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Automation and Safety

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Presentation Outline

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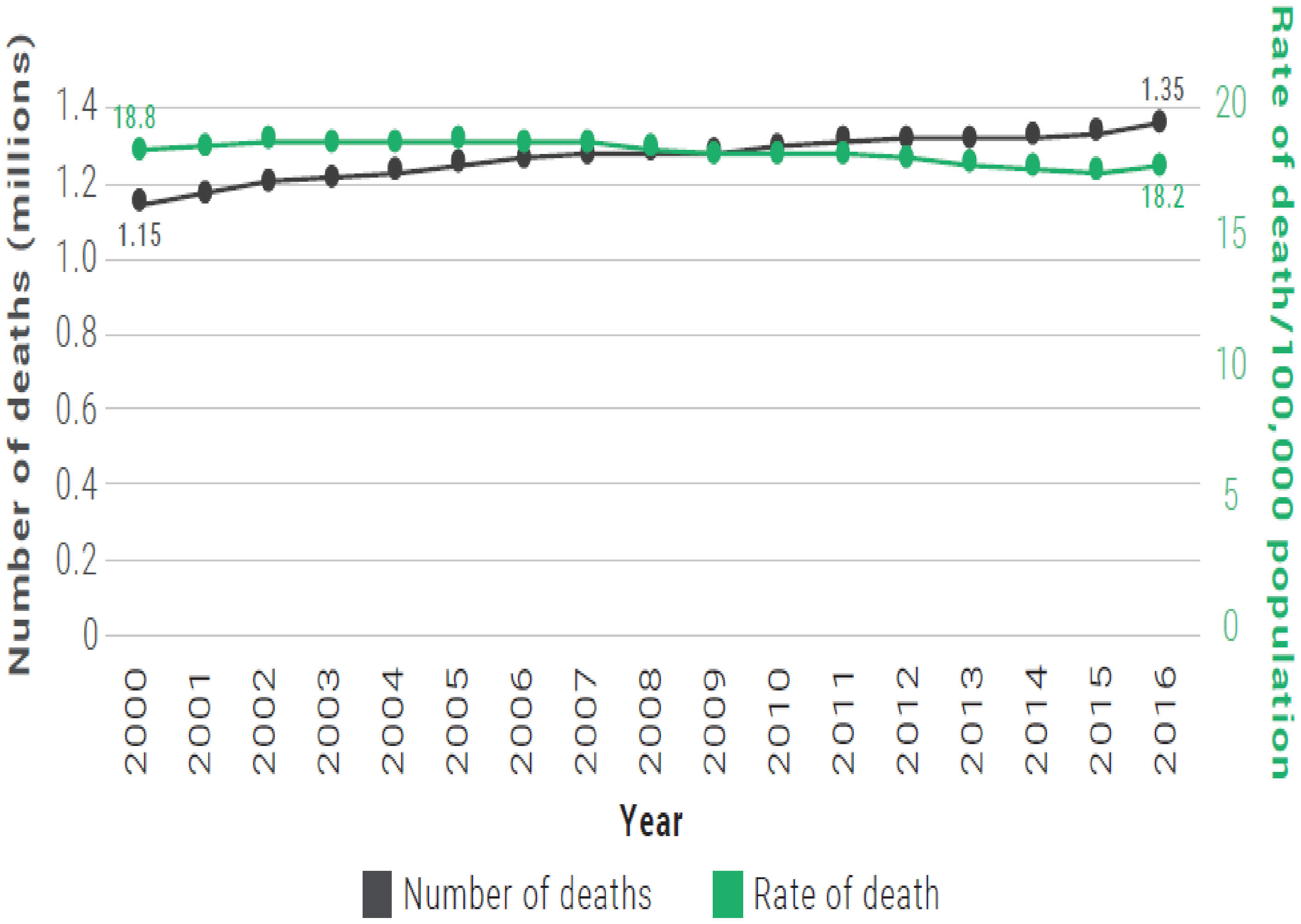
Automation and Safety - Key Questions

Present traffic safety state

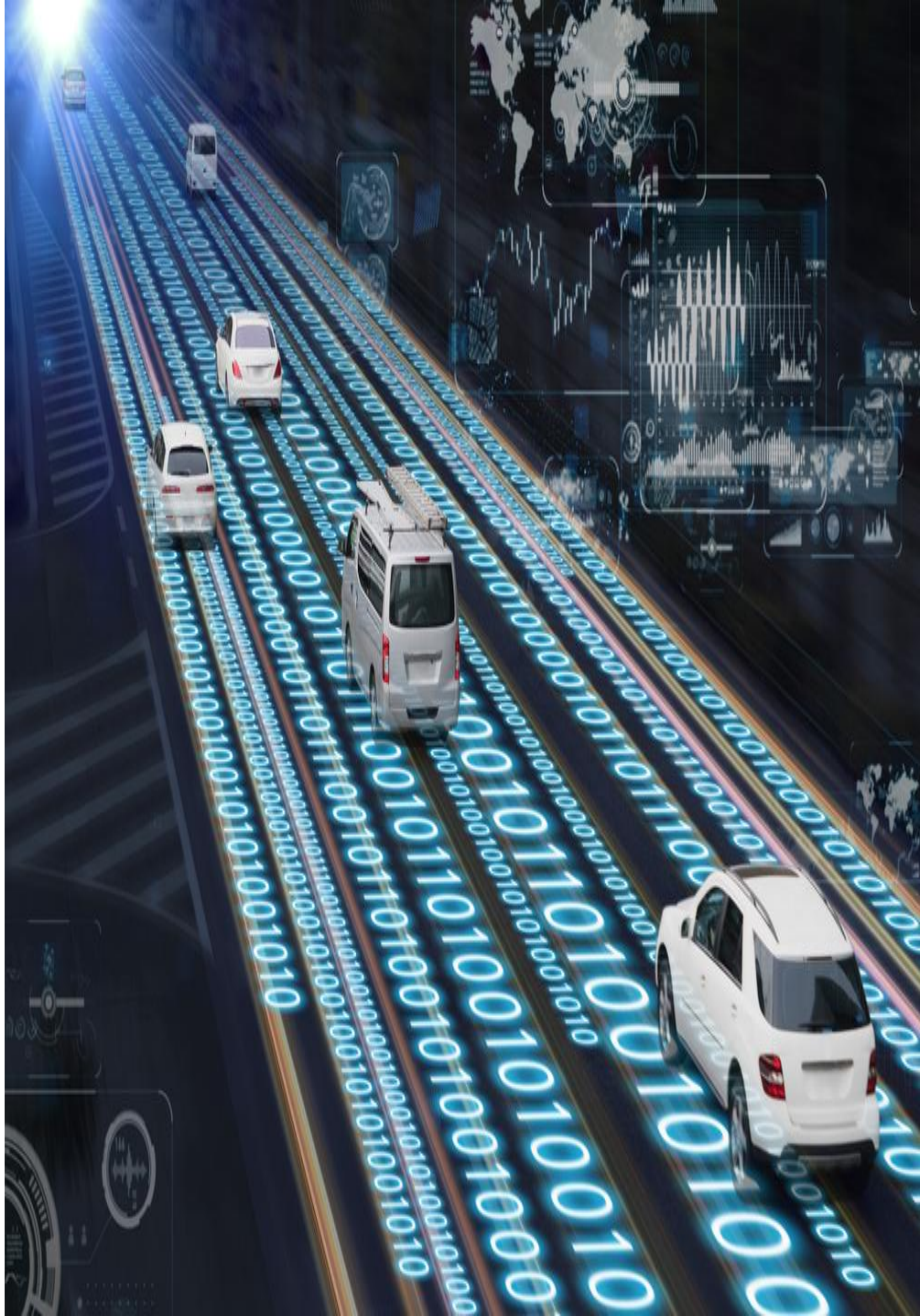
- Despite progress, traffic safety remains a major issue worldwide
- Road traffic deaths continue to increase, reaching a high of 1.35 million in 2016; however, the rate of deaths per population has stabilized.
- Ambitious targets remain (e.g. Sweden's Vision Zero)
- Crashes are estimated to be caused mainly by human error (90%-95% of total)
- AVs would aim to eliminate that error: no distraction, emotions, fatigue, poor/clouded judgment, cognitive impairments, instant reactions, greatly improved perception (no need for line-of-sight) etc…



Source: WHO, 2018

What is it all about?

- In the past decade, autonomous vehicles (AVs), connected vehicles (CVs) and relative technology have been in the spotlight
- Intensely researched by both academia and industry
- Interest spurred by computational advances, both in processing power (CPUs) and methodology (Neural Networks)
- Competition and breakthroughs from the involvement of non-traditional automotive industry players (e.g. Google)



Questions regarding traffic safety

- Will there be an impressive reduction in crashes when full automation is reached?
- Could vehicles be freely repurposed when there is no need for human hands-on driving?
- What do we have to change from the current state to reach safe automation?
- Where does the fault or liability lie in the event of a crash?
- What will happen during the transition phase - human drivers sharing the road with AI algorithms?

