Development of Connected and Automated Shuttle, Testing of 5G communication, and Development of Use cases in Thailand

Nuksit Noomwongs, D.Eng

Smart Mobility Research Center, Faculty of Engineering, Chulalongkorn University

Vice President Society of Automotive Engineering Thailand (TSAE)

31 August 2023

About Smart Mobility Research Center, Chulalongkorn University

Established 2012

SAFE

- Road Safety
- Driver Behavior
- Advanced Driver Assistance System (ADAS) and Autonomous Driving system

-Aging Driver
-Near-Miss Incident Database
-Driver Behavior Monitoring / Telemetric
-ADAS/AD High level design
-Autonomous Driving System Integration and Testing

SMART

- Smart Mobility
- Intelligent Transport System (ITS)

-Road/IT infrastructure
-Eco-Driving
-Connected Vehicle (V2X)
-New Mobility Business
-Smart Grid

SUSTAINABILITY

- Vehicle Electrification
- Carbon Neutrality and Net Zero for Mobility
- Future Mobility Service

-Light-Weight Structure
-EV Platform
-Battery packing
-FCEV
-Mobility-as-a-service

"Networking for Smart Mobility at Chulalongkorn University Developing Smart, Safe and Sustainable Mobility for Thai society"

Milestone of Autonomous Vehicle Research at Smart Mobility Research Center Chulalongkorn University

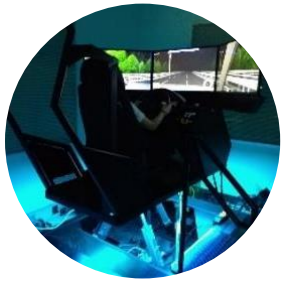
Established 2012

2012-2017

Focusing on ADAS, Driver behavior, HILS, Driving simulator research

June 2016

Driving Simulator for elderly driver ability assessment



May 2017

6-DOF Driving Simulator

October 2018

The 1st Seminar on Automated Vehicle in Bangkok / Demo of AUTOWARE (Co-organized by Nagoya university)

April 2019

The 1st 5G Connected Car in Thailand

August 2019

Demo at GITSDA for MULTI GNSS ASIA Conference (GNSS RTK /2D LiDAR Object detection and avoidance)

December 2019

CU Toyota Ha:mo Autonomous Relocation System prototype (GNSS RTK /3D LiDAR Object detection and avoidance)

February 2020

Demo at GITSDA (GNSS PPP)

July 2020

NBTC Project: 5G Teleoperated Vehicle

2017-2021

3 Autonomous vehicle prototypes were developed in house

April 2021

Autonomous Delivery Vehicle prototype platform (GNSS/3D LiDAR Localization/Delivery Application)

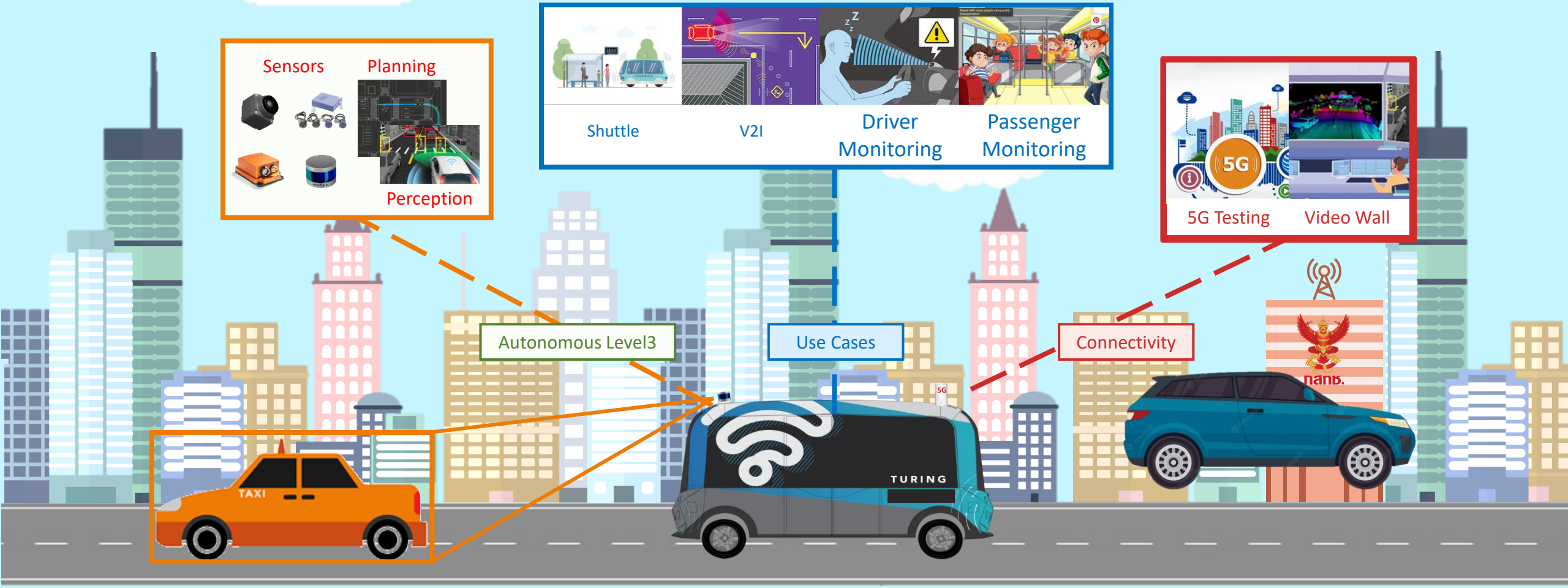
April 2021

NBTC Project: Autonomous Shuttle golf cart prototype (GNSS/3D LiDAR Localization)

April 2021 – February 2023

NBTC Project: 5G Testing for Autonomous Shuttle

The Experiment of 5G Communication for Autonomous Vehicle Project



Research team

The Experiment of 5G Communication for Autonomous Vehicle Project

Civil Engineering
ITS/ Transport
Transport policy

Project leader
Assoc. Prof. Sorawit Narupiti, Ph.D

CHULA ENGINEERING
Foundation toward Innovation

Automotive Engineering
Vehicle Safety and Advance Driver Assistance Systems
Autonomous Driving

Autonomous Vehicle
Asst.Prof.Nuksit Noomwongs, D.Eng

Use Cases/ V2X

Computer Engineering

Assoc. Prof. Kultida Rojviboonchai, Ph.D.
Assoc. Prof. Peerapon Vateekul, Ph.D

Mechanical Engineering
Vehicle Electrification

EV
Assoc. Prof. Angkee Sripakagorn, Ph.D.

HD Map
AV Pilot Test
Asst.Prof.Nuksit Noomwongs, D.Eng

Electrical Engineering
5G, Telecommunication

5G & Communication
Asst. Prof. Widhyakorn Asdornwised, D.Eng

Video Wall

Electrical Engineering

Prof. Lunchakorn Wuttisittikulkij, Ph.D
Lect. Pitchaya sitthi-amorn, Ph.D

Communication

Electrical Engineering

Assistant Professor Panuwat Janpugdee, Ph.D

Policy Guideline
Assoc. Prof. Sorawit Narupiti, Ph.D

Project advisors

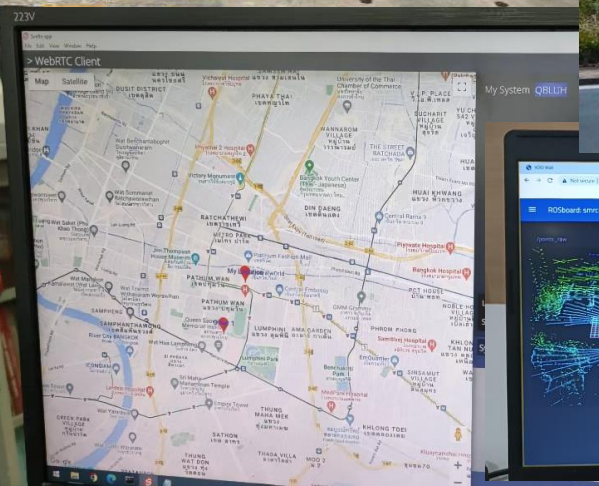
SAE THAILAND
THAILAND AUTOMOTIVE INSTITUTE สถาบันยานยนต์
ITS Thailand สมาคมระบบขนส่งและจราจรอัจฉริยะไทย

