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ASEAN Autonomous Vehicle Landscape Report on Regulatory Pilot Space (RPS) to Facilitate Cross-Border Digital Data Flows to Enabling Self-Driving Car in ASEAN

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List of Abbreviation

ACMP	: ASEAN Communication Master Plan
ADAS	: Advanced Driver Assistance Systems
ADGSOM	: ASEAN Digital Senior Officials' Meeting
ADM	: ASEAN Digital Masterplan
ACC	: Adaptive Cruise Control
AEC	: ASEAN Economic Community
AFAFGIT	: ASEAN Framework Agreement on Facilitation of Goods in Transit
AFAFIST	: ASEAN Framework Agreement on the Facilitation of Inter-State Transport
AFAMT	: ASEAN Framework Agreement on Multimodal Transport
AI	: Artificial Intelligence
AMS	: ASEAN Member States
ASEAN	: Association of South East Asian Nations
AV	: Autonomous Vehicle
AVRI	: Autonomous Vehicle Readiness Index
bps	: bits per second
DMS	: Driver Monitoring System
GPS	: Global Positioning System
GPUs	: Graphics Processing Units
GHz	: Giga Hertz
HMTOT	: Human-to-machine hand-over and take-over
ICT	: Information and Communications Technology
LIDAR	: Light Detection and Ranging
LTE	: Long-Term Evolution
Mbps	: Megabits per second (Mbps)
MHz	: Mega Hertz
ms	: milliseconds
M2H	: Machine-to-human handover
NSA	: Non-Stand Alone

ODD	: Operational Design Domains
QoS	: Quality of Services
RADAR	: Radio Detection And Ranging
SA	: Stand Alone
SAE	: Society of Automotve Engineers
SDC	: Self-Driving Cars
SMART	: Singapore-MIT Alliance for Research and Technology
SONAR	: Sound Navigation and Ranging
STOM	: ASEAN Senior Transport Officials Meeting
V2I	: Vehicle to Infrastructure
V2V	: Vehicle to Vehicle
V2X	: Vehicle to Everything
WIFI	: Wireless Fidelity

1. Introduction

1.1. Background

The Association of Southeast Asian Nations (ASEAN) has been committed to addressing connectivity as one of its key pillars of integration and development. ASEAN member countries have recognized the importance of enhancing physical, institutional, and people-to-people connectivity to promote economic growth, trade, and regional stability.

To help realize this, steps should be taken to ensure that the market for digital services is competitive and open to market entry. This section sets out proposals for enabling actions which will help achieve this desired outcome. Around the world regulators and governments are tackling the challenge of facilitating adequate competition in the telecoms and digital sectors. Competition is vital for driving innovation and ensuring that end-users pay a fair price for services. Yet the economics of many markets in the sector means that effective competition may be unlikely to emerge organically.

This is especially true of many digital services markets – such as digital advertising, search, and social networking. These markets exhibit strong network effects, which work to the advantage of larger market players. In addition, the global scale and portfolio of services offered by platforms like Google and Facebook enable them to maintain strong positions in a number of digital markets. Appropriate regulations can help promote effective competition and shield users from some of the adverse effects of uncompetitive markets (such as high prices). However, overly burdensome regulations can restrict investment and hinder market development. A balance must therefore be struck between intervening to promote competition and allowing markets to innovate and evolve organically. There are a number of different areas where action could help develop the competitive environment in ASEAN: national telecommunications sectors; the content services market; and the market for digital services. In addition, work to align regulations and facilitate cross-border trade in digital services will also enhance the competitive environment within ASEAN.

Related to autonomous vehicles (AV), support for a sustainable competitive market for its supply of digital services is a must to achieve ASEAN as a market. Each AMS is supposed to move forward into adaptation-oriented regulation for AV. However, with the diversity of AMSs, the actual progress or readiness is unknown. Moreover, with the nature of transport activities, ASEAN needs to identify opportunities to harmonize digital regulation to facilitate cross-border data flows embedded in the AV's technology. Besides those digital sector beneficiaries, the primary sector that would gain from this project is the transport sector. As one of the backbones of the ASEAN economy, the transport and logistics sectors would be leveraged at a new level of service.

Some of the commitments and initiatives that ASEAN member countries have undertaken to address connectivity related to AV are explained below.

ASEAN Digital Masterplan 2025 (ADM 2025)

ADM 2025 (ASEAN, 2010) aims to promote ASEAN as a leading digital community and economic bloc, powered by secure and transformative digital services, technologies, and ecosystems. Achieving such a vision is a great prize that will require governments, regulators, and market players to work together in complementary ways (ASEAN, 2021):

- Market players should continue to invest in new technologies, to innovate in the services they offer, and to compete to supply them to end users in new ways.
- Governments and regulators could work towards removing unneeded regulatory barriers to these market processes; to fund social measures for digital inclusion and digital skills; to build trust in digital services; to harmonize regulation and standards across ASEAN; and to promote awareness of the value of digital services.

In order to achieve the above, these conditions also have to be met:

- There is high quality and ubiquitous connectivity throughout ASEAN – delivered through the underlying telecommunications infrastructure. Excellent, ubiquitous, and high-speed connectivity is clearly essential to enable digital services. This means both improving infrastructure in those areas that are already connected and bringing connectivity to unconnected and underserved areas.
- The services which run over this connectivity must be safe and relevant to the needs of end users. This means removing barriers to innovation by market players, improving e-government services, and developing services which are safe and can better support international trade. It also means building services which ASEAN consumers and businesses can trust.
- The barriers which now prevent many businesses and consumers from using digital services need to be removed. Separate actions are needed for businesses and consumers – the two key users of digital services. For businesses, the focus is on improving productivity through digital skills, and for consumers on improving basic digital literacy and affordability so that digital services can be widely used.

Based on ADM 2025, the AV connectivity is related to Desire Outcome (DO4): A sustainable competitive market for the supply of digital services. The DO4 To help realize the vision steps should be taken to ensure that the market for digital services is designed to encourage the sound and sustainable development of digital services and to enhance the competitiveness of different players in the market.

Related to the facilitation of cross-border data flows, the timetable for implementation at the year 2022 is to do research on barriers to trade. There are two metrics to measure these actions I.e. (a) the growth in the number of ASEAN companies providing digital services measured annually, and (b) the growth in spending on digital services measured annually.

ASEAN Economic Community Blueprint 2025

ASEAN recognizes that regional economic integration is a dynamic, ongoing process as economies as well as domestic and external environments are constantly evolving. To achieve this, the ASEAN Economic Community (AEC) was established in 2015. The AEC is designed to create a single market and production base in the region. It aims to eliminate tariffs and non-tariff barriers, promote the free flow of goods, services, investment, and skilled labor, and foster economic integration among member states. The measures taken have to lead in creating a networked, competitive, innovative, highly integrated, and contestable ASEAN (ASEAN, 2015).

ASEAN Economic Community Blueprint 2025 (ASEAN, 2015) is built on the AEC Blueprint 2015 consisting of five interrelated and mutually reinforcing characteristics, namely: (i) A Highly Integrated and Cohesive Economy; (ii) A Competitive, Innovative, and Dynamic ASEAN; (iii) Enhanced Connectivity and Sectoral Cooperation; (iv) A Resilient, Inclusive, People-Oriented, and People-Centred ASEAN; and (v) A Global ASEAN.

Regarding the AV implementation, there are characteristics and elements of the ASEAN Economic Community Blueprint 2025 that are relevant, which is the C.2. Information And Communications Technology (ICT). ICT is recognized as a key driver in ASEAN's economic and social transformation. A strong ICT infrastructure with pervasive connectivity in ASEAN can facilitate the creation of a business environment that is conducive to attracting and promoting trade, investment, and entrepreneurship. ASEAN will need to continue prioritizing the bridging of the digital gap and ensure that all communities and businesses can benefit from ICT adoption. The AEC 2025 vision will be built upon the successes of the past ASEAN ICT Masterplan. It will aspire to propel ASEAN towards a digitally enabled economy that is secure, sustainable, and transformative, and to further leverage ICT to enable an innovative, inclusive, and integrated ASEAN.

Strategic measures that are relevant with AV implementation is part C.2 iii Innovation: Support ICT innovations and entrepreneurship as well as new technological developments such as Smart City, and Big Data and Analytics.

Masterplan on ASEAN Connectivity 2025

In 2010, ASEAN adopted the ACMP (ASEAN, 2017), which outlines the strategic framework and action plans to improve physical infrastructure, enhance institutional connectivity, and strengthen people-to-people ties. The ACMP serves as a comprehensive roadmap for regional connectivity. The Master Plan on ASEAN Connectivity 2025 is the successor document to the Master Plan on ASEAN Connectivity adopted on October 28, 2010.

The vision of ASEAN Connectivity 2025 is to achieve a seamlessly and comprehensively connected and integrated ASEAN that will promote competitiveness, inclusiveness, and a greater sense of Community. Connectivity in ASEAN encompasses the physical (e.g., transport, ICT, and energy), institutional (e.g., trade, investment, and services liberalization), and people-to-people linkages (e.g., education, culture, and tourism) that are the foundational supportive means to achieving the economic, political-security, and socio-cultural pillars of an integrated ASEAN Community.

The strategies that support AV implementation is seamless logistics (S3). Ongoing Efforts that will continue from the Master Plan on ASEAN Connectivity 2010 that are relevant to AV implementation is to:

1. Transport facilitation strategy, with initiative to:

- Accomplish the implementation of AFAFGIT and AFAFIST (including developing necessary ASEAN transport facilitation-related procedures)
- Assessment on the implementation of AFAMT
- Operationalize AFAFGIT and AFAFIST (which is under the overall measure to accomplish the implementation of AFAFGIT and AFAFIST)

2. Substantially improve trade facilitation in the region, with an initiative to:

- Activate and operate the ASEAN Single Window in selected ports as early as possible for ASEAN Member States who are ready to implement it, and eventually for all ASEAN Member States
- Fully roll out the National Single Windows in all ASEAN Member States

3. Accelerate the development of an efficient and competitive logistics sector, with an initiative to:

- Remove substantially all restrictions on trade in services for all other service sectors

Outcome and Output Metrics for the Master Plan on ASEAN Connectivity 2025 related to S3 and relevant to AV implementation is to strengthen ASEAN competitiveness through enhanced trade routes and logistics, with output metrics:

- Establish a public database with regularly updated information on key trade routes (land and maritime) across ASEAN
- Establish an outreach campaign to allow users to benefit from the data

1.2. Current Problem

Self-driving cars or Autonomous Vehicles (AV)s have been all the rage in recent years. However, not everyone is convinced that ASEAN is fully ready to embrace such technology since AMS's policy on AV varies from no-response, prevention-oriented, control-oriented, toleration-oriented, and adaptation-oriented.

AV relies on communication technology, sensors, actuators, complex algorithms, machine learning systems, and powerful processors to execute software to ensure a super-fast response to serve traffic safety. Meanwhile, in each AMS, the traffic conditions and the roadside IT infrastructures vary greatly to suit minimum data-flow requirements in traffic safety (e.g., max. latency, payload size, reliability, data rate, and min. range).

The compliance of data flow requirements is more questionable when the AV operation is handled over among operators in roaming mode across state borders. Other than that, if any AMS adopts a different technology standard, compliance becomes more critical. Also, if the adopted standard is the same, the availability of spectrum and types of licenses in each country might vary to allow a smooth transition.

Under a high standard of data flow requirement for safety in the transport sector, supporting policy and regulation for harmonizing standards from the telecommunication sector is critical in state border crossing. While previous studies and policy documents for personal mobility roaming are available, specific research on vehicle mobility compliance with cross-border data flow is barely found.

1.3. Method

This project uses desk study and direct engagement approaches. The figure below shows that desk study research was conducted to gain information on the following areas:

1. Data flow requirements for Autonomous Vehicles
2. Current adoption stage of AV by AMS
3. Gaps in digital data flow requirements and available services
4. Gaps in regulation that drive data flow requirement

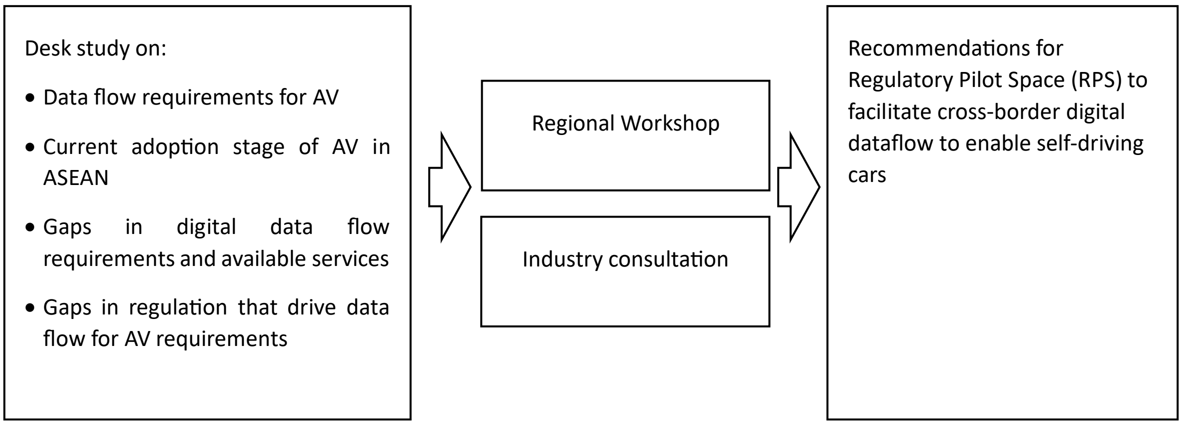

Figure 1. Project methodology

Following the desk study, a regional workshop was conducted as a means to disseminate the findings from the desk study, confirm findings, and discuss the way forward for the regulatory pilot space to facilitate cross-border digital flows enabling AVs. The workshop also served as a platform for industry consultation by inviting AV industries in the region to present their technology development and how they collaborate with academia and government in pilot testing. The final part of the project is the development of the final report, which includes recommendations agreed upon during the regional workshop.

2. Data flow requirement for autonomous vehicles

2.1. Definition of AV technology

Autonomous vehicle technology, often referred to as self-driving or driverless car technology, is a rapidly advancing field that aims to develop vehicles capable of operating without human intervention. These vehicles use a combination of sensors, cameras, radar, lidar, GPS, and advanced software to navigate, perceive their environment, and make driving decisions. Here are some key components and concepts related to autonomous vehicle technology (CETRAN, 2020; SAE 2021a, 2021b; Visnic, 2021; Warrendale, 2021):

1. Sensors. Autonomous vehicles are equipped with various sensors to perceive their surroundings. These sensors include radar, lidar (Light Detection and Ranging), cameras, ultrasonic sensors, and GPS. These sensors work together to provide a comprehensive view of the vehicle's environment (Ayala & Mohd, 2021; UdacityTeam, 2021).
2. Machine Learning and AI. Machine learning algorithms and artificial intelligence are crucial for processing the vast amount of data collected by sensors and making real-time decisions. Deep learning techniques are often used for tasks like object detection, lane following, and decision-making.
3. Mapping and Localization. High-definition maps are essential for autonomous vehicles to know their exact position and navigate accurately. Simultaneous Localization and Mapping (SLAM) technology helps the vehicle create and update maps while simultaneously determining its location within those maps.
4. Control Systems. Autonomous vehicles rely on sophisticated control systems to manage acceleration, braking, and steering. These systems ensure safe and precise driving based on the information gathered from sensors and processed by the AI algorithms.
5. Connectivity. Autonomous vehicles often communicate with other vehicles (V2V) and infrastructure (V2I) using vehicle-to-everything (V2X) technology. This connectivity can enhance safety and traffic management.
6. Testing and Validation. Developing and testing autonomous vehicles is a complex and time-consuming process. Companies in this field conduct extensive real-world testing, simulations, and validation to ensure safety and reliability.
7. Regulations and Safety. Governments and regulatory bodies are working on establishing guidelines and regulations for autonomous vehicles to ensure their safety on public roads. Safety remains a top priority for the development of this technology.
8. Challenges. Autonomous vehicles face numerous challenges, including navigating in complex urban environments, handling adverse weather conditions, cybersecurity threats, and addressing ethical and legal issues related to accidents and liability.