Current technological state

Automated Vehicles

- Automated vehicles (AVs) are vehicles operated by an artificial intelligence (AI) in place of a human driver
- AVs use an array of sensors and auxiliary devices to collect information of the surroundings of the vehicle
- AI receives input and provides all driving related controls and decision making that substitutes traditional drivers
- Intercommunication of vehicles with other vehicles or elements of the road environment
  - vehicle-to-vehicle communication (V2V)
  - vehicle-to-infrastructure communication (V2I)
  - collectively known as V2X schemes

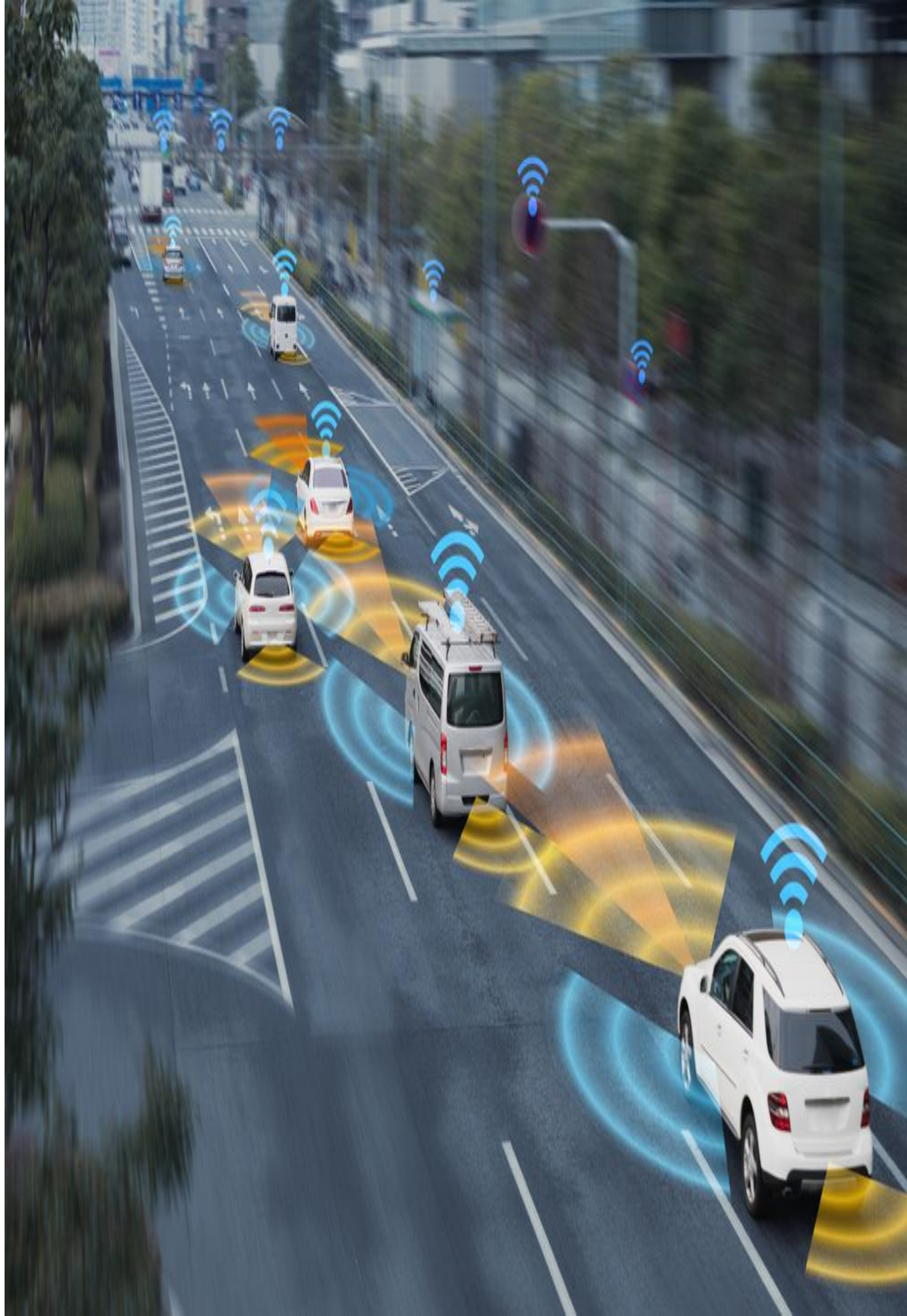
Connected Vehicles

- Connected vehicles (CVs) are conventional vehicles, (still operated by a human driver), but are also enhanced via various telematics-electronic devices and upgrades

- Intercommunication of vehicles through V2X schemes as well

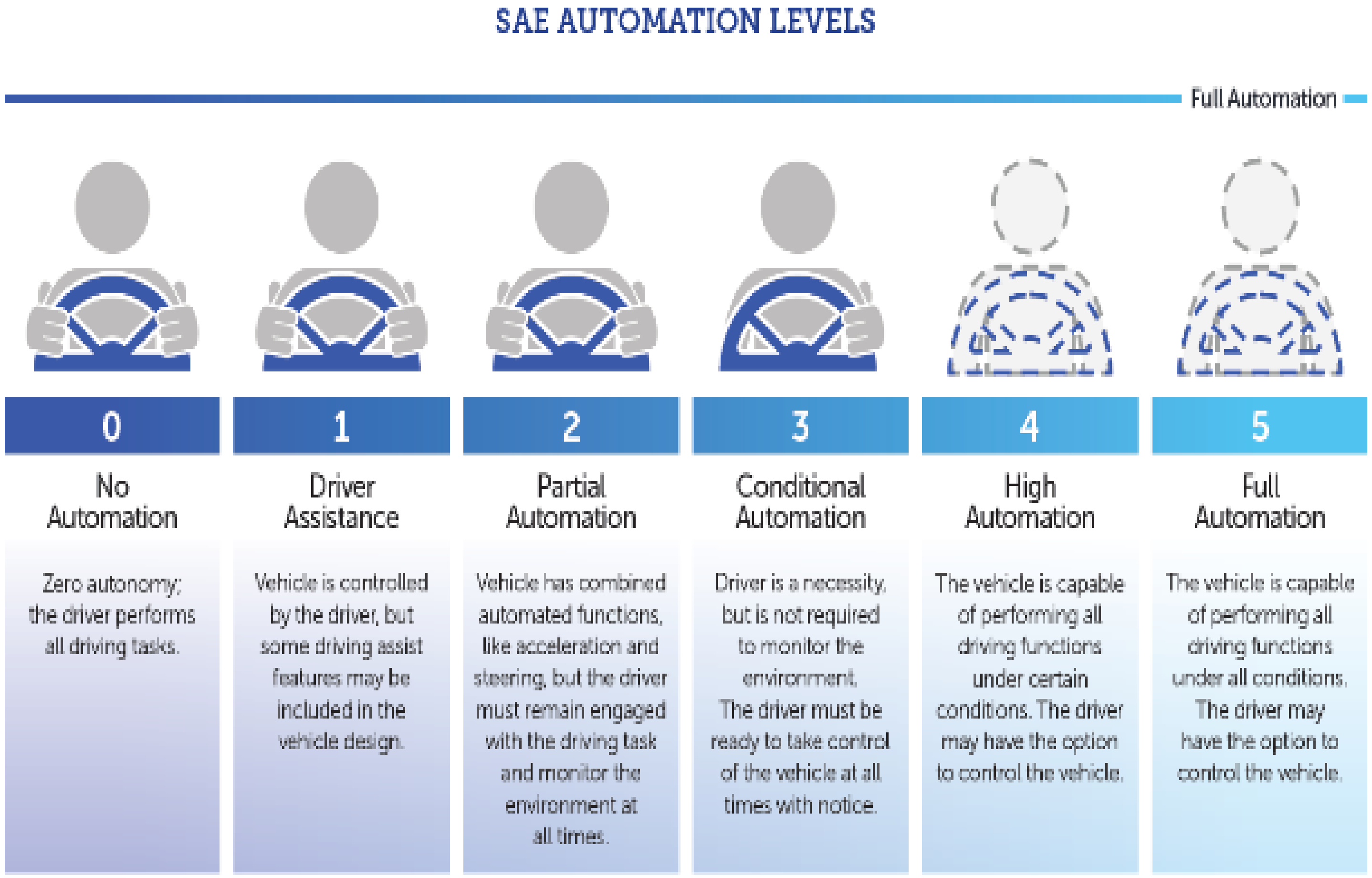
- Drivers receive more enriched information about the driving environment than they normally would (expected benefits when implemented in a wide scale)

- Certain technologies currently available



Connected and Automated Vehicles

- 5 Levels of automation (additional to baseline) have been introduced (SAE, 2016)
- As Levels increase, vehicles become more independent but require more sophisticated equipment to operate.
- Levels are descriptive rather than normative and technical rather than legal
  - No particular order of market production is implied
  - Minimum capabilities for each Level



Source: NHTSA, 2017

Connected Vehicle Progress

Level 1 driver assistance available systems (ADAS) available for decades:

