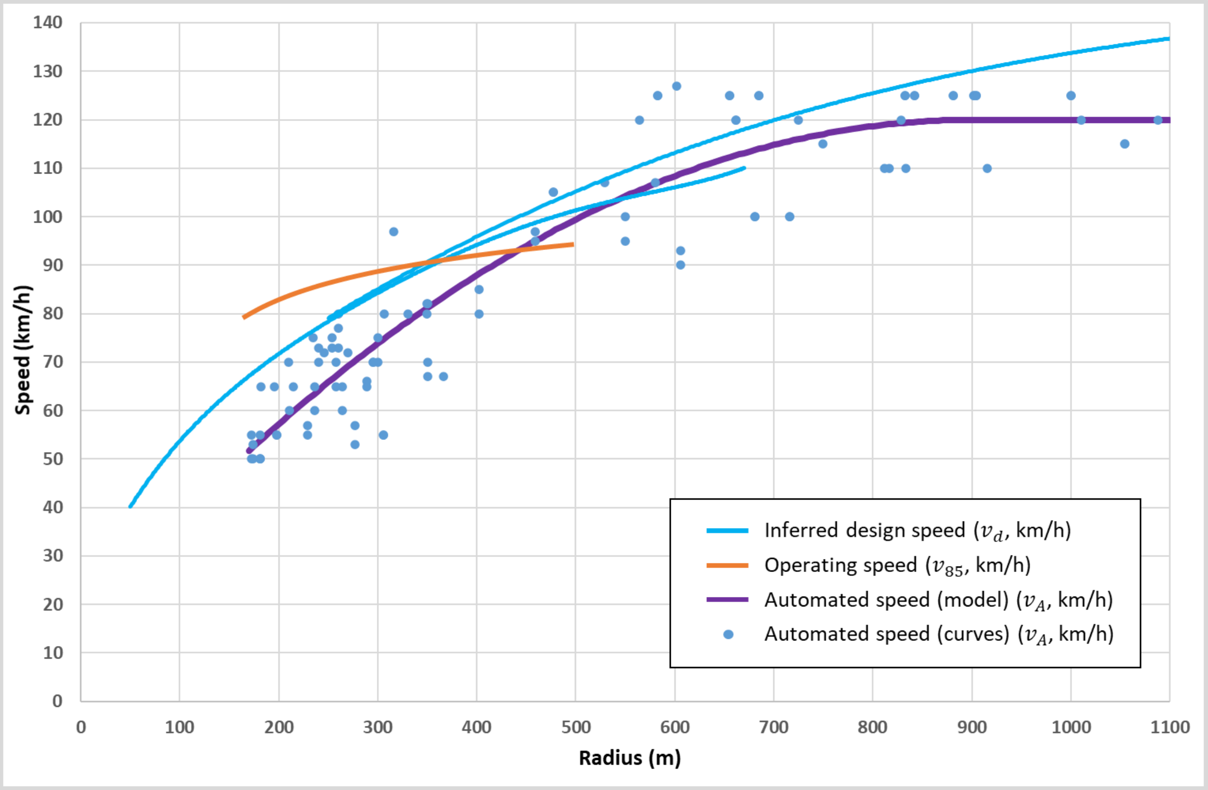
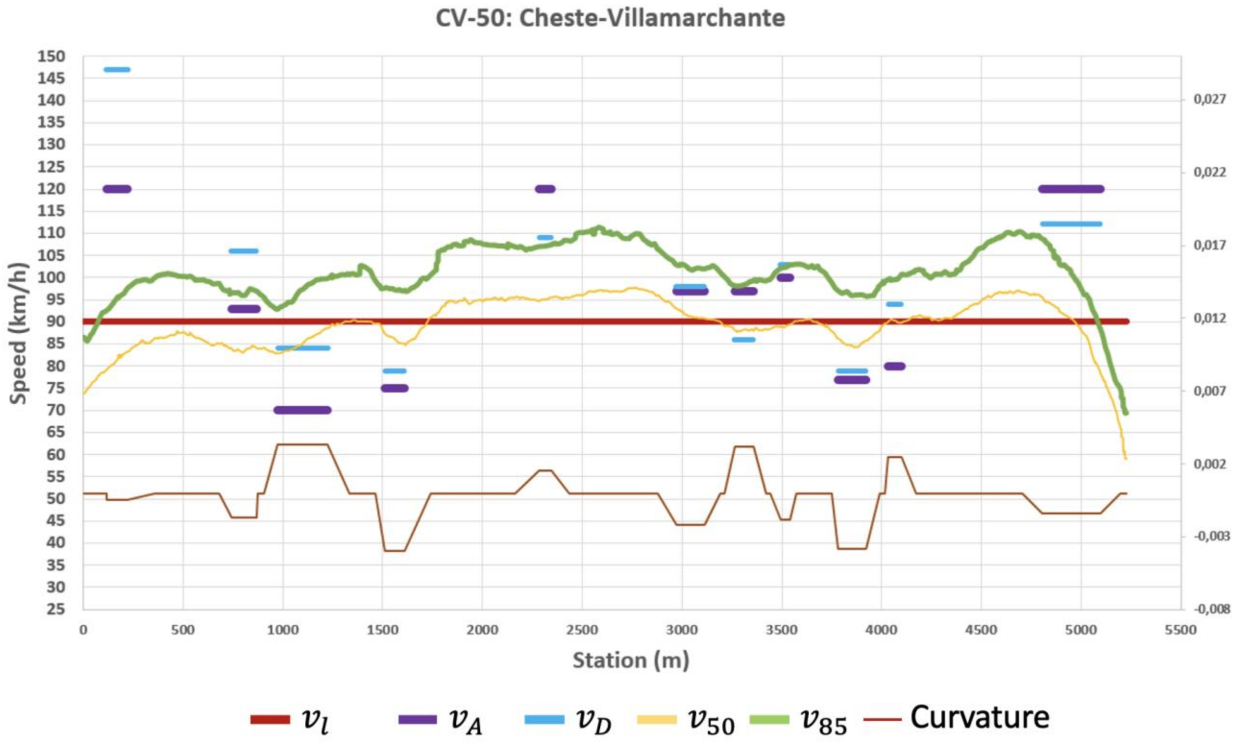