9. Applications. Autonomous vehicle technology has a wide range of potential applications beyond passenger cars. It can be used in logistics and delivery services, public transportation, agriculture, mining, and more.

10. Levels of Autonomy. The Society of Automotive Engineers (SAE) has defined levels of automation ranging from Level 0 (no automation) to Level 5 (full automation) (SAE, 2021a, 2021b; Warrendale, 2021). Current autonomous vehicles are at Level 2 or Level 3, which means they require some level of human supervision. These levels help clarify the capabilities and responsibilities of both the vehicle and the human operator. The five levels of autonomous vehicles are:

    Level 0 (No Automation).

    The level when vehicle have no automation features. The human driver is responsible for all aspects of driving, including control of the vehicle and monitoring of the environment. These vehicles may have basic systems like antilock brakes or cruise control, but they do not assist with driving tasks.

    Level 1 (Driver Assistance).

    Level 1 vehicles provide limited assistance to the driver in specific functions. Common features at this level include adaptive cruise control (ACC) and lane-keeping assistance. The driver is still responsible for most driving tasks but can delegate some specific functions to the vehicle.

    Level 2 (Partial Automation)

    Level 2 vehicles offer more advanced automation but still require the driver to monitor the environment and be prepared to take over at any time. Features like lane-centering and traffic jam assist are examples of Level 2 capabilities. The driver must remain engaged and keep their hands on the steering wheel.

    Level 3 (Conditional Automation)

    Level 3 vehicles can handle most driving tasks under specific conditions. The driver can disengage from active driving and turn their attention away from the road in certain situations, like highway driving. However, the driver must be ready to intervene if requested by the system, which can happen when transitioning out of the defined conditions or if the system encounters a scenario it cannot handle.

    Level 4 (High Automation)

    Level 4 vehicles are capable of fully autonomous driving within specific operational design domains (ODD). In these predefined conditions, the vehicle can manage all aspects of driving without human intervention. Outside of these specific scenarios or conditions (e.g., off-road or extreme weather), a Level 4 vehicle may require a human driver to take control.

Level 5 (Full Automation)

Level 5 is the highest level of automation, where the vehicle is capable of performing all driving tasks under all conditions without any human intervention

Companies like Waymo (formerly a project within Google), Tesla, General Motors, and numerous startups are actively developing autonomous vehicle technology. While fully autonomous vehicles are not yet currently commonplace on the roads, significant progress has been made, and it is expected that autonomous vehicles will play a more prominent role in the transportation landscape in the coming years as the technology matures and regulations evolve (Chavhan et al., 2021; Myers, 2022).

2.2. Type of data Required for AV

Data flow requirements for Self-Driving Cars (SDC) or Autonomous Vehicles (AV) encompass the processes and pathways by which data is collected, transmitted, processed, and utilized within the vehicle's systems and with external entities. These requirements are essential for the safe and effective operation of autonomous vehicles.

Some key identified data flow requirements for SDCs/AVs (Ebert & Weyrich, 2019; GlobeNewswire, 2021; Peick, 2022; UNECE, 2019, 2019; WEF, 2021):

- Sensor Data Collection. Autonomous vehicles rely on various sensors, including cameras, lidar, radar, ultrasonic sensors, and GPS, to perceive the surrounding environment. Data from these sensors must be continuously collected and processed in real-time to create a comprehensive view of the vehicle's surroundings.
- Data Fusion and Perception. Sensor data from different sources must be fused and processed to generate a coherent and accurate perception of the environment. Algorithms within the vehicle's system combine and analyze sensor data to identify objects, lanes, traffic signs, and other relevant information.
- High-Definition Maps. Autonomous vehicles often use high-definition maps to enhance localization and navigate safely. Maps, including road geometry, lane information, and landmarks, are updated and used by the vehicle's system to understand its precise position.
- Communication with Infrastructure. Autonomous vehicles may communicate with traffic infrastructure, such as traffic lights and road signs, to optimize traffic flow and enhance safety. Data is exchanged with infrastructure through Vehicle-to-Infrastructure (V2I) communication, allowing the vehicle to receive information and instructions.

- V2V Communication. Vehicles may communicate with each other (Vehicle-to-Vehicle or V2V) to share information about their positions, speeds, and intentions. V2V data exchange is used for collision avoidance, cooperative merging, and improved traffic flow.
- Remote Data Services. Autonomous vehicles may rely on remote data services for real-time traffic information, software updates, and cloud-based processing. Data is transmitted between the vehicle and remote servers via cellular networks or other communication channels.
- Control Commands. The vehicle's control system must receive and execute commands for acceleration, braking, steering, and other driving actions. Control commands are generated based on sensor data and high-level decision-making algorithms and are transmitted to the vehicle's actuators.
- Internal Data Processing. Data processing within the vehicle's onboard computers is critical for perception, decision-making, and control. Data flows between various onboard components, including processors, sensors, and communication modules, to support the vehicle's autonomous functions.
- Data Logging and Storage. Autonomous vehicles log sensor data and operational information for diagnostic, safety, and regulatory purposes. Data is stored in secure onboard storage systems and may also be transmitted to remote servers for analysis.
- Safety Critical Data Paths. Safety-critical systems, such as collision avoidance and emergency braking, require ultra-low latency and high-reliability data flows. Specialized communication channels and protocols ensure rapid data exchange between safety-critical components.
- Cybersecurity Monitoring. Continuous monitoring of data flows is essential to detect and prevent cybersecurity threats and unauthorized access. Intrusion detection systems and cybersecurity measures protect the integrity and security of data.

These identified data flow requirements are integral to the operation of autonomous vehicles, enabling them to perceive their environment, make real-time decisions, navigate safely, and communicate with other vehicles and infrastructure. Ensuring the robustness, reliability, and security of these data flows is critical for the widespread adoption of self-driving cars.

Table 1. Use cases group requirements

Best Practices

Use Case Group	Max Latency	Payload Size	Reliability (%)	Data Rate	Min Range
Vehicle Platooning	10 – 500	50 – 6000	90 – 99.99	50 - 65	80 – 350
Advanced Driving	3 – 100	300 – 12000	90 – 99.999	10 - 50	360 – 500
Extended Sensor	3 – 100	1600	90 – 99.999	10 - 1000	50 - 1000
Remote Driving	5	-	99.999	UL: 25 DL: 1	-

2.3. Data-flow requirement for self-driving cars

Data-flow requirements serve as a blueprint for the development and operation of self-driving cars (Ranjan & Senthamilarasu, 2020). They ensure that data is processed, communicated, and used effectively to enable safe and reliable autonomous driving while addressing critical aspects like redundancy, cybersecurity, and regulatory compliance. Understanding and adhering to these requirements are essential for the successful deployment of self-driving cars on public roads.

Below are some key reasons why it is important to understand data-flow requirements for self-driving cars:

- System Development and Architecture. Data-flow requirements are essential for designing the architecture of self-driving car systems. They dictate how data is collected, processed, and shared among various components of the autonomous vehicle, such as sensors, control systems, and decision-making algorithms.
- Data Fusion and Perception. Self-driving cars rely on a multitude of sensors, including cameras, lidar, radar, and GPS, to perceive the environment. Data-flow requirements define how these sensor inputs are fused and processed to create a comprehensive and accurate perception of the vehicle's surroundings.

- Decision-making and Control. The data-flow requirements play a critical role in the decision-making process of autonomous vehicles. Data from sensors, maps, and other sources are used to make real-time decisions such as lane changes, braking, and steering.
- Sensor Redundancy and Failover. Self-driving cars often employ redundant sensors to enhance safety. Data-flow requirements determine how data is used from these redundant sensors and how the system reacts in the event of sensor failures.
- Redundancy and failover mechanisms are essential for maintaining vehicle safety.
- Localization and Mapping. Accurate localization and mapping are fundamental for autonomous navigation. Data-flow requirements define how sensor data is used to update maps and estimate the vehicle's precise position in real-time.
- Communication with Infrastructure and Other Vehicles. Autonomous vehicles need to communicate with other vehicles, infrastructure, and central control systems to share data and receive critical information. Data-flow requirements outline how this communication is established and maintained.
- Cybersecurity and Data Privacy. The flow of data within and outside the vehicle is vulnerable to cybersecurity threats. Data-flow requirements include measures to ensure data security and protect against cyberattacks. It also addresses data privacy concerns, ensuring that sensitive information is handled appropriately.
- Regulatory Compliance. Autonomous vehicles are subject to regulatory standards and requirements. Understanding data-flow requirements is crucial for compliance with safety and data-handling regulations set by government authorities.
- Continuous Improvement and Updates. Self-driving car technology is continually evolving. Data-flow requirements must allow for updates and improvements to the system, including the integration of new sensors and algorithms.
- Safety and Reliability. The safety and reliability of autonomous vehicles depend on accurate and well-defined data-flow requirements. Errors or delays in data flow can lead to unsafe conditions or accidents.
- Testing and Validation. Data-flow requirements guide the development of testing and validation procedures. Engineers and developers use these requirements to create test scenarios and evaluate the system's performance.

2.3.1. Digital Infrastructure performance requirement scenarios

Performance requirements for high data rate and traffic density scenarios are critical considerations, especially in the context of modern telecommunications, wireless networks, and data-intensive applications. These requirements ensure that the network and infrastructure can handle the increased data traffic and deliver reliable and responsive services.

Below are some key performance requirements for such scenarios:

- High Data Throughput is the ability to handle a significant volume of data traffic simultaneously. In high data rate scenarios, networks must provide high throughput to accommodate data-intensive applications like video streaming, online gaming, and real-time data analytics. Throughput is typically measured in bits per second (bps) or megabits per second (Mbps) and should support the required data rates for the applications in use.
- Low Latency is the delay between data transmission and reception, including processing and propagation delays. Low latency is crucial for applications that require real-time communication, such as autonomous vehicles, augmented reality, and telemedicine. Reduced latency ensures quick response times. Latency is measured in milliseconds (ms) and should be minimized to meet application-specific requirements.
- High Reliability is the ability to maintain network connectivity and data transfer even in congested or challenging environments. High reliability is essential to prevent service interruptions in scenarios with high traffic density. Redundancy and failover mechanisms are often needed. Reliability is usually expressed as a percentage, indicating the probability of uninterrupted service.
- Quality of Service (QoS) is a set of network performance parameters that guarantee a certain level of service quality for different types of traffic (e.g., voice, video, data). QoS ensures that critical applications receive the necessary bandwidth, priority, and latency guarantees while maintaining a high-quality of experience for users. QoS metrics include packet loss rates, jitter, and the mean opinion score (MOS) for voice quality.
- Scalability is the ability to accommodate an increasing number of users and devices without degrading performance. Scalability ensures that the network can handle growing traffic density as more users and devices connect. This may involve expanding infrastructure or optimizing resource allocation. Scalability is assessed by monitoring network performance under increasing loads.
- Spectrum Efficiency is the ability to use available radio frequency spectrum efficiently to transmit data. Spectrum efficiency is crucial in scenarios with limited available bandwidth. Advanced modulation schemes, interference mitigation techniques, and spectrum sharing may be required. Spectral efficiency is measured in bits per second per Hertz (bps/Hz) and should be maximized.
- Security and Privacy is the protection against unauthorized access, data breaches, and privacy violations. High-traffic density scenarios are attractive targets for cyberattacks. Strong security measures, encryption, and privacy safeguards are

necessary. Security and privacy are assessed through compliance with security standards and incident monitoring.

- Network Density and Capacity Planning is the planning for the number of network access points, base stations, or infrastructure elements needed to support high traffic density. Adequate network density and capacity ensure that users experience reliable connectivity even in crowded areas. Capacity planning involves analyzing historical and predicted traffic patterns and adjusting network resources accordingly.
- Sustainability and Energy Efficiency is the measure to minimize energy consumption and environmental impact while maintaining performance. Sustainability considerations are increasingly important. High-traffic density scenarios should optimize energy use and minimize the carbon footprint. Energy efficiency metrics may include watts per user or per unit of data transmitted.

Table 2. Performance requirements for high data rate and traffic density scenarios

No	Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)	Area traffic capacity (UL)	Overall user density	Activity factor	UE speed	Coverage
1	Urban macro	50 Mbps	25 Mbps	100 Gbps/km^2 (note 4)	50 Gbps/km^2 (note 4)	10000/km^2	20%	Pedestrians and users in vehicles (up to 120 km/h)	Full network (note 1)
2	Rural macro	50 Mbps	25 Mbps	1 Gbps/km^2 (note 4)	500 Mbps/km^2 (note 4)	100/km^2	20%	Pedestrians and users in vehicles (up to 120 km/h)	Full network (note 1)
3	Indoor hotspot	1 Gbps	500 Mbps	15 Tbps/km^2	2 Tbps/km^2	250000/km^2	note 2	Pedestrians	Office and residential (note 2) (note 3)
4	Broadband access in a crowd	25 Mbps	50 Mbps	[3.75] Tbps/km^2	[7.5] Tbps/km^2	[500000]/km^2	30%	Pedestrians	Confined area
5	Dense urban	300 Mbps	50 Mbps	750 Gbps/km^2 (note 4)	125 Gbps/km^2 (note 4)	250000/km^2	10%	Pedestrians and users in vehicles (up to 60 km/h)	Downtown (note 1)
6	Broadcast like services	Maximum 200 Mbps (per TV channel)	N/A or modest (e.g., 500 kbps per user)	N/A	N/A	[15] TV channels of [20 Mbps] on one carrier	N/A	Stationary users, pedestrians and users in vehicles (up to 500 km/h)	Full network (note 1)
7	High-speed train	50 Mbps	25 Mbps	15 Gbps/train	7.5 Gbps/train	1000/train	30%	Users in trains (up to 500 km/h)	Along railways (note 1)
8	High-speed vehicle	50 Mbps	25 Mbps	[100] Gbps/km^2	[50] Gbps/km^2	4000/km^2	50%	Users in vehicles (up to 250 km/h)	Along roads (note 1)
9	Airplanes connectivity	15 Mbps	7.5 Mbps	1.2 Gbps/plane	600 Mbps/plane	400/plane	20%	Users in airplanes (up to 1000 km/h)	(note 1)

NOTE 1: For users in vehicles, the UE can be connected to the network directly, or via an on-board moving base station
NOTE 2: A certain traffic mix is assumed; only some users use services that require the highest data rates [2].
NOTE 3: For interactive audio and video services, for example, virtual meetings, the required two-way end-to-end latency (UL and DL) is 2-4 ms while the corresponding experienced data rate needs to be up to 8 K 3D video [300 Mbps] in uplink and downlink
NOTE 4: These values are derived based on overall user density. Detailed information can be found in [10].
NOTE 5: All the values in this table are targeted values and not strict requirements.

2.3.2. Low-latency and high-reliability performance scenario

Performance requirements for low-latency and high-reliability scenarios are critical in applications where real-time communication, minimal delays, and uninterrupted connectivity are paramount. These scenarios are common in various industries, including telecommunications, autonomous systems, healthcare, and industrial automation.