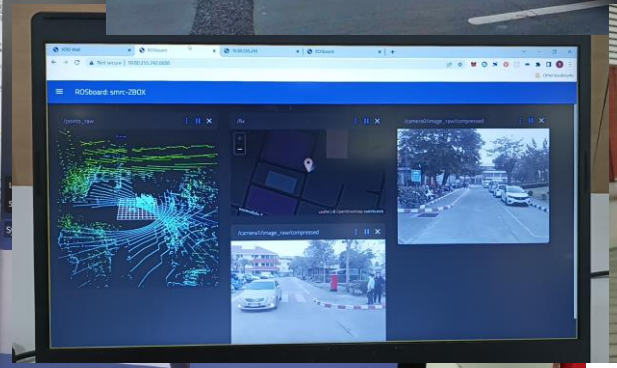
ROAD 2023 Smart mobi

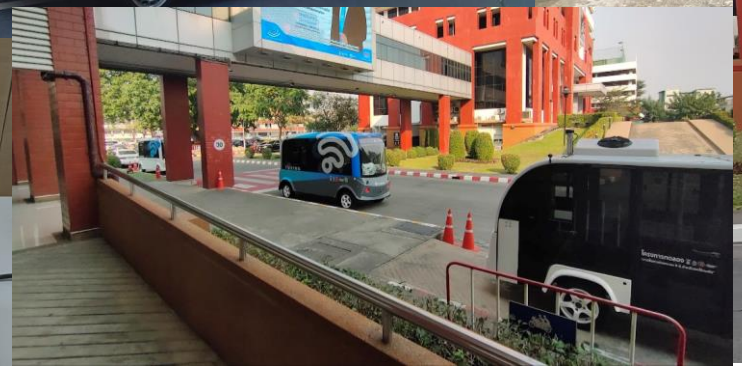
ISAVT2023
Smart MOBI
TURING

TURING
โครงการทดลองการสื่อสารด้วยระบบ 5G สำหรับรถไร้คนขับ

Charging Station
CHULA ENGINEERING


WebRTC Client
My System QBLUH


ROSboard: smrc-2BOX

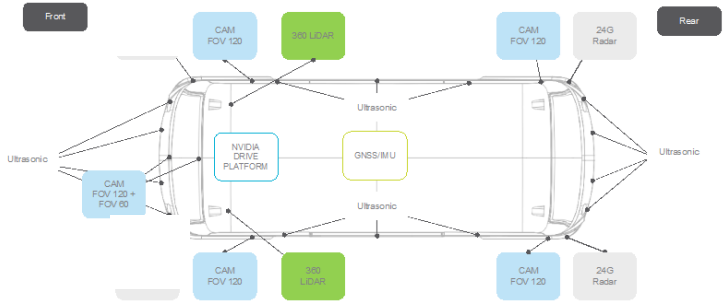


Auto Driving Mode
TURING

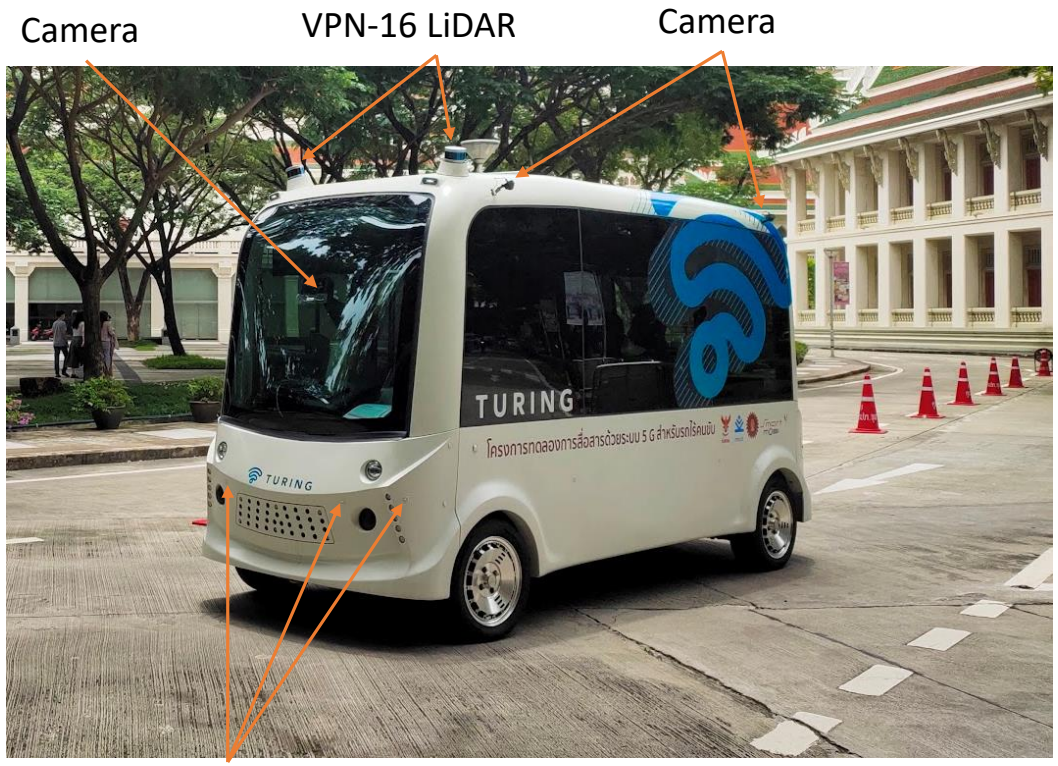
Connected Automated Vehicle

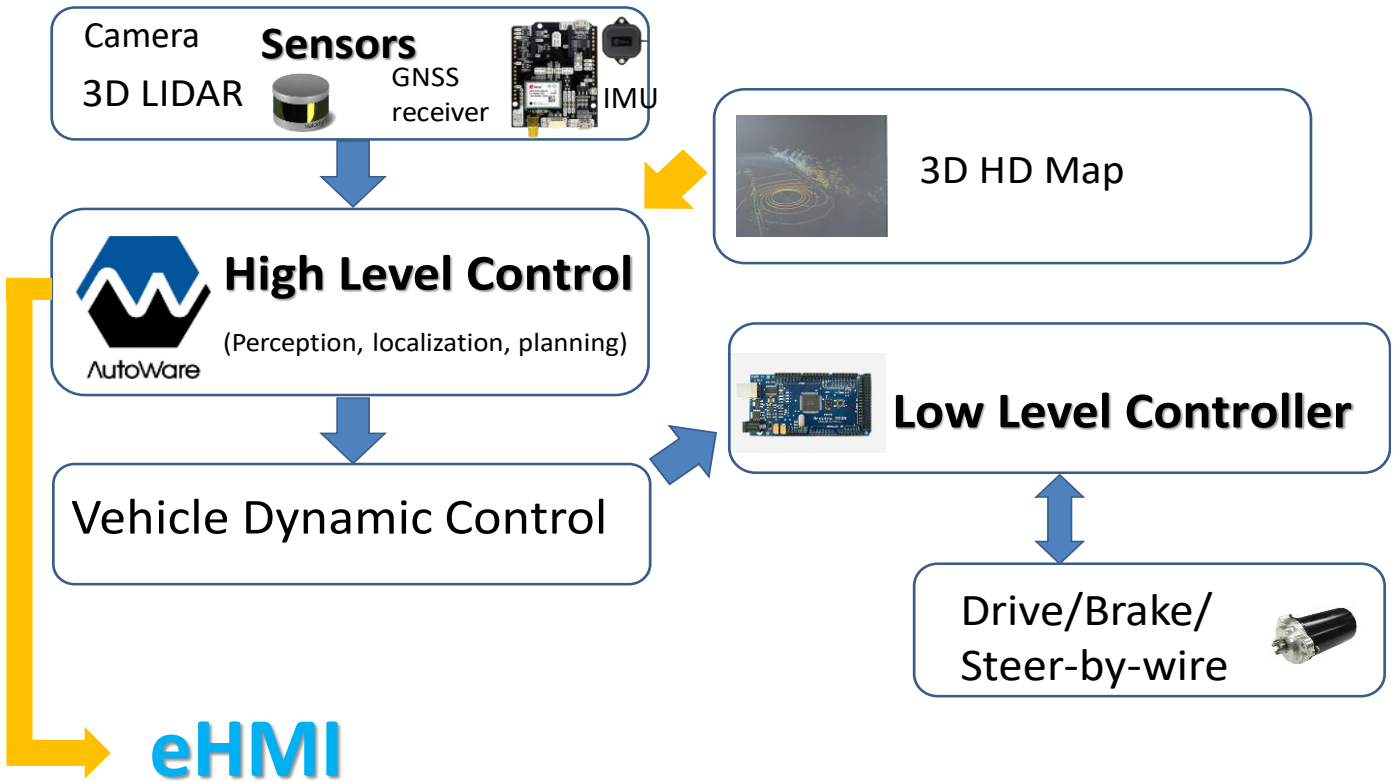
Vehicles

Parameter		Unit	Specs
Dimension	Length	mm	4300
	Width	mm	1610
	Height	mm	2430
	Wheelbase	mm	2894
Passenger		pax	10+2
Seats		pcs	10
Weight	Curb Weight	kg	1374
	Gross Vehicle Weight	kg	2200
Performance	Max. Speed	km/h	40
	Gradeability	%	≥20
Battery	Type	--	Lithium Ion
	Nominal Capacity	Ah	160
	Nominal Voltage	V	72
Motor	Type	--	IM
	Rated Power	kW	7.5
	Peak Power	kW	20
Wheel	Type	--	185 65R15



System of LV-3 Autonomous Driving in the demo prototype





In this project, our Focus is on Level 3 (Low speed in predefined route)

eHMI

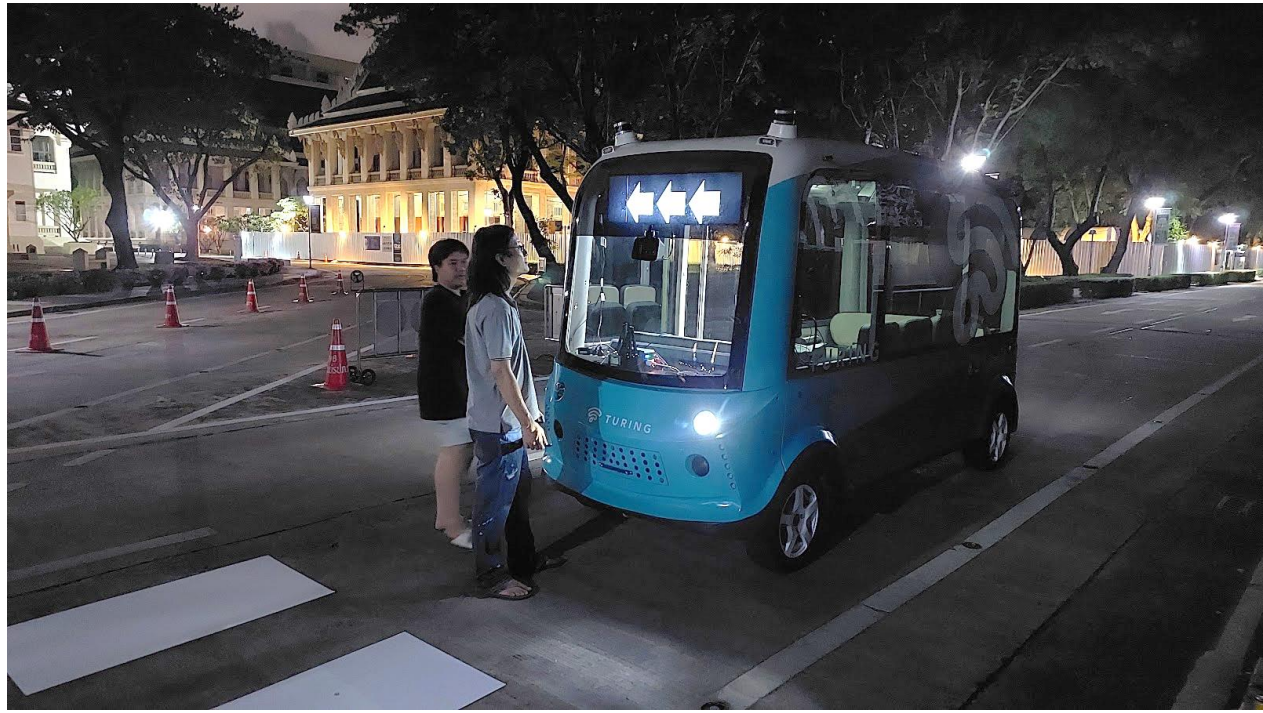
Auto Driving Mode
5G
TURING

Manual Driving Mode
5G
TURING
TURING

eHMI

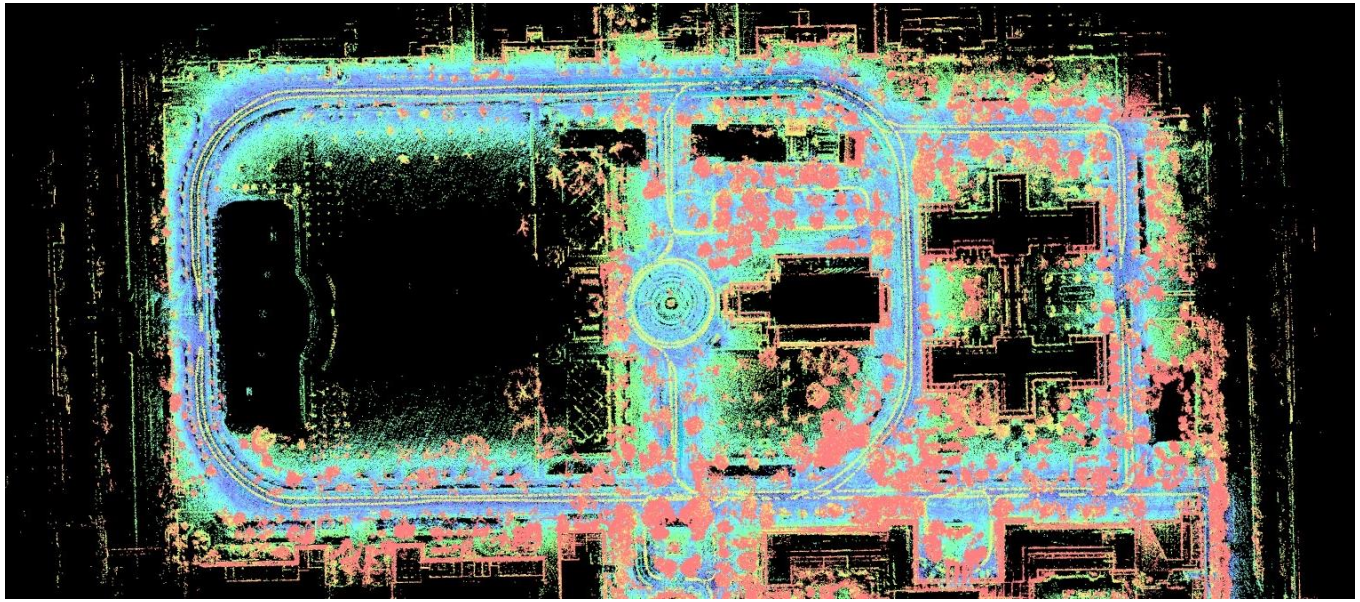
Design	Set of eHMI prototype			
Text				
Icon				
Combine				