Figure 9. Comparison of the automated speed (v_A) with the inferred design speed (v_d) and operating speed (v_{85}) depending on the radius of the curve. There are two representations of the design speed, provided that Spanish standards use different criteria for lower- and higher-end roads.

A first, important conclusion, is that the Automated Speed is lower than design speed for curves sharper than 550 m. The same applies to operating speed: the 85th-like driver performs faster than the analysed system is able to cope with for curves sharper than 450 m. This has a direct consequence: the LKA system examined is not able to deal with most of the curves on two-lane rural and multilane roads at a reasonable speed. Therefore, the driving automation system will not take control of the vehicle at these curves. This is counterproductive indeed, deceptively reducing the perceived risk.

To see how this condition may impact drivers along a corridor, a 5.5 km-long two-lane road segment was also covered by the test vehicle. This road segment was selected because the authors collected continuous speed data from actual drivers in a previous research, following the methodology proposed by Pérez-Zuriaga et al (2013). Thus, the 50th and 85th operating speed percentile speed profiles were available. The road segment connected two towns – Cheste and Villamarchante, and its geometry was recreated to determine the design and automated speeds (Figure 10).


CV-50: Cheste-Villamarchante
Speed (km/h)
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
0,027
0,022
0,017
0,012
0,007
0,002
-0,003
-0,008
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Station (m)
v_l
v_A
v_D
v_{50}
v_{85}
Curvature