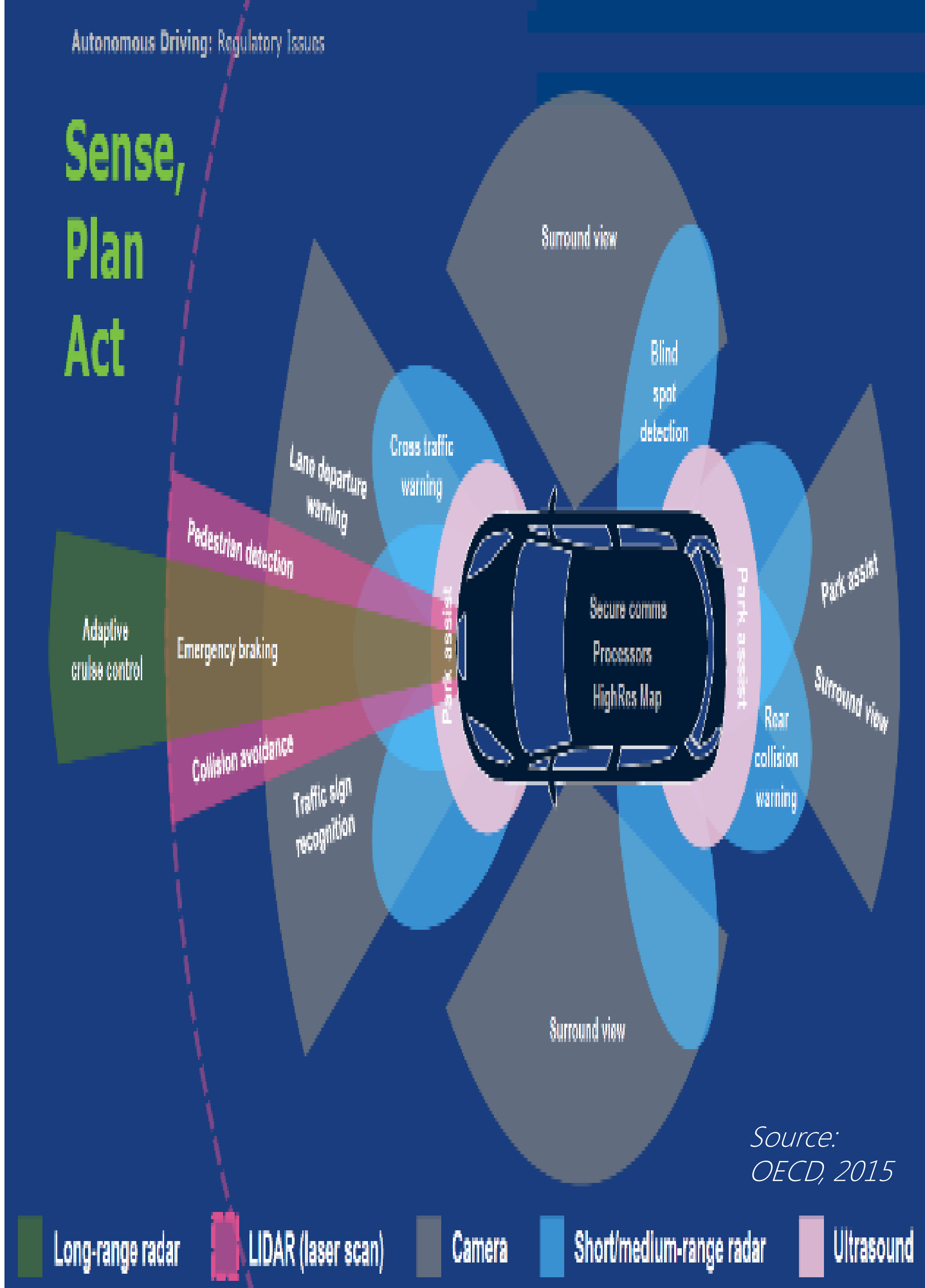
- Cruise control (since 1960s)
- Electronic stability control (since 1990s)
- Lane keeping/departure warning systems (LK/LDW) (since 2000s)
  - nudging the steering wheel, providing a warnings, or a counter-force or torque
- Adaptive Cruise Control (ACC), Intelligent Speed Adaptation (ISA), Autonomous Emergency Braking (AEB) & Collision Warning systems more recently
- Several parking assistance systems in use

Category / Domain	System / Mechanism
Perception - Information	Surround view
	Parking assist
Collision avoidance	Collision warning – avoidance
	Cross traffic warning
	Autonomous emergency braking
	Pedestrian detection
Navigation control	Intelligent speed adaptation
	Lane departure warning
	Adaptive cruise control
	Traffic sign recognition
Safety augmentation	Seatbelt reminders
	Electronic stability control
	Alcohol interlock systems
Post-crash aid	E-call
	In-vehicle event data recorders

Automated Vehicle Progress (1/2)

Two main fronts:

- 'Sensor-based' technology
  - Focus on devices to observe the road environment and navigate independently from driver
- 'Connectivity-based' technology
  - Focus on devices to observe the road environment and navigate independently from driver
- Systemic fusion – convergence phase:
  - The latest approach to shrink costs and reach 100% functionality



Source: OECD, 2015

Automated Vehicle Progress (2/2)

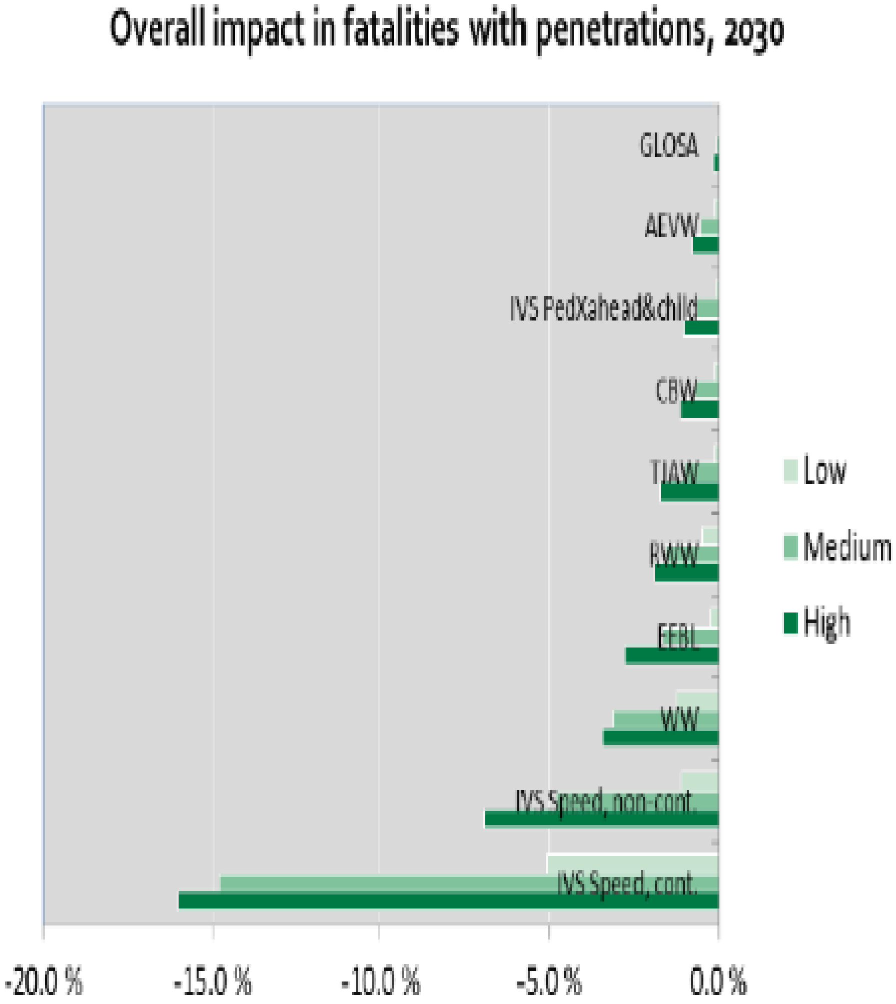
Previous CV systems adapted for AVs:

- ‘Never leaving factory’
  - Updating remotely (like a PC)
- Industry constantly creating prototypes:
  - Waymo, Tesla, Volvo between Levels 2 and 4, many others closely following
  - Original Equipment Manufacturers began to orient towards higher Level automation, independently developing singular systems
- Road authorities closely monitoring and struggling to keep up
  - Roadmap documents, implementation predictions (see right)

Source: ERTRAC, 2015

Findings from the literature for CV traffic safety

- Crash avoidance technologies have considerable potential for preventing crashes of all severities (applying to more than a million crashes in the US annually). LK/LDW systems show similar but smaller effects.
- Cooperative Intelligent Transport Systems have been assessed from Field Operational Tests (FOTs) in EU, USA, Australia and Japan
- AEB systems were effective in preventing 38%-44% of rear-end collisions
- ISA reductions in fatalities estimated between 19-28% (even higher depending on regulations)
  - All effects highly dependent on penetration rate and exposure parameters (e.g. see right)



