Smart Transportation Alliance

ADAPTATION OF ROAD INFRASTRUCTURES TO THE NEW MOBILITY

TECHNICAL REPORT 2/2019

June 2019

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1. Introduction

At the European level, the transport sector accounts for approximately 5% of gross added value and employs 11 million people, with road transport representing 32%.

These figures show the importance of road transport and it explains why the European Union has set ambitious targets in order to increase sustainability without harming the economic competitiveness of the Union.

To achieve these objectives, the European Union has fostered innovation to modernize the car fleet and to develop electric vehicles with European technology. An example of this commitment is the Horizon 2020 Green Vehicles programme, followed by specific calls for the development of the electric vehicle.

In addition to vehicle innovation, it is necessary to implement plans that accelerate, as far as possible, the adaptation of infrastructures to this new reality, using public and private resources to adapt the transport sector to future social demands.

We must not forget the importance that ‘intelligent management systems’ will have on the modernisation and improvement of our means of transport and specifically on road transport. Infrastructures must play a fundamental role in our present and future development, improving the efficiency and safety of these new technologies.

2. A new paradigm

The transport sector and, in particular the road freight transport segment, is undergoing such a profound revolution that it is likely that current vehicle and infrastructure assets will become obsolete within a few years.

The Internet age, digitalisation, the 4.0 economy, electric vehicles and autonomous vehicles will require a radical change in infrastructure, opening new opportunities for traditional sectors. To understand these opportunities, it is first necessary to analyse the evolution of intelligent transport systems, the electric vehicle and the autonomous vehicle.

2.1. Electric Vehicles

Pollution problems in cities, the need to transfer CO_2 emissions from the so-called diffuse sectors to regulated sectors, and the higher efficiency of electric vehicle motors have led Public Administrations to promote the integration of this type of vehicle into the vehicle fleet.

Non-pluggable hybrid vehicles are now a technological reality. However, plug-in hybrid vehicles and 100% electric vehicles do not yet enjoy a significant market share. One of the reasons is their lack of economic competitiveness, but another relevant cause is the lack of adaptation of current roads to their needs.

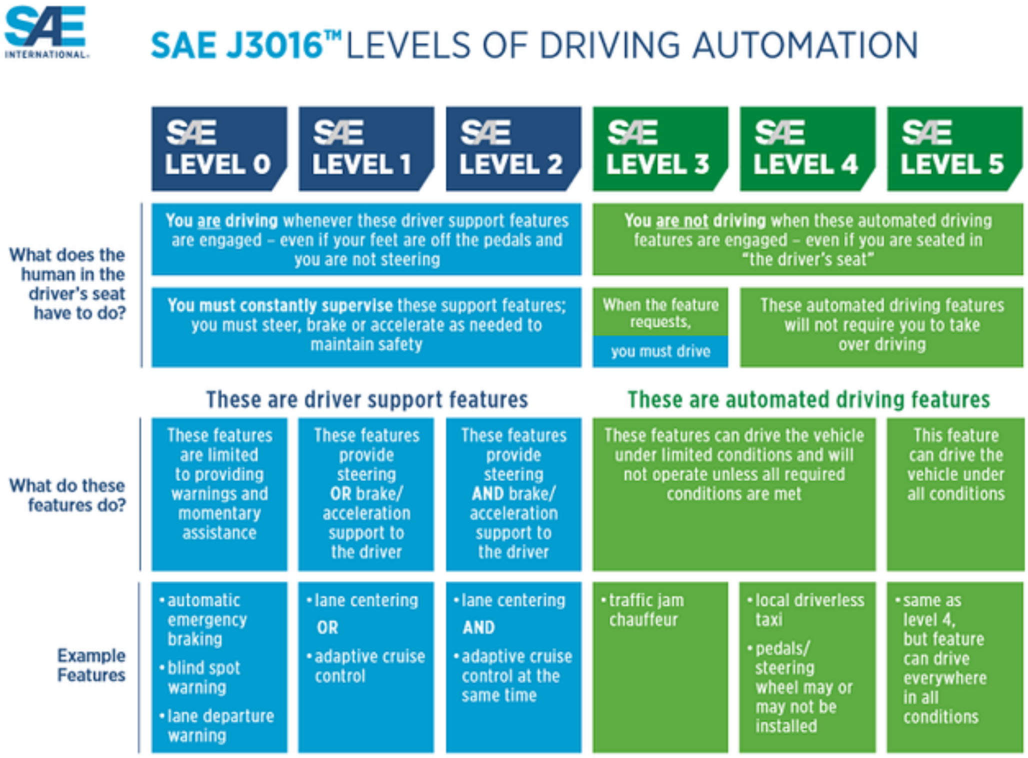
The electric vehicle needs an infrastructure that allows easy access to charging points. Currently, there are very few static charging stations and the 'continuous charging while driving' concept is non-existent. Solving this deficit is a challenge for the road sector, which must increase the autonomy of the electric vehicle, either through inductive systems or through physical contact systems, thus reducing or even eliminating the uncertainty of charging.