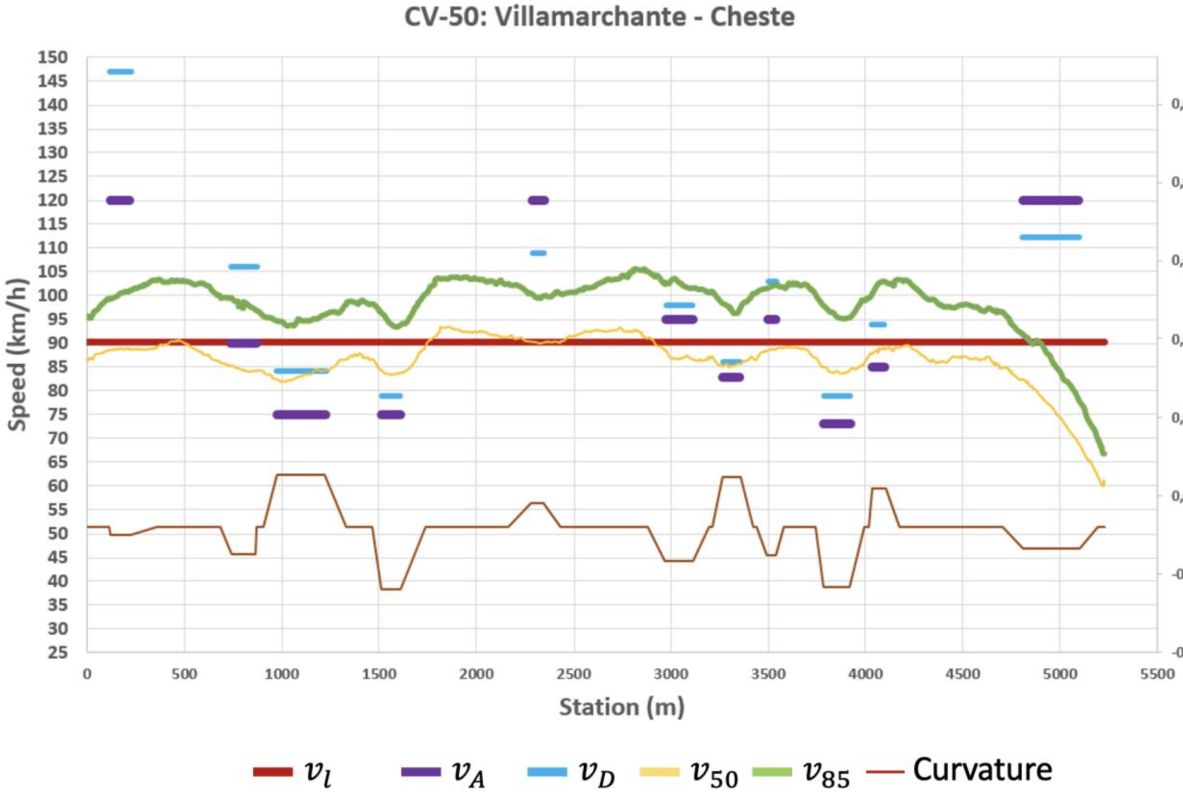

CV-50: Villamarchante - Cheste
Speed (km/h)
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
0,027
0,022
0,017
0,012
0,007
0,002
-0,003
-0,008
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Station (m)
v_l
v_A
v_D
v_{50}
v_{85}
Curvature

Figure 10. CV-50 road speed profiles, between Cheste and Villamarchante (forward and backward directions). v_l: speed limit, v_A: automated speed, v_d: inferred design speed, v_{50}: 50th percentile of the operating speed, v_{85}: 85th percentile of the operating speed.

It can be seen that in 4 curves in the forward direction and 5 in the backward direction (out of 11 in both cases), automated speed is lower than speed limit (90 km/h). The automated speed is also lower than the 50th percentile of the operating speed in these curves, and below the 85th percentile of the operating speed in 8 curves (considering both directions). The test vehicle was driven at 90 km/h, being disengaged 35% of the time. The curves that were not expected to disengage performed correctly.

In conclusion, automated speed for this system has been found to be below most design and operating speeds of the corridor, especially at curves with radius lower than 500-600 m. This high disengagement rate makes the system unreliable along this corridor. Provided that the LKA does not negotiate the vehicle but prevents road departure, the driver might overlook this issue along this corridor, if no accidental departures take place.

It is important to highlight that there are other ADAS that work on the lateral negotiation from other perspectives. The Lane Departure Warning (LDW) alerts the driver about lane departures, with no action on the vehicle negotiation. The Lane Centring Assist (LCA) continuously negotiates the lateral position of the vehicle, just releasing control to the driver if disengaged. The consequences of a disengagement event for any of these technologies differs:

- LDW systems: since the driver is responsible for the steering action, their attention on the road tends to be maximum at sharper curves. Distractions may happen at smoother ones, with occasional intervention of LDW. Fortunately, these ADAS are less likely to disengage at these curves.

- LKA systems occasionally take control of the vehicle, but the driver is continuously negotiating the lateral position. As a result, the disengagement implications are similar to LDW. However, it is important to highlight that the system is not designed for continuous assistance of the driving task, so drivers of vehicles equipped with these systems must be clearly aware of these limitations.
- LCA systems perform the lateral negotiation of the vehicle, which might reduce the driver's attention on road. Therefore, a disengagement is clearly undesirable since it would abruptly transfer the control to the driver. The higher the time between disengagements, the higher the driver's distraction; so paradoxically, a better system might have worse safety implications until Level 4 is achieved.

Regardless the type of ADAS, these might be based on very different technologies, which hamper a detailed assessment. In addition, many of them are protected as industrial secrets, so their limitations might not be explicitly analysable. However, the methodology proposed in this paper is replicable and can explicit the geometric limitations of these systems in an indirect – and verifiable – way. Thus, every driving automation system can be analysed, plotting its automated speed as a function of curve geometry. Further experiments following this methodology should try to limit the existing variability, e.g. by controlling these parameters:

- Road segments should be flat, to prevent interaction with the vertical alignment.
- Road markings should be neat and with a constant pattern (solid and/or dashed, with no gaps and/or on/off ramps).
- Weather conditions affect how road markings are perceived.
- Road segment orientation, and presence of sun glaring that might impede correct perception of other users and road markings.