Source: Malone, 2014

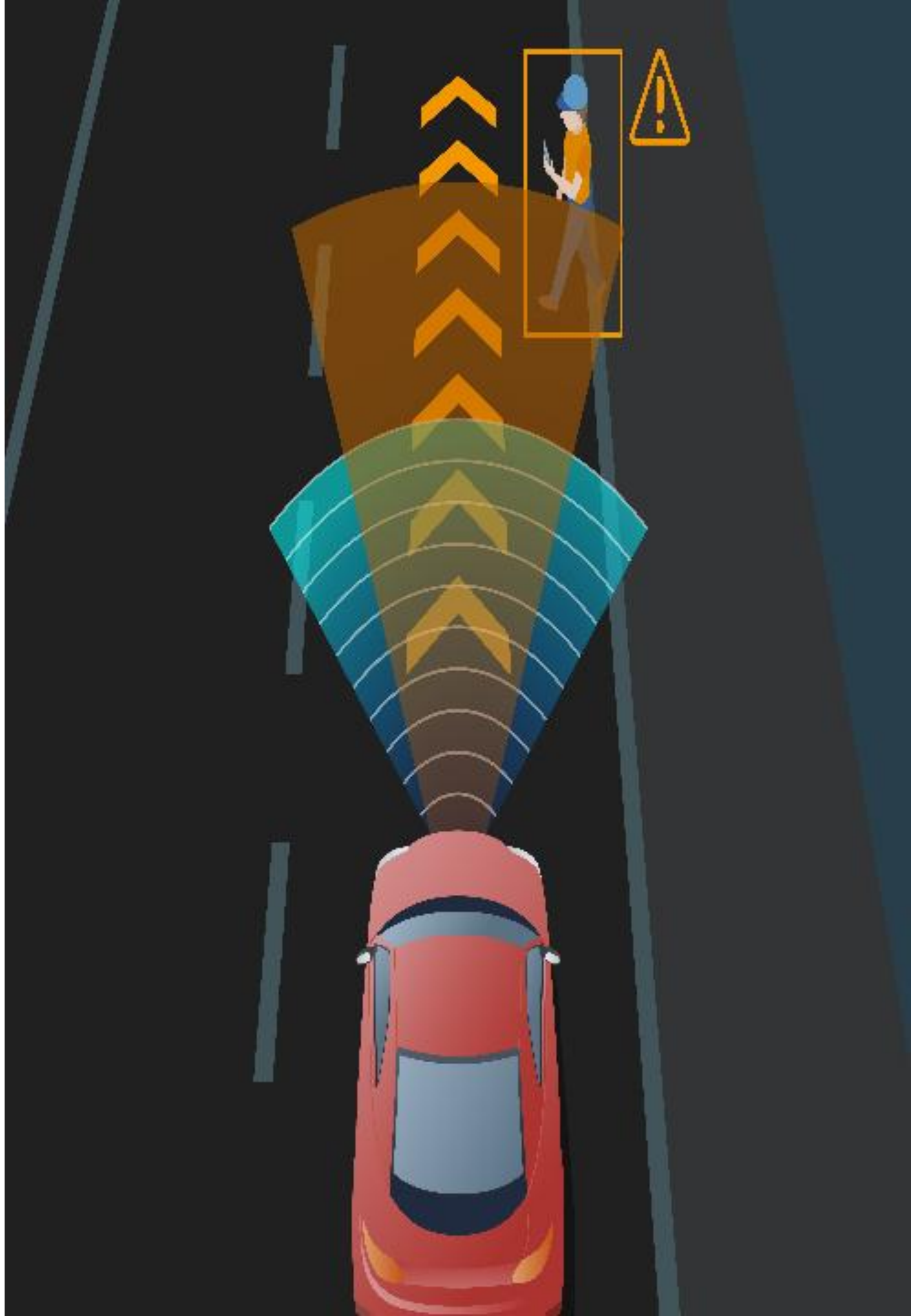
Safety lessons from incidents to date

- Majority of AV crashes attributed to either their operation by a human at the time crash or as fault of another vehicle (13 of 14 incidents for Waymo/Google cars)
  - PDO crash for Waymo/Google (2016):
    AV in autonomous mode, falsely 'believed' it was going to be granted priority
  - Fatal crash for Tesla (2016):
    AV in autonomous mode; sensors failed to detect a trailer
  - Injury crash for Waymo/Google (2018):
    AV not in autonomous mode, another car collided into AV
  - Fatal crash for Uber (2018):
    AV in autonomous mode, sensors detected pedestrian but AEB was disabled
- Strong publicity: Nonetheless, 89.2% of participants in a survey answered they would surrender navigation to an AV

Transition phase

Traffic safety during the transition phase

- Zero fatalities cannot be expected
  - Safety levels might decline temporarily, at least for human drivers
- Mixed traffic
  - Several road users will not know what to expect; increased risk
- Penetration rate – adequate exposure
  - Critical for measurable differences
- Vulnerable Road Users
  - Need to take into account increased conflicts and interactions with pedestrians, cyclists, mobility impaired people etc.



Transition phase – things to consider

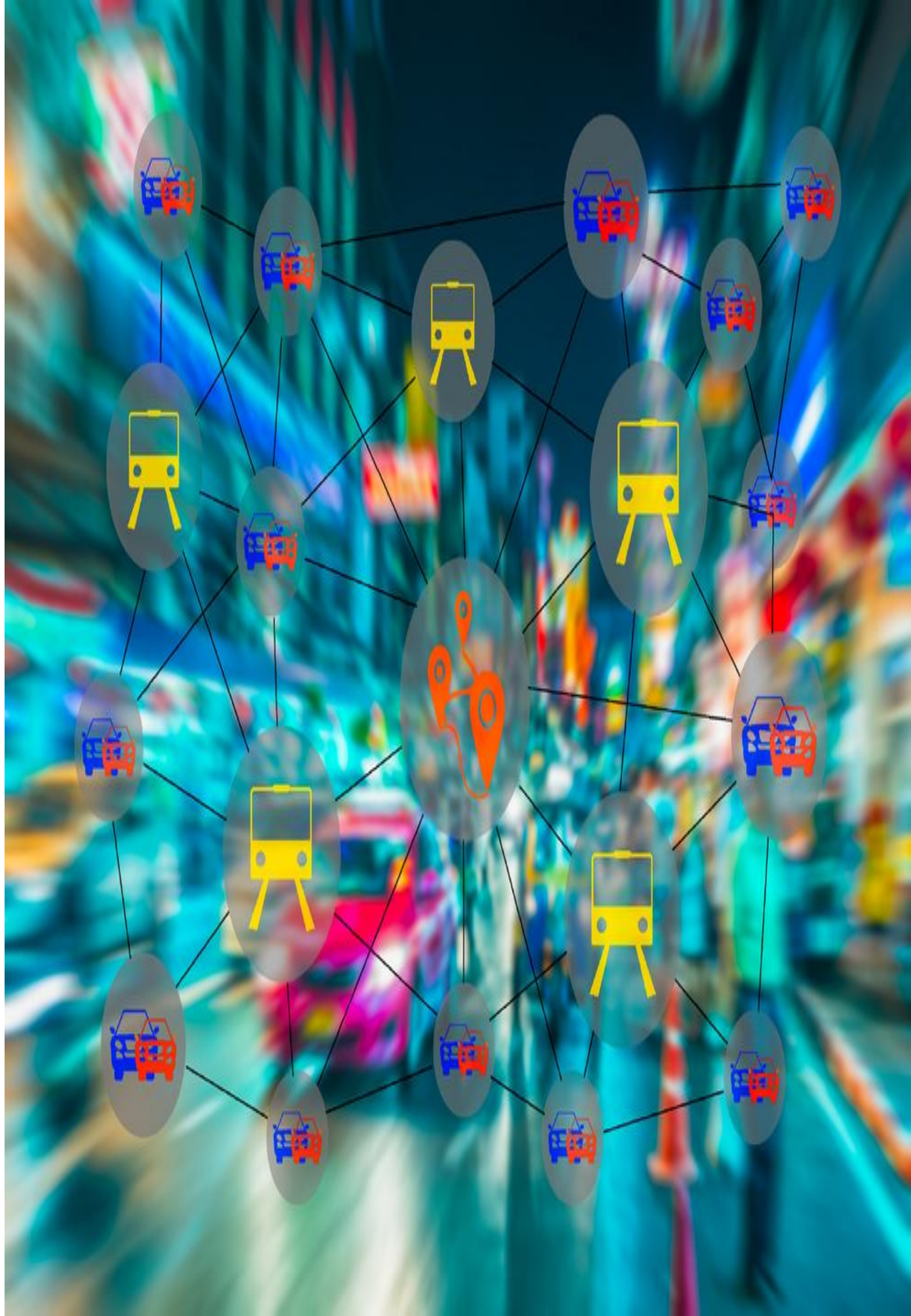
- Non-linear progression through AV Levels
  - Perceivable gap between Levels 3 and 4 of automation: industry will develop independent AVs over 'grey area'
  - Level 3 technologies are proving too difficult to engineer for meaningful safety impacts mitigation
- Pending barriers
  - Conventional road safety improvements will help AVs as well, and they are not done yet (e.g. DUI tackling)
  - More FOTs for observation replications
  - Sensor capabilities, ADAS and HMIs need to be upgraded and standardized
  - Additional concepts possible (e.g. smart tyres)