Key performance requirements for such scenarios:

- Ultra-low latency is an extremely short delay between data transmission and reception, including processing and propagation delays. Ultra-low latency is crucial for applications where real-time responsiveness is essential, such as autonomous vehicles, remote surgery, and financial trading systems. Latency should be minimized to a few milliseconds (or even microseconds) to meet application-specific requirements.
- Deterministic Latency is the consistency in latency, ensuring that delays remain predictable and within a specified range. Deterministic latency is essential for safety-critical applications where timing precision is critical. Variability in latency must be minimized. Variance in latency should be quantified and controlled within defined bounds.
- High Network Reliability is a measure to ensure uninterrupted network connectivity and data transfer, even in challenging or congested environments. High reliability is vital for applications that cannot tolerate service interruptions, such as critical infrastructure, emergency services, and remote monitoring. Reliability is usually expressed as a percentage, indicating the probability of uninterrupted service, and should approach 100%.
- Redundancy and Failover is the deployment of redundant systems and paths to maintain service continuity in the event of component failures or network issues. Redundancy and failover mechanisms are essential to ensure continuous operation and fault tolerance in high-reliability scenarios. The effectiveness of redundancy and failover strategies should be tested and verified.
- Quality of Service (QoS) Guarantees is the provision of specific QoS parameters, such as bandwidth, latency, and packet loss guarantee, to ensure consistent and high-quality service. QoS guarantees are necessary to meet the performance expectations of applications like video conferencing, voice-over IP (VoIP), and industrial control systems. QoS parameters should be monitored and maintained within defined thresholds.
- End-to-End Security is ensuring the confidentiality, integrity, and authenticity of data and communications. Strong security measures, including encryption, authentication, and access control, are essential to protect against cyber threats and ensure data privacy. Security compliance and incident monitoring are used to assess the effectiveness of security measures.
- High Availability is to maximize system uptime and minimizing planned or unplanned downtime. High availability is essential for critical infrastructure,

telecommunications, and emergency services, where continuous operation is non-negotiable. Availability is expressed as a percentage, indicating the proportion of time the system is operational, and should approach 100%.

- Robustness to Congestion is the ability to maintain performance even in high-traffic scenarios. Robustness to congestion ensures that the system remains responsive and reliable even when usage peaks. Network performance should be tested under various traffic conditions to assess its robustness.
- Resource Efficiency is the optimizing of resource utilization, including bandwidth, computing power, and energy, to ensure efficient operation. Efficient resource usage is important for sustainability and cost-effectiveness in high-reliability scenarios. Resource efficiency metrics, such as bandwidth utilization or energy consumption, should be optimized.
- Disaster Recovery is the planning and procedures to recover from catastrophic events or major disruptions, ensuring minimal downtime. Disaster recovery plans are critical for high-reliability scenarios to restore operations swiftly after disasters or emergencies. The effectiveness of disaster recovery plans should be tested and evaluated periodically.

Meeting these performance requirements in low-latency and high-reliability scenarios often involves a combination of advanced technology, rigorous testing, redundancy strategies, and adherence to industry standards and best practices. These requirements are essential for applications where safety, responsiveness, and continuous operation are of utmost importance.

Table 3. Examples of requirements for low-latency and high-reliability scenarios

Scenario	Max allowed end-to-end latency (note 2)	Survival time	Communication service availability (note 3)	Reliability (note 3)	User experienced data rate	Payload size (note 4)	Traffic density (note 5)	Connection density (note 6)	Service area dimension (note 7)
Discrete automation	10 ms	0 ms	99.99%	99.99%	10 Mbps	Small to big	1 Tbps/km^2	100000/km^2	1000 x 1000 x 30 m
Process automation – remote control	60 ms	100 ms	99.9999%	99.999%	1 Mbps up to 100 Mbps	Small to big	100 Gbps/km^2	1000/km^2	300 x 300 x 50 m
Process automation – monitoring	60 ms	100 ms	99.9%	99.9%	1 Mbps	Small	10 Gbps/km^2	10000/km^2	300 x 300 x 50 m
Electricity distribution – medium voltage	40 ms	25 ms	99.9%	99.9%	10 Mbps	Small to big	10 Gbps/km^2	1000/km^2	100 km along power line
Electricity distribution – high voltage (note 1)	5 ms	10 ms	99.9999%	99.999%	10 Mbps	Small	100 Gbps/km^2	1000/km^2 (note 8)	200 km along power line
Intelligent transport systems – infrastructure backhaul	30 ms	100 ms	99.9999%	99.999%	10 Mbps	Small to big	10 Gbps/km^2	1000/km^2	2 km along a road

NOTE 1: Currently realized via wired communication lines
NOTE 2: This is the maximum end-to-end latency allowed for the 5G systems to deliver the service in the case the end-to-end latency is completely allocated to the 5G system from the UE to the Interface to Data Network
NOTE 3: Communication service interfaces, and reliability relates to a given system entity. One or more retransmissions of network layer packets may take place in order to satisfy the reliability requirement.
NOTE 4: Small: payload typically ≤ 256 bytes
NOTE 5: Based on the assumption that all connected applications within the service volume require the user-experienced data rate.
NOTE 6: Under the assumption of 100% 5G penetration
NOTE 7: Estimates of maximum dimensions; the last figure is the vertical dimension.
NOTE 8: In dense urban areas
NOTE 9: All the values in this table area example values and not strict requirements. Deployment configurations should be taken into account when considering service offerings that meet the targets.

2.4. Digital wireless technology and mobility support

AV is closely related to digital wireless technology and mobility support (Banerjee et al., 2023). Digital wireless technology refers to the use of digital signals and protocols for wireless communication. It has revolutionized telecommunications by providing faster, more reliable, and more efficient wireless connectivity compared to older analog technologies. Digital wireless technology encompasses various generations of wireless networks, including 2G, 3G, 4G, and 5G, each offering increased data rates and improved capabilities.

Mobility support in digital wireless technology is the ability of a wireless network to seamlessly connect and provide continuous service to mobile devices as they move within the network's coverage area. Key aspects of mobility support include handovers (the smooth transition of a device from one cell or access point to another), location tracking, and network resource management to ensure uninterrupted connectivity for users on the move (Banerjee et al., 2023; IEEE, 2020; Rouse, 2011; Sen, 2010).

Digital wireless technology and mobility support have transformed various industries, enabling services like mobile communication, internet access, IoT connectivity, and the foundation for emerging technologies like autonomous vehicles and smart cities. These technologies have become integral to our modern, connected world.

Table 3 shows some wireless technologies that may support the existence of AV. However, some of them may only be applied not in the core network since making driving autonomous completely, high speed-speed networks such as fifth generation (5G) or beyond (B5G) technologies will be necessary.

Table 4. Types of wireless technology with specification

Wireless Technology	Network Type	Spectrum	Transmission Range	Transmission Throughput	Mobility Support
LoRa [48]	WAN	433.868 & 915 MHz	2 – 5 km (urban) and 15 km (suburban)	27 Kbps	Yes
Zigbee [49]	PAN	433.868 & 915 MHz	10 – 100 m	250 Kbps for 2.4 GHz; 40 Kbps for 915 MHz; 20 Kbps for 868 MHz	Yes
DSRC [42]	Wireless Ad-hoc	5.8 – 5.9 GHz	1 km	2.5 Mbps	Yes
Bluetooth Low Energy (BLE) [50]	PAN	2.4 GHz	100 m (Class 1 device); 10 m (Class 1 device); 1 m (Class 1 device);	1400 Kbps (BLE 5)	Limited
WiMAX [51]	Wireless Broadband	5.8 GHz	50 km	70 Mbps	Yes
C-V2X [52]	Cellular Wireless	5.9 GHz	>DSRC $ LoRa	>DSRC $ LoRa	Yes

High speed of up to 10 GB with incredibly low latency of 1 ms is the key feature in 5G technology that realization of AVs should be possible. Compared to the previous generation of cellular networks, 5G technology offers many enhancements. The comparison of specifications between 4G and 5G is depicted in Figure 1. In 2015, the International Telecommunication Union (ITU) initiated is new cellular communication standard called 5G new radio (NR). It has the potential to support massive delay-sensitive applications through key use-cases as follows.

1. Enhanced Mobile Broadband (eMBB). This use case is focused on providing much faster data speeds and more reliable mobile broadband experiences to users. It's about increasing the capacity in dense urban areas and providing better performance in terms of higher data rates across the coverage area. This will support high-definition (HD) and ultra-high-definition (UHD) video streaming, virtual reality (VR), and augmented reality (AR).
2. Massive Machine Type Communication (mMTC). mMTC is designed for large-scale machine-to-machine (M2M) applications. This includes the Internet of Things (IoT) devices such as connected sensors, meters, and trackers. The goal is to enable communication between a massive number of devices in a small area, which might not necessarily need high data speeds but requires wide-area coverage and deep penetration.
3. Ultra-reliable Low-latency Communication (URLLC). URLLC targets applications that require very high reliability and very low latency. Examples include autonomous vehicles that need to make split-second decisions, remote surgeries where doctors operate on patients from miles away, or industrial automation where machinery needs to coordinate in real-time.

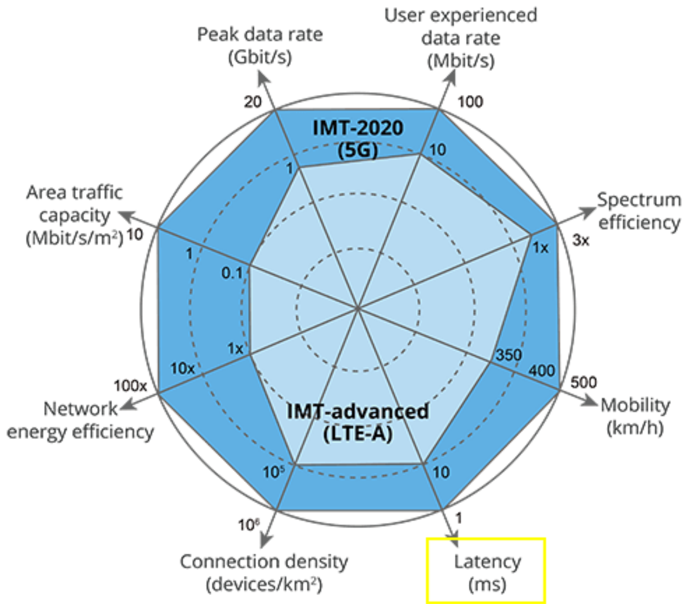

Figure 2. 4G LTE vs 5G Specification

URLLC represents a novel 5G service designed for vital communications, targeting a latency of just 1 millisecond, along with stringent security measures and a reliability of 99.999%. This advanced, high-speed, and dependable wireless communication is perfectly suited for applications that demand low latency, like autonomous vehicles. It allows cars to instantly connect, exchanging data both with nearby vehicles (through vehicle-to-vehicle interactions) and local infrastructure (via vehicle-to-infrastructure links).

In situations like fully autonomous vehicles without any human input, cars can leverage data from nearby infrastructure or other vehicles for tasks like automated passing, collaborative crash prevention, or efficient platooning. Additionally, at intelligent crossroads, vehicles can sync with traffic signals and systems to prioritize emergency vehicles or buses. All these functions demand extreme reliability and tight end-to-end latency, which only a URLLC network can assure.

Storing and handling the vast data from smart vehicles, produced by numerous high-resolution cameras and sensors like RADAR, LIDAR, SONAR, and GPUS, presents a challenge. Even though the best human drivers react within 100 to 150ms, ensuring better safety requires processing real-time traffic conditions within 100ms. Relying solely on onboard processing or cloud computing won't be adequate for this task.

In-vehicle processing and storage have their limits due to resource and power boundaries. For instance, GPUs required for swift computation and inference consume a lot of power. The additional need for cooling to address thermal limits can notably reduce the vehicle's driving range and fuel efficiency. Sensor data can quickly max out local storage devices like SSDs. While these onboard systems might handle interactions between passengers and their vehicles, they're inadequate for managing communications between vehicles or between vehicles and infrastructure.

At the same time, the extended delays and significant data transmission challenges suggest that cloud computing isn't the complete solution for linking smart vehicles within an Internet of Vehicles. The solution lies in placing storage and computational resources at the edge of the wireless network, encompassing edge caching, edge computing, and edge AI, all under an MEC (either "Mobile Edge Computing" or "Multi-access Edge Computing") network framework. It is an approach to network architecture that involves the processing of data at the edge of the network rather than in a centralized data center. This means that data is processed closer to the source of data generation (e.g., a mobile device or IoT device).

The integration of 5G technology with other existing technologies will open doors to thousands of other use-cases. The recommendations for integration strategy can be roughly divided into Non-Stand Alone (NSA) and Stand Alone (SA).

NSA refers to a deployment mode where the 5G network is built upon an existing 4G LTE network infrastructure. The 5G New Radio (NR) is connected to the existing 4G Evolved Packet Core (EPC). This means that 5G NR relies on the 4G LTE network for control functions, while data can be transmitted over both 4G and 5G bands. It is seen as a transitional step and is typically used by operators for their initial 5G rollouts. It allows them to provide 5G services without building a complete 5G core network from scratch. Since it leverages the existing 4G infrastructure, NSA provides a cost-effective and faster way to deploy 5G services. It gives operators the ability to launch 5G more rapidly while planning a transition to a full 5G standalone (SA) network in the future. While NSA allows for a quicker 5G deployment, it may not support all the advanced features and use cases that 5G promises, especially those that require ultra-low latency or network slicing as required in the AV architecture. For these, a Standalone (SA) architecture, where the 5G NR is connected to the 5G core without dependency on 4G, would be more appropriate.

While SA refers to a deployment mode where the 5G network operates independently without relying on an existing 4G LTE network infrastructure. In SA, the 5G New Radio (NR) is connected directly to the 5G core network, eliminating the need for 4G as a foundational layer. It's an end-to-end 5G system. SA supports all the advanced features that 5G promises, such as network slicing, ultra-reliable low-latency communication (URLLC), and enhanced mobile broadband (eMBB). While many operators initially launched 5G using NSA due to its cost-effectiveness and quicker deployment benefits, the transition to SA is seen as the eventual goal to fully exploit 5G's potential.

As explained previously fully automatic vehicles must be deployed in the stringent network requirement, the candidate of the network is 5G with stand-alone deployment mode.

2.5. AV system hand-overs

There are three main issues relating to AV system hand-overs: network connectivity hand-over, human-to-machine hand-over and take-over, and machine-to-human hand-over.

2.5.1. Network connectivity hand-over

Network connectivity handover is a critical concept in the context of autonomous vehicles and connected transportation systems, and is the main issue discussed in this report. It refers to the seamless transfer of network connectivity from one network infrastructure (e.g., Wi-Fi, cellular network) to another as a vehicle moves through different coverage areas. This technology is vital for ensuring continuous and reliable connectivity for autonomous vehicles, which rely heavily on data exchange with external systems for navigation, safety, and various other functions.

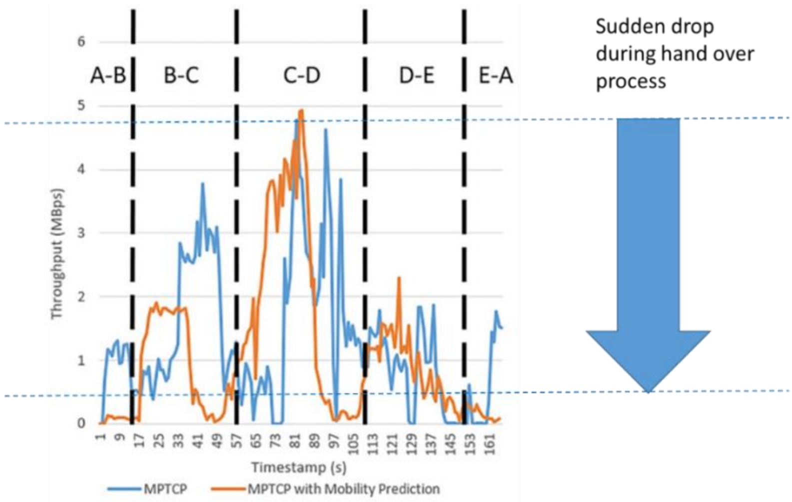

Figure 3. Illustration of changes in network connectivity

Here is an overview of network connectivity hand-over related to autonomous vehicles:

- Continuous Connectivity: Autonomous vehicles require uninterrupted connectivity to access real-time data, such as traffic information, road conditions, weather updates, and communication with central control systems. Network handover ensures that the vehicle remains connected as it moves through areas with different network coverage or changes in network conditions.
- There are two types of networks: cellular and network. In Cellular Networks, Autonomous vehicles typically connect to cellular networks (e.g., 4G LTE, 5G) for high-speed data communication. Network handover may involve switching between different cellular towers or networks operated by various carriers. While in Wi-Fi Networks, vehicles can also connect to local Wi-Fi networks, such as public hotspots or private networks. Network handover may occur when transitioning from one Wi-Fi network to another or between Wi-Fi and cellular networks.
- Seamless Transition. The goal of network connectivity handover is to ensure that the vehicle's communication links remain uninterrupted during the transition. This requires a smooth and rapid transfer of data sessions without noticeable disruptions.
- Multi-Connectivity: To enhance reliability, many autonomous vehicles are designed to simultaneously connect to multiple networks. For example, a vehicle might be connected to both a cellular network and a Wi-Fi network. This redundancy ensures that if one network becomes unavailable or experiences high latency, the vehicle can seamlessly switch to the other network.
- Quality of Service (QoS): Network handover protocols consider the quality-of-service requirements for different applications within the vehicle. For instance, safety-critical applications may have higher priority, ensuring that they maintain connectivity even in challenging network conditions.
- Communication Protocols: To facilitate network handover, communication protocols and standards are essential. Organizations like the Society of Automotive Engineers (SAE) and the 3rd Generation Partnership Project (3GPP) develop standards for vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication.
- Challenges for this process related to these aspects:
    - Latency: Network handover should occur with minimal latency to avoid disruptions in data exchange. High latency can affect real-time decision-making by autonomous systems.
    - Security: Secure handover mechanisms are crucial to protect the vehicle's communication channels from cyber threats during the transition.