eHMI

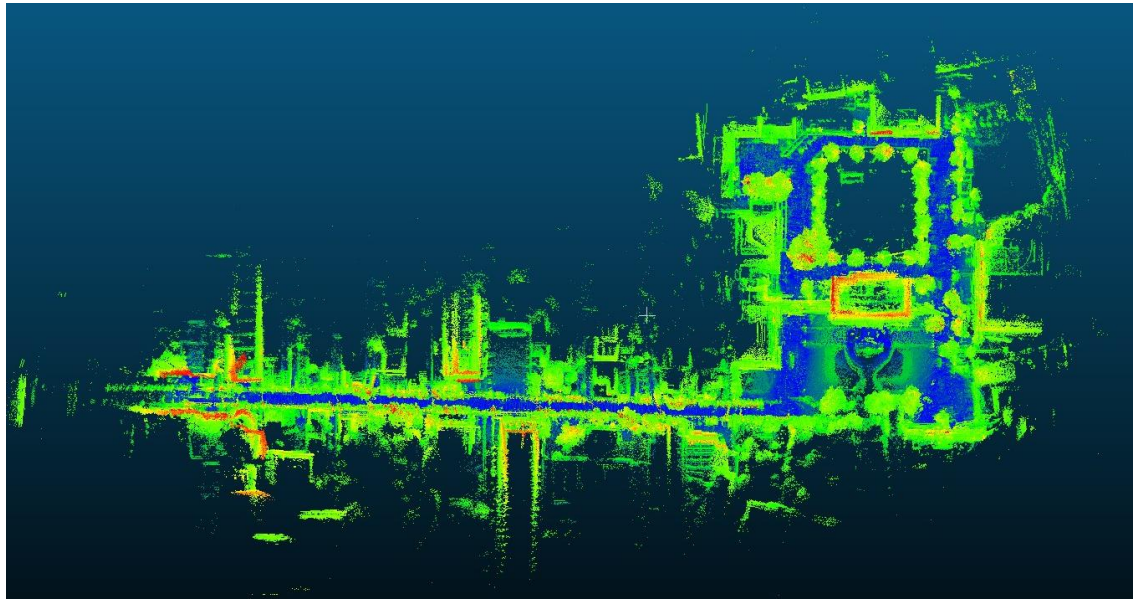


HD Map

Chulalongkorn University



NBTC Office

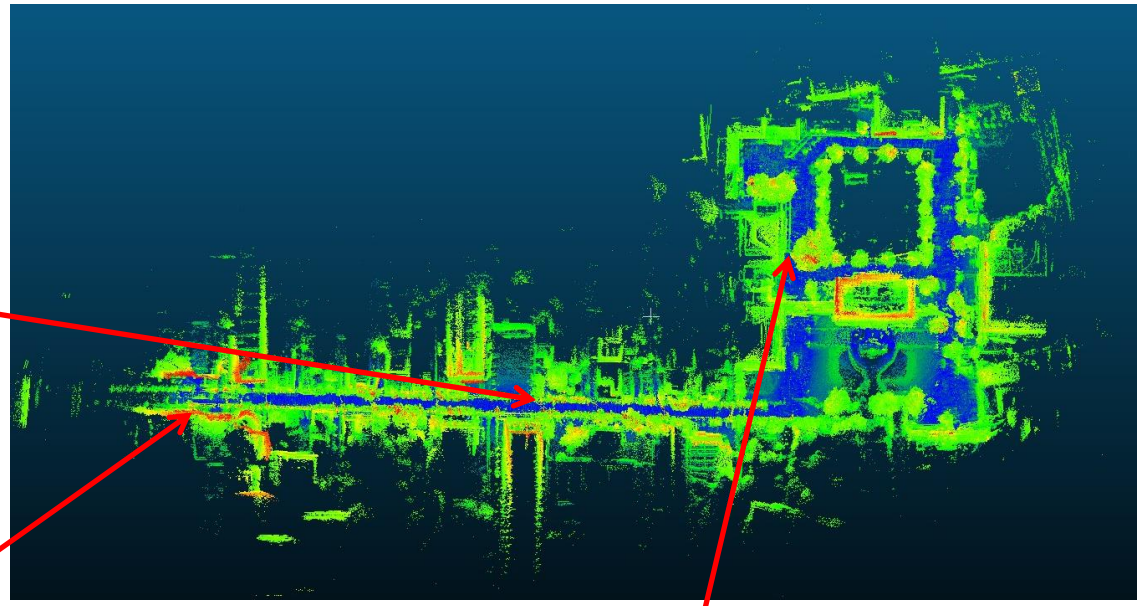


Connected Automated Vehicle

ISAVT2023

HD Map

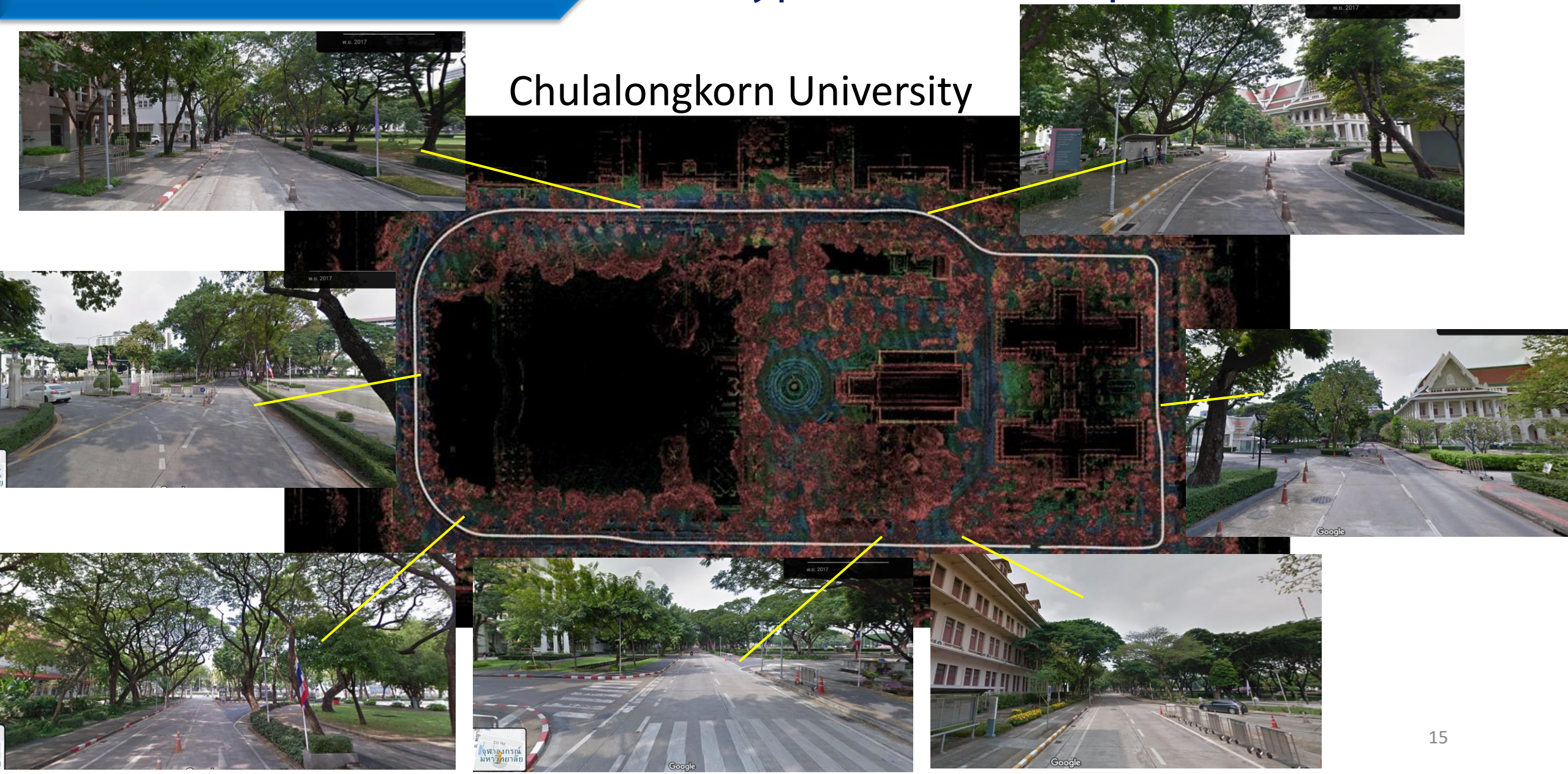
NBTC Office



Connected Automated Vehicle

Waypoint on HD Map

Chulalongkorn University



Chula Digital Twin for AV Testing

Builder

VECTORZERO
RoadRunner

blender
Blender

Simulator

UNREAL ENGINE
Unreal Engine

CARLA
Carla

Controller

THE AUTOWARE FOUNDATION
Autoware

Virtual environment

Real world environment

Virtual

Physical

CARLA

CARLA

Generating Environment

CARLA ROS Bridge

Ego Vehicle

Sensor Data

CARLA Autoware Bridge

Autoware

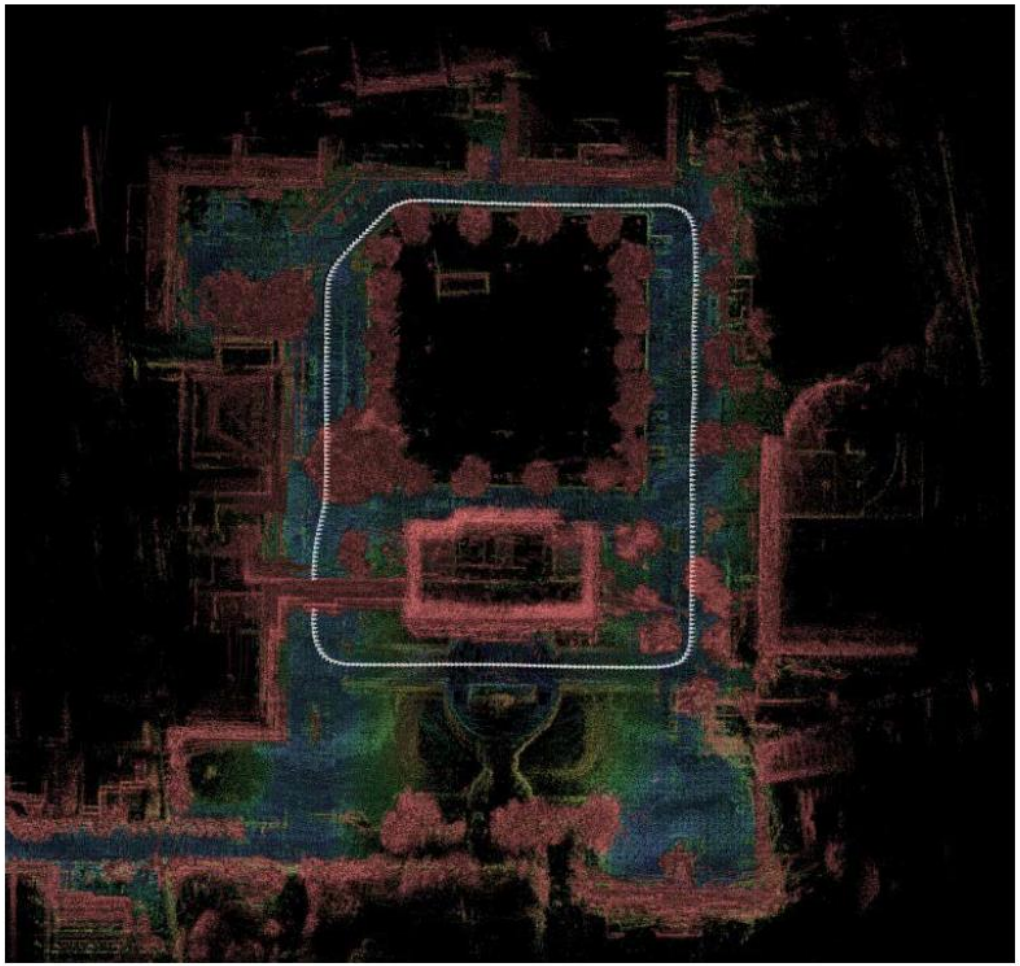
Autoware

Localization

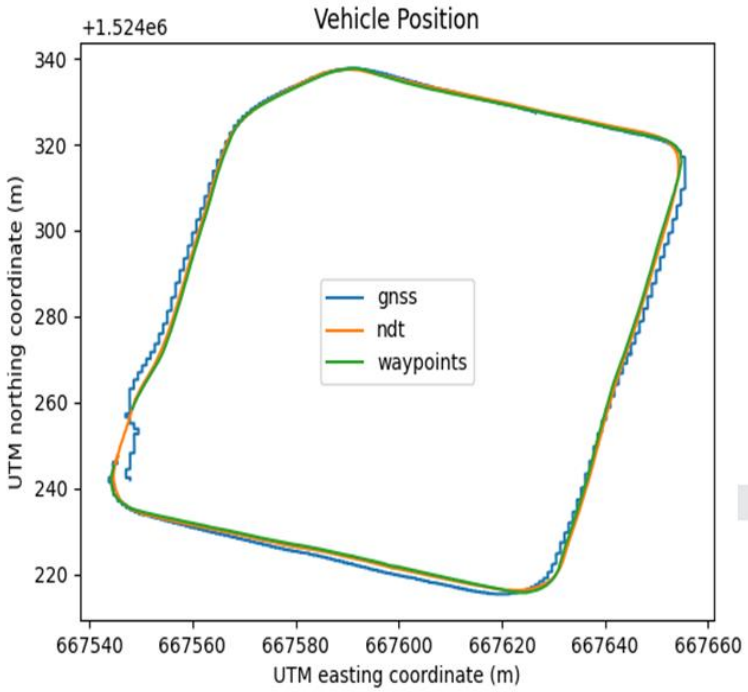
Motion Planning

Path Following

Waypoint on HD Map