This automated speed – curve geometry characterization can be used in two ways:

- Manufacturers can set a clear goal for the technological development of their driving automation systems (for instance, making sure that their systems do not disengage at a certain percentile of the operating speed). In fact, the automated speed is a dynamic parameter – evolves with technological development.
- Road authorities can establish minimum requirements for driving automation systems to achieve. This would help establishing harmonized and controlled Operational Design Domains (ODDs) for Automated Vehicles, fostering the development of Level 4 AVs.

Reaching Level 4 driving automation systems should be set as a major priority, in line with establishing clear ODDs. A lower-level system would present – more or less – disengagements. Counterintuitively, a system causing less disengagements might be less safe than a system that presents more: a lower-end LCA system that presents many disengagements does not produce major impact on drivers' attention, since the driver might be expecting one. However, a higher-end system would follow the road path better on average, reducing the driver's attention. After long time performing well, the driver would be less active to successfully react to an unexpected transfer of control.

Thus, a new concept can be introduced: the **automated driving consistency**, defined as the difference between the automated speed and the operating speed. A higher value implies that the AV can perform autonomously along the curve with less problems. A negative value indicates that the operating speed is higher than the automated speed, so the system is likely to disengage – since many other factors affect, this consistency criterion does not produce a True/False result of the driving automation system performance.

For a single curve, the lower this parameter, the higher the disengagement probability. This does not necessarily imply a lower level of safety, since it also depends on how consistent the whole corridor is. A corridor which presents many curves with low automated driving consistency would not be a safety concern. Instead, the corridor would not be ready for current AV technology, and drivers would prefer human driving. On the other hand, a corridor with a few curves showing low consistency are a safety concern: drivers would be willing to drive in automated mode, but an unexpected disengagement would arise when the inconsistent curves are reached.

This issue will be addressed as soon as Level 4 vehicles are available for clear ODDs. Meanwhile, other solutions could be used to characterize road corridors and therefore match their geometric layout to the performance of Level 2 and Level 3 driving automation systems.

A possible solution is introduced as the **Level of Service for Automated Driving** (LOSAD). Like other Level Of Service indicators, it may characterize how well a certain driving automation system performs along a certain corridor. This parameter would differ among vehicles, provided the different capabilities they present. The LOSAD could be based on the expected disengagements along a corridor for a certain driving automation system (e.g. A: no disengagements, B: disengagements every 30 minutes, C: disengagements every 20 minutes, D: disengagements every 10 minutes, E: disengagements every 5 minutes, F: almost all corridor producing disengagements). This information could be calculated by every driving automation system using the road geometric layout (extracted from the HD maps of the GPS navigator) and compared to its capabilities (as explained above). This information could be shown to drivers in navigators, like nowadays traffic information is shown. With it, drivers would know in advance whether to connect or not the autonomous driving mode. In this case, reliable and updated HD maps should be provided by road administrations.

This new concept should not only be based on horizontal alignment, but consider vertical alignment, cross section, and other limitations that might cause disengagement and have not been controlled in this paper. A global consideration would allow us consider all curves along the roads examined in this paper, as well as reduce the observed variability.

7. CONCLUSIONS

A strong correlation between horizontal curvature and the automated speed has been found. Automated speed has been defined as the maximum speed that a certain driving automation system can attain along a certain geometric layout (horizontal curves in this research). This speed has also been found to be well below design and operating speeds for sharp-to-medium curves. As a result, the examined driving automation system can operate along high-end freeways but cannot on most two-lane rural roads.

A lower automated speed would result in a) vehicles operating at a lower speed that a human driver would, or b) vehicles disengaging at a variable number of curves. Thus, road administrations should focus on establishing clear automated speed requirements as a function of road geometry, and vehicle manufacturers should concentrate on developing technology to fulfil these ones.

Two new additional parameters have been introduced: the automated driving consistency and the Level Of Service for Autonomous Driving (LOSAD). The former refers to the difference between the automated and operating speeds. The lower this value, the more likely a certain system is to disengage. The latter summarizes how ready a corridor is for a certain driving automation system, by comparing the corridor geometry to the driving automation system capabilities. This information should also be provided by the GPS navigator, so the driver can take a decision about using the autonomous driving mode or not.

Finally, it is important to highlight that the automated speed values shown in this paper strictly apply to the vehicle tested for it. These cannot be extended to other systems. However, this paper establishes a framework on how these systems might be checked and how their geometric-related limitations might be compared to the road infrastructure. Additional research should be directed towards determine on how close other systems' limitations are. Other types of roads, traffic conditions, geometric layouts, vertical alignment, cross section, road markings, weather and sun glaring, etc. should also be explored to find similar limitations or synergic constraints. A global consideration will allow us define LOSAD more accurately.

AUTHOR STATEMENT

Alfredo García: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing – review and editing, supervision, project administration, **F. Javier Camacho-Torregrosa**: conceptualization, formal analysis, writing – review and editing, visualization, **Pedro Baez**: investigation, writing – original draft.

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