    - Interoperability: Ensuring that vehicles can seamlessly hand over connectivity between different network technologies and carriers is a complex challenge.
- V2X Communication: Vehicle-to-everything (V2X) communication is a key use case for network connectivity handover. It involves vehicles communicating with not only other vehicles but also infrastructure, pedestrians, and traffic management systems to enhance safety and efficiency.

Network connectivity handover is a vital component of autonomous vehicle technology to ensure that autonomous vehicles can maintain continuous and reliable communication with external systems, which is essential for their safe and efficient operation. Developing robust and seamless network handover solutions is an ongoing focus for researchers, automotive manufacturers, and telecommunication companies in the evolution of autonomous transportation.

5G networks offers one feature called Heterogeneous Network (HetNet) which refers to the integration of various types of cellular networks to provide seamless coverage and service continuity. A 5G HetNet is composed of a mix of large cells (like macro cells), smaller cells (such as micro, pico, and femto cells), and other technologies like WiFi. These different cell types have varying coverage areas and capacities. One of the primary objectives of HetNet is to provide seamless handovers between these different cell types and technologies. For instance, a user might begin a call in a macro cell coverage area and then move into an area covered by a pico cell without any disruption.

In summary, the integration of HetNet features in the 5G network makes the technology a leading contender for supporting seamless handovers, which are essential for autonomous vehicles.

2.5.2. Human to machine hand-over and take over

Human-to-machine hand-over and take-over (HMTOT) in autonomous vehicles is a critical aspect of autonomous driving systems. It refers to the transition of control and responsibility between a human driver and the vehicle's autonomous driving system. HMTOT procedures are designed to ensure safe and smooth transitions in various driving scenarios.

Below is an overview of HMTOT in autonomous vehicles:

- Levels of Automation. The Society of Automotive Engineers (SAE) defines different levels of automation in autonomous vehicles, ranging from Level 0 (no automation) to Level 5 (full automation). HMTOT primarily occurs at Levels 2 and 3, where the vehicle can perform some or most driving tasks but still requires human intervention in certain situations.

- Scenarios for HMTOT:
  - Request for Control: In Level 2 and 3 vehicles, the human driver can typically request control when they feel uncomfortable or when the vehicle encounters a situation it cannot handle. The system should respond promptly to these requests.
  - Failure or Transition Conditions: HMTOT may be necessary for scenarios like sensor or system failures, adverse weather conditions, or when the vehicle approaches the end of a designated autonomous driving zone.
  - Critical Situations: When the autonomous system encounters a situation it cannot safely navigate, it may prompt the human driver to take over immediately. This can include sudden road closures, accidents, or other unexpected obstacles.
- Driver Monitoring and Awareness. Driver Monitoring System (DMS) is an important part of AV. Many autonomous vehicles are equipped with DMS, which tracks the driver's attention and ensures they are ready to take over if needed. DMS may use cameras, sensors, and other technologies to monitor the driver's behavior. Vehicles often provide warnings and alerts to the driver to regain their attention and prepare for HMTOT.
- Communication and Handover Protocol:
  - Clear Communication: The vehicle's HMTOT system communicates the need for a handover clearly to the driver through visual and auditory cues, such as warnings on the dashboard, flashing lights, and verbal instructions.
  - Handover Time: There should be a defined and reasonable time for the driver to take over control. This allows the driver to transition safely and calmly.
  - Driver Response: The driver must confirm their readiness to take over control. This can involve pressing a button, touching the steering wheel, or providing some other form of acknowledgment.
- Redundancy and Fail-Safe Mechanisms. Autonomous vehicles often have redundant systems and fail-safe mechanisms to ensure safety during HMTOT. For example, if the driver fails to respond to a handover request, the vehicle may initiate a safe stop or follow predetermined protocols.
- Training and Education. Training and education to ensure that drivers are aware of how HMTOT procedures work and are trained to respond effectively is essential. Manufacturers and regulatory bodies often provide guidelines and training for drivers of autonomous vehicles.

- Regulatory Framework. Many countries and regions are developing or updating regulations and standards related to HMTOT in autonomous vehicles to ensure safety and consistency across the industry.

In summary, human-to-machine hand-over and take-over in autonomous vehicles is a complex process that involves clear communication, driver monitoring, fail-safe mechanisms, and adherence to predefined protocols. Ensuring safe and effective HMTOT procedures is crucial for the deployment and acceptance of autonomous driving technology. Manufacturers, regulators, and drivers all play essential roles in making HMTOT a seamless and secure aspect of autonomous vehicle operation.

2.5.3. Machine to human hand over

Machine-to-human handover, also known as M2H handover, refers to the transition of control and responsibility from an autonomous machine or system to a human operator.

1. Scheduled handover, when the driver is notified in advance of the handover situation, and has time to prepare;
2. Non-scheduled system-initiated handover, when the driver is not notified in advance, the system realizes that the driver must take control immediately because in the current situation, the system would need to operate beyond its functional limits; the driver may not expect this situation;
3. Non-scheduled system-initiated handover, where the driver decides to take control while there is no specific need to do so;
4. Non-scheduled used initiated emergency handover, where the user spots a potential risk that was not recognized by the system, and the user takes immediate control;
5. Non-scheduled system-initiated emergency, where the system can no longer operate (the cause of this emergency is internal system failure), and notifies the driver

This type of handover is essential in various fields, including manufacturing, healthcare, and autonomous vehicles. Depending on the context and the level of automation, there are several types of M2H handovers:

1. Supervisory Control. In supervisory control, the autonomous machine or system performs most tasks independently, with a human operator supervising and intervening only when necessary. The human operator typically monitors the machine's performance and intervenes when deviations from expected behavior occur or when the system encounters unexpected situations. The human operator may have access to override controls or emergency stop buttons to take control if needed.

2. Emergency Handover. Emergency handover occurs when an autonomous system encounters a situation it cannot handle or when a critical failure occurs, necessitating an immediate transfer of control to a human operator. This type of handover takes place in safety-critical situations where rapid human intervention is required to prevent accidents or mitigate risks. The autonomous system initiates the handover and alerts the human operator, who then assumes control and takes appropriate action to address the emergency.

3. System Failure Handover. System failure handover happens when the autonomous machine or system experiences a technical malfunction or failure that prevents it from functioning as intended. It occurs when the machine's sensors or components fail, causing the system to lose its operational capabilities. The machine or system automatically transfers control to a human operator, and the operator takes over responsibility for the task or operation until the issue is resolved.

4. Adaptive Handover. Adaptive handover involves a dynamic and context-aware transition of control from the machine to the human operator based on the system's assessment of its own capabilities and the current situation. Adaptive handover occurs when the autonomous system determines that it can no longer perform optimally or when it encounters a situation that exceeds its capabilities. The system assesses the situation, and if it deems human intervention necessary, it initiates the handover. The operator assumes control, resolves the issue, and may hand back control when the situation stabilizes.

5. Routine Manual Control. Routine manual control involves a planned, scheduled, or predefined transfer of control from the autonomous system to the human operator as part of regular operations. It occurs when a specific phase of the operation or task is better suited for human control, such as a manual inspection or a complex decision-making process. The transition is preplanned and occurs at specified points in the operation. The operator assumes control and performs the required tasks until the system is ready for autonomous operation again.

The type of M2H handover employed depends on the specific application, safety considerations, the capabilities of the autonomous system, and the role of the human operator. In all cases, clear communication and well-defined procedures are critical to ensure a smooth and safe transition of control.

3. Progress of Autonomous Vehicle Technology around the World

Autonomous vehicle technology is a rapidly evolving field that involves many aspects such as sensors, software, hardware, communication, and artificial intelligence. According to some sources, the progress of autonomous vehicle technology around the world can be measured by the level of autonomy, the market size, and the ranking of companies involved in the development.

Some of the key milestones and trends in autonomous vehicle technology are:

- **Level of autonomy**: There are six levels of autonomy, from level 0 (no automation) to level 5 (full automation). Most current vehicles are at level 1 (driver assistance) or level 2 (partial automation), while some companies are testing level 3 (conditional automation) or level 4 (high automation) vehicles on public roads. Level 5 vehicles are still in the research stage and face many technical and regulatory challenges.
- **Market size**: The global market for autonomous vehicles is expected to grow significantly in the next decade, reaching $556.67 billion by 2026, according to one estimate. The main drivers of this growth are the increasing demand for safety, convenience, and mobility, as well as the advancement of technology and infrastructure.
- **Ranking of companies**: There are many companies developing autonomous vehicle technology, ranging from tech giants like Microsoft, Alphabet, Baidu, and Tesla, to traditional automakers like General Motors, Ford, and Toyota, to startups like Waymo, Cruise, and Zoox. These companies are using different approaches and strategies to achieve higher levels of autonomy and safety. Some of the factors that influence their ranking are the number of miles driven, the number of patents filed, the amount of funding raised, and the partnerships formed.

The AV Readiness Index serves as a valuable tool for governments, organizations, and businesses to identify strengths, weaknesses, and opportunities related to autonomous vehicle deployment. It can help guide policy decisions, investments, and initiatives aimed at fostering a supportive environment for AV technology and mobility solutions.

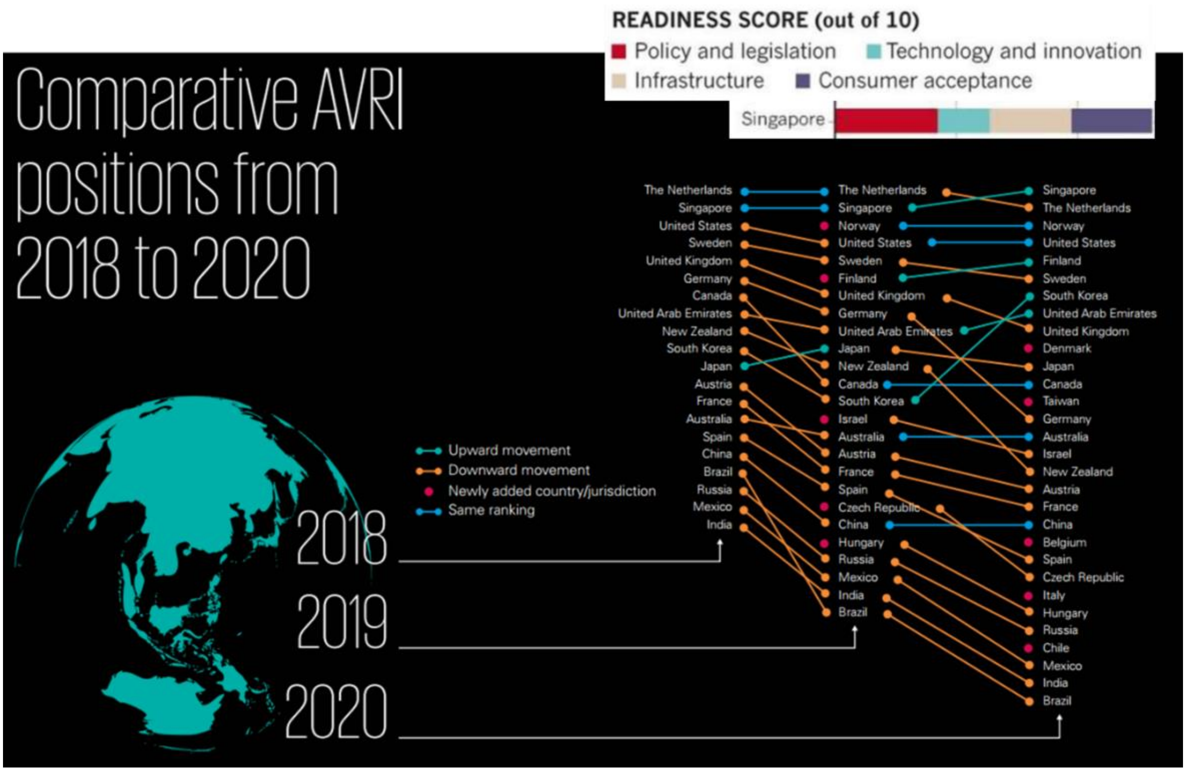

Figure 4. Global Comparative AV Readiness Index 2018-2020

Timeline of AV in Asia

2000s-2010

Autonomous vehicle technology research and development begin to gain traction globally, including in Asian countries

Research institutions and universities in countries like Japan, South Korea, and China have started exploring autonomous vehicle technologies, focusing on advanced sensors, computer vision, and control systems

Mid 2010s

Major automotive companies in Asia, particularly in Japan and South Korea, invest in autonomous driving research and development

Japanese car manufacturers like Toyota, Honda, and Nissan announce plans to integrate autonomous features into their vehicles

South Korean companies like Hyundai and Kia showcase autonomous vehicle prototypes and concept cars

Late 2010s

Japan's government expresses interest in hosting the 2020 Tokyo Olympics as a platform to showcase autonomous vehicle technology, leading to an increased focus on testing and demonstrations

China ramps up efforts in autonomous vehicle development, with companies like Baidu, Alibaba, and Tencent investing in research and testing

Baidu, a Chinese tech giant, announces its Apollo project, an open-source platform for autonomous driving, to accelerate the development of self-driving technology

Singapore emerges as a hub for autonomous vehicle testing and deployment, with various trials of autonomous shuttles and delivery bots in controlled environments

Autonomous vehicle testing regulations and guidelines have started to be developed in some Asian countries, particularly in Singapore

Early 2020s

China continues to be a global leader in autonomous vehicle development, with companies like Baidu and Pony.ai testing self-driving vehicles on public roads

Autonomous driving features, such as advanced driver assistance systems (ADAS), become increasingly common in vehicles across Asia

South Korea's government and companies collaborate on building a comprehensive infrastructure to support autonomous vehicle testing and deployment

Japan's automotive companies continue to make advancements in autonomous vehicle technology, focusing on safety and reliability

4. Current Adoption Stage of Autonomous Vehicle Technology in ASEAN

The future of mobility depends on various factors such as regulations, technology readiness, consumer preferences, eco-sensitivity. the technology acceptance model can be used to assess and forecast autonomous vehicle adoption, which includes understanding adoption progress by looking into various aspects as elaborated below.

4.1. Research on AV in ASEAN

Research on autonomous vehicles among ASEAN (Association of Southeast Asian Nations) member countries was in varying stages of development. While some countries were actively engaged in research and development related to autonomous vehicles, others were still in the early stages of exploring this technology. Below is a brief overview of the research efforts in some ASEAN member countries (Abu Kassim et al., 2021; Noomwongs, 2022; Ramjan & Sangkaew, 2022; Trueman, 2019):

1. Singapore. Singapore was one of the most active ASEAN countries in autonomous vehicle research. It had established research centers and initiatives focusing on autonomous transportation technologies. Research institutions, such as the Nanyang Technological University and the Singapore-MIT Alliance for Research and Technology (SMART), were conducting extensive research on autonomous vehicles. Various testbeds and trials were conducted on Singaporean roads to assess the feasibility and safety of autonomous vehicles.