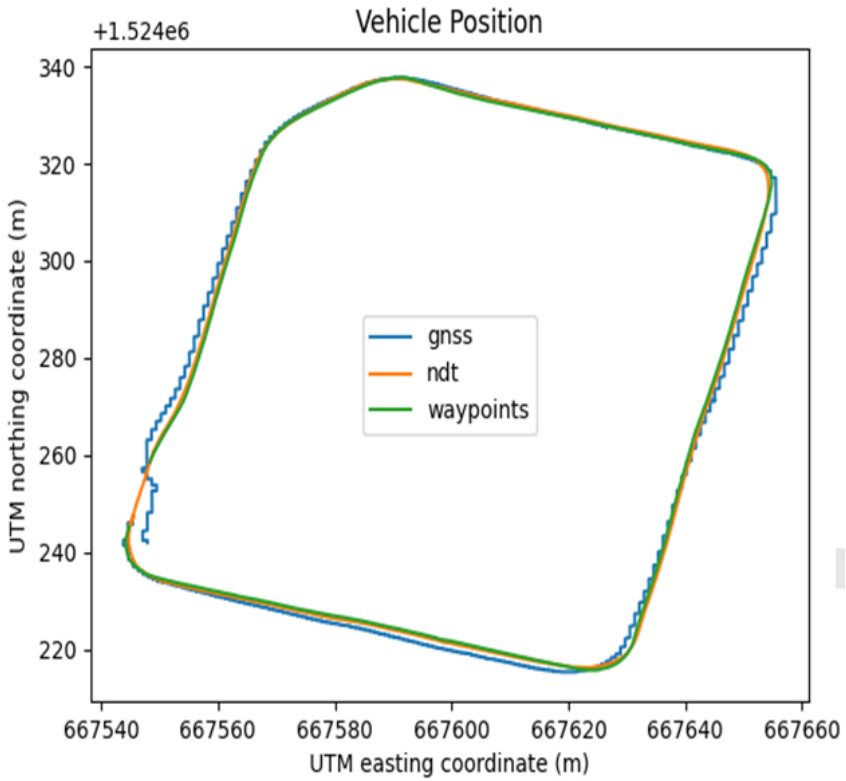


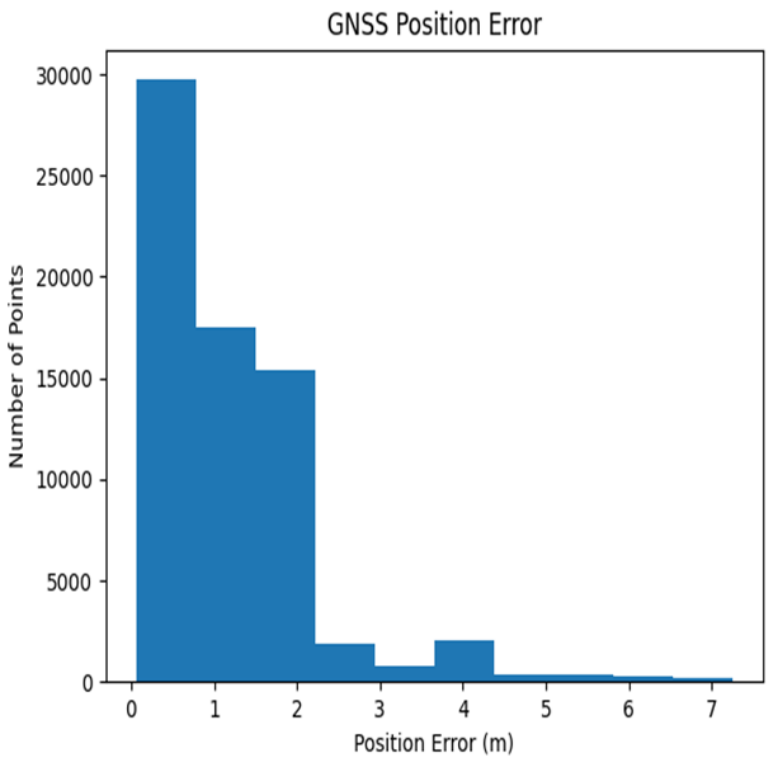
NBTC Office

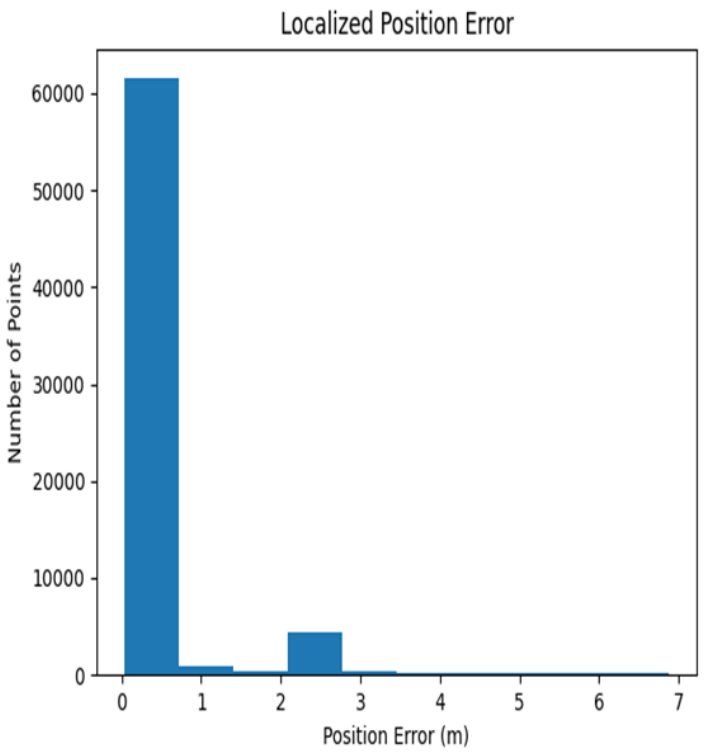


Waypoint on HD Map

NBTC Office

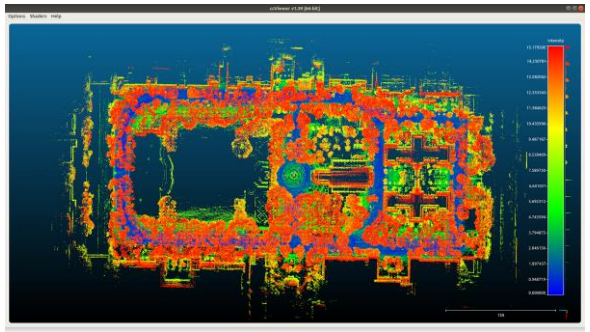


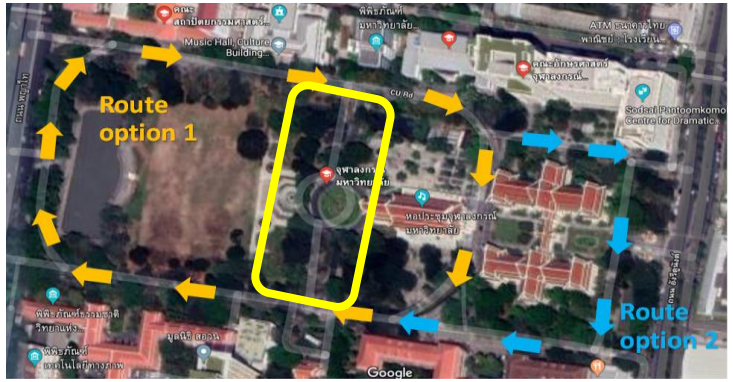




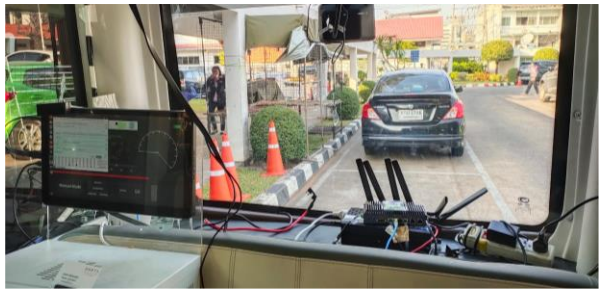
Testing in closed area in Chulalongkorn University Campus

Autonomous driving test (Predefined way point)



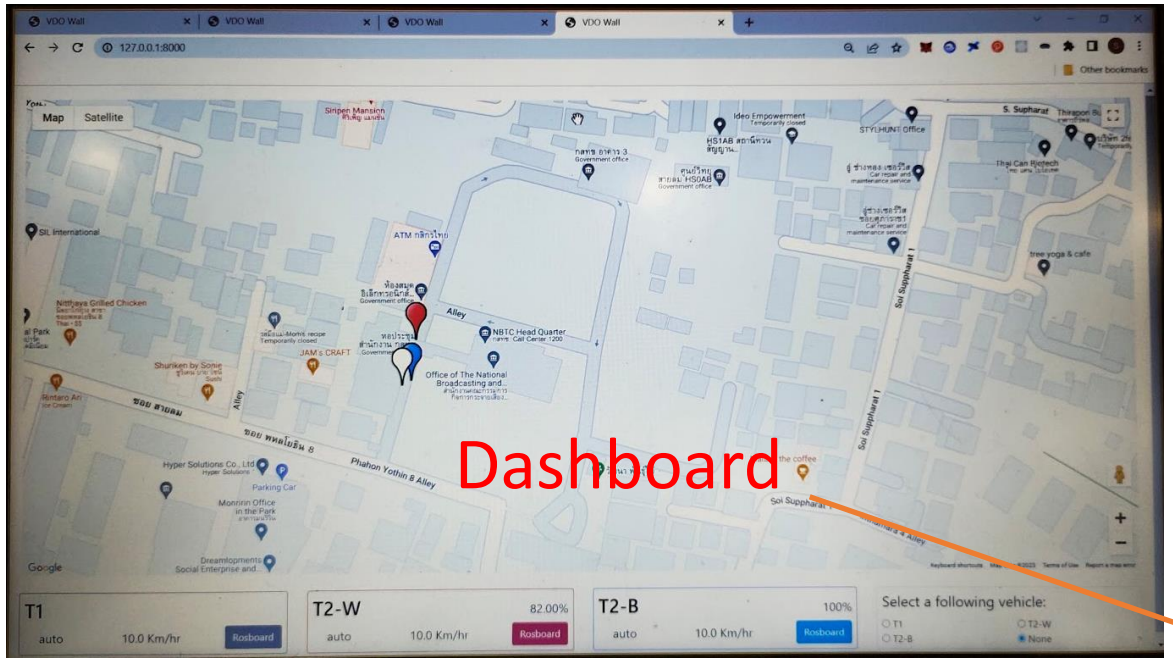


Testing in closed area in NBTC Office (กสทช)

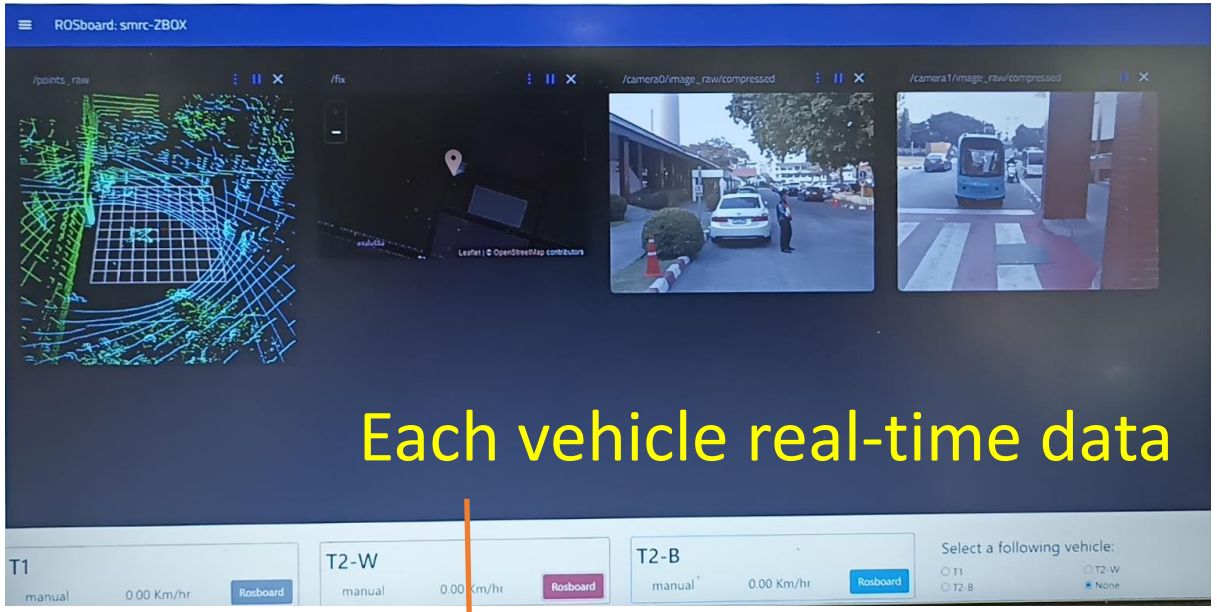


Connected Automated Vehicle

Operation Dashboard

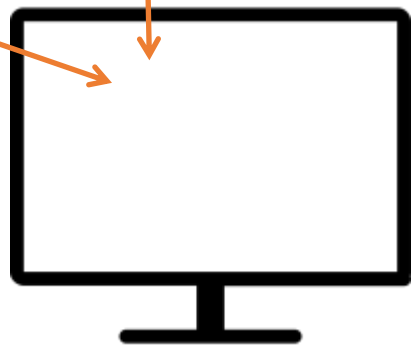


Dashboard



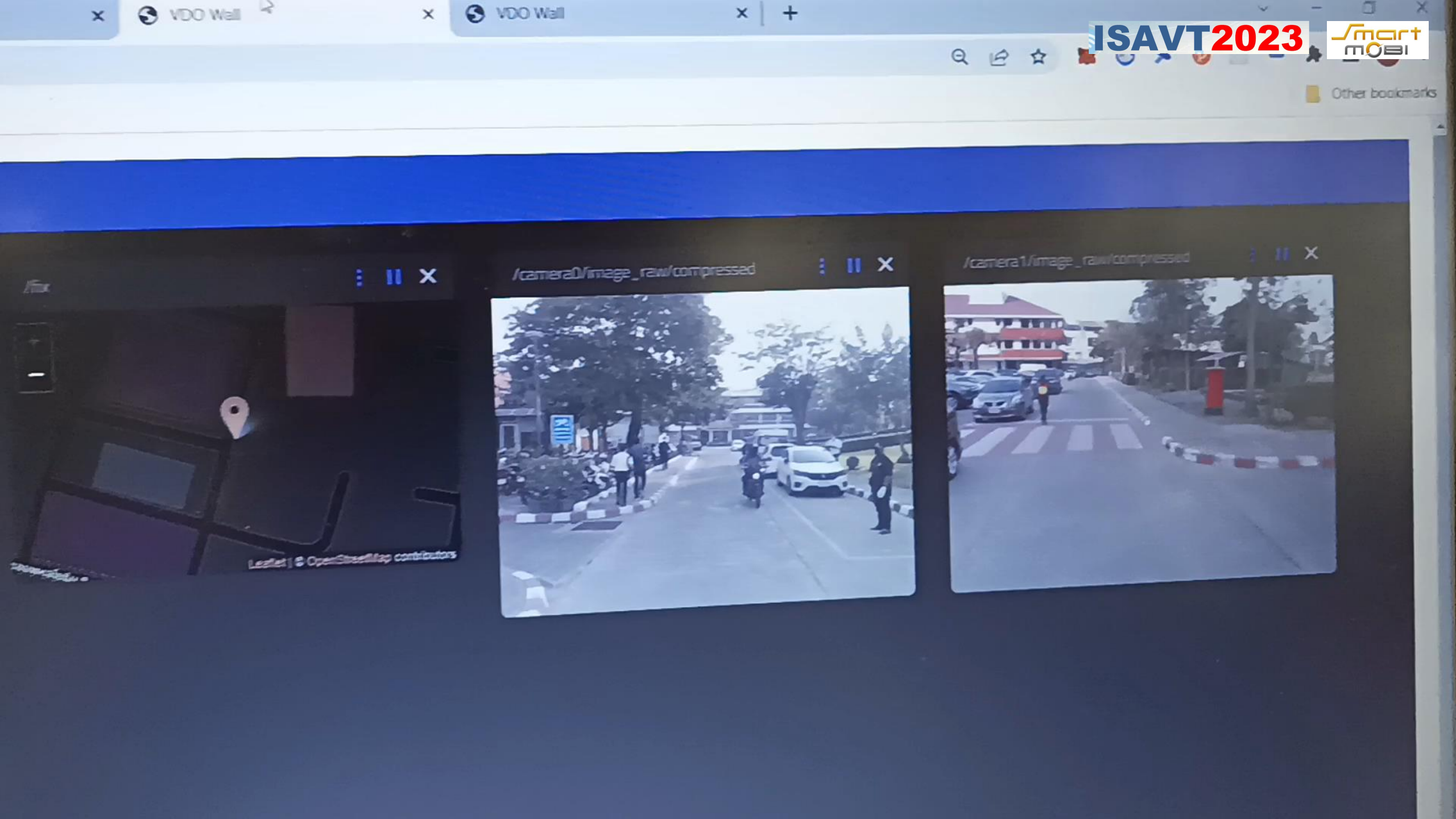
Each vehicle real-time data

Vehicles



Dashboard

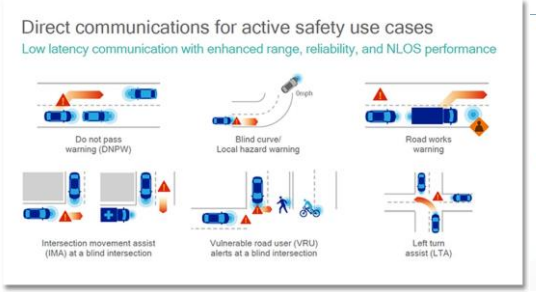
Position
Speed
Battery SOC
Driving Mode
Fr & Rr Camera
Lidar point cloud