2.2. Autonomous vehicles

An autonomous vehicle is a vehicle that is capable of imitating human driving and control abilities, being able to perceive the environment that surrounds it and move accordingly.

Although it may seem recent, the origin of autonomous cars dates to the 1940s, where vehicle guidance tests were carried out by soaking materials into the pavement that could be detected and followed. Later, as early as the 1980s, the detection of obstacles via radar was achieved.

Today, there is a set of technologies that include the latest advances in geolocation, identification and environmental analysis, thanks to camera motion recognition and laser detection systems. Between 2020 and 2024, motorway autopilots are expected to become common and the automatic overtaking and lane change function is also expected to be added. Automatic city traffic will be technologically feasible around 2030 and completely autonomous driving is expected by 2050 [1], [2].



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 Autonomy levels of a car (source: Society of Automotive Engineers)

2.3. Cooperative systems

ITS (Intelligent Transport Systems) includes the so-called Cooperative Intelligent Transport Systems (C-ITS), based on communications and information exchange between vehicles (V2V), vehicles and infrastructure (V2I), and between different points of the infrastructure (I2I).

Cooperative systems make it possible to implement a wide variety of applications and services to improve safety, increase driver comfort, reduce the environmental impact caused by transport, improve the capacity of existing infrastructure, increase transport efficiency and improve the productivity of all companies, but especially transport companies.

In addition to having its own data and perceiving its environment by means of sensors, a vehicle connected to a cooperative environment receives information from other vehicles, from the infrastructure or from traffic centres. In this way, the driver increases his time and geographical horizon, which favours more efficient and safe driving. On the side of infrastructure managers, the continuous flow of infrastructure-vehicle information facilitates maintenance work, mobility management and more efficient management of both the capacity of roads and transport resources.

In recent years, various C-ITS systems and services have been developed, some at the prototype level, but with others already implemented in real environments. Among the technologies on which the cooperative services are based, we can mention Wi-Fi, UMTS, Bluetooth or Radio Frequency Identification (RFID). On the other hand, for V2I/I2V and V2V communications to be possible, it is necessary for the vehicle to be equipped with on-board devices that allow communications, such as an information transmitter, commonly known as OBU, or a Smartphone or Tablet PC.

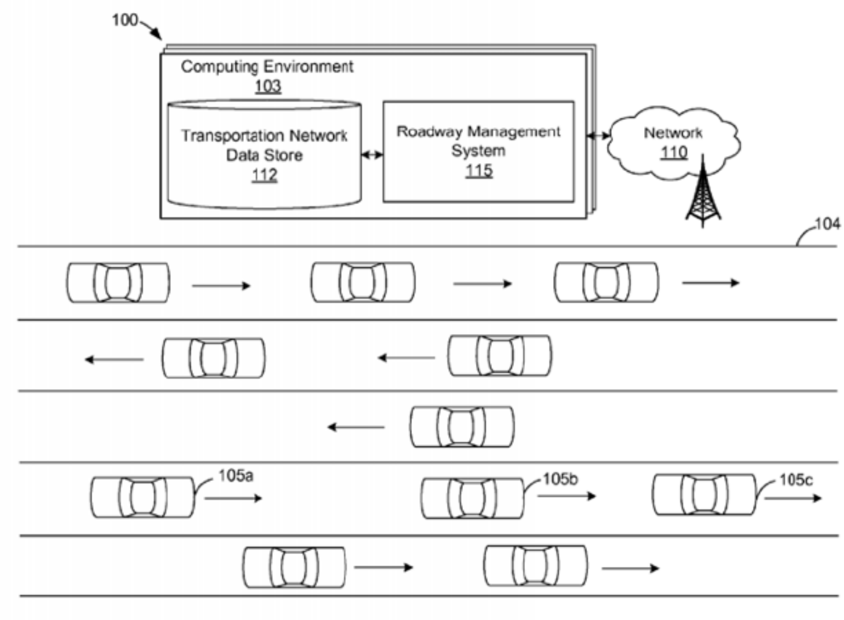


Figure 2. Detail of the dynamic system patented by Amazon

3. Infrastructure: a new opportunity

The technological revolution described in terms of vehicles and communication between vehicles and infrastructure will determine the future design of roads, which will necessarily have to adapt to the new reality.

Each one of the developments described (electric vehicle, autonomous vehicle and cooperative driving) has different infrastructure requirements that must be integrated for joint use.

3.1. Road requirements arising from cooperative driving (C-ITS)

Cooperative driving, which requires the use of new technologies that must be conveniently housed in the infrastructure in an efficient and practical way, makes it necessary to have a durable infrastructure that offers structural and long-term protection.

The infrastructure must protect a technology with high added value and costs, while allowing access for repair and upgrade. In this sense, pavement and safety barriers must function as service galleries where high-technology devices may be embedded. There is high divergence in the relative development velocities of technology and infrastructure, and it is necessary to combine and align both.

In addition to the need for protection, cooperative driving also has relevant implications for road conservation. When a vehicle detects a risk associated with poor road conditions (possibility of skidding, wet or icy pavement, deteriorated road surface or safety barriers, etc.), it will transmit this information to the rest of the vehicles, which will modify their driving behaviour accordingly, for example, adapting their speed to the road conditions or choosing an alternative route. Road condition will thus play a decisive role in the efficiency of new technologies and road transport.

3.2. Road requirements arising from the use of the electric vehicle

Charging stations with fixed electrical outlets can charge batteries when electric vehicles are parked in public spaces such as office, shopping or leisure centre car parks. This solution may be suitable for well-planned and relatively short journeys, eliminating or reducing so-called "range anxiety". However, it is clearly insufficient for regular unplanned trips or for vehicle fleet operators, such as taxis or buses. These difficulties are exacerbated in the case of road transport vehicles, where stops have a direct impact on the service provided. It is also clear that both this type of vehicle and road freight vehicles cannot make stops beyond those established by regulations, and neither is it operationally desirable to wait long enough for the battery to be sufficiently charged.

The answer to these problems can be provided by the so-called electrified roads (eRoads), where the vehicles receive the necessary electric energy while driving without the need to stop (dynamic charging). This concept is still in development, but some test sections have already been built with positive results.

The systems used can be classified as follows:

a. Direct contact between the vehicle and the energy supply element.

b. No contact between the vehicle and the power supply element (wireless charging).

Figure 3. eHighway for freight transport developed by Siemens

Siemens built the first section of type ‘a’ in the United Stated in 2014, under the name ‘eHighway’. This consisted of hybrid heavy vehicles combined with intelligent energy collectors powered by catenaries [3], [4]. In California tests were carried out on the road between Los Angeles and Long Beach (about 3 km long) together with the manufacturer Volvo, assisted by favourable state legislation. In 2015, another catenary system for hybrid trucks of the company Scania was installed in Sweden on a stretch linking the cities of Dalarna and Gävleborg, 2 km away, thanks to a contract tendered by the Swedish Transport Administration.

Although the results are positive, the system presents the disadvantages of catenary-based methods: among others – visual intrusion, occupation of lateral space, gauge limitations in existing tunnels, possible acts of vandalism, protection against vehicle crashes, etc.

On the other hand, the wireless charging systems are mainly based on inductive transmission of energy. There is a coil inside the pavement where an electromagnetic field is created that reaches a pad or plate placed on the underside of the vehicle. There is a reciprocal coil in the vehicle plate, in which electrical current is induced, thanks to the electromagnetic field emanating from the coil road plate, thus charging the battery.

Wireless magnetic induction charging is being used in many devices in addition to electric or hybrid vehicles. Given the great interest that has been aroused, wireless charging techniques are being developed by different academic institutions and businesses [5]:

- TU Braunschweig, Germany: Contactless Power System (CPS).
- Auckland University, New Zealand: Inductive Power Transfer (IPT).
- MIT, USA: WiTricity.

- Other specific developments of companies and institutions, such as KAIST (South Korea).

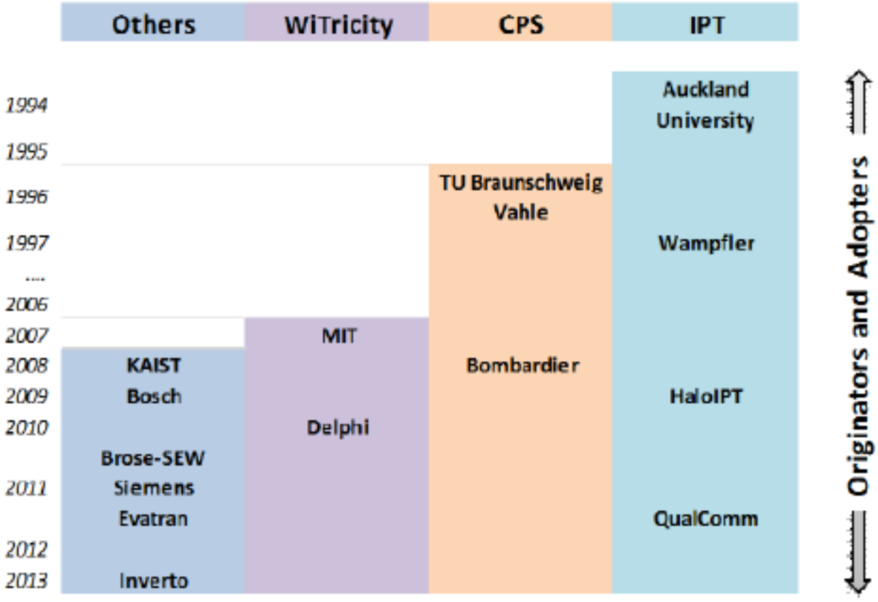


Figure 4. Main inductive wireless charging methods and their applicators

Most have been used only in static charging systems, but there is also experience of their use in dynamic charging of both cars and buses.

In the city of South Korean city of Gumi, two electric buses were tested in 2013. This important development was carried out by the Korean Advanced Institute of Science and Technology (KAIST) using OLEV (Online Electric Vehicle) technology. Cables housed inside the pavement provide electrical power to vehicles traveling on its surface. The buses were able to travel 24 kilometres, while maintaining the electromagnetic levels within safety limits, which are one of the main pitfalls in the use of this technology. The OLEV system only supplies energy when the presence of a bus is detected, thus minimising the risk to pedestrians and other vehicles.

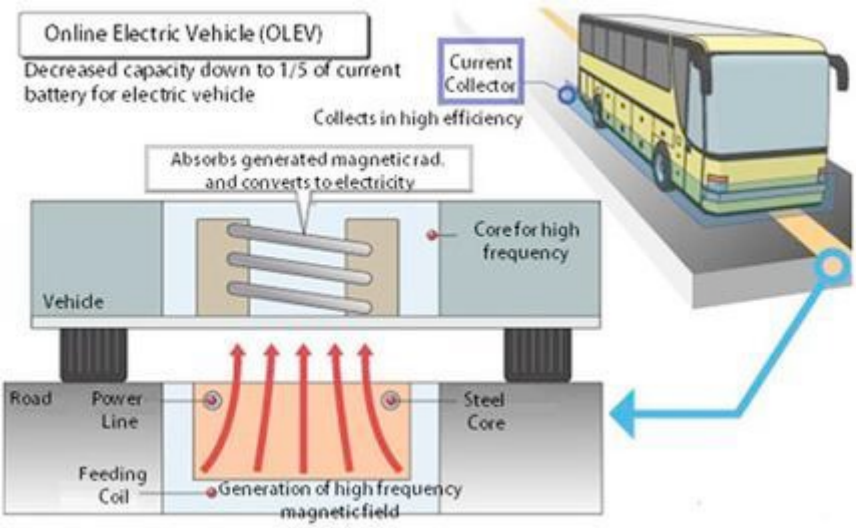


Figure 5. Detail of the OLEV System developed in South Korea in 2013

Simplicity is one of the strong points of the OLEV system: electric vehicles do not have to be equipped with large, heavy batteries, and stop times for charging are eliminated thanks to its dynamic wireless charging system.

Endesa carried out the Victoria Project in Spain in 2015, where the main objective was to wirelessly charge a moving electric bus. Moreover, the project achieved a pioneering global first: the triple charging mode, which combines conventional static charging, static induction and dynamic induction, making it possible to double the autonomy of the electric bus without detriment to operating times. This system requires installation of the primary electrical coils in watertight, concrete housings at different sections inside the pavement.

Highways England, the state-owned company that manages England's road network, already started a programme of motorway test sections in 2015, equipped to dynamically charge cars and has a plan to install these devices on fast lanes every 32 kilometres, within the next 5 years.

The most recent development belongs to the Israeli company Electroad, which has worked with this type of wireless technology since 2017 to modernize existing roads by placing buried coils that inductively charge moving electric vehicles. The company has successfully tested this technology and it is currently developing electric roads for a public bus route in Tel Aviv. Electromagnetic radiation has been minimized by using shielding, thus ensuring the safety of the driver and passengers.

Within the broad experience of dynamic charging, it may be interesting to detail a trial program carried out in Belgium between 2010 and 2013 [6]. The program was promoted by the Flemish Administration and funded by both them and nine industrial partners (including Bombardier), with two universities also participating.

A 500 m long and 20 cm thick trench was excavated in an existing asphalt section of the N769 road near Lommel in the north of the country, with in-built loops to generate electromagnetic fields. The loops were installed with a 5 cm distance to the surface. The trench was then filled with 125 m of concrete and the rest with asphalt mixtures. During the tests, the section was closed to ordinary traffic.

The figure shows various details of the trench and loops, as well as the concrete pavement, first under construction and then in service.

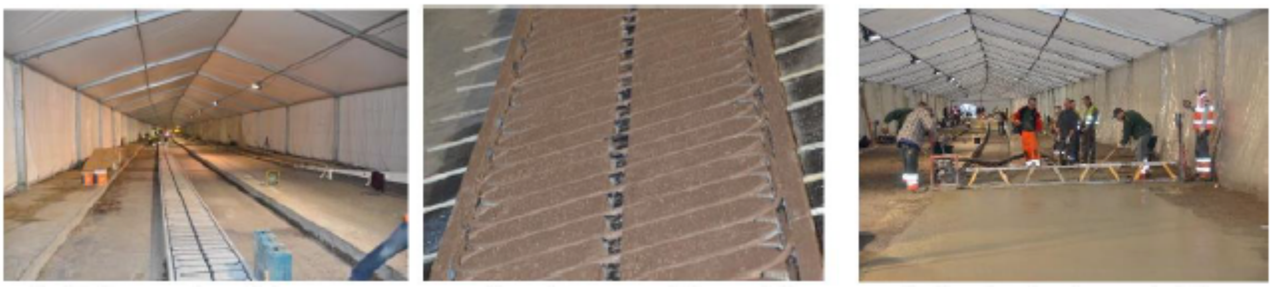


Figure 6. Construction of the concrete test section and details of the induction loops

Figure 7. View of the concrete test section

Both static (stationary vehicle) and dynamic (moving vehicle) load tests were performed. During the latter, a vehicle detection system enabled the corresponding module to be activated, leaving those whose energy could not be captured by the bus uncharged or inactive. A light vehicle was also used in the static tests.

One of the topics studied in the section was the influence of vehicle deviations on the transmission efficiency of the energy generated in the pavement. According to the results obtained, which are shown in the following figure, vehicles should not deviate more than 30 - 40 cm from their original trajectory in order to obtain a transmission efficiency over 80%.

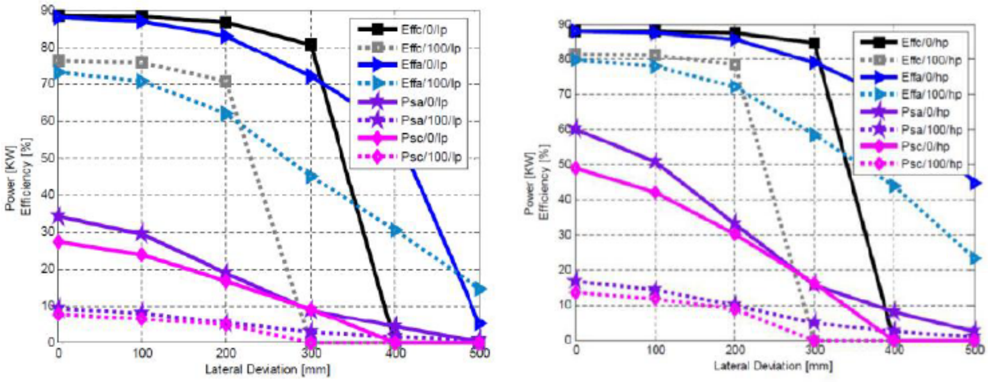


Figure 8. Energy transmission efficiency in concrete and asphalt sections as a function of lateral and height deviations with low (left) and high (right) energy supply.

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The results show that inductive, dynamic charging methods benefit most from autonomous driving, as they should have at least one guidance system to limit their direction of travel achieve maximum induction efficiency.

Other conclusions of the Belgian trial that can be highlighted are the following:

- It is possible to achieve energy transmission efficiencies of around 90%, which is only about 4% lower than those obtained with a cable charge.
- Satisfactory charging can be achieved even with gaps of 10 - 20 cm between transmitter and receiver.
- It is possible to transmit 100 kW of power.
- The dynamic transmission of energy is possible both from the point of view of its integration into the pavement and from the perspective of the design of the inductive system.
- The performance of the dynamic system was similar to the static one.
- The closer the loops are to their theoretical position, the better the results.

In summary, achieving greater than 80% wireless charging efficiency demands of the infrastructure a combination of the protection of the embedded systems (the same as for cooperative driving), and the use of autonomous driving systems, thus preventing vehicles from moving further than 30 cm from the optimum trajectory.

3.3. Road requirements arising from the use of the autonomous vehicle

Although there are several technologies currently under development for autonomous driving, as mentioned above, all of them must in general have lateral guidance systems, especially on motorways and high-capacity roads. Of these, the following guidance systems stand out:

- Optical (road markings on the pavement captured by a camera installed in the vehicle).
- Magnetic (magnetic elements on the surface or installed inside the pavement, which generate a reference magnetic field that is measured by a sensor).
- By cable (of a similar concept to the previous one, in which an electric cable installed inside the pavement generates a magnetic field).
- GPS systems, and especially the so-called DGPS (Differential Global Positioning System), which makes it possible to achieve an accuracy of 2 to 5 cm.

Each system has advantages and disadvantages, so at present it is not possible to say which of them has the greatest potential. On the other hand, if one of the objectives of autonomous mobility is to drive as independently as possible, it will be necessary not to entrust all the responsibility to a single guidance system, but to use two or more that are complementary and that prevent guidance failure in the case of breakdown or adverse weather conditions.

Regardless of the system used, the vehicle wheel paths will be concentrated in two relatively narrow bands over the width occupied by the contact traces of a pair of twin wheels plus 30 - 40 cm on each side, leaving the central part with residual traffic load.

The consequences of this new type of roadway on the pavement are more important than might be expected. The study "Effects of Wide Single Tyres and Dual Tyres" draws an interesting conclusion about how the concentration of treads in reduced bands, which is a consequence of autonomous guidance systems, can increase the permanent deformation of pavements by more than 30%, thus accelerating their degradation.

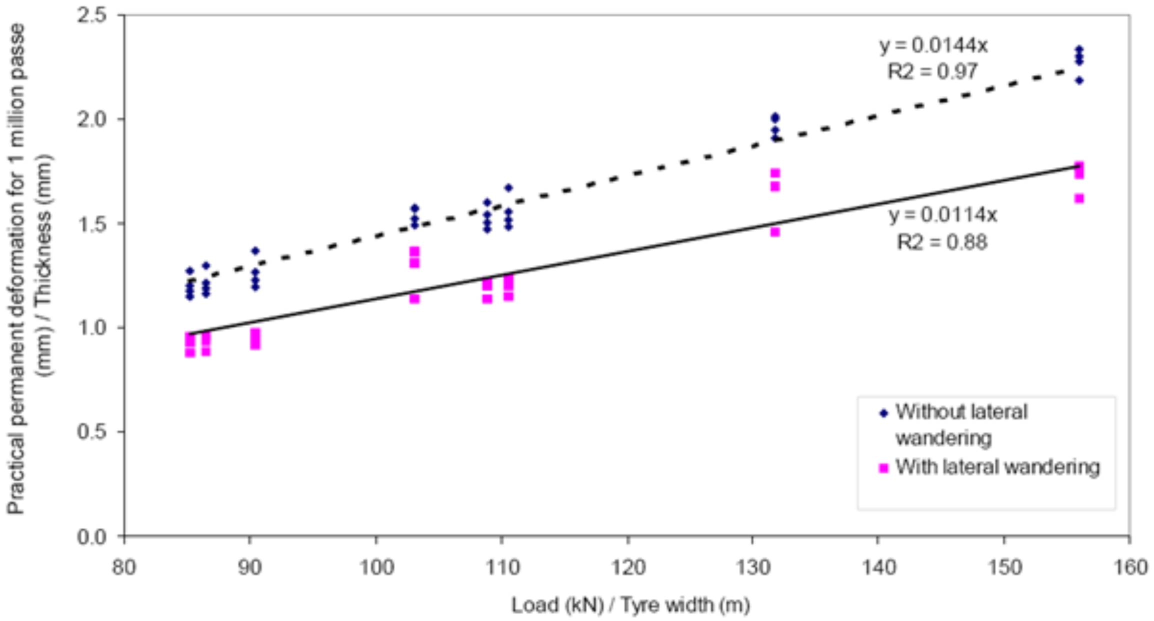

Figure 9. Relationship between permanent deflection rate, thickness of viscoelastic layers and load configuration for different tyres and structures

The structural integrity of the pavement will not only affect driving comfort, but also the accuracy of the guidance systems.

4. Adaptation of infrastructure to new demands

Although there are still many technical aspects to be developed, the transport of goods by road will in the near future be articulated around electric with dynamic charging. This new type of transport will require the road to:

- Have enough structural capacity to protect the embedded systems.
- Allow access to installed systems for repair and upgrade.
- Maintain surface characteristics over the long term to ensure the efficiency of cooperative driving.
- Tolerate plastic deformations that do not jeopardise both the technology embedded in the pavement and the effectiveness of the guidance system.

Consequently, it can be said that future roads must be durable, must not suffer permanent deformations that are incompatible with autonomous and electric mobility, must resist impacts (safety barriers) without large deformations, must protect technology and must permit its replacement without further disturbance.

In the specific case of road surfaces, both micro and the macrotexture of the surface must last for 30 years, thus ensuring that, during this period, the slip resistance and the surface water evacuation capacity of the pavement will remain optimal. Consequently, the efficiency of the cooperative conduction systems will not be affected, especially with regards to vehicle velocities.

5. Conclusions

Intelligent, electrified, cooperative and autonomous driving in road transport is assumed to be the European Union's main means of achieving non-polluting, safer, quieter and more efficient transport.

However, these intelligent systems will not be implemented on today's roads, but on a new road generation, and it is in this field that a lack of planning is identified. The role that a good road system plays in the socio-economic efficiency and sustainability of transport must urgently be recognised. In the middle of the last century, and especially in the late-1970s, such considerations frequently disappeared from academic debate and have so far not achieved the relevance they deserve.

The accelerated changes taking place in intelligent transport systems, and especially in the fields of autonomous, electric and cooperative driving, offer new opportunities to rethink the role and concept of road infrastructure and its possible contribution to transport efficiency and sustainability. Potential improvements from new road concepts exceed by far the incremental improvements that can be found in the niches of combustion engines, fuels or vehicle design.

These new infrastructures will have to meet a set of requirements: to be able to withstand concentrated loads typical of autonomous systems; to maintain surface characteristics in the long term; and to equip the road with redundant steering and safety systems, which means the placement of multiple embedded sensors, which at the same time must be practicable for maintenance or replacement.

On the other hand, the electrification of the fleet requires an adequate balance between autonomy and charging possibilities. Ongoing charging (continuous or discontinuous) is the ideal solution from both an economic and environmental point of view. This scheme is compatible with complementary systems of combustion engines that charge batteries for those areas that lack the service and, of course, it is compatible with vehicles that have traditional propulsion systems.

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