Performance aspect	Human	AV			CV	CAV
		Radar	*Lidar*	*Camera*	*DSRC*	*CV+AV*
Object detection	Good	Good	Good	Fair	n/a	Good
Object classification	Good	Poor	Fair	Good	n/a	Good
Distance estimation	Fair	Good	Good	Fair	Good	Good
Edge detection	Good	Poor	Good	Good	n/a	Good
Lane tracking	Good	Poor	Poor	Good	n/a	Good
Visibility range	Good	Good	Fair	Fair	Good	Good
Poor weather performance	Fair	Good	Fair	Poor	Good	Good
Dark or low illumination performance	Poor	Good	Good	Fair	n/a	Good
Ability to communicate with other traffic and infrastructure	Poor	n/a	n/a	n/a	Good	Good

Source: Schoettle, 2017

Transition phase –
Authority activities and enforcement

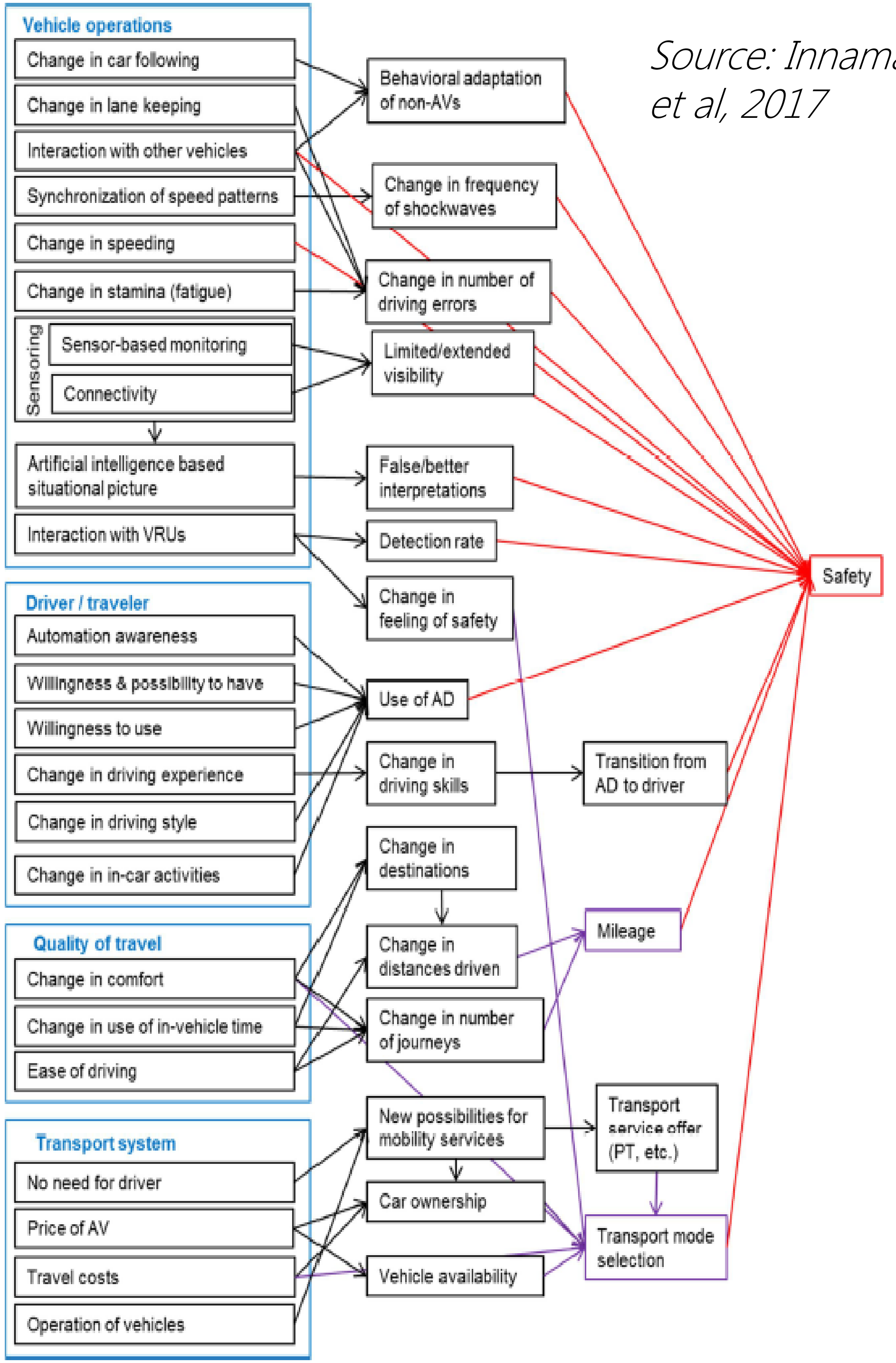
- Enforcement agencies need increased readiness
  - In an AV crash police should be able to determine:
    1. Involved AV capabilities
    2. Whether the AV was operating in automated mode
    3. Whether the AV was operating inside or outside its operational design domain
  - Visual identification has been proposed for AVs
- Road Authorities have started to mobilize:
  - Australian, AUSTROADS (2017)
  - European Parliament (2016)
  - Germany, Department for Transport (2016)
  - UK, Department for Transport (2015)
  - US, NHTSA (2013)



Direct and indirect safety implications

Direct AV impacts on safety

- Too complex to describe casually!
- For AV penetration rates of 10%, 50% and 90%, Fagnant and Kockelman (2015) project 1.100, 9.600 and 21.700 lives saved/year (for USA)
- Behavioral adaptations for human drivers as well from AV interaction
- Personal driving styles will be suppressed (perhaps 'manufacturer styles'?)
- Best case scenario: a virtuous circle of increased safety-trust-safety
  - Currently many unknown parameters



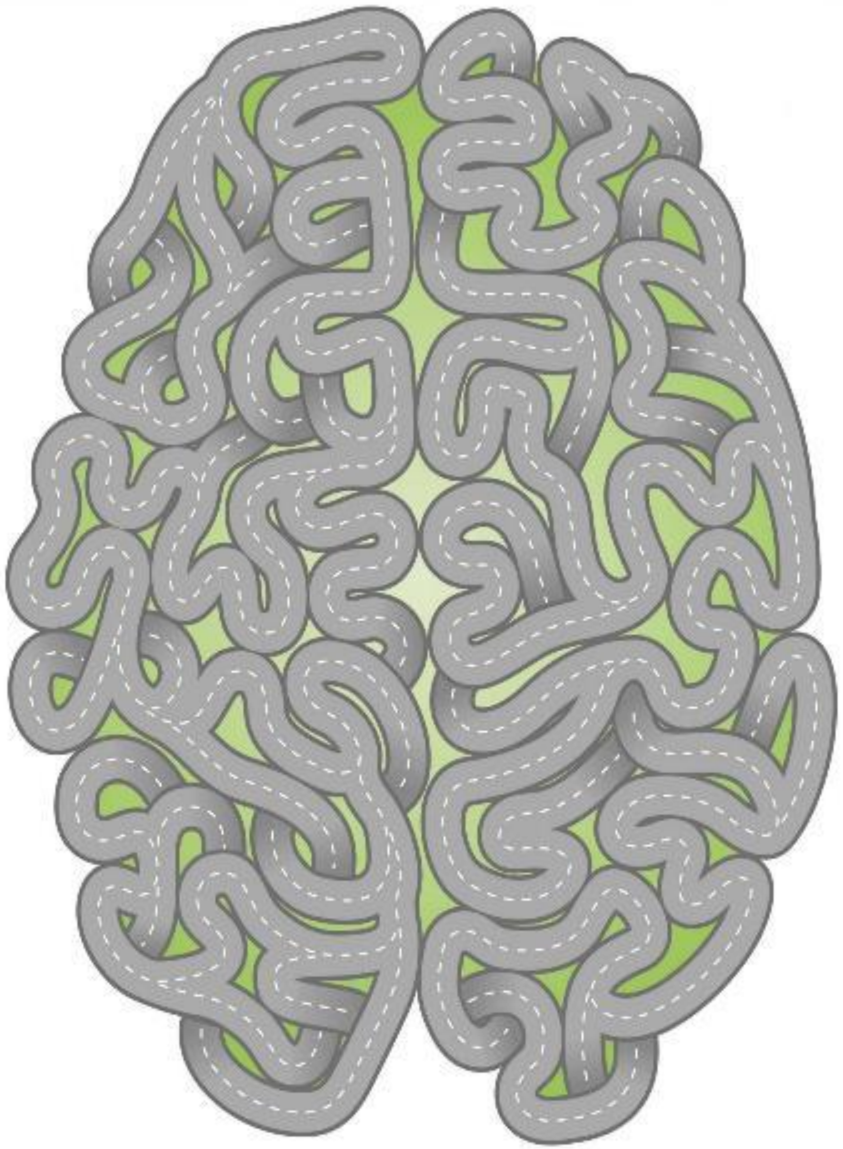
Source: Innamaa et al, 2017

Human factors issues

- Behavioural adaptation more imminent with CVs
  - Positive effects (e.g. increased speed reductions and sign compliance rates in Japan with C-ITS)
  - Must tackle rebound effects (driver overreliance on a system and not paying attention)

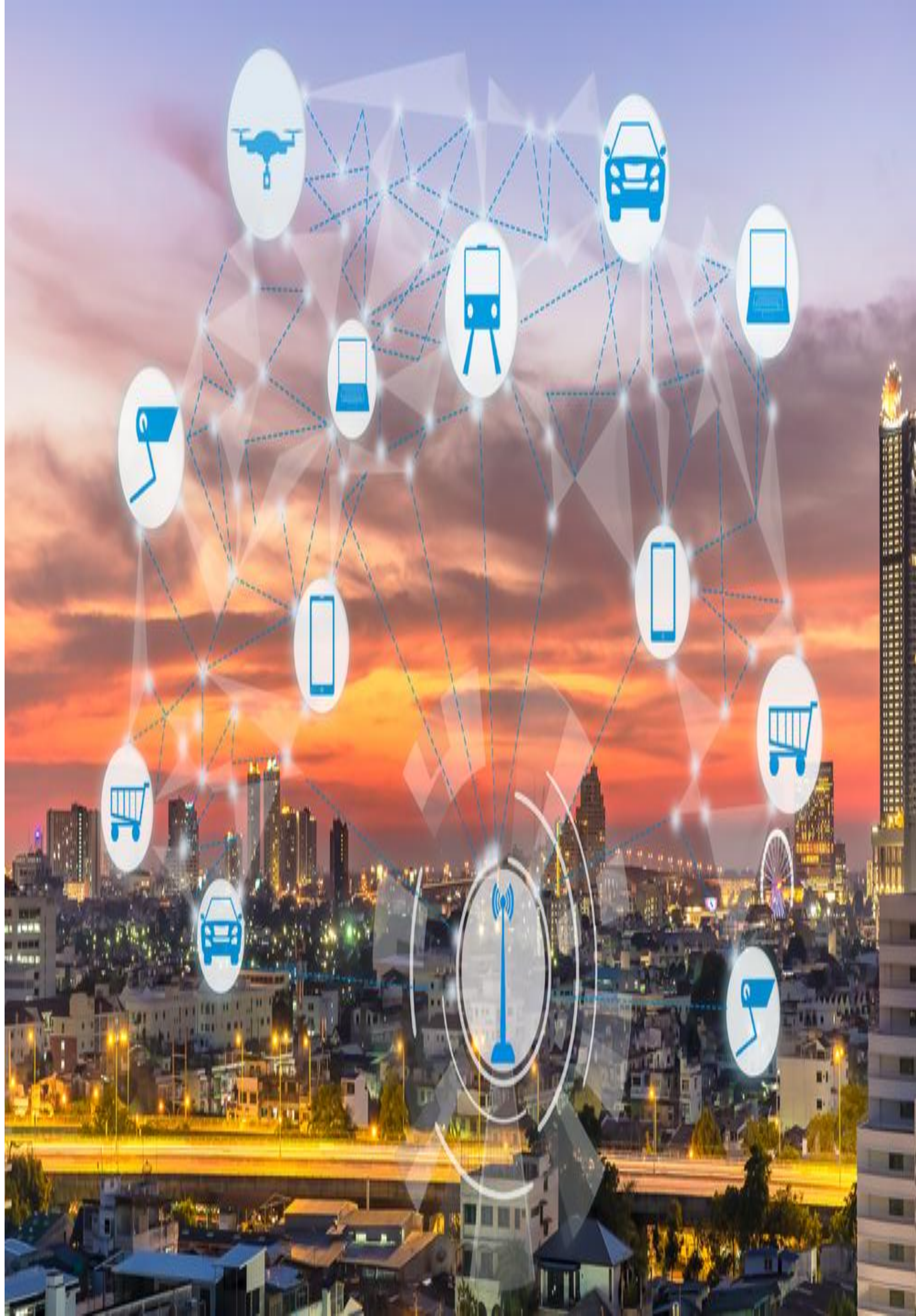
- Forward (in)compatibility must be avoided
  - Absence of important human cues and mannerisms

- Need to anticipate unconventional road user behavior. Examples:
  - School zones
  - Wheelchairs
  - Skateboarders



Application issues

- Temporal and spatial headways will be minimized
- Gradual increase for AADT and vehicle-kilometers travelled (VKT) from increased demand.
- No need for drivers; new AV users (children, elderly, people with impairments)
- Repurposing of vehicles (leisure or business-oriented),
  - Changing passenger orientation will pose safety challenges
- Infrastructure adaptation possible
  - Possible roadside equipment needs (e.g. reflective signs, infrastructure collision warning systems etc.)



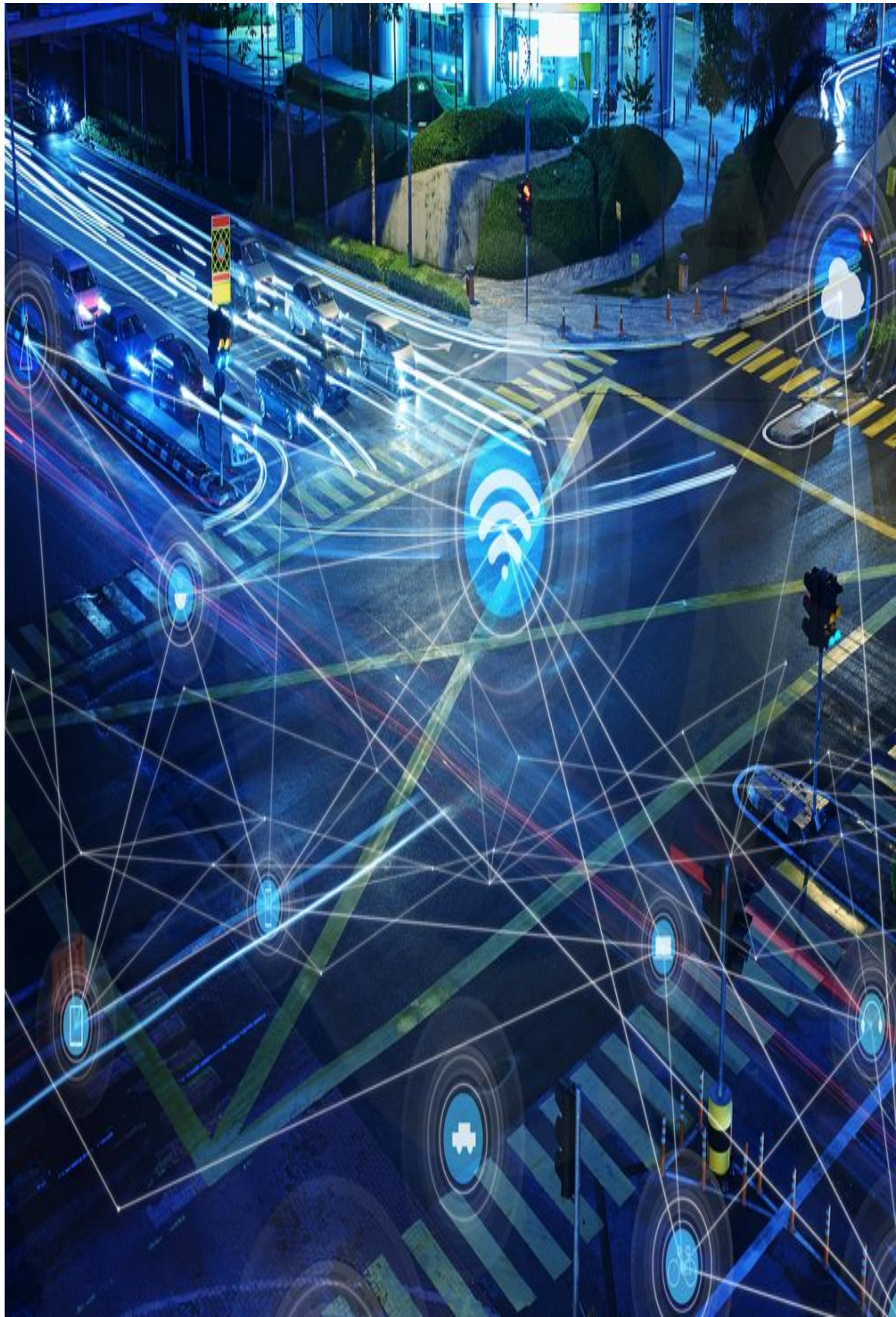
Indirect implications – Mechanical safety

- VKT increases will lead to more material fatigue - mechanical faults; chance for sophisticated equipment failures
- Black box area: AV occupants will be out of touch with the technology they use
- Vehicle redesign traps
  - Should avoid overeager 'lighter' designs due to increased AV traffic safety
- Cybersecurity issues
  - Anticipation of malicious acts; steps to denying hackers vehicle control are critical
- Traffic safety measured differently (Time To Collision etc.)