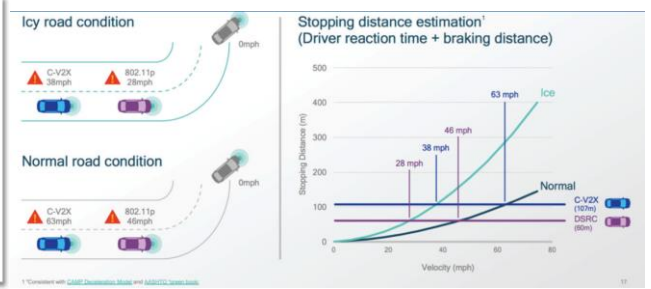

VDO Wall
VDO Wall
ISAVT2023
Other bookmarks
/fix
Leaflet | © OpenStreetMap contributors
/camera0/image_raw/compressed
/camera1/image_raw/compressed

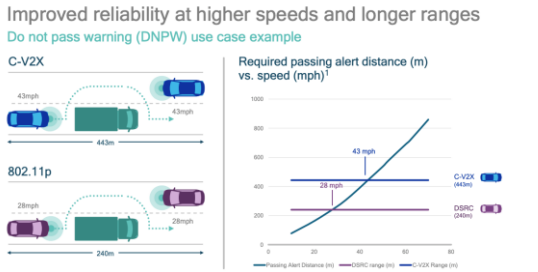
5G V2X Communications

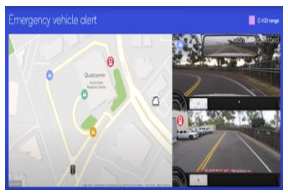
Cellular V2X: Other Communication technologies generally cannot support large-scale UAV communications in a cost-effective manner.

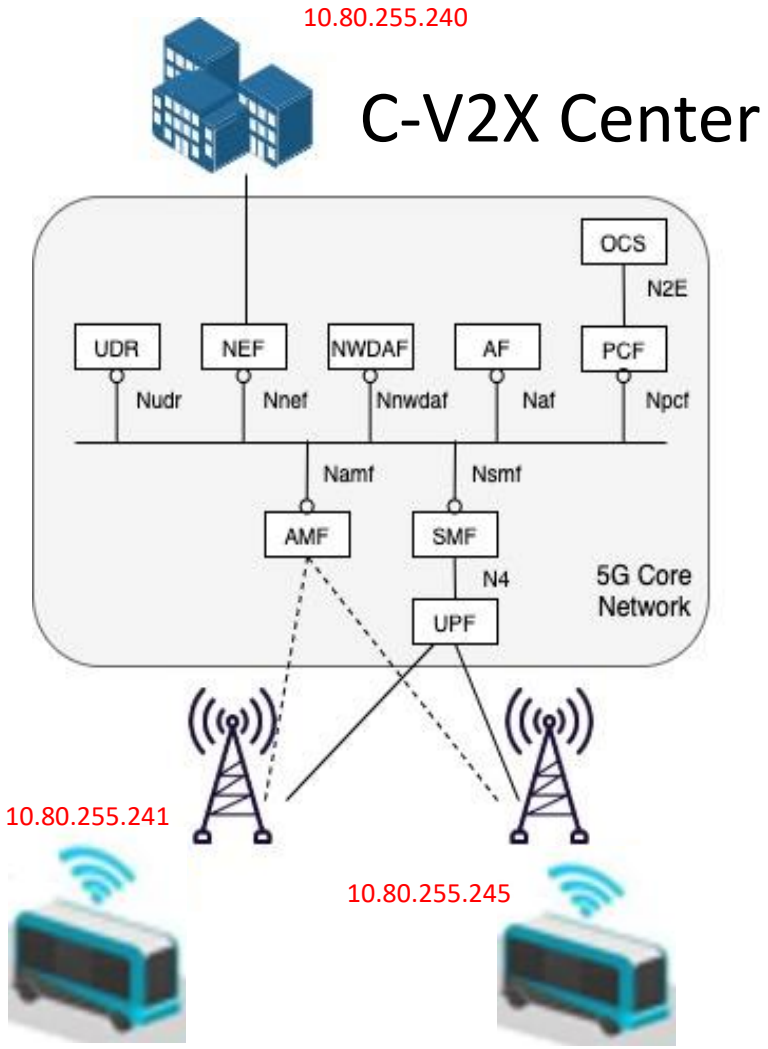
- *Capacity* and Distance – Dense Autonomous Vehicles, Bandwidth and Spectrum Efficiency
- *Latency* – Mostly Latency is from over-the-air interface (OTA): longer distance: longer delay for direct link
- *Safety* – Reliability, Collision Avoidance, Jamming, GPS Accuracy and GPS Spoofing Resistance (3GPP Release 18)
- *Security* – Cyber Security



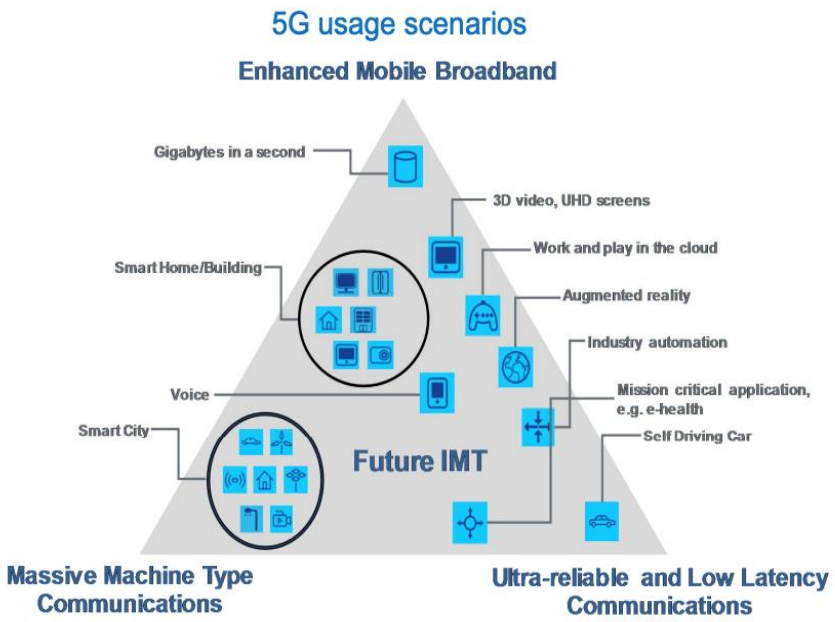


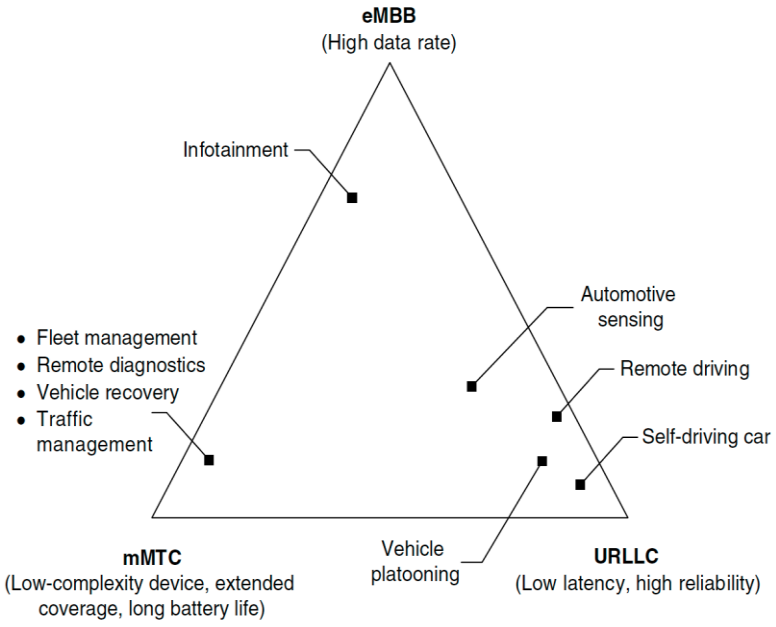


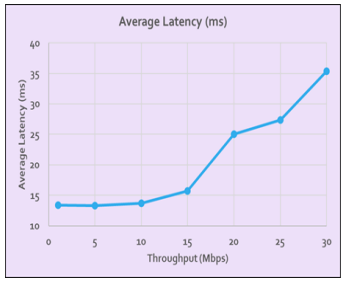


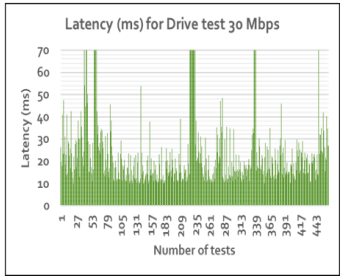


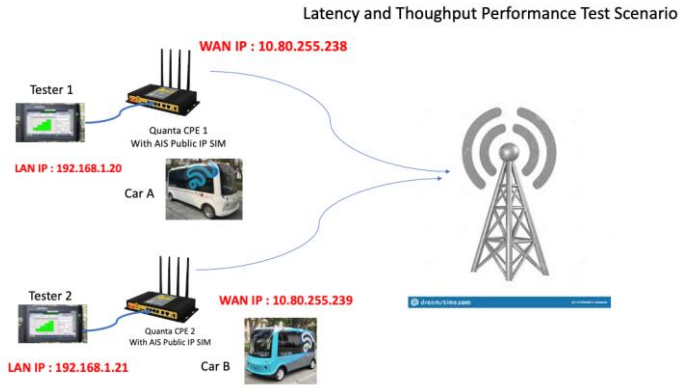
5G V2X Communications











5G Use Cases

5G Automotive Use Cases

URLLC	2	Autonomous driving	Variable rate	0.99999	Up to 10 Mbps	<10 ms	100	UE speed up to 300 kmph

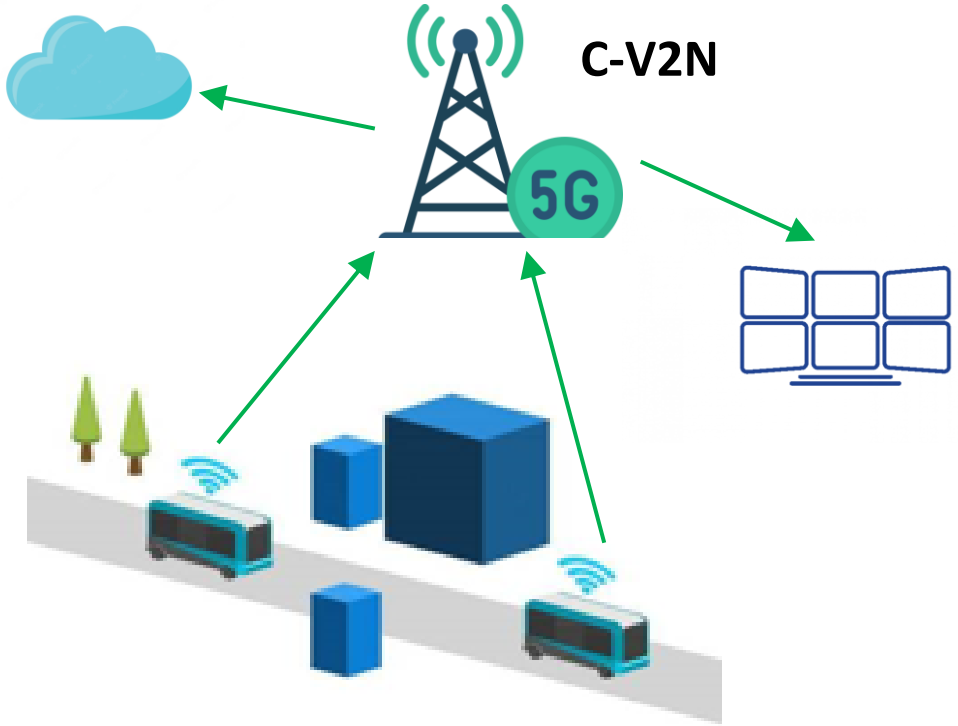
Applications on C-V2X often generate a lot of data that need to be uploaded, typically leading to high uplink data rates.

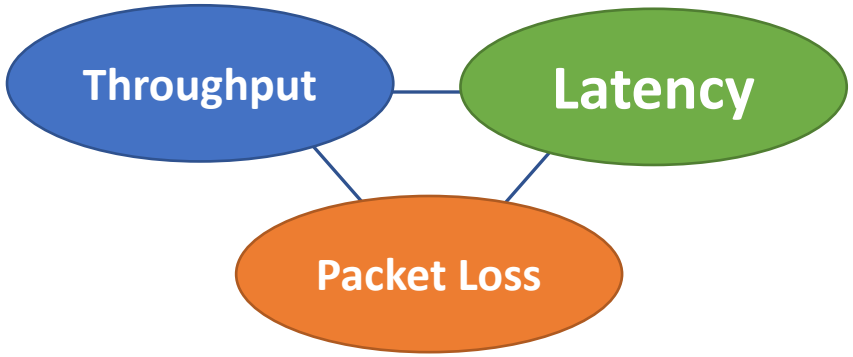
Level 1 autonomous driving features such as Adaptive Cruise Control (ACC) and early warning systems are widely used in Thailand currently.