2. Malaysia. Malaysia has initiated research and development efforts related to autonomous vehicles. Several universities and research institutions were involved in autonomous vehicle research projects. The Malaysian government and industry stakeholders expressed interest in developing autonomous vehicle technologies for both domestic use and export.

3. Thailand. Thailand has shown interest in autonomous vehicle research, particularly in the context of smart cities and public transportation. Research institutions and government agencies were collaborating on projects to study and develop autonomous vehicle technologies. The Thai government was exploring the potential of autonomous vehicles to address urban congestion and improve transportation efficiency.

4. Indonesia. Indonesia has started exploring autonomous vehicle technology, with some universities and startups conducting research in this area. Research was focused on autonomous navigation systems and the development of autonomous vehicles suitable for Indonesian traffic conditions.

5. Vietnam. Vietnam's research on autonomous vehicles was relatively limited compared to some other ASEAN countries. However, there was growing interest in autonomous technology, and universities and research institutions were beginning to explore this field.

6. Other ASEAN Countries. Cambodia, Laos, Myanmar, and Brunei had limited research and development activities related to autonomous vehicles. These countries were generally focused on basic transportation infrastructure development and faced various challenges in adopting advanced technologies.

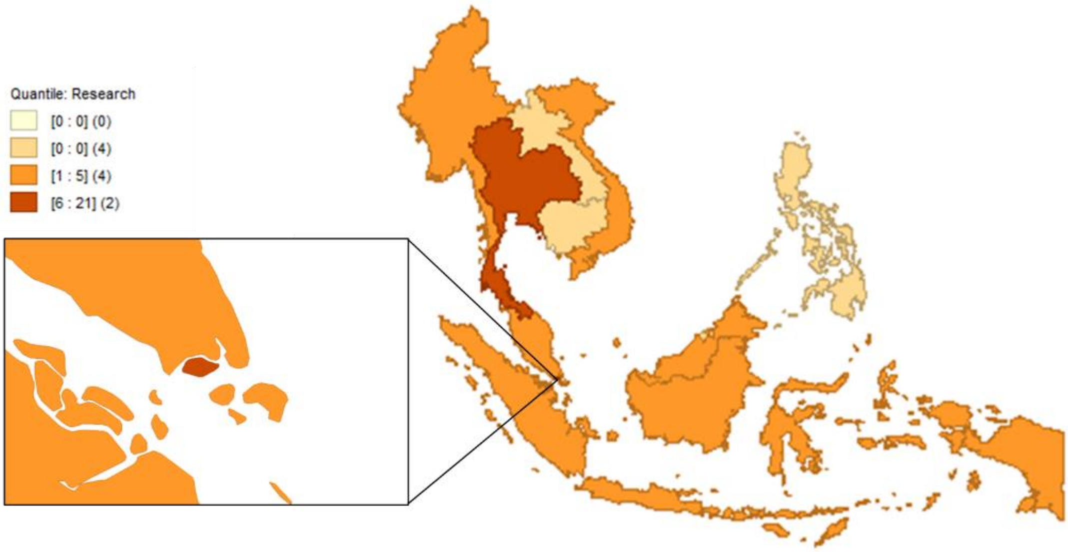

Figure 5. Research on AV

Challenges in autonomous vehicle research across ASEAN member countries included:

- Regulatory Framework: Developing comprehensive regulations for autonomous vehicles to ensure safety and compliance with international standards.
- Infrastructure: Upgrading road infrastructure and traffic management systems to accommodate autonomous vehicles.
- Funding: Securing funding for research and development initiatives.
- Talent and Expertise: Attracting and retaining talent in the field of autonomous vehicle technology.
- Public Awareness: Increasing public awareness and understanding of autonomous technology.

4.2. Pilot testing on AV in ASEAN

The progress of autonomous vehicle pilots in ASEAN (Association of Southeast Asian Nations) countries was still relatively limited compared to regions like North America and Europe. However, there were some developments and initiatives in several ASEAN member countries. Below is an overview of the progress up to that point (Ananto, 2021; DNA, 2020; Jakarta Globe, 2022; NSTDA, 2022; VNA, 2021; Wood, 2021):

1. Singapore. Singapore has been at the forefront of autonomous vehicle testing in the ASEAN region. The country has been conducting autonomous shuttle trials and is also working on implementing autonomous taxis in selected areas. Various autonomous

shuttle services were in operation within specific districts, such as Sentosa Island and the Jurong Innovation District.

2. Malaysia. Malaysia initiated autonomous vehicle testing in specific areas, primarily for research and development purposes. Several universities and research institutions were actively involved in autonomous vehicle research. The country showed interest in using autonomous technology for public transportation in the future.

3. Thailand. Thailand has been exploring the potential of autonomous vehicles in the context of smart cities and public transportation. Several pilot projects aimed to test autonomous shuttles in selected urban areas. The Thai government expressed interest in adopting autonomous technology for public transportation to alleviate traffic congestion.

4. Indonesia. Indonesia's progress in autonomous vehicles was relatively nascent, with some research institutions and startups working on autonomous vehicle technology. The country faced significant infrastructure and regulatory challenges that needed to be addressed before widespread autonomous vehicle deployment could occur.

5. Vietnam. Vietnam had shown interest in autonomous vehicle technology but had not yet launched significant pilot projects. The country had been focusing more on improving its urban infrastructure and transportation systems.

6. Other ASEAN Countries. Cambodia, Laos, Myanmar, and Brunei had limited progress in terms of autonomous vehicle pilots. These countries were generally more focused on basic transportation infrastructure development.

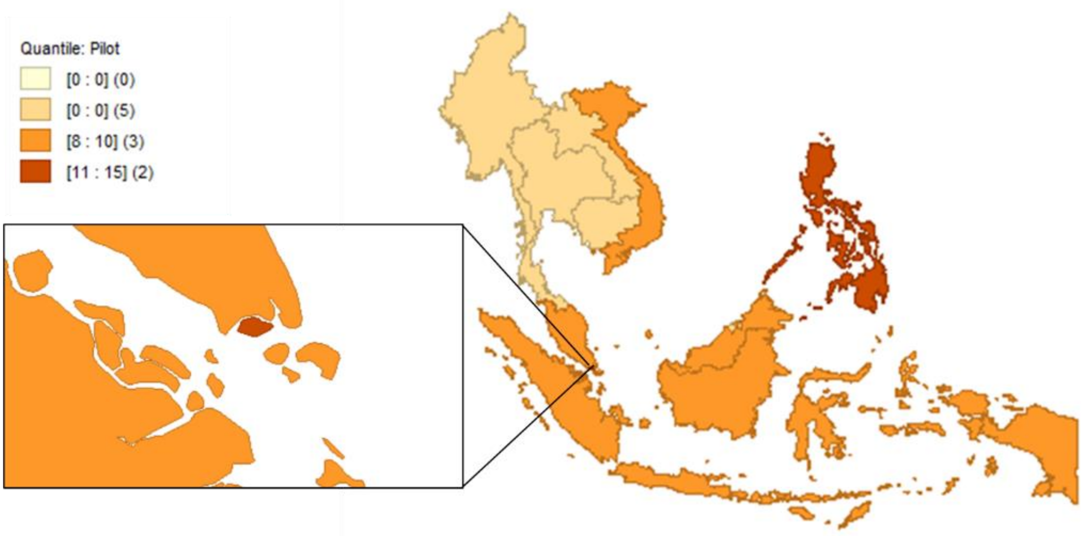

Figure 6. Pilot on AV

Challenges to the widespread adoption of autonomous vehicles in ASEAN included:

- Infrastructure: In many ASEAN countries, road infrastructure and traffic management systems needed significant upgrades to support autonomous vehicles effectively.
- Regulations: Clear and comprehensive regulations for autonomous vehicles were often lacking, which posed a hurdle to testing and deployment.
- Safety Concerns: Ensuring the safety of autonomous vehicles, especially in densely populated urban areas, was a primary concern.
- Public Acceptance: Public awareness and acceptance of autonomous technology needed to be addressed through education and demonstration projects.

It is important to check the latest developments in each ASEAN country regarding autonomous vehicles, as the situation may have evolved significantly since 2021. Autonomous vehicle technology is continually advancing, and some governments in the region may have accelerated their efforts to harness its potential for improving transportation and mobility.

4.3. Gaps in data flow requirement and available services

4.3.1. Digital Infrastructure Services in ASEAN

The digital infrastructure services within ASEAN have seen significant growth and diversification in recent years, driven by technological advancements, increasing internet penetration, and a growing digital economy. The digital infrastructure services in ASEAN (ADB, 2021; Corner, 2022; Guild, 2023):

1. Internet Connectivity:
    - Wired Broadband: ASEAN countries have been expanding their wired broadband infrastructure, including fiber-optic networks and high-speed DSL connections, to provide reliable internet access to urban and rural areas.
    - Mobile Internet: Mobile internet usage is widespread across ASEAN, with 4G and 5G networks being rolled out to enhance mobile broadband services.
2. Cloud Services:
    - Cloud Computing: ASEAN countries have embraced cloud services offered by global tech giants like Amazon Web Services (AWS), Microsoft Azure, and Google Cloud. Local cloud providers have also emerged, catering to specific regional needs.
    - Data Centers: There has been significant investment in data center infrastructure to support cloud services and the growing demand for data storage and processing.

3. E-commerce Infrastructure:
    - ASEAN has a booming e-commerce sector with various platforms and payment gateways facilitating online shopping. These services rely on secure payment processing, logistics networks, and digital marketplaces.
4. Digital Payment Solutions:
    - Mobile payment systems, digital wallets, and payment gateways are widely adopted in ASEAN. Services like GrabPay, GoPay, and AliPay have gained popularity for digital transactions.
5. Cybersecurity Services:
    - The rise in digital activities has also increased the importance of cybersecurity. Companies offer a range of services, including threat detection, data protection, and cybersecurity consulting.
6. Telecommunications Services:
    - Traditional telecommunications providers offer services such as voice calling, messaging, and high-speed internet access. Some companies also offer bundled services that include television and home phone services.
7. Government Initiatives:
    - Many ASEAN governments have launched initiatives to improve digital infrastructure and promote digital literacy. These initiatives often involve public-private partnerships to expand access to underserved areas.
8. Fintech Services:
    - The fintech sector is growing rapidly in ASEAN, offering digital banking, peer-to-peer lending, and investment services. This sector relies on robust digital infrastructure and regulatory frameworks.
9. Smart Cities:
    - Several cities in ASEAN are implementing smart city initiatives, which involve digital infrastructure components such as IoT devices, sensors, and data analytics to improve urban living.
10. Startups and Innovation Hubs:
    - ASEAN countries have seen a surge in technology startups, incubators, and innovation hubs. These entities often rely on a strong digital infrastructure to develop and launch their products and services.
11. Cross-border Data Flows:
    - The flow of data across borders is crucial for businesses in ASEAN. Governments are working on data protection regulations and agreements to facilitate secure cross-border data transfers.

12. Digital Inclusion Efforts:

- To bridge the digital divide, ASEAN nations are working on initiatives to ensure that rural and underserved populations have access to digital infrastructure and services.

Overall, the diversity of digital infrastructure services in ASEAN reflects the region's dynamic and rapidly evolving digital landscape. Governments, businesses, and technology providers are collaborating to expand and enhance these services to support the region's economic growth and connectivity in the digital age.

4.3.2. Diversity of Digital Infrastructure Service Among ASEAN Member Countries

The digital infrastructure services among ASEAN (Association of Southeast Asian Nations) member countries exhibit significant diversity due to variations in economic development, technological capabilities, and government policies.

Internet infrastructure in Southeast Asia is developing rapidly, but there are still significant disparities among countries in terms of connectivity, speed, and reliability. Here's a general overview of the internet infrastructure conditions in the region

- Singapore has one of the most advanced and robust internet infrastructures in the region. The country had high-speed broadband coverage across the entire island and was known for its reliable and fast internet connectivity
- Malaysia has been investing in improving its internet infrastructure, especially in urban areas. Broadband penetration was growing, and the government had initiatives to expand coverage to rural and remote areas. However, there were still challenges in providing consistent high-speed connectivity throughout the country
- Thailand's internet infrastructure was also progressing, with efforts to expand broadband access to rural areas. The country had a growing number of internet users, and mobile internet usage was particularly popular
- Indonesia's internet infrastructure was improving but faced challenges due to the country's vast geography and dispersed population. Internet penetration rates were growing, driven by mobile internet usage. Major cities had better connectivity compared to rural areas
- Vietnam has been making strides in improving its internet infrastructure. The government aimed to expand broadband access across the country, and there was a growing tech-savvy population. However, there were variations in connectivity quality between urban and rural regions
- The Philippines had been working on enhancing its internet infrastructure, but there were still issues with slow and unreliable internet in some areas. Efforts were being made to address these challenges and improve overall connectivity
- Other countries in the region, such as Cambodia, Laos, and Myanmar, were in various stages of developing their internet infrastructures. While progress was being made, challenges like limited access in rural areas and political instability in some cases could impact the pace of development.

Table 5. Diversity of digital infrastructure services among some of the ASEAN member countries

NO	COUNTRY	PROGRESS
	Singapore	Advanced Digital Infrastructure: Singapore boasts one of the most advanced digital infrastructures in the region, with high-speed internet access, extensive fiber-optic networks, and a robust data center ecosystem. Fintech Hub: It serves as a regional fintech hub with well-established digital payment systems and a supportive regulatory environment for innovation. Smart City Initiatives: Singapore is a pioneer in smart city projects, using digital technology for urban planning, public services, and sustainability.
	Malaysia	Broadband Access: Malaysia has been investing in improving broadband access, including high-speed fiber-optic networks and 5G deployment. Fintech Growth: The country has witnessed significant growth in fintech services and digital payments. Digital Economy Initiatives: Malaysia's Digital Economy Blueprint outlines plans to accelerate digital adoption across various sectors.
	Indonesia	Mobile-First Nation: Indonesia is known for its mobile-first approach, with widespread mobile internet usage and a growing e-commerce market. Digital Payment Ecosystem: Digital wallets and payment platforms like GoPay and OVO have gained popularity, driving the digital economy. Challenges: The country faces infrastructure challenges in rural areas and varying levels of internet access.
	Thailand	Digital Government Services: Thailand has been digitizing government services to enhance efficiency and transparency. E-commerce Growth: E-commerce platforms like Lazada and Shopee are thriving, and digital payments are becoming more common. Smart City Projects: Cities like Bangkok are implementing smart city initiatives to improve urban services.

NO	COUNTRY	PROGRESS
	Vietnam	Digital Transformation: Vietnam is undergoing a rapid digital transformation, with a focus on improving digital literacy and expanding internet access. Startups and Innovation: The country has a thriving startup ecosystem, with a focus on technology, e-commerce, and fintech. Government Initiatives: The government is investing in digital infrastructure and smart city projects to support economic growth.
	Philippines	Mobile Internet: The Philippines relies heavily on mobile internet access due to its archipelagic geography. E-commerce Growth: E-commerce platforms are expanding, and digital payments are becoming more prevalent. Challenges: Connectivity can be inconsistent in remote areas, and digital infrastructure development is ongoing.
	Cambodia, Laos, Myanmar, and Brunei	These countries are at various stages of digital infrastructure development, with efforts focused on expanding access to the Internet, improving connectivity, and fostering digital innovation. The development of digital infrastructure services varies widely across these nations, with some making significant strides in recent years.

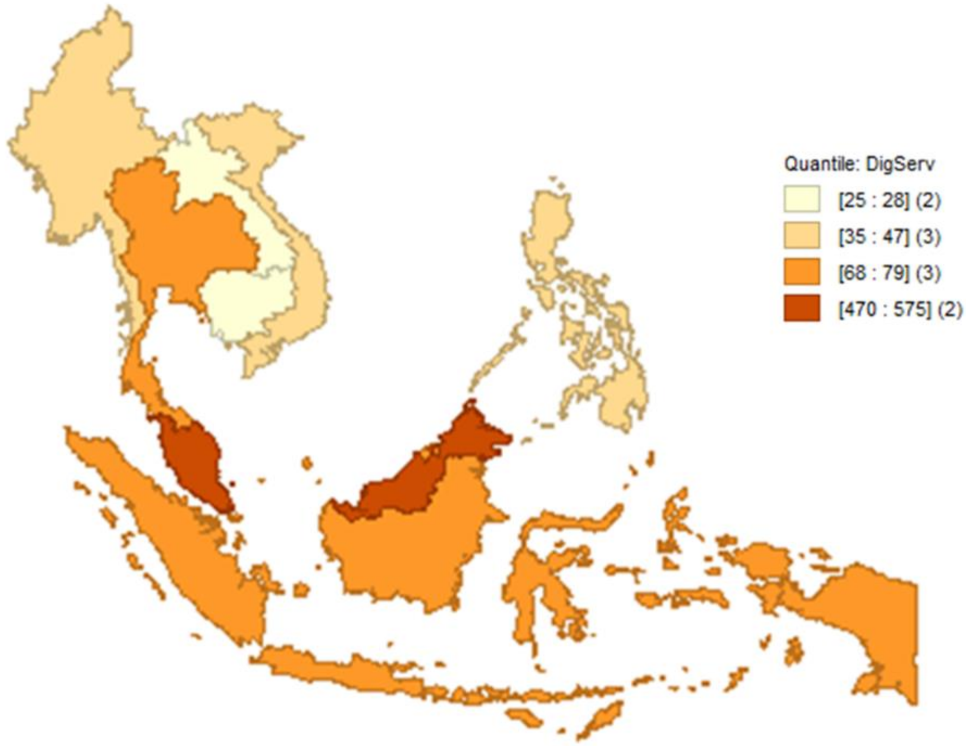

Figure 7. Diversity of Digital Infrastructure Service

In summary, the diversity of digital infrastructure services among ASEAN member countries reflects the varying levels of economic development, technology adoption, and government initiatives in the region. Some nations have established advanced digital ecosystems, while others are in the process of building their digital infrastructure to support economic growth and technological advancement. Collaborative efforts within ASEAN aim to bridge the digital divide and promote digital inclusion across the region.

4.4. Availability of policy and regulation to support the compliance of AV data flow

Several countries in Southeast Asia were exploring and developing policies related to autonomous vehicles, but the level of advancement varied from country to country. Some key points include:

- Singapore has been a pioneer in autonomous vehicle testing and development. The country has established a comprehensive regulatory framework for autonomous vehicles, including guidelines for testing and deployment on public roads. Various trials of autonomous vehicles, including shuttles and delivery bots, have taken place in controlled environments.

- Malaysia has shown interest in autonomous vehicle technology, especially as part of its efforts to develop smart cities. The government has indicated a willingness to explore pilot programs and collaborations with technology companies to develop and test autonomous vehicles.
- Thailand has also been actively looking into autonomous vehicle technology. The government has expressed its commitment to creating an environment conducive to testing and deployment of autonomous vehicles, with a focus on developing necessary regulations and infrastructure.
- Indonesia has initiated discussions around autonomous vehicles, primarily in the context of urban mobility challenges. The government has expressed interest in leveraging technology to address transportation issues, but concrete policies were still in the early stages as of 2021.
- Autonomous vehicles have gained some attention in Vietnam as part of its efforts to modernize transportation systems. While discussions have taken place, specific policies and regulations have not been as developed compared to some other countries in the region.
- The Philippines has shown interest in autonomous vehicle technology, particularly for addressing traffic congestion and improving transportation efficiency. However, formal policies and regulations were still in the early stages of development.

4.5. Gaps in regulation that drive data flow for AV requirements

4.5.1. AV Readiness Index

The Autonomous Vehicle (AV) Readiness Index is a tool or framework used to assess and measure the readiness of regions, cities, or countries for the deployment and integration of autonomous vehicles. This index helps stakeholders, including governments, policymakers, businesses, and researchers, evaluate various factors that contribute to the successful implementation of autonomous vehicle programs. The AV Readiness Index typically takes into account a range of factors and indicators that influence the readiness of a specific geographic area.

Here are some key aspects of the AV Readiness Index:

1. Infrastructure and Technology Readiness, related to the evaluation of the region's existing transportation infrastructure, including road quality, traffic management systems, and the presence of dedicated lanes or infrastructure for autonomous vehicles. The other factor is the assessment of the availability of necessary technology, such as high-definition maps, vehicle-to-infrastructure (V2I) communication systems, and sensor infrastructure.
2. Regulatory and Policy Environment, related to the examination of the regulatory framework and policies related to autonomous vehicles, including laws, licensing requirements, safety standards, and liability rules as well as the analysis of the

government's willingness to adapt regulations and policies to accommodate autonomous vehicles and promote innovation.

3. Safety and Security Measures, comprises the assessment of safety protocols and cybersecurity measures to protect autonomous vehicles from cyber threats and ensure the safety of passengers and other road users, and evaluation of testing and validation processes to ensure that autonomous vehicles meet safety standards.
4. Consumer Acceptance and Adoption, analysis of public awareness, trust, and acceptance of autonomous vehicles. This includes public opinion, willingness to use autonomous vehicles, and factors influencing adoption. This also considers the examination of initiatives to educate the public about autonomous vehicle technology and its benefits.
5. Industry and Innovation Ecosystem, related to the evaluation of the presence and growth of companies, startups, and research institutions involved in autonomous vehicle development, testing, and manufacturing. The other aspect is the assessment of investment in autonomous vehicle research and development within the region.
6. Transportation and Mobility Integration, related to the examination of efforts to integrate autonomous vehicles into existing transportation and mobility systems, including public transit, ride-sharing services, and last-mile solutions, as well as the assessment of public-private partnerships aimed at advancing autonomous mobility solutions.
7. Economic Impact. Analysis of the potential economic benefits, including job creation, increased tourism, and revenue generation, resulting from the deployment of autonomous vehicles. The other is the evaluation of cost savings associated with autonomous vehicle technology in areas like logistics and public transportation.
8. Environmental Considerations, such as the assessment of the environmental impact of autonomous vehicles, including their potential to reduce emissions through efficient driving and electrification; and evaluation of sustainability initiatives related to autonomous mobility.
9. Data and Privacy. Examination of data-sharing policies and privacy measures concerning the collection and use of data generated by autonomous vehicles. This aspect also includes the assessment of data management and governance practices.
10. Infrastructure Investments. Evaluation of government investments in upgrading infrastructure to support autonomous vehicle operations, such as road modifications, traffic management systems, and charging infrastructure for electric AVs.

4.5.2. Key problems in self-driving cars at country's cross border

Key problems self-driving cars might face when crossing borders:

1. Regulatory Differences. Different countries have varying regulations, leading to potential delays and complications at the border.
2. Mapping and Navigation. This can result in navigation errors, misinterpretations, and even accidents.
3. Communication Infrastructure. Different countries might have varying levels of infrastructure readiness, compatibility issues, and language barriers in communication systems.
4. Data Privacy and Security. Crossing borders could raise concerns about data privacy and security, as different jurisdictions might have different requirements for data handling and protection.
5. Liability and Insurance. Leading to challenges in settling claims and legal disputes.
6. Emergency Services and Support. Crossing borders could lead to delays in response times due to a lack of understanding of technology's communication protocols or requirements.
7. Cultural and Behavioral Differences. Driving style affects decision-making algorithms based on the local driving culture to ensure safe and efficient operation.
8. Infrastructure Compatibility. Self-driving cars must be able to recognize and interpret these cues accurately to navigate effectively.
9. Weather and Environmental Conditions. The technology must be adaptable to changing conditions and be aware of local weather patterns.

4.5.3. Summary of analysis AS IS situation

Summary of analysis AS IS situation in ASEAN as

- Digital infrastructure determines the level of AV (Level 1: Feet OFF, Level 2: Hands OFF, Level 3: Eyes OFF, Level 4: Mind OFF, Level 5: Driver OFF).
- With a diversity of digital infrastructure performance among AMS, an AV that crossing the country border may turn down the level of AV.
- During crossing a border, a handover among networks may disrupt the flow of data and temporarily turn down the level of AV, even though both AMS have a similar level of digital infrastructure service performance.
- During the network handover in the cross border, if the decreased level of AV requires the driver to take over the vehicle control a protocol for safety is a must.
- A location-based scheduled hand-over from machine to human should be designed in the country border.

- Under the current level of digital infrastructure service, no Level 2 and above of AV/Self-driving cars is permitted to across the AMS border.
- AV/Self-driving cars are only allowed to be operated in the ASEAN Highway if all safety requirements is in compliant.

5. Regional workshop

5.1. Workshop Description

The Regional Workshop on Regulatory Pilot Space to Facilitate Cross-Border Digital Data Flow for Enabling Self-Driving Car in ASEAN was held virtually on October 18, 2023.

The workshop aims to revisit data-flow requirements and map the barriers of cross-border digital data flows for self-driving or autonomous vehicles (AV) within ASEAN. Moreover, based on the disclosed gaps, a Regulatory Pilot Space (RPS) will be conducted to facilitate cross-border digital data flows to enable AV in ASEAN.

5.2. Rundown

Table 6. Regional Workshop Agenda

Time	Duration	Agenda	Speaker and Moderator
08.00 – 08.30	30'	Registration	
Speeches Session			
08.30 – 08.35	5'	Opening	MC
08.35 – 08.40	5’	Indonesia Raya national anthem	
08.40 – 08.45	5’	ASEAN anthem	
08.45 – 08.55	10'	Welcoming speech	Ikaputra, Ph.D Head of Center for Transportation and Logistic Studies Universitas Gadjah Mada
09.00 – 09.05	10'	Opening speech	Dian Wulandari Deputy Director for Post Media and Public Communications affairs, Center of International Affairs, Ministry of Communications and Informatics (MCI), Republic of Indonesia
09.05 – 09.15	10’	Opening remark	Mr. Sakamoto Mitsuhide The first Secretary Mission of Japan to ASEAN
09.15 – 09.20	5’	Photo Session	
Panel Session			
Presentation and Discussion on Regulatory Pilot Space to Facilitate Cross-Border Digital Data Flow in ASEAN Member Countries			Moderator: Mohamad Rachmadian Narotama, Ph.D.
09.20 – 09.35	15’	Introduction of research activities and workshop agenda	Speaker: Dr. Arif Wismadi
09.35 – 09.55	20’	Network infrastructure to support AV operation	Sigit Basuki Wibowo, Ph.D.
AMS Country Update on AV Related Policy and Regulation			Moderator: Dr. Arif Wismadi
09.55 – 10.05	10’	Country 1 – Brunei Darussalam	Active participants from ADGSOM and STOM
10.05 – 10.15	10’	Country 2 - Cambodia	
10.15 – 10.25	10’	Country 3 – Indonesia	
10.25 – 10.35	10’	Country 4 – Lao PDR	
10.35 – 10.45	10’	Country 5 – Malaysia	
10.45 – 10.55	10’	Country 6 – Myanmar	
10.55 – 11.05	10’	Country 7 – The Philippines	

Time	Duration	Agenda	Speaker and Moderator
11.05 – 11.15	10’	Country 8 – Singapore	
11.15 – 11.25	10’	Country 9 – Thailand	
11.25 – 11.35	10’	Country 10 – Viet Nam	
Industrial AV Pilot Lesson Learned			Moderator: Sigit Basuki Wibowo, S.T., M.Eng., Ph.D
11.35 – 12.25	50’	Industries: • Phenikaa X – Vietnam • Reka – Malaysia	Active participants from industry
12.25 – 13.30	65’	– Lunch Break–	
Workshop Session			
13.30 – 14.45	75'	Facilitated Workshop	Dr. Arif Wismadi
14.45 – 14.55	10'	Wrap Up and Conclusion	Dr. Arif Wismadi
14.55 – 15:00	5'	Closing Speech	Ikaputra, Ph.D Head of Center for Transportation and Logistic Studies Universitas Gadjah Mada

5.3. Attendance

This regional workshop activity was held virtually and attended by 69 participants from policymakers and representatives from 7 ASEAN member countries, especially from ADGSOM and STOM. Also present were representatives from the ASEAN Secretariat, the Japanese Government as well the autonomous vehicle and smart mobility solutions industry sectors.

This activity presented a number of speakers, including Dr. Arif Wismadi who delivered material related to the introduction of research activities and the workshop agenda, and Sigit Basuki Wibowo, Ph.D. who delivered material entitled network infrastructure to support AV operations. In the AV Industrial pilot learning session in ASEAN, there were two active participants, including Dr. Son Le Anh who delivered lessons from Phinekaa X-Vietnam, and Mr. Haziq Faris who delivered lessons from REKA Initiative-Malaysia.

Head of PUSKI Kemkominfo represented by Dian Wulandari, together with the head of Pustral UGM Ikaputra, Ph.D. and the Japanese government representative to ASEAN Mr. Sakamoto Mitsuhide gave a speech at the start of the meeting.

Figure 8. The Regional Workshop on Regulatory Pilot Space (RPS) to Facilitate Cross-Border Digital Data Flow For Enabling Self-Driving Car in ASEAN

5.4. Key notes from Regional Workshop

- AMS delegates have no objections towards the desk study findings regarding the AV readiness level presented in *Sub-chapter 4*. Most AMSs predominantly have 4G connection, 5G is not currently widespread across the region.
- Additional information was shared by Thailand delegate that there has been an AV pilot testing in Siriraj Hospital using 5G connectivity.

  AMS delegates agreed the need to address key problems self-driving cars might face when crossing borders:

  1. Regulatory differences
  2. Mapping and navigation
  3. Communication infrastructure
  4. Data privacy and security
  5. Liability and insurance
  6. Emergency services and support
  7. Cultural and behavioral differences
  8. Infrastructure compatibility
  9. Weather and environmental conditions

6. Industry consultation

Based on discussions with participants representing AV industries during the regional workshop, some considerations were expressed that could be addressed by the transportation and digital sectors.

Considerations addressed to STOM:

- In terms of border crossing, AVs depend on various sensors, including recognizing road signs, hence the need of either standardize road signs among AMSs or share road sign standards that can then be taught to AVs so they can recognize them when crossing borders. Other aspects that need to be embedded within AVs are different road regulations, lane changes, etc.
- Regarding piloting, the transportation sector needs to prepare regulations regarding pilot testing AVs. This includes providing dedicated areas for AV pilot tests.

Considerations addressed to ADGSOM:

- For a large number of level 5 autonomous vehicles to operate simultaneously, a high-speed and highly reliable network is needed. To operate safely, fully autonomous vehicles require a very low data latency level. This could be facilitated with a 5G network, hence the need to prepare the infrastructure to support AVs.
- In regards to cross-border mobility, the continuous flow of data connection is needed to ensure seamless AV functionality, hence discussions between AMSs regarding interoperability are needed.

7. Recommendations for regulation harmonization/ interoperability to support AV/self-driving cars in ASEAN

7.1. Regulatory Framework and Infrastructure Development

In this approach, ASEAN member states would collaborate closely to establish a regulatory framework for self-driving cars. This would involve creating a set of guidelines for vehicle safety, data privacy, cybersecurity, and road infrastructure requirements. This set of guidelines would facilitate the deployment of self-driving cars across the region, ensuring that these vehicles can operate seamlessly across borders.

Additionally, ASEAN Member States could begin developing the necessary smart infrastructure to support self-driving cars. This includes upgrading roads with sensors, establishing communication networks, and building charging stations for electric autonomous vehicles. By working together, ASEAN member states could create a more cohesive environment for self-driving cars to operate, reducing regulatory hurdles and technical barriers.

7.2. Gradual Pilots and Public Education.

In this approach, ASEAN member states would start by conducting small-scale pilot programs of self-driving cars in controlled environments. These pilots could be limited to specific cities or regions, allowing governments to gather data and assess the technology's performance and impact on local traffic patterns.

Simultaneously, there would be a strong emphasis on public education and awareness campaigns. Governments would engage with citizens to inform them about the benefits and safety features of self-driving cars, as well as address any concerns related to job displacement, data privacy, and vehicle safety. This approach would build public trust over time and pave the way for broader adoption of self-driving cars.