Indirect implications – Additional domains

- Legislation issues
  - Currently laws and regulations assume human drivers
  - AV systems are not persons, thus not liable
  - 'Control' and 'Proper Control' are undefined
  - Industry has begun to lobby for their AV products to find a robust legal framework

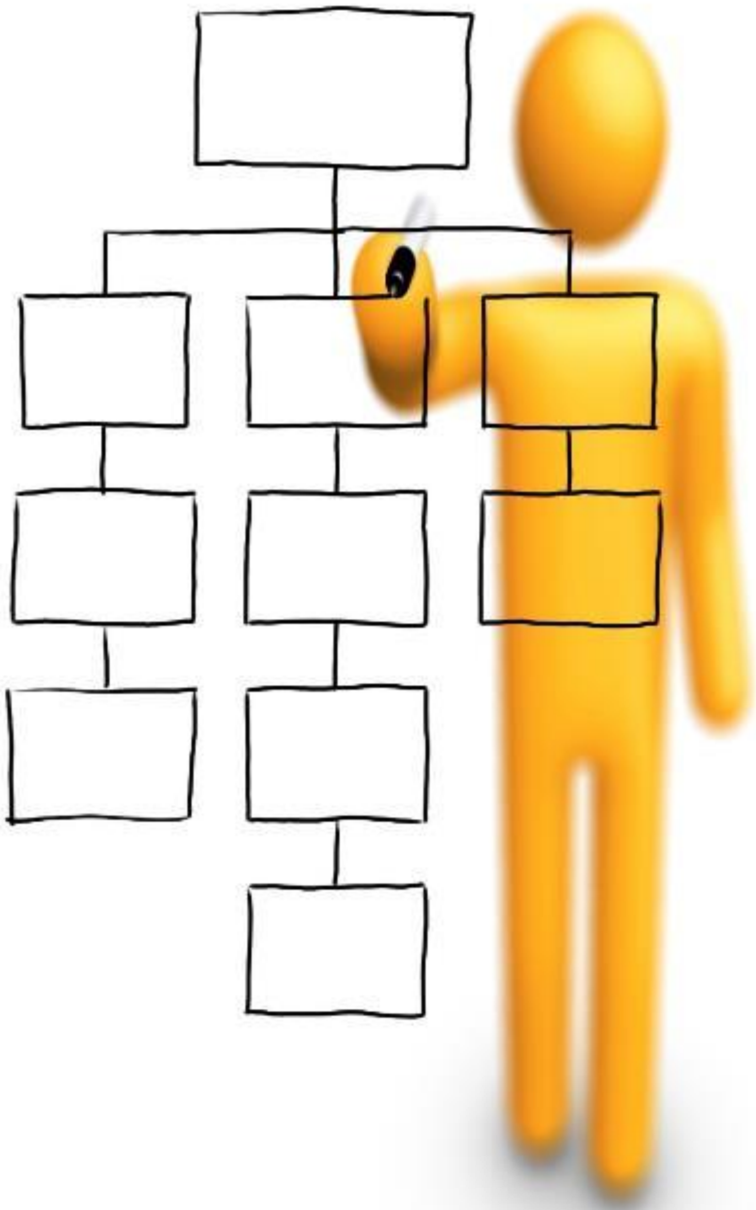
- Economic impacts
  - Potential large savings from traffic safety improvements
  - Services like e-call will reduce delays and minimize costs even after crash
  - Cost reductions are not universal: Safety benefits for a Park and Ride public transport AV scheme in Greece were not feasible, for instance
  - AV/CV circulation will reduce crash externalities



Societal level impacts

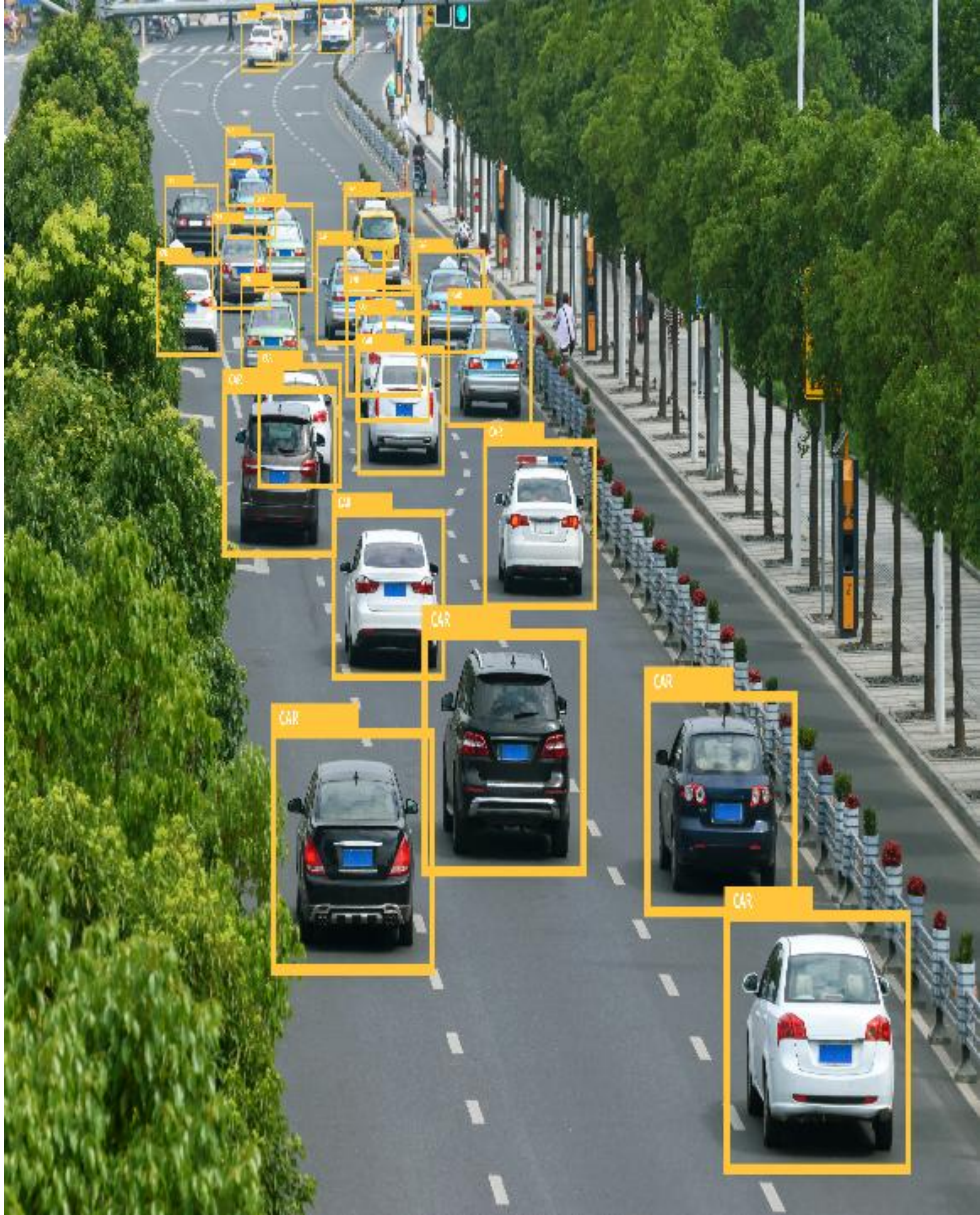
Impact taxonomy

- First order impacts: Noticed by each road user on each trip
  - Travel time. Travel comfort, valuation of time, vehicle operating cost, vehicle ownership cost, access to travel
- Second order impacts: System-wide impacts occurring in the transport system
  - Amount of travel, road capacity, congestion, infrastructure wear, infrastructure design, modal split of travel, optimization of route choice, vehicle ownership rate, shared mobility, vehicle utilization rate, parking space, traffic data generation
- Third order impacts: Wider societal impacts occurring outside the transport system



Third order impacts

- Road Safety
- Environment
  - Propulsion energy
  - Energy efficiency
  - Vehicle emissions
  - Air pollution
- Society
  - Public health
  - Geographic accessibility
  - Inequality in transport
  - Commuting distances
  - Land use
  - Trust in technology
- Economy
  - Employment
  - Public finances



Environment

- AVs coordination in fleets
  - Reduced total environmental costs during production, operation and maintenance due to less overall number of vehicles
  - Reduced overall emissions from compression of temporal and spatial headways as a result of coordinated movement of fleets

- Incentive for conversion towards hybrid or electric vehicles and for fleet renewal

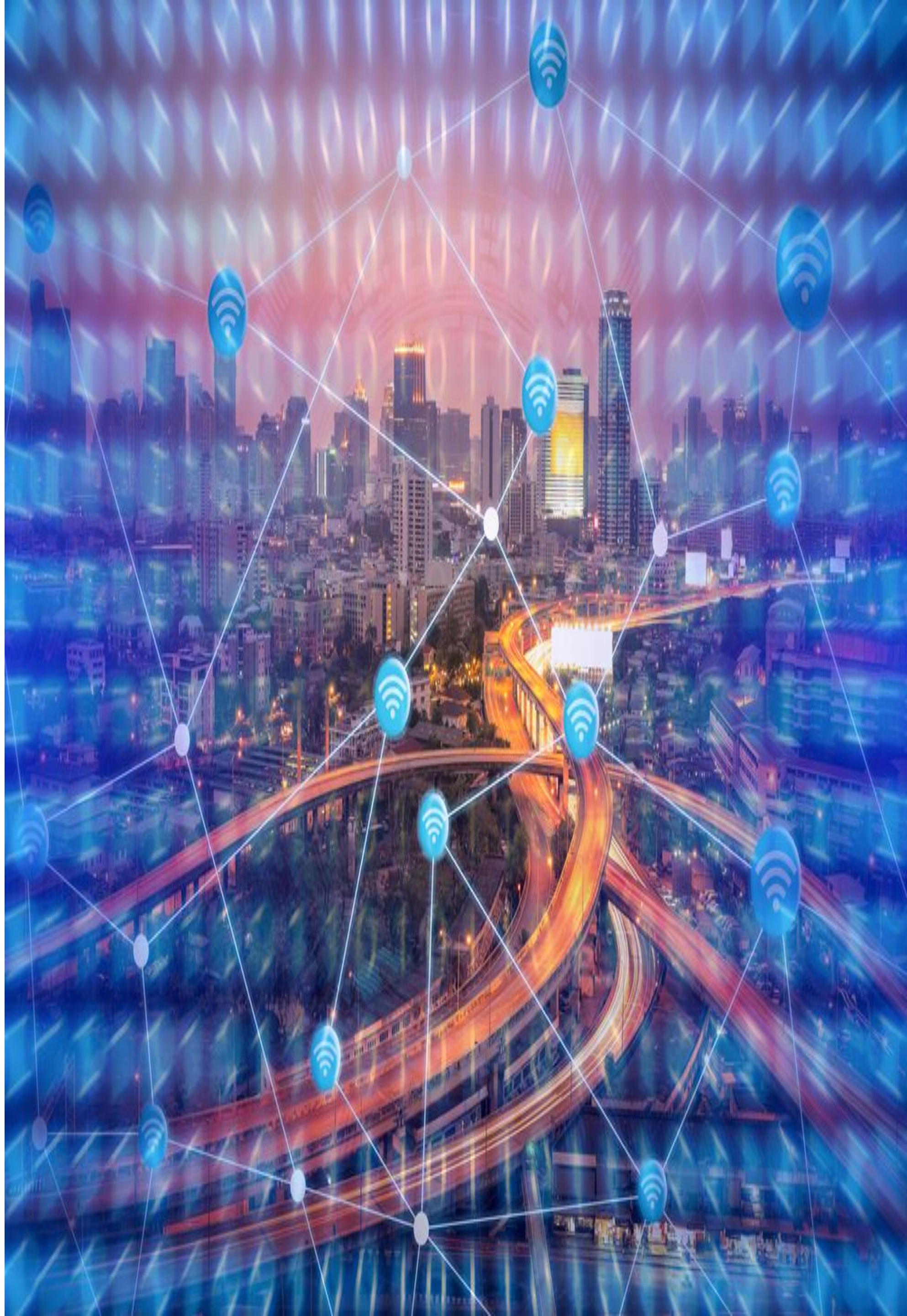
- Reduced noise levels (though artificial noise devices might still be necessary)

Society

- Public health improvements through previous environmental boons
- Expansion of accessibility and road user categories; children/elderly/disabled individuals will gain access to independent car transport
- Reduced parking spaces that can be repurposed and wide-scale land-use changes
- Possibility of increased urban sprawl due to increased mobility opportunities (Mobility as a Service)
- Massive data collection for further transport research and improvement that is currently limited

Economy

- Seamless 24/7 transport operations potential
  - only maintenance costs instead of wages
  - increased distance coverage
  - linking with production lines through IoT
- Possibly severe negative impacts in employment opportunities
- However, new capabilities from reduced personnel demands (e.g. single-employer transport company operating several vehicles)
- Limited present legal framework that might form barriers as it is defined and redefined
- Cost of AVs will define penetration rate and partially AV acceptance
- Economic growth via accessibility expansion



Forecasting methods

- Historical or retrospective methods
  - Longitudinal studies; time-series models
  - Before-and-after studies (several versions exist)
  - Epidemiological studies; retrospective risk analyses
  - In-depth studies of accidents
  - Meta-analyses
  - Household travel surveys (to reconstruct actual travel)
  - Travel demand modelling
  - Willingness to pay studies
  - Naturalistic driving studies
- Future oriented methods
  - Scenario analyses
  - Delphi surveys
  - Biomechanical modelling (of impacts involving future vehicles)
  - Traffic simulation; mathematical modelling of traffic
  - Reliability engineering; prospective risk analyses
  - Surveys; stated preference studies
  - Naturalistic driving studies
- Combining methods

Future Automation Challenges

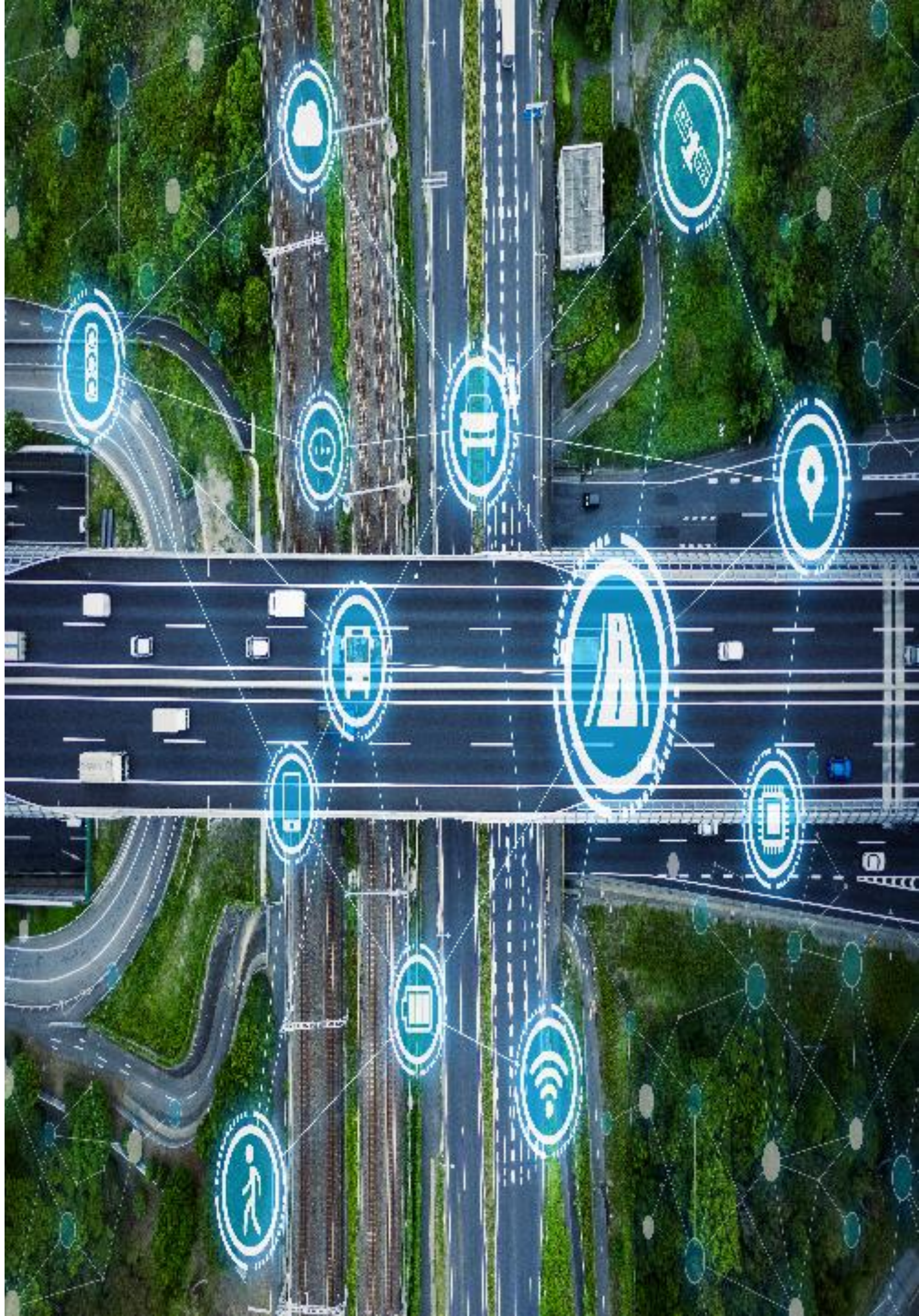
Future Automation Challenges (1/2)

- Do not lose sight of traffic safety amidst AV enthusiasm!
  - New opportunities for capacity increases – vehicle repurposing will entice manufacturers and network administrators
  - Traffic safety must be a primary target

- Public acceptance is critical
  - A gradual trust-building exercise
  - Possibility of virtuous cycle of safety-trust-more safety
  - A challenge to prove AV-dominated roads are safer
  - However, penetration rates and VKT will affect AV traffic safety outcomes

Future Automation Challenges (2/2)

- Significant initiatives from industry so far
  - A lot of ground to cover for smooth transition and integration
  - A consensus on how to determine whether an automated system is roadworthy is required at the very least (adhesion to standards or self-policing demonstrations)
- AVs and CVs will never leave the factory
  - Dedicated environments to test calibrations (like virtual machine PC environments)
  - Ability to influence, handle and manage vehicle fleets remotely (e.g. regulations for traffic bans)
- … and the road infrastructure?
  - Do we have sufficient roads?
  - Is road infrastructure ready for safe CAV traffic?



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