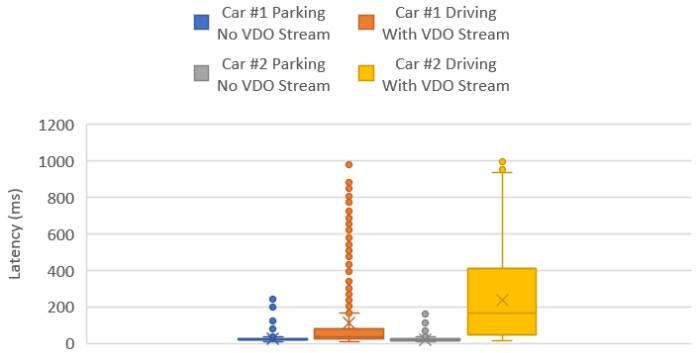
For Level 2 and Level 3 autonomous driving, also known as semi-automated driving, high data transmission rates are required. V2V (Vehicle-to-Vehicle) communication requires a bandwidth of up to 0.55 Mbps, while V2I (Vehicle-to-Infrastructure) communication requires a bandwidth of up to 0.5 Mbps, with a latency of 100 ms. For Level 4 and Level 5 autonomous driving, also known as fully automated driving, even higher data transmission rates are needed. V2V communication requires a bandwidth of up to 53 Mbps, and V2I communication requires a bandwidth of up to 50 Mbps, with a latency of 100 ms and a reliability of 99.99%. This poses challenges as the capacity of a single cell site may not be sufficient to handle these requirements.

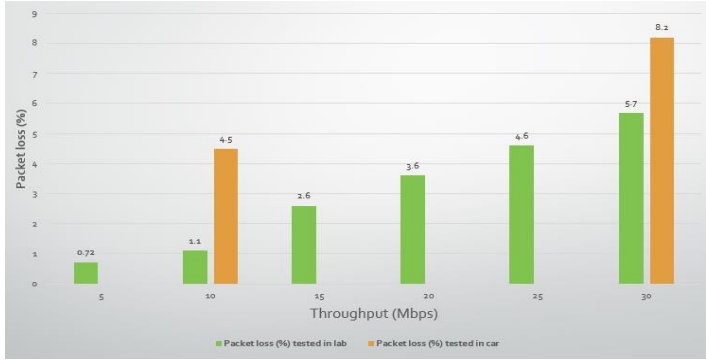
5G V2X Communications

5G communication performance test



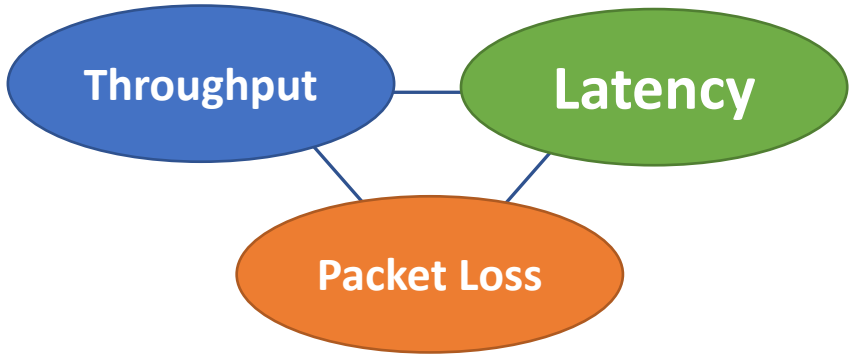


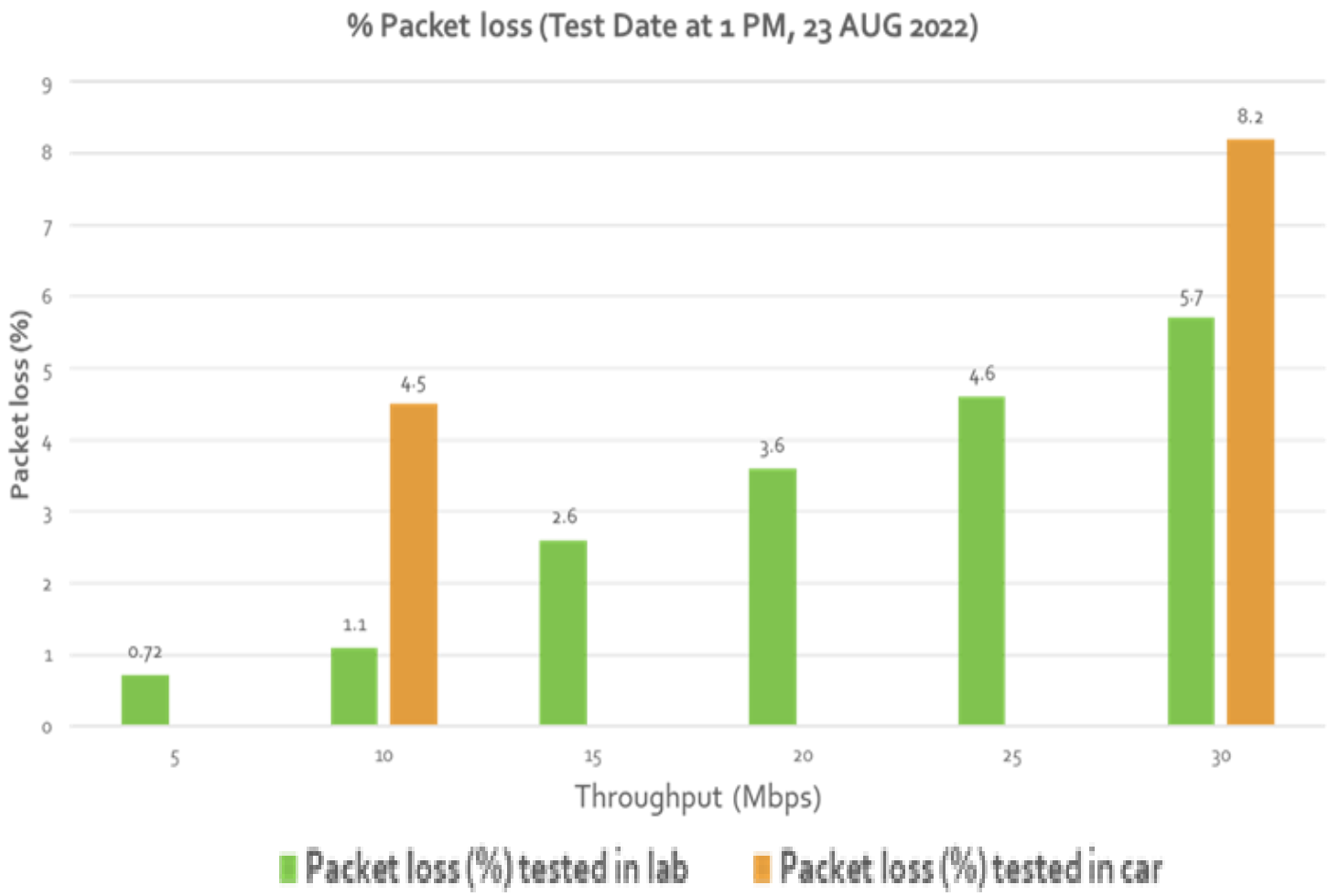




5G communication performance test

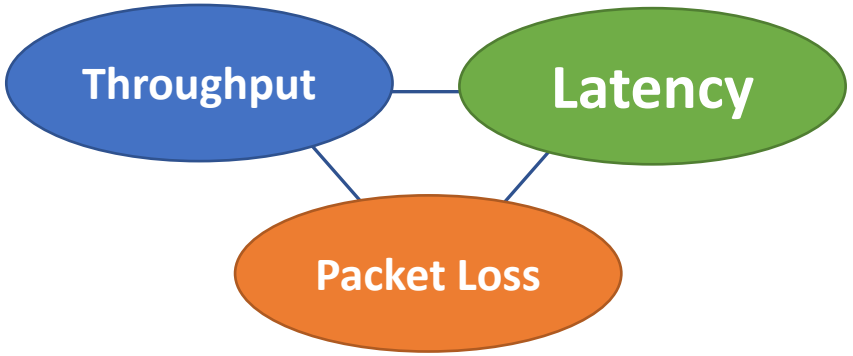
Packet loss vs. Throughput

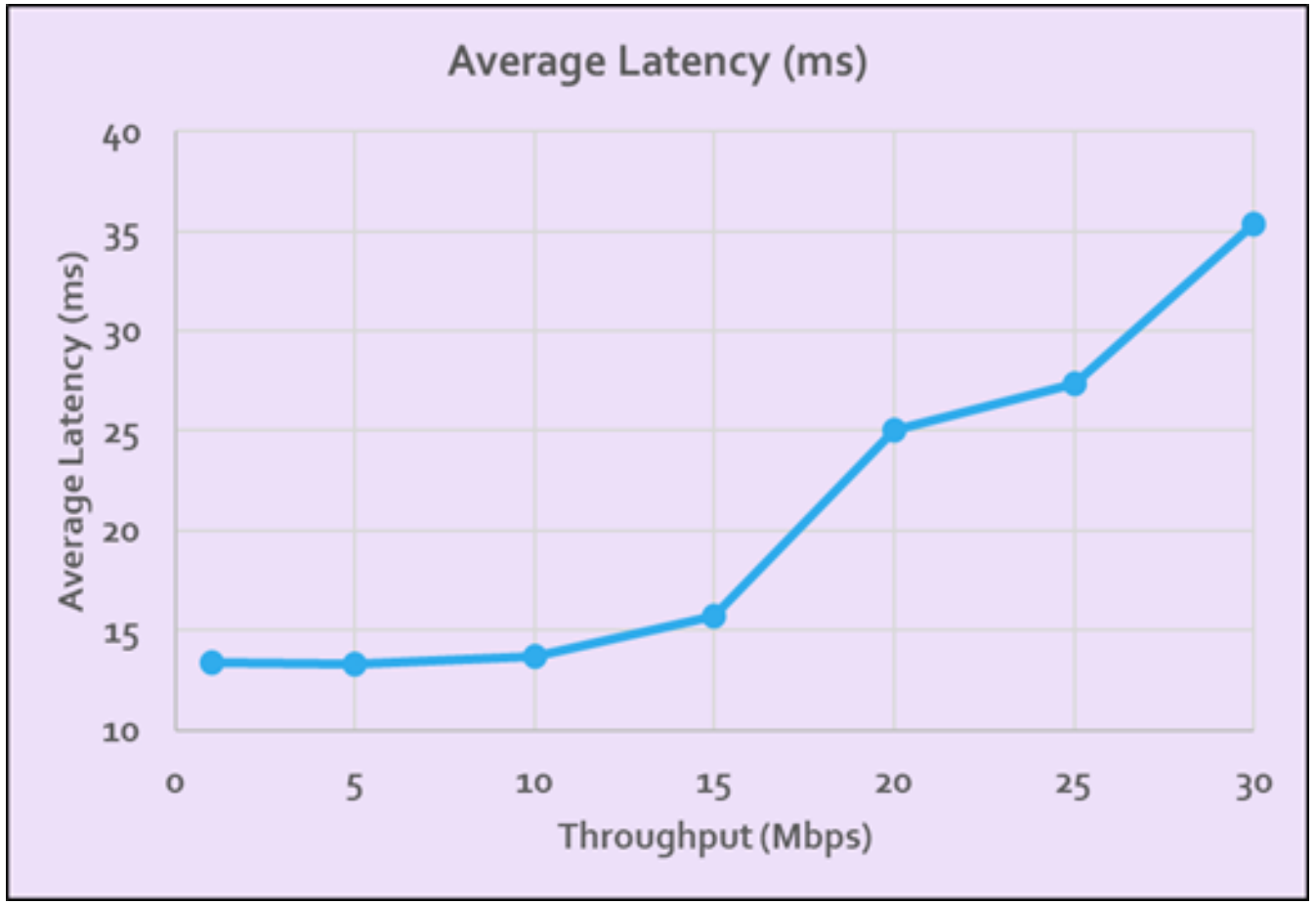




5G communication performance test

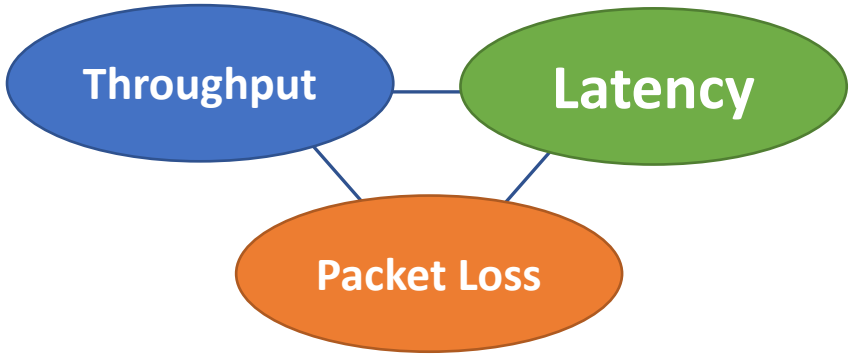
End-to-end latency vs. Throughput

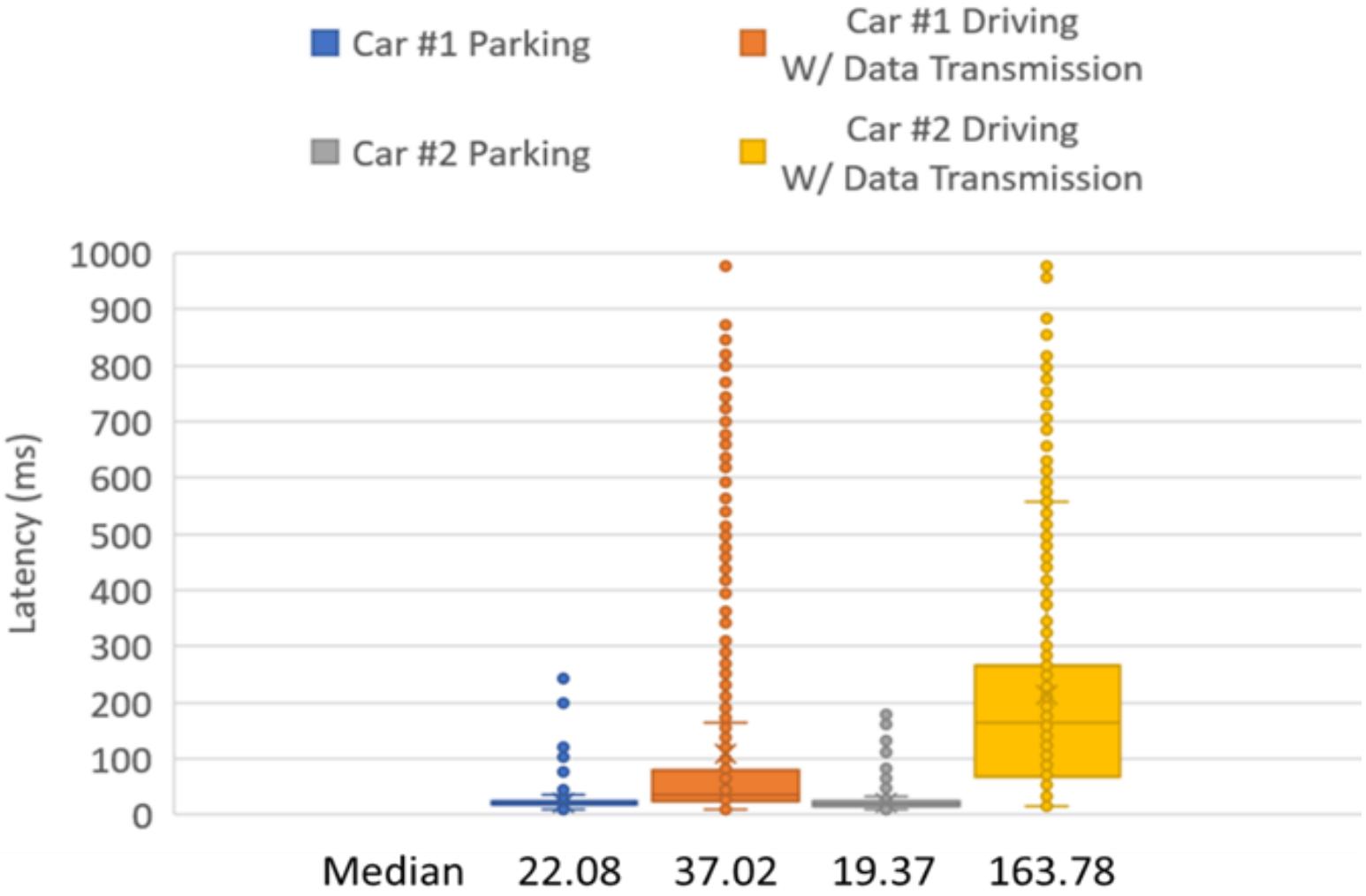




5G communication performance test

End-to-end latency between Autonomous Shuttle and Operation dashboard



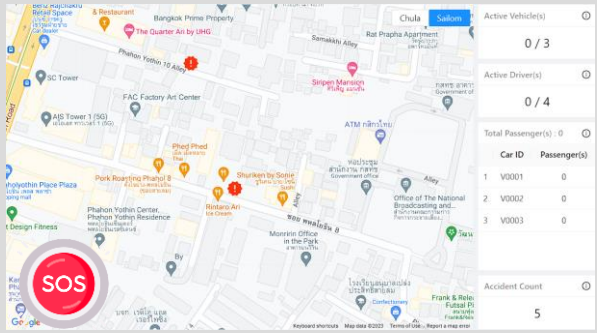


Car #1: W outdoor antenna

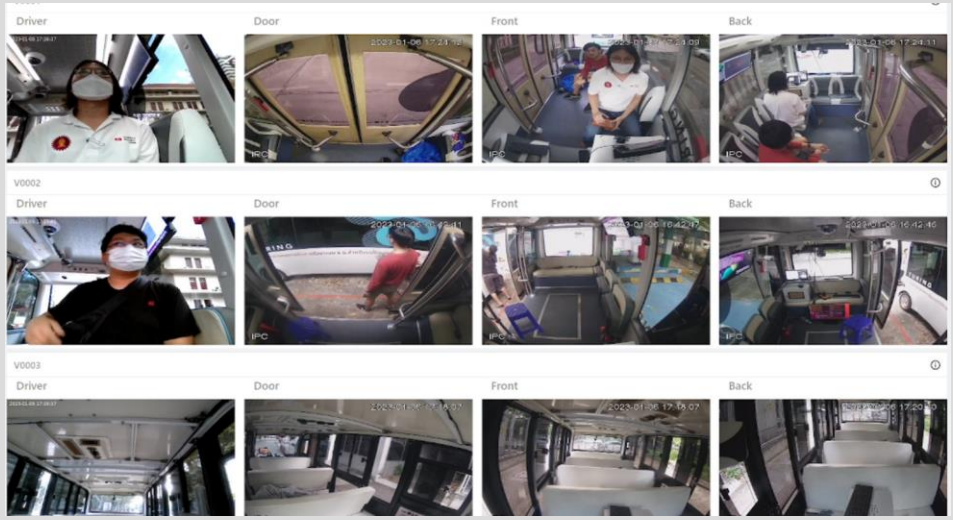
Car #2: W indoor antenna

USE CASES

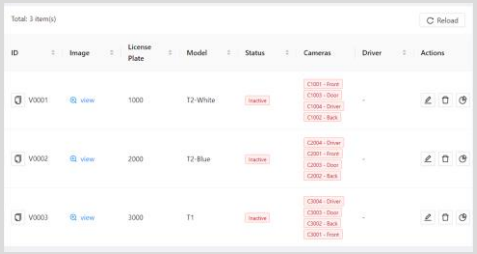
Accident Notification



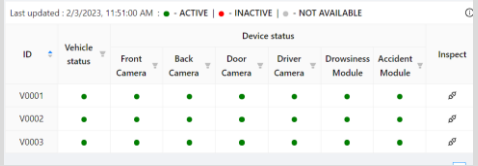
Video Streaming from 3 Autonomous Vehicles



Management Web Application & Monitoring Dashboard

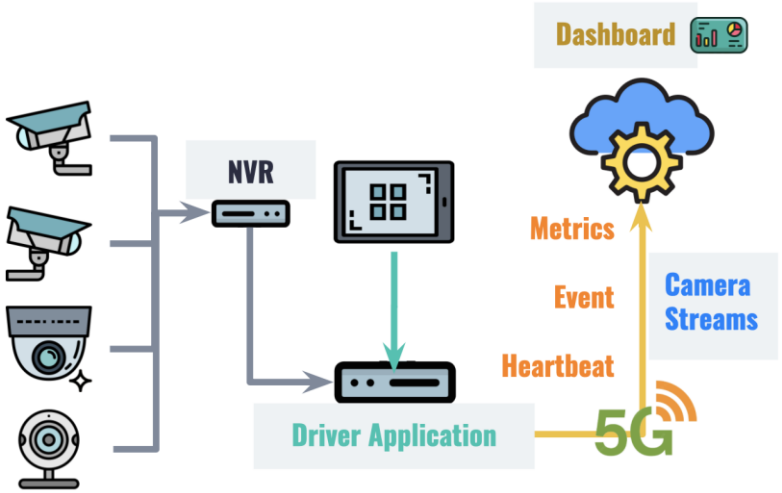


Heartbeat of vehicles and devices

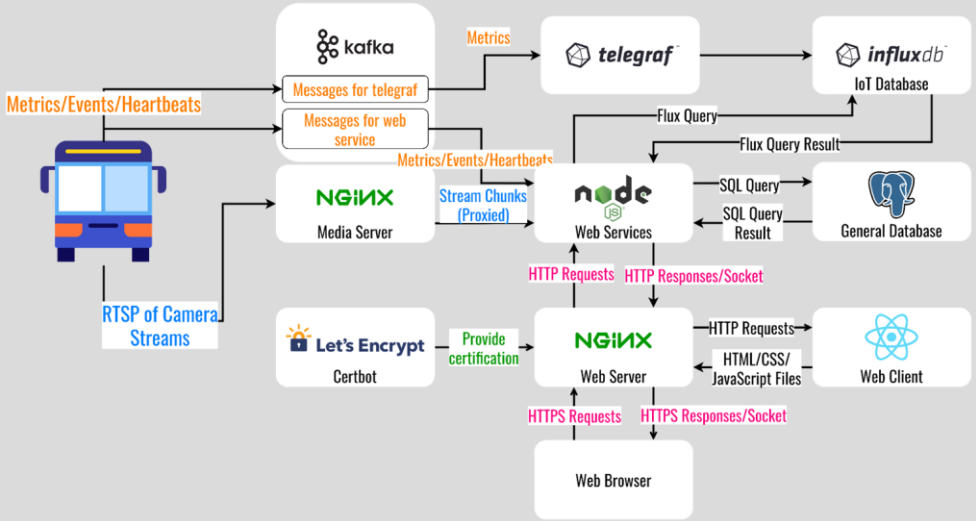


Drowsiness Detection

Passenger Counting

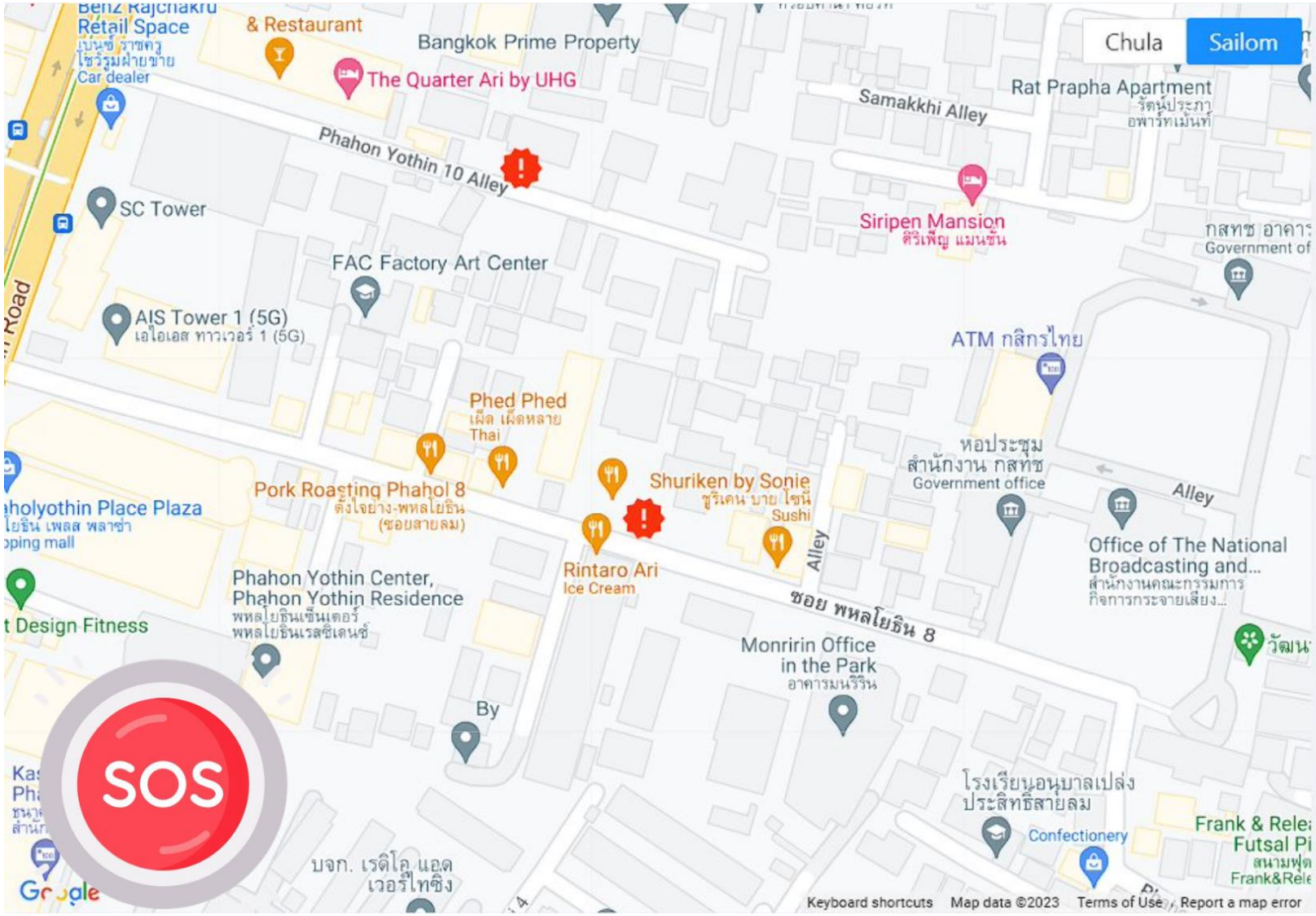


Public Server/Cloud Architecture



Use cases

Accident notification module



Active Vehicle(s)

0 / 3

Active Driver(s)

0 / 4

Total Passenger(s) : 0

	Car ID	Passenger(s)
1	V0001	0
2	V0002	0
3	V0003	0

Accident Count

5

Use cases

Management web application and Monitoring dashboard

Total: 3 item(s)

Reload

ID	Image	License Plate	Model	Status	Cameras	Driver	Actions
V0001	view	1000	T2-White	Inactive	C1001 - Front C1003 - Door C1004 - Driver C1002 - Back	-	
V0002	view	2000	T2-Blue	Inactive	C2004 - Driver C2001 - Front C2003 - Door C2002 - Back	-	
V0003	view	3000	T1	Inactive	C3004 - Driver C3003 - Door C3002 - Back C3001 - Front	-	

Last updated : 2/3/2023, 11:51:00 AM : ● - ACTIVE | ● - INACTIVE | ● - NOT AVAILABLE

ID	Vehicle status	Device status						Inspect
		Front Camera	Back Camera	Door Camera	Driver Camera	Drowsiness Module	Accident Module	
V0001	●	●	●	●	●	●	●	
V0002	●	●	●	●	●	●	●	
V0003	●	●	●	●	●	●	●	

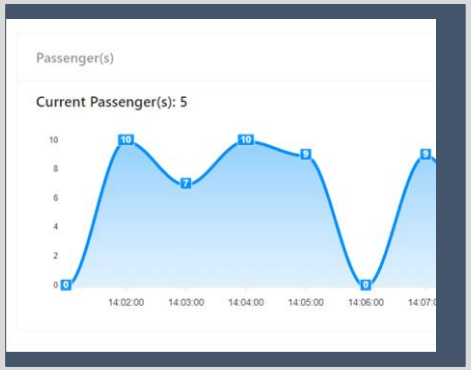
USE CASES: AI Modules

Passenger Counting

1. People Detection

2. Bounding Box

3. Passing Detection



4. Passenger Graph

IP Camera

ISAVT2023

Smart MOBI

Future Work

YOLOX

Exceeding YOLO series in 2021

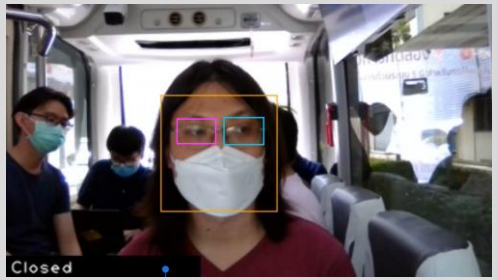
An anchor-free version of YOLO: Real-time object detection

Drowsiness Detection

1. Brightness and Gamma Correction

2. Facial Key Point Detection with Dlib

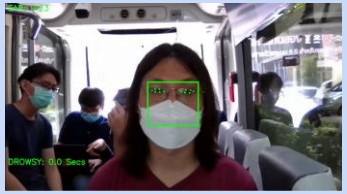
3. Non-interested Face Filtering



4. Detect Eyes Aspect Ratio with OpenCV

Webcam

Future Work



MediaPipe

Machine learning pipelines for processing video

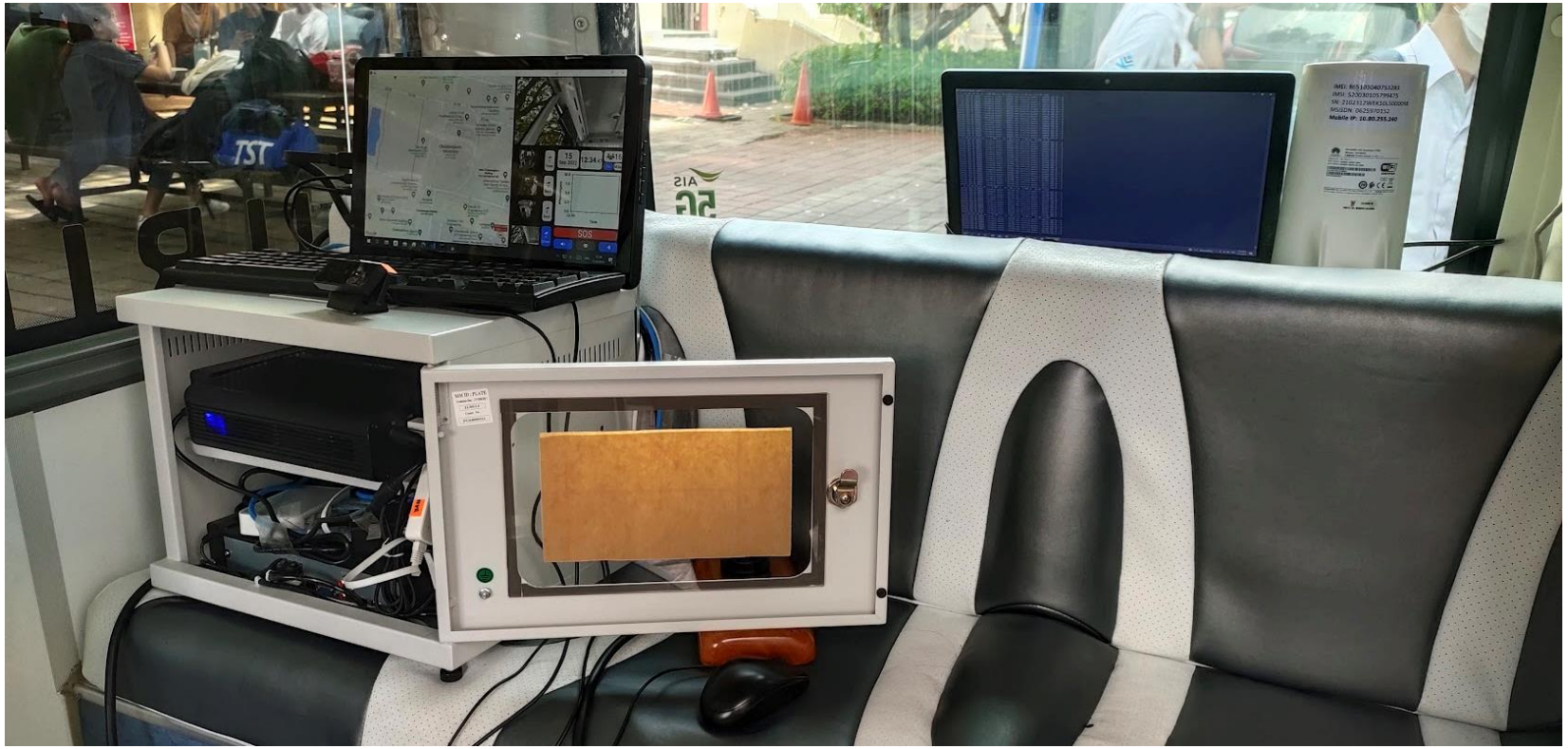
Demonstration of Autonomous Shuttle @CU campus

Demo information

ODD:

- Low speed automated vehicle in predefined route at CU campus
- Autonomous mode will be operated between Shuttle pod bus stop and brief stop location
- Safe driver will operate vehicle manually anytime for safety
- Safe driver must confirm for safety before start autonomous mode at bus stop / brief stop

- Route distance: 1.3 km
- Max speed: 10 km/h
- No. of passenger: 5-6
- No. of staff : 3



Demonstration of 5G Communication for Autonomous Vehicles Project

Date: February 8, 2023

Demonstration of Autonomous Shuttle @NBTC

- Start of Autonomous driving
- Start/Stop of Demo
- Shuttle pod Bus stop
- Brief stop
- Automated driving route
- Manual driving route

ODD:

- Low speed automated vehicle in predefined route inside NBTC
- Autonomous mode will be operated between Shuttle pod bus stop and brief stop location
- Safe driver will operate vehicle manually anytime for safety
- Safe driver must confirm for safety before start autonomous mode at bus stop / brief stop

- Total Demo route distance: 0.6 km
- Max speed: 10 km/h
- No. of passenger: 5-6
- No. of staff on vehicle: 2

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วันพุธที่ 8 กุมภาพันธ์ 2566 เวลา 13.00-16.30น.

CHULA ENGINEERING

CHULA ENGINEERING
สาธิตการทำงาน โครงการ การทดลองการสื่อสารด้วยระบบ 5G สำหรับรถไร้คนขับ (Demo Day)
วันพุธที่ 8 กุมภาพันธ์ 2566 เวลา 13.00-16.30น.

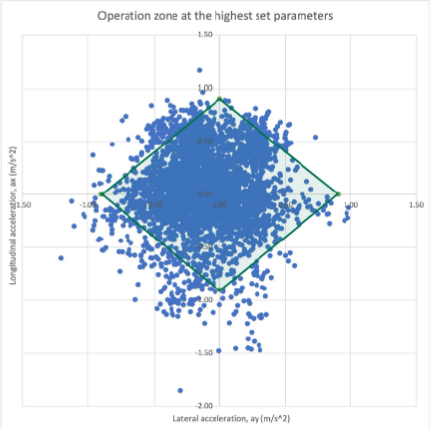
Demo sequence
VIP 1
A → B → C → D
B → C → D → A

Study on Operation and Comfort Level of Autonomous Shuttle

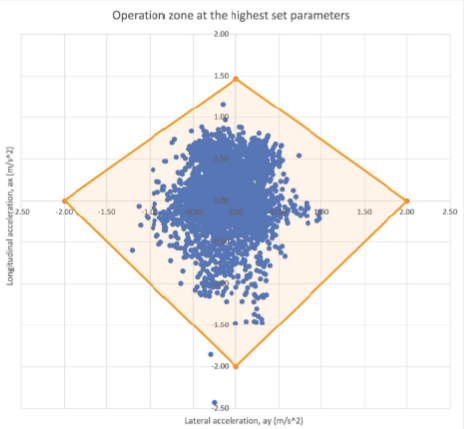
ISAVT2023 Smart Mobi

The suggested driving zone for comfortable public transportation: ax , ay ≤ ±0.9 m/s2.

The suggested driving zone for normal driving zone: -2.0 ≤ ax ≤ 1.47 m/s2 and ay ≤ ±2.0 m/s2



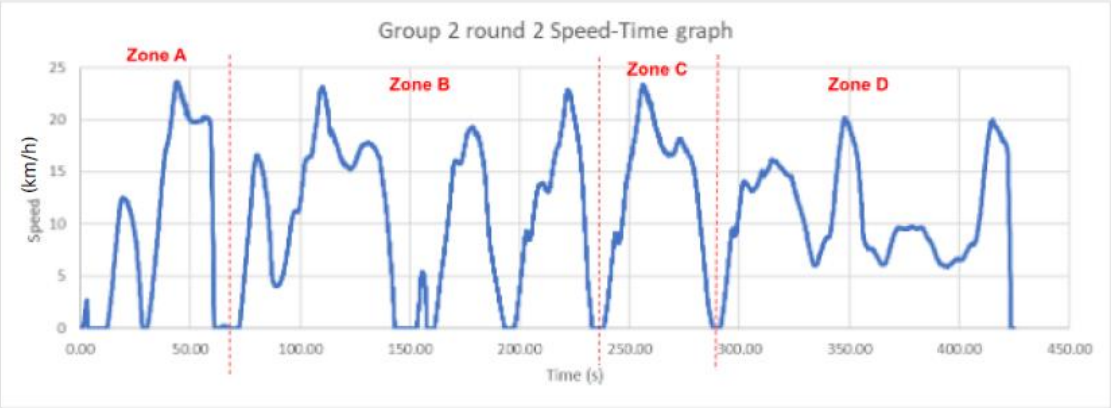
Comparison to **Comfort** Public Transportation



Comparison to **Normal** Driving Zone

Topics for the passengers to rate in each zone of testing

Zone A	Zone B	Zone C	Zone D
Start acceleration	Start acceleration 1	Start acceleration	Start acceleration 1
Linear speed	Cornering 1	Linear speed	Cornering 1
Braking	Braking 1	Cornering	Braking 1
	Start acceleration 2	Braking	Start acceleration 2
	Cornering 2		Cornering 2
	Braking 2		Braking 2
	Start acceleration 3		
	Braking 3		



How experiment is conducted

1. Staff explain testing procedures, volunteer expectations, and rating criteria.
2. Staff guide volunteers to their seats.
3. Volunteers scan QR code, enter name, status, group, and seat position.

Development of Incident Database system for Autonomous Shuttle Testing

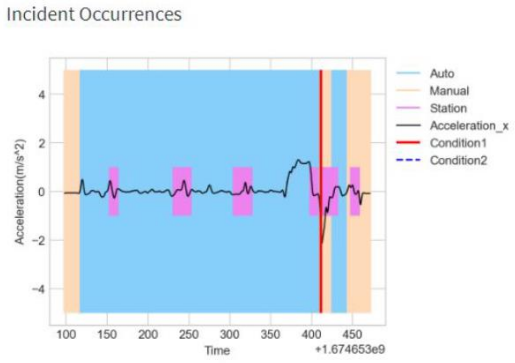
ISAVT2023 smart mobi

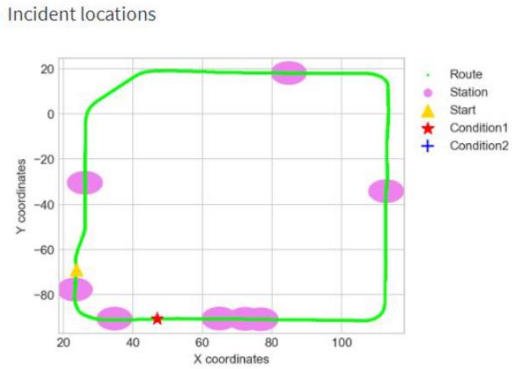
Incident categorization

External			Internal	
Actor	**Environment**	**Scenario**	**Occupant**	**System**
1. Vehicle 2. Truck 3. Tuk-Tuk 4. Bus 5. Motorcycle 6. Pedestrian 7. Animal 8. Cyclist 9. Scooter 10. Non-Motor Vehicle 11. Other Vehicle	12. Obstacle 13. Slope 14. Straight road 15. Corner 16. Crosswalk 17. Junction 18. Roundabout 19. Speed bump	20. Cut In 21. Parking 22. Emergency Brake 23. Red Light Running 24. Wrong-Way Driving 25. Turning Across Lane 26. Other Scenario	27. Driver 28. Passenger 29. Emergency	30. Battery 31. Sensing 32. localization 33. Planning 34. Computing Node