7.3. Innovation Hubs and Research Collaboration

This approach involves ASEAN member states strategically positioning themselves as innovation hubs for self-driving car technology. Governments could incentivize research and development by offering grants, tax incentives, and favorable regulatory conditions (such as clear regulatory framework for AV pilot testing, flexible testing environment, and ensuring open access AV research reports) to attract both domestic and international companies working on autonomous vehicles.

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APPENDIX 1. Regional Workshop Report

Rundown

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09.05 – 09.15	10'	Opening remark	Mr. Sakamoto Mitsuhide The first Secretary Mission of Japan to ASEAN
09.15 – 09.20	5'	Photo Session	
Panel Session			
Presentation and Discussion on Regulatory Pilot Space to Facilitate Cross-Border Digital Data Flow in ASEAN member countries			Moderator: Mohamad Rachmadian Narotama, Ph.D.
09.20 – 09.35	15'	Introduction of research activities and workshop agenda	Speaker: Dr. Arif Wismadi
09.35 – 09.55	20'	Network infrastructure to support AV operation	Sigit Basuki Wibowo, Ph.D.
AMS Country Update on AV Related Policy and Regulation			Moderator: Dr. Arif Wismadi
09.55 – 10.05	10'	Country 1 – Brunei Darussalam	Active participants from ADGSOM and STOM
10.05 – 10.15	10'	Country 2 - Cambodia	
10.15 – 10.25	10'	Country 3 – Indonesia	
10.25 – 10.35	10'	Country 4 – Lao PDR	
10.35 – 10.45	10'	Country 5 – Malaysia	
10.45 – 10.55	10'	Country 6 – Myanmar	
10.55 – 11.05	10'	Country 7 – The Philippines	
11.05 – 11.15	10'	Country 8 – Singapore	
11.15 – 11.25	10'	Country 9 – Thailand	
11.25 – 11.35	10'	Country 10 – Viet Nam	
Industrial AV Pilot Lesson Learned			Moderator: Sigit Basuki Wibowo, S.T., M.Eng., Ph.D
11.35 – 12.25	50'	Industries: • Phenikaa X – Vietnam • Reka – Malaysia	Active participants from industry
12.25 – 13.30	65'	– Lunch Break–	
Workshop Session			
13.30 – 14.45	75'	Facilitated Workshop	Dr. Arif Wismadi
14.45 – 14.55	10'	Wrap Up and Conclusion	Dr. Arif Wismadi
14.55 – 15:00	5'	Closing Speech	Ikaputra, Ph.D

Time	Duration	Agenda	Speaker and Moderator
			Head of Center for Transportation and Logistic Studies Universitas Gadjah Mada

List of participants

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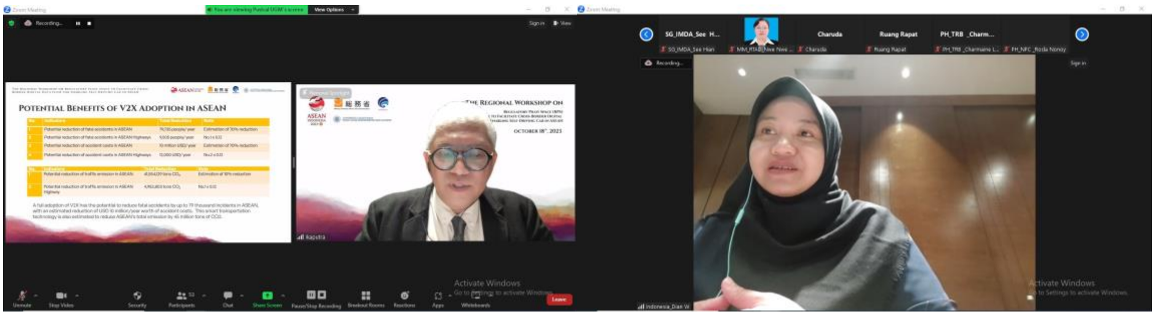
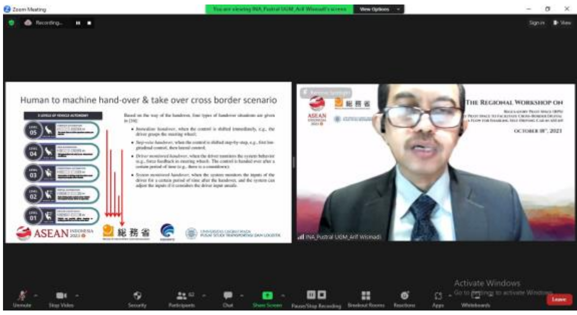
Workshop Photo Documentations

ASEAN INDONESIA 2023 総務省 Ministry of Internal Affairs and Communications KOMINFO UNIVERSITAS GADJAH MADA PUSAT STUDI TRANSPORTASI DAN LOGISTIK

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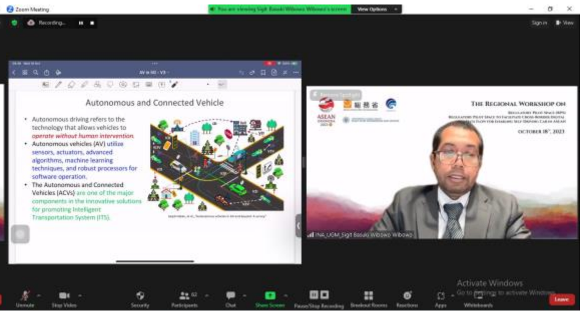
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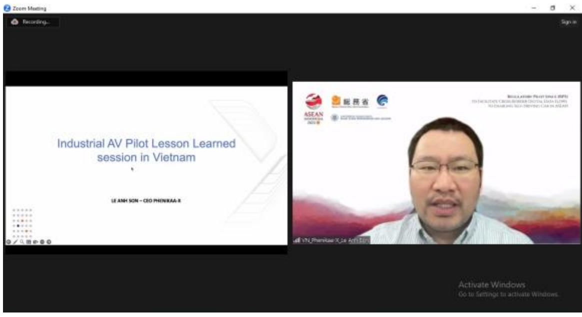
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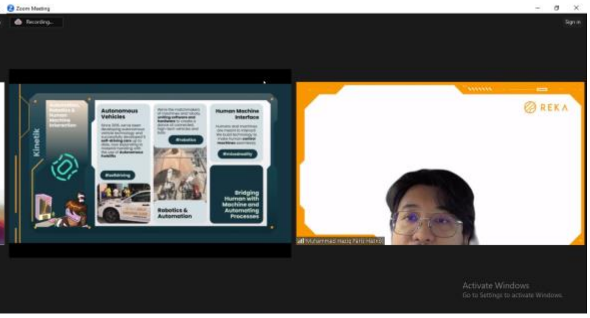
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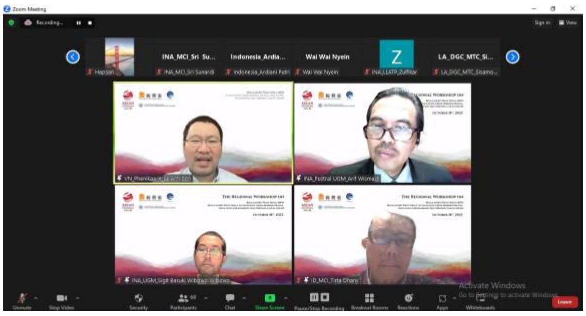
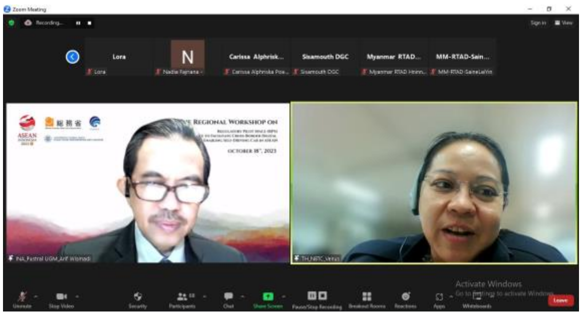
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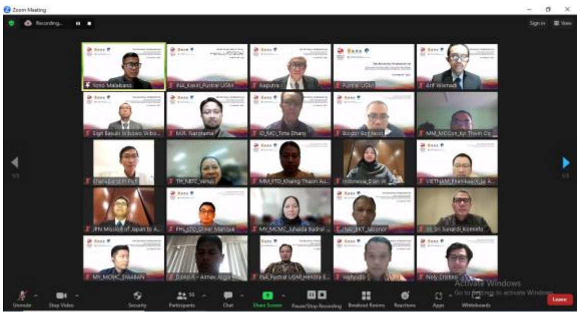
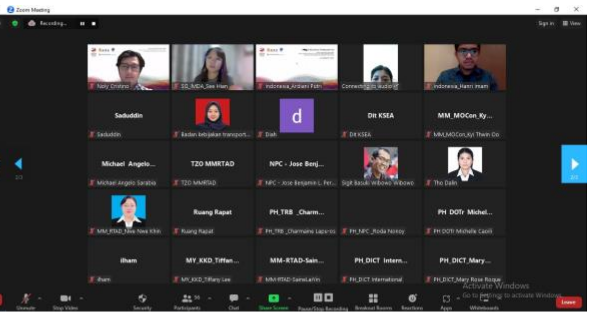
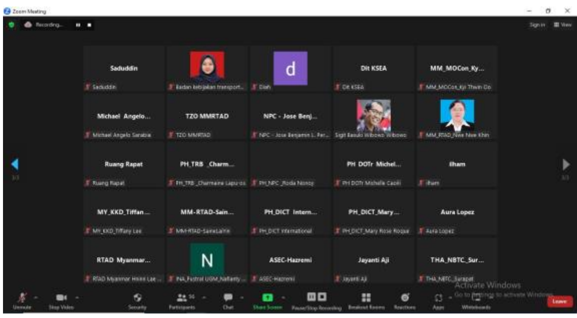
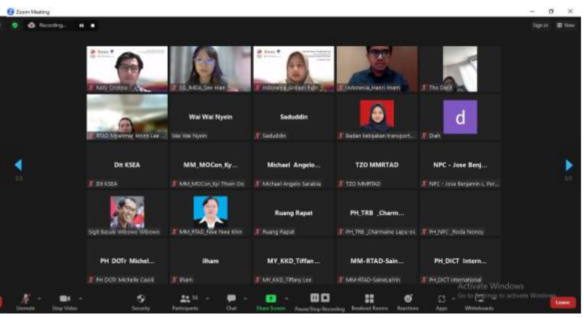

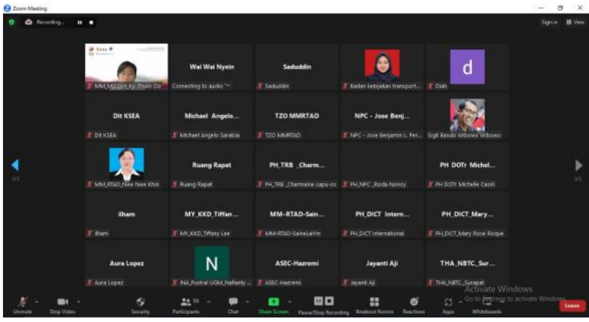
Zoom Meeting
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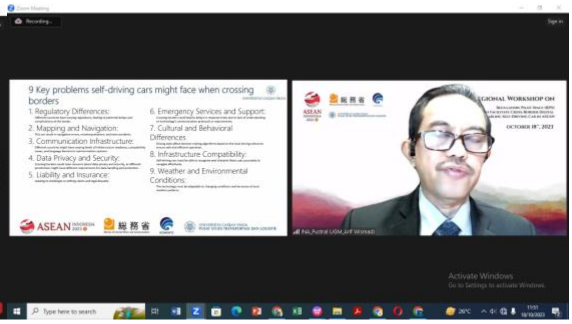
Wai Wai Nyein
Saduddin
Dit KSEA
TZO MMRTAD
Ruang Rapat
Ilham
Aura Lopez
ASEC-Hazremi
Jayanti Aji


9 Key problems self-driving cars might face when crossing borders
1. Regulatory Differences:
2. Mapping and Navigation:
3. Communication Infrastructure:
4. Data Privacy and Security:
5. Liability and Insurance:
6. Emergency Services and Support:
7. Cultural and Behavioral Differences
8. Infrastructure Compatibility:
9. Weather and Environmental Conditions:
ASEAN
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APPENDIX 2. Minutes of Meeting (MoM) or Regional Workshop

Minutes of Meeting

Regional Workshop on Regulatory Pilot Space to Facilitate Cross-Border Digital Data Flow for Enabling Self-Driving Car in ASEAN

Yogyakarta, Indonesia, 18 October 2023

1 Welcoming Speech by the Head of Center for Transportation and Logistic Studies Universitas Gadjah Mada

1.1 Ikaputra, Ph.D. Head of Center for Transportation and Logistic Studies, Universitas Gadjah Mada welcomed delegates and participants.

1.2 He begins by sharing findings from previous research, where the adoption of V2X can reduce fatal accidents by up to 79 thousand incidents in ASEAN, with an estimated reduction of USD 10 million/year in accident costs. This intelligent transportation technology is also estimated to reduce ASEAN's total emissions by 45 million tons of CO_2.

1.3 He reiterates numerous surveys have forecasted substantial expansion in the autonomous vehicle market by 2030. Projections indicate that the average market size is expected to grow by over 30% from 2020 to 2030. This market analysis underscores the pressing need to carefully consider autonomous vehicle technology in all long-term planning efforts, particularly those concerning mobility.

1.4 Ikaputra, Ph.D. highlights how Singapore is the sole representative from the ASEAN region to be ranked within the top 30 countries, and notably, it holds the coveted first position. While this is an encouraging sign for the prospects of autonomous vehicle adoption within our region, it also highlights a significant disparity in readiness among ASEAN member states.

1.5 Finally, He emphasizes the importance of the regional workshop which serves as a crucial starting point for deliberations on how ASEAN policies can facilitate regional mobility.

2 Opening Speech by the Head of Center of International Affairs, Ministry of Communication and Informatics of the Republic of Indonesia

2.1 Ms. Dian Wulandari, Director of the Post, Media, and Public Communications Team, represents Mr. Ichwan Makmur Nasution, the Head of the Center of International Affairs, Ministry of Communications and Informatics of The Republic of Indonesia (MCI).

2.2 After greeting and welcoming delegates and participants, Ms. Dian begins by describing how autonomous vehicles have the potential to dramatically enhance road safety, alleviate traffic congestion, reduce environmental impact, and improve access. These transformative changes, however, are closely tied to the ability of vehicles to seamlessly exchange data, not just within a single country but across international borders.

2.3 She emphasizes that as a region, ASEAN needs to anticipate the movement of autonomous vehicles, as part of the wider endeavor to ensure the ease of cross-border mobility within the region. The success of autonomous vehicles depends on harmonizing the diverse regulations, standards, and infrastructure necessary for the global flow of digital data. It requires bridging the gap between technological innovation and regulatory frameworks that were designed for a different era. To make this vision a reality, Ms. Dian reiterates the need to ensure that the vehicles of the future can communicate effortlessly across borders while maintaining the highest standards of safety, privacy, and security.

2.4 Ms. Dian states the goal of the workshop is to foster dialogue and collaboration to navigate the complexities of regulatory support for cross-border digital data flow, identify best practices, and chart a path forward that promotes innovation, safety, and regional cooperation.

3 Opening Remarks by Mr. Sakamoto Mitsuhide, The first Secretary Mission of Japan to ASEAN

3.1 Mr. Sakamoto begins with greetings and expresses his appreciation to the organizers.

3.2 Since 1973 Japan has had a special relationship with ASEAN. This year marks 50 years of cooperation and partnership. This workshop is part of a flagship project in the digital sector, sponsored by the ASEAN-JAPAN ICT Fund.

3.3 Regarding AV technology, Japan aims to have AV on highways by 2025. This technology is needed with the increase in logistics and passenger movement. AV is especially important to support the mobility of vulnerable people such as the elderly and children.

3.4 For AV to work at a regional level, data flow and data regulations must be unified, therefore this workshop is timely and important.

3.5 Mr. Sakamoto ends with hopes that the workshop is fruitful for all participants.

4 Presentation from expert

4.1 Introduction of research activities and workshop agenda by Dr. Arif Wismadi

4.1.1 Dr. Wismadi explains that the project background is aligned with three ASEAN masterplans: ASEAN Digital Masterplan (ADM) 2025, ASEAN Economic Blueprint, and ASEAN Connectivity Masterplan 2025. This workshop especially addresses the ADM agenda to "continue to identify opportunities to harmonize digital regulation to facilitate cross-border data flows''. The issues of data flows not only assist human communication but also non-human communication.

4.1.2 Dr. Wismadi states the objectives of the project, which is to map barriers of digital data flow, especially for self-driving cars on the ASEAN Highway Network. This project aims to see the regulatory readiness levels of AMS which can be categorized into: No response, prevention-oriented, control-oriented, toleration-oriented, and adaptation-oriented. He further states the output of this project:

1. Identify data flow required for self-driving cars
2. Map the availability of policy and regulation to support the compliance of AV data flow requirement
3. Assess and map the gap between data flow requirements and available service levels
4. Identify regulations that drive the data flow requirement gaps for AV
5. Provide recommendations of RPS to harmonize digital regulations between AMS to support interoperability of data flow for autonomous vehicles.

4.1.3 Outlook of AV. There are 5 levels of AV: the lowest being driver assistance and the highest level being full automation. Market research has predicted that partial automation (level 2) will be prominent in the market by 2030. To prepare for the adoption of AV at a regional level, there are different sectoral roles: ADGSOM should focus on data flow requirements, while STOM should provide regulatory support for AV to operate safely on public roads.

4.1.4 Dr. Wismadi elaborated on the results of the project. **Result 1**: Identified data flow requirements for self-driving vehicles. AV needs low latency and high reliability of data flow. He shows a table on technical requirements in terms of data. **Result 2**: availability and service level for AV data flow. Dr. Wismadi shows different levels of AV readiness among AMSs, based on desk study (based on digital infrastructure, Pilot testing on AV, and research on AV). **Result 3**: Gaps between data flow requirements and available service level. He delivered the consequences of changing data flow service levels, types of machine to human handovers, and ends with summary of presentation.

4.1.5 Next, Mr Arif delivered a summary analysis of the AS IS situation in ASEAN:

- Digital infrastructure determine the level of AV (Level1: Feet OFF, Level 2: Hands OFF, Level 3: Eyes OFF, Level 4: Mind OFF, Level 5: Driver OFF);
- With the diversity of digital infrastructure performance among AMS, an AV that crosses the country border may turn down the level of AV;
- During crossing a border, a handover among network may disrupt the flow of data and temporarily turn down the level of AV, even though both AMS has a similar level of digital infrastructure service performance;
- During the network handover in the cross border, if the decreased level of AV requires the driver to take over the vehicle control a protocol for safety is a must;
- A location-based scheduled hand-over from machine to human should be designed in the country border;

- Under the current level of digital infrastructure service, no Level 2 and above of AV/Self-driving cars are permitted to across the AMS border;
- AV/Self-driving cars are only allowed to be operated in the ASEAN Highway if all safety requirement is in compliant.

4.1.6 Dr. Wismadi ends with a summary of the presentation.

4.2 Network infrastructure to support AV operation by Sigit Basuki Wibowo, Ph.D.

4.2.1 Mr. Sigit reiterates the concept of autonomous and connected vehicles, and what they are or should be capable of. He shares the anatomy of AV features in cars. Level of automation and required level of latency and reliability. Emphasize on how each level of automation requires different degrees of latency, reliability, data rate, traffic density, and connection density.

4.2.2 Mr. Sigit further discusses the technicality of 5G in supporting AV. He elaborates about the solution architecture for AV, including mobile edge cloud. He also explains different systems, namely non-stand-alone and stand-alone systems. The presentation ends by concluding that the most likely solution for transitioning would be to have a hybrid system between 5G and non-5G.

5 Country Update of AMS on national mechanism to facilitate and enhance Logistics and Rural SMEs

This session was moderated by Dr. Arif Wismadi. he explained different types of AV readiness according to the AV Readiness Index (AVRI). Next, Dr. Wismadi Invites delegates to share information the following information: (1) AMS regulatory readiness; (2) Policy documents regarding AV (if any); (3) AV piloting and (4) any concern regarding AV.

5.1 Malaysia

Ms. Tiiffany Lee apologizes that she could not share any information, as she is not an expert in this field. Her colleagues from the transport sector would be in a better position to share on this matter, but they are not currently present.

5.2 Myanmar

Ms. Nwe Nwe Khinn (RTAD road transport) shares that AV is very new to Myanmar, but she has learned a lot from the workshop. Regarding policy documents, Myanmar does not have any regulations concerning AV, and neither does it have any AV pilot project for the time being. Mr. Sigit explained that 5G is crucial, but right now Myanmar only has a 4G network.

5.3 Thailand

Venus_NBTC (infrastructure of telecommunication). Regarding telecommunication infrastructure, Thailand has launched 5G and has a pilot for self-driving cars. Thailand 5G use case of self-driving cars is at Siriraj Hospital.

5.4 Singapore

Sie Hyin. (ADGSOM Singapore). She apologized because Amanda could not attend today. Singapore started its AV journey early. However, unfortunately, the transportation sector of Singapore cannot join at this time to explain the development of AVs in Singapore.

6 Industry sharing session

6.1 Phinekaa-X (Vietnam) by Dr. Son Le Anh

Presentation Session

6.1.1 We believe if AV can be applied in Vietnam, it can be applied everywhere because Vietnam has one of the worst traffic, with a mix of motorcycles, bicycles, and cars.

6.1.2 Our company makes autonomous systems for vehicles, drones, and robots. Our core technologies are self-driving technology, cloud computing, artificial intelligence, IoT, and energy.

6.1.3 We make our own HD map, simulation, AI, and path planning. We are currently building SEA level 4 automation without a steering wheel. We use cameras, LIDAR, and other sensors. We have real-time tracking, real-time vehicle data, and birds eye view. We can control the vehicle from the station if we want.

6.1.4 In terms of prototypes in action, we are testing in the Ecopark smart city area, and also in Binh Durang smart city with the Japanese embassy. We also have tested small autonomous robots for delivery, which we call last-mile delivery robots.

Q & A Session

6.1.5 Dr. Arif Wismadi: I would like to discuss the story of your company. What kind of setup does your company have relating to your country?

Dr. Son Le Anh:

- I work for the university. Phinekaa is a spin-off from the university. We have many experts in the university so we made this company.
- Regarding how to bring our product to ASEAN, In Vietnam we do not have regulations for AV, so we can only use small areas in smart cities. We would like to collaborate with other countries. it does not have to be our vehicle, we have the software, so we can collaborate with other countries in ASEAN.

6.1.6 Dr. Arif Wismadi: Can it be applied in any car?

Dr. Son Le Anh: Yes. it can.

6.1.7 Dr. Arif Wismadi: How is the credibility of the network?

Dr. Son Le Anh: We have 5G covered by partners in some areas, and some areas without 5G. 4G is actually enough to transfer information, however, we cannot control it remotely in real-time without 5G.

6.1.8 Dr. Arif Wismadi: So with 5G, we can connect better and control remotely when needed. Are there any problems with handover from one BTS to another?

Dr. Son Le Anh: Only real-time information is location and vehicle situation is transferred, so we do not need that much speed and high specification of the network. So there is no problem, but if you transfer video, there is a problem.

6.1.9 Dr. Arif Wismadi: You mentioned there is less dependency towards the network. For 2 AV or more needs to communicate, what if there are more vehicles?

Dr. Son Le Anh: We have 5 AVs operating in Phinekaa University, and all vehicles are connected. Changing BTS does not affect too much in operation, but if there are a lot of vehicles, maybe there will be some trouble. Sometimes there is a lost connection, but we have supercomputers inside the vehicles, so there are no problems.

6.1.10 Indonesia_MCI_Tirta Dhany: Based on the video presentation, irregularities in traffic flow greatly affect the ability of LIDAR sensors to provide navigation guidance, so an integrated mechanism is needed that includes sensors and other systems to create more accurate and real-time guidance. What is your advice regarding this?

Dr. Son Le Anh: if we have a lot of sensors, how we mixed them together is important.

Indonesia_MCI_Tirta Dhany: I think your advice regarding the sensor is a good solution. We cannot predict all moving objects. I think 5G is important to reduce delay and add more sensors to become more accurate.

6.1.11 Sigit Basuki Wibowo, Ph.D: how is the state of 5G in Vietnam?

Dr. Son Le Anh: All providers provide 5G in big cities such as Hanoi. Outside that, we have 4G. We predict all Vietnam will eventually have 5G.

6.1.12 Sigit Basuki Wibowo, Ph.D: Is it stand alone 5G?

Dr. Son Le Anh: Yes, stand-alone. In Phinekaa University we also have millimetre 5G.

6.2 Malaysia, Reka Industry by Muhammad Haziq Faris (CEO of Reka)

<u>Presentation Session</u>

6.2.1 We are an RnD company focusing on AI-based in Malaysia, we do a lot of AI services in the region. We connect human and technology.

6.2.2 We started the company in 2013, we launched Malaysia's first self-driving car. continue to expand autonomous vehicles since 2017. Our key activities are in sensing & digitalization, automation, robotics & human machine interaction, AI driven application, digital transformation, and humanising technology.

6.2.3 We have conducted many test drives across the Malaysian peninsula, and we have helped develop Malaysia's AV policy. We collaborate with OEMs, car manufacturers, tier 1 providers, and we provide them with AV technology.

6.2.4 Most of our development is on level 3 on the SEE scale. In our first project, we retrofitted our national car 'Proton'. We have tested the AV with many obstacles such as toll booths, drive-throughs, etc. This can be seen on the REKA Youtube channel.

6.2.5 Right before the pandemic we already had 4 prototype vehicles. Right now we are working on level 4 automation. REKA just showcased in Malaysia auto show 2023, collaborating with MARii and PERODUA.

6.2.6 Malaysia has several AV testing sites, but the main testing site in Malaysia is in Cyberjaya.

6.2.7 The pilot testing AV conducts 90% processing offline, due to the fact that right now 5G is not widespread yet across Malaysia.

6.2.8 We make our own digital HD mapping and path planning. We continue to focus on the following areas: mapping, path planning, perception, and sensors.

Q & A Session

6.2.9 MM RTAD_Nwe Nwe Kinh: What is the maximum speed of AV? Do they understand road signs and markings?

M. Haziq Faris: Right now, on Malaysia Highway, the maximum speed is 110 km/hour. For AV on average 60-80km/hour, but we have testing for 120km/hour. Our coptic vision can recognize 95% of road signs in Malaysia. Some are a bit old and blurred or rusted. These are challenges to help recognize.

6.2.10 Dr. Arif Wismadi: In this workshop, there are two ASEAN sectoral bodies; ADGSOM and STOM. What do you expect or request from digital and transport sector regulators?

M. Haziq Faris:

- When we first started testing in 2016, we had to go to a lot of ministries for approval. We had supervision from the government at the time. We did testing in a designated area.
- From our experience, my first request is to have a designated area for testing AV. Now there are 5 areas where we can test AV in Malaysia. Now only Cyberjaya can be used for on-road testing. There are now guidelines on which roads can be used
- So the second request is the need to outline regulations for the type of vehicles and tests, especially certain classes of vehicles, and now there are speed limits. In our experience, full autonomous testing in highways was allowed when first testing, now you cannot do that anymore, someone has to sit in the front seat.

- Most of our program runs on the vehicle itself. We have also tested our system with 5G in Japan and it works. 5G will extend its operability.

6.2.11 Dr. Arif Wismadi: what if your car operates across borders?

M. Haziq Faris: Some issues that might need consideration are road signage, regulations, lane change, and network capability.

6.2.12 Sigit Basuki Wibowo, Ph.D.: How is the collaboration between academic institutions?

M. Haziq Faris: We collaborated with a few universities here such as UTM for specific modeling.

6.2.13 Sigit Basuki Wibowo, Ph.D.: You showed a picture of a vehicle with actuator equipment. When you test this car, how do you take over if there are some problems?

M. Haziq Faris: There is a fail safe system. The pedals are not locked, so the driver can control them.

6.2.14 Sigit Basuki Wibowo, Ph.D: How about the latency?

M. Haziq Faris: We tried 5G in cyberjaya and Japan, and worked fine.

6.2.15 Sigit Basuki Wibowo, Ph.D: Have you tried edge cloud?

M. Haziq Faris: yes we have tried.

7 Facilitated workshop

7.1 Arif Wismadi concludes with key problems for self-driving cars when crossing borders:

- <u>Regulatory Differences</u>: Different countries have varying regulations, leading to potential delays and complications at the border.
- <u>Mapping and Navigation</u>: This can result in navigation errors, misinterpretations, and even accidents.
- <u>Communication Infrastructure</u>: Different countries might have varying levels of infrastructure readiness, compatibility issues, and language barriers in communication systems.
- <u>Data Privacy and Security</u>: Crossing borders could raise concerns about data privacy and security, as different jurisdictions might have different requirements for data handling and protection.
- <u>Liability and Insurance</u>: Leading to challenges in settling claims and legal disputes.
- <u>Emergency Services and Support</u>: Crossing borders could lead to delays in response times due to a lack of understanding on technology's communication protocols or requirements.
- <u>Cultural and Behavioral Differences</u>: Driving style affect decision-making algorithms based on the local driving culture to ensure safe and efficient operation.

- <u>Infrastructure Compatibility</u>: Self-driving cars must be able to recognize and interpret these cues accurately to navigate effectively.
- <u>Weather and Environmental Conditions</u>: The technology must be adaptable to changing conditions and be aware of local weather patterns.

7.2 Three possible approaches that ASEAN for embracing AV:

7.2.1 Harmonized Regulatory Framework and Infrastructure Investment:

- In this approach, ASEAN member states would collaborate closely to establish a harmonized regulatory framework for self-driving cars. This would involve creating common standards for vehicle safety, data privacy, cybersecurity, and road infrastructure requirements. Member states could agree on a set of guidelines that facilitate the deployment of self-driving cars across the region, ensuring that these vehicles can operate seamlessly across borders.
- Additionally, ASEAN could collectively invest in developing the necessary smart infrastructure to support self-driving cars. This includes upgrading roads with sensors, establishing communication networks, and building charging stations for electric autonomous vehicles. By working together, ASEAN could create a more cohesive environment for self-driving cars to operate, reducing regulatory hurdles and technical barriers.

7.2.2 Gradual Pilots and Public Education:

- In this approach, ASEAN member states would start by conducting small-scale pilot programs of self-driving cars in controlled environments. These pilots could be limited to specific cities or regions, allowing governments to gather data and assess the technology's performance and impact on local traffic patterns.
- Simultaneously, there would be a strong emphasis on public education and awareness campaigns. Governments would engage with citizens to inform them about the benefits and safety features of self-driving cars, as well as address any concerns related to job displacement, data privacy, and vehicle safety. This approach would build public trust over time and pave the way for broader adoption of self-driving cars.

7.2.3 Innovation Hubs and Research Collaboration:

- This approach involves ASEAN member states strategically positioning themselves as innovation hubs for self-driving car technology. Governments could incentivize research and development by offering grants, tax incentives, and favorable regulatory conditions to attract both domestic and international companies working on autonomous vehicles.

7.3 All participants from AMS at the workshop had no objections to the recommendations produced so that they could proceed for formal endorsement.

8 CLOSING STATEMENT

8.1 Ikaputra, Ph.D., The Head of PUSTRAL UGM said that Indonesia thanked speakers, esteemed delegates, and diligent organizers for contributing to the remarkable success of this workshop.

8.2 He emphasized for us to continue our collaborative efforts, fostering the exchange of knowledge to bolster the digitization of cross-border movements within the ASEAN community. He also invited us to persist in our advocacy for a transportation system that is safer, environmentally friendly, and more efficient. Together, let's remain resolved in our commitment to forge a better-connected ASEAN.

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