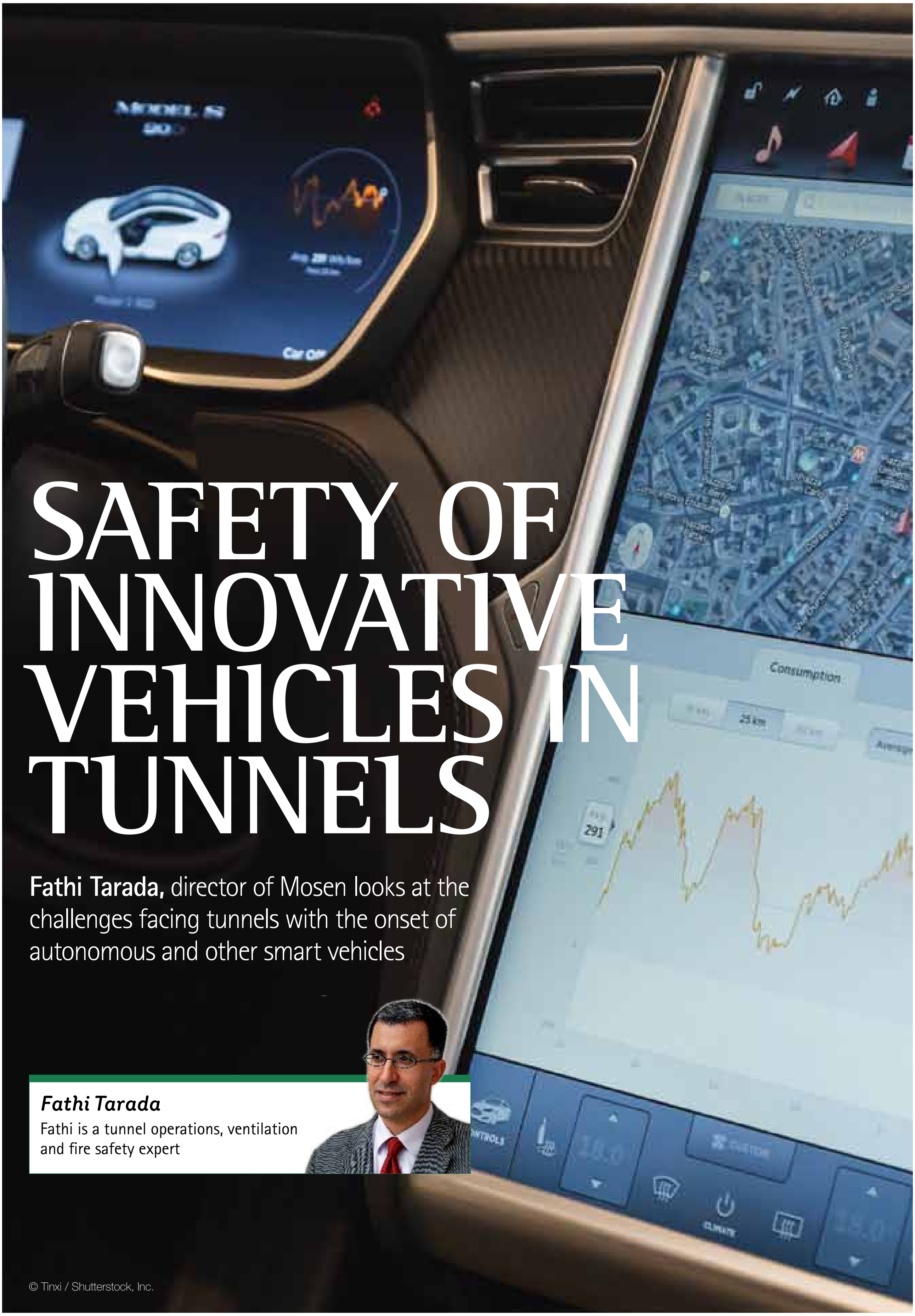

SAFETY OF INNOVATIVE VEHICLES IN TUNNELS

Fathi Tarada, director of Mosen looks at the challenges facing tunnels with the onset of autonomous and other smart vehicles

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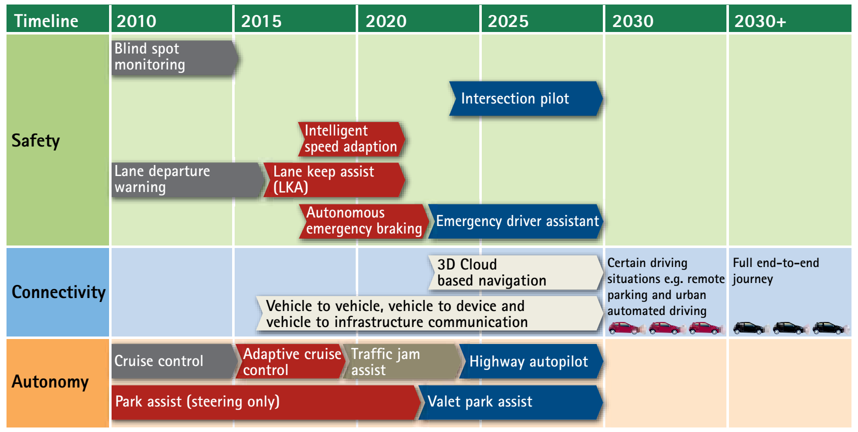
VEHICLE TECHNOLOGY IS EVOLVING quickly, with autonomous cars now a reality, and with an increasing proportion of hybrid and electric vehicles on the road. Such innovation can bring many advantages in the management of traffic flow and the reduction of emissions. However, innovative vehicles can present significant risks to road users, particularly in tunnels. A good understanding of the sources of these risks, and how to mitigate them is essential for manufacturers, designers, tunnel owners and operators, as well as for the fire service.

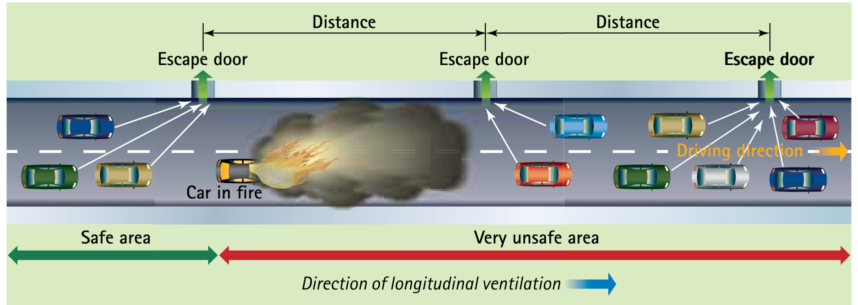
AUTONOMOUS AND CONNECTED VEHICLES

Autonomous vehicles such as those driven by the Tesla Autopilot can sense their environment and navigate without human input, at least in certain traffic conditions and within specific time periods (Figure 1, page 37). They achieve that by using a combination of cameras, radar, ultrasonic sensors and other data to automatically steer along the road, change lanes, brake and adjust speed in response to traffic. Such autonomous vehicles can be connected to the data cloud, uploading locations where braking was manually undertaken to avoid objects, so that other connected cars can benefit from fleet learning.

Although autonomous vehicles are a recent innovation, they actually represent a development of existing technologies including adaptive cruise control to maintain a safe distance from vehicles ahead (for which there is an existing international standard, ISO 15622:2010), on-board satellite navigation systems and steering automation.

The U.S. Department of Transportation's National Highway Traffic Safety Administration has defined five levels of vehicle automation[1], ranging from Level 0 (where the driver completely controls the vehicle at all times) to Level 4 (where the vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time). Along this spectrum, the Tesla Autopilot can be classified as somewhere between Level 2 (at least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping) and Level 3 (the driver can fully cede control of all safety-critical functions in certain conditions; the car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so). KPMG predicts that the





Top: Figure 2, Evolution of Autonomous and Connected Vehicle Technologies[2]

Above: Figure 3, Smoke Spread in a Longitudinally Ventilated Tunnel[3]

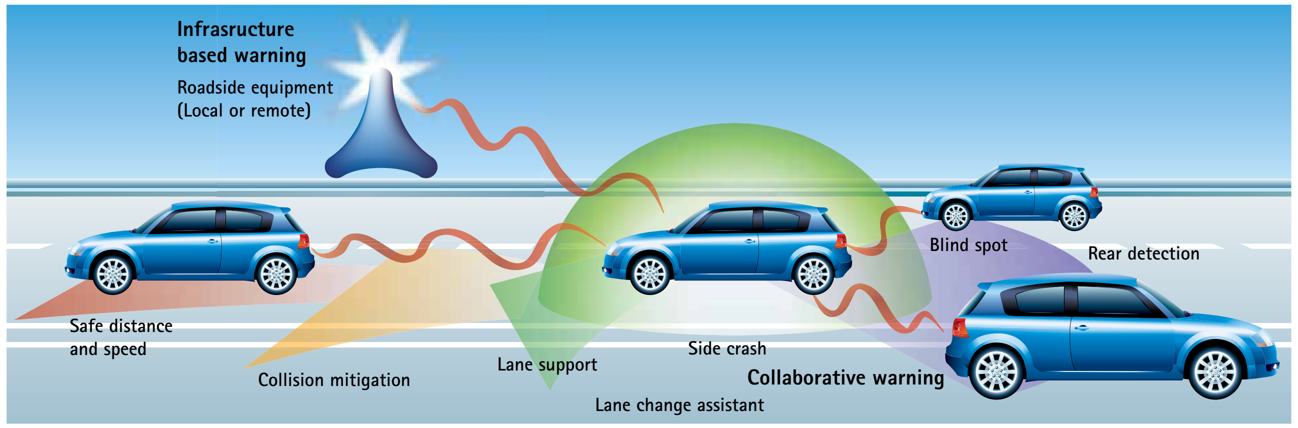
evolution of current technologies will enable full vehicle autonomy to be realised by 2030 (Figure 3).

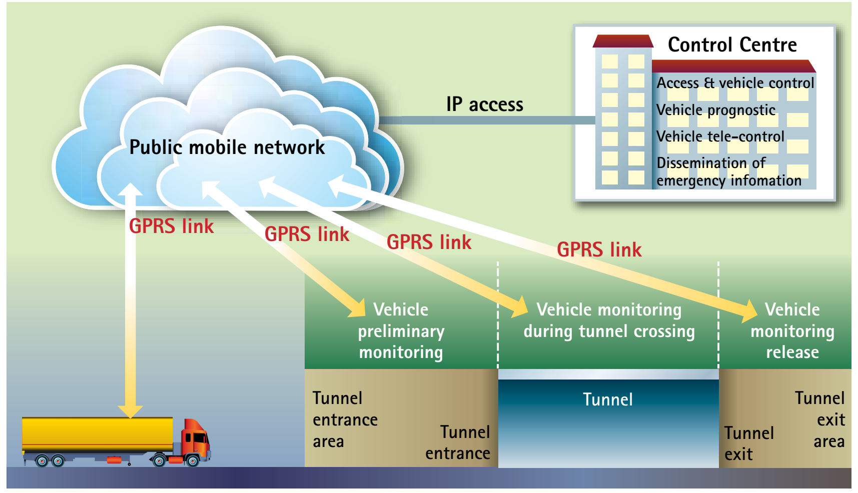
Over 90% of traffic accidents worldwide are due to driver error, and the introduction of automation in vehicle navigation thus provides an opportunity to reduce accidents and injuries. It is estimated that by 2030, connected and autonomous vehicles could save over 2,500 lives and prevent more than 25,000 serious accidents in the UK alone[2]. However, the risks presented by the current state of autonomous technology have been highlighted by a fatal accident on 7th May 2016, where a Tesla Model S's sensors system failed to identify a large white 18-wheel truck and trailer crossing the highway. The car attempted to drive full speed under the trailer, with the bottom of the trailer impacting the windshield.

Tunnels present a number of specific safety challenges for autonomous cars. Their restricted geometry means that any lateral deviations due to incorrect steering could lead to collisions with one or more tunnel walls. Wireless channels, which can permit both vehicle-to-infrastructure (V2I) as well as vehicle-to-vehicle (V2V) communications, can be attenuated along a tunnel, leading to loss of signal strength. Global Positioning System (GPS) signals, required for satellite navigation systems, are disrupted in tunnels. However, the main risk with using autonomous cars in tunnels is that they may not operate in a safe manner in case of fire.

The most dangerous tunnel fires such as the Tauern tunnel fire in 1999 have involved heavy goods vehicles. In that respect, the introduction of V2V communications between heavy goods vehicles with automatic distance control as well as V2I warnings could potentially lead to enhanced safety in tunnels.

Should a fire break out in a tunnel, human drivers are assumed to remain in a clear (smoke-free) tunnel zone. Designers typically specify ventilation systems that either push the smoke-laden air downstream of the fire via longitudinal ventilation systems such as jetfans or Saccardo nozzles (Figure





3), or to extract the smoke locally via transverse or semi-transverse ventilation systems.

Autonomous cars cannot detect fire or smoke in the tunnel, and may therefore drive past a burning vehicle and into a dangerous, smoke-laden zone. It would be uneconomic and impractical to install fire or smoke detectors in autonomous cars to deal with this scenario, and in any case, such detectors may trigger too late to guide an autonomous car. Instead, the solution may be to rely on the V2I channels to transmit a warning about the burning vehicle, on the basis of fire and smoke detectors installed in the tunnel, as well as V2V communications between connected vehicles (Figure 4). Vehicle-mounted cameras can be programmed to detect tunnel lane closure signs as well as redirection signs to an exit ramp. There may be an opportunity for the tunnel operator to use the V2I channels during an emergency in order to direct vehicles: for example, in order to prevent vehicles from entering a tunnel, to stop them travelling any further into a tunnel, or to drive out via the main bore or through a ramp.

In the EU's Safe Tunnel research project, GPRS networks were proposed in tunnel entrance areas, within the tunnel itself and in tunnel exit areas, in order to communicate with suitably equipped vehicles (Figure 5). Tunnel operators can use the GPRS networks to impose lower speed limits and/or safety distances between vehicles during emergencies, maintenance works and during periods when the tunnel equipment functionality is below the minimum operating requirements for safety. The EU's SAFESPOT research project reported improved V2I communications using the IEEE 802.11p protocol, an approved

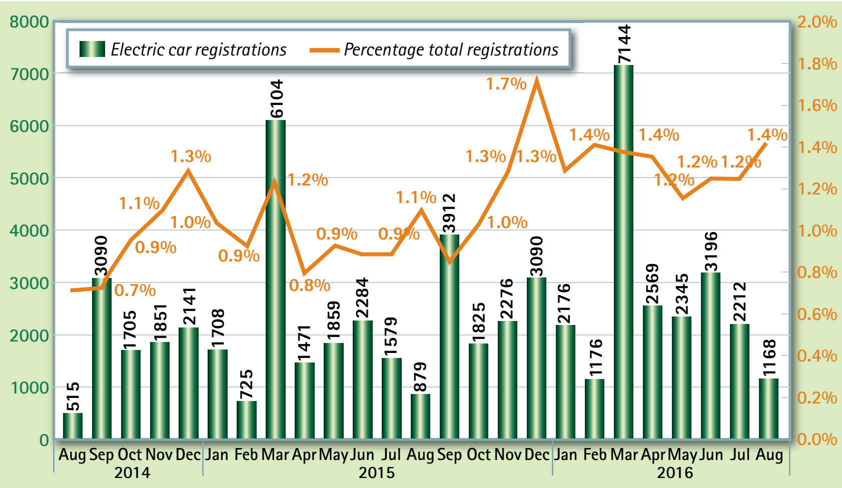
Top: Figure 4, Vehicle-to-Infrastructure and Vehicle-to-Vehicle communications[4]

Above: Figure 5, Communication Architecture in the Vicinity of a Tunnel[5]

amendment to the IEEE 802.11 standard (Wi-Fi) which adds wireless access in vehicular environments.

The location of an incident within a tunnel could be transmitted from the tunnel detectors to the on-board computer. Although GPS reception is not generally available in tunnels, the satellite navigation systems may be able to use "dead reckoning" [using a fixed starting point and calculating vehicle progression based on factors such as speed], to work out the vehicle's current location and to base its navigation decisions accordingly. However, research is required as to how the on-board navigation algorithm should be programmed in order to maximise tenability. For example, if the incident is close to the exit portal and the burning vehicle is not blocking the lanes, it may be safer to simply drive out of the tunnel. In cases where a significant tunnel chainage is present downstream of the incident, it may be safer for the vehicle to stop, for the occupants to disembark and to evacuate from the tunnel. Because of the complexity of the decision-making processes involved, it is likely that driver and tunnel operator intervention will be required when driving through tunnels for the foreseeable future. It is interesting to note that neither the EU SAFESPOT nor the EU Safe Tunnel research projects permitted autonomous driving in tunnels, for safety reasons.

In order to deliver the required communication channels with autonomous and connected vehicles in tunnels, significant investment will be required by tunnel owners and operators to ensure wireless connectivity along the whole tunnel chainage. For short tunnels with clear lines of sight, the installation of broadcast antennae at the portals may be adequate, while leaky feeders and line amplifiers are required for long tunnels and those with restricted lines of sight. Since the wireless installation will be considered a safety-related device,



Above: ***Figure 6, Electric car registrations in the UK, 2014 - 2016 (Society of Motor Manufacturers and Traders)***

adequate equipment redundancy and software verification may be required to achieve an approved Safety Integrity Level to BS EN 61508-6:2010. In addition, high-speed data connections between the tunnel incident detectors and the V2I channels will be required. The availability of funding for such infrastructure investment is likely to be a key prerequisite to providing safe driving conditions for autonomous vehicles in tunnels.

HYBRID AND ELECTRIC VEHICLES

Statistics published by the Society of Motor Manufacturers and Traders (SMMT) show that electric car sales in the UK have risen dramatically during the past two years (Figure 6). As a percentage of new car registrations, electric cars (including hybrids) now represent around 1.3% of the total new car market in the UK. Bloomberg New Energy Finance predicts that electric vehicles will be 35% of global new car sales by 2040[6].

Whilst in hybrid mode, emissions are significantly reduced for hybrid vehicles compared to conventional petrol and diesel models. These include reductions in carbon monoxide, nitrogen oxides and particulate matter. Small hybrid cars driven in electric-only mode typically produce around 40% less CO_2 than equivalent petrol cars[7], and no nitrogen oxides or particulate matter are discharged from the tailpipe. Electric and hybrid vehicles can therefore improve tunnel air quality and reduce ventilation requirements during normal operation. However, batteries installed in electric and hybrid vehicles can pose a special fire risk, and such fires would present a significant challenge to fire-fighters.

Fire incidents related to plug-in electric vehicle fire incidents are rare, but there have been a number of documented instances of such fires. Most plug-in vehicle fires have been thermal runaway incidents related to lithium-ion batteries. Such batteries contain a flammable organic electrolyte which can be ignited by several methods including overcharging, charging at too high a rate, discharging at too high a rate and by damaging the battery during a crash or by impact with high-speed debris. Once ignited, such fires can be very difficult to extinguish, due to the risk of re-ignition.

In order to reduce the risk of battery fires in electric vehicles, manufacturers such as Tesla have designed liquid cooling systems in order to cool the battery cells; impact protection of the battery pack via metal plates; and a firewall to prevent a battery-pack fire from entering the passenger compartment. Some hybrid electric vehicles available in the market today use nickel-metal hydride batteries, which do not pose the same risk of

Below: ***Figure 7, Tesla Model S lithium-ion battery pack[9]***

thermal runaway as lithium-ion batteries.

An example of a plug-in vehicle incident is the fire which occurred on 1st October 2013 when a Tesla Model S hit road debris on a highway in Washington, USA. According to the Fire Department incident report, initial attempts to extinguish the fire with water were unsuccessful, as the fire reignited underneath the vehicle after appearing to be extinguished. The Tesla battery pack is configured as a long, flat slab at the bottom of the car (Figure 7). The fire fighters had to use a jack to turn the car on its side and then cut holes in battery's protective metal plate to apply water directly to the burning battery. Tesla subsequently improved the impact protection around the battery.

Tunnel fires are rare events, and fires due to vehicle batteries in tunnels should be even rarer – the author is not aware of any such fire being reported. However, electric and hybrid vehicle fires in tunnels would represent a significant challenge to fire fighters.

It may not initially be clear to the fire fighters that the seat of the fire is a vehicle battery. Ideally, graphite dry powder (class D) extinguishers should be used on lithium ion battery fires. If graphite dry powder extinguishers are not available, copious amounts of fresh water as a fine spray should be used to swamp the fire. However, the use of water on a lithium ion battery fire will generate hydrogen, which may in extreme cases increase the severity of a fire or cause an explosion if insufficient ventilation is provided in the tunnel.

Due to the physical restrictions imposed by the tunnel geometry, it may be difficult to use a jack within a tunnel to turn a burning car in order to provide access to the underside battery, and such a manoeuvre could potentially cause the fire to damage the tunnel wall.

Some manufacturers recommend disconnecting the battery before commencing fire-fighting operations, but that may be an unrealistic expectation. There may be a risk of electrocution, but that is limited due to battery current/voltage protection and fire fighters' personal protection equipment. Water is not effective at extinguishing a large lithium-ion battery fire. Due to these difficulties, fire fighters may simply decide to allow such a fire to burn out, depending on the outcome of their dynamic risk assessment[10]. In any case, fire-fighting operations to extinguish a burning vehicle's battery can be expected to last significantly longer than those for a conventional vehicle, exposing fire-fighters to additional risk.

In view of the special risks involved, fire-fighting procedures should be developed for dealing with fires in electric and hybrid vehicles, and these should be incorporated in the training of fire-fighters fires in areas where tunnels are located. Ideally, such training should be combined with live and table-top exercises involving tunnel operators and other emergency services, including the police and the ambulance service.

An increasing number of tunnels are being equipped with fixed fire suppression systems, including high-pressure mist and low-pressure deluge. If promptly activated, such fire suppression systems can reduce the risk of fires spreading from one vehicle to the next. However, they would not be effective in extinguishing a shielded fire such as that originating from a vehicle battery. There may be a risk of re-ignition of a vehicle battery, and hence the fire suppression system should not be turned off until it has been ensured that the fire is under effective control[11].

NEXT STEPS

A lot is already known about the risks inherent in innovative vehicles, and much effort has already been expended in developing and implementing mitigation measures that have gone a long way towards addressing these risks. To date however, not much effort has gone into considering the specific risks in relation to the use of innovative vehicles in tunnels. It is hoped that a database of best practice can be developed, building upon the experience of countries that already have a significant proportion of such vehicles on their road network. Lessons learnt from future tunnel incidents involving innovative vehicles should be disseminated widely, in order to positively influence product design, tunnel installations and operation and emergency service deployment. Significant investment will be needed in order to ensure that tunnel safety is not only maintained, but even improved from today's levels

References

1: http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development (accessed on 14-09-2016)

2: "Connected and Autonomous Vehicles – The UK Opportunity", KPMG, March 2015 (kpmg.co.uk).

3: "Systems and Equipment for Fire and Smoke Control in Road Tunnels", World Road Association, PIARC Committee on Road Tunnels Operation (C3.3), 2007.

4: EU's SAFESPOT research project, http://www.safespot-eu.org/ (accessed on 15/09/2016).

5: EU's Safe Tunnel research project, http://www.crfproject-eu.org/ (accessed on 15/09/2016).

6: https://about.bnef.com/press-releases/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/#_ftn1 (accessed on 14-09-2016)

7: http://www.nextgreencar.com/hybrid-cars/environmental-benefits/ (accessed 15-09-2016)

8: http://www.greencarreports.com/news/1084682_what-goes-into-a-tesla-model-s-battery--and-what-it-may-cost (accessed on 15-09-2016).

9: http://www.nytimes.com/2013/10/04/business/car-fire-a-test-for-high-flying-tesla.html?ref=automobiles&_r=1 (accessed on 14-09-2016)

10: "Fire and Rescue Authorities – Health, Safety and Welfare Framework for the Operational Environment", Department for Communities and Local Government, June 2013.

11: "Fixed fire-fighting systems in road tunnels: current practices and recommendations", Technical Committee C3.3 Road Tunnel Operations, 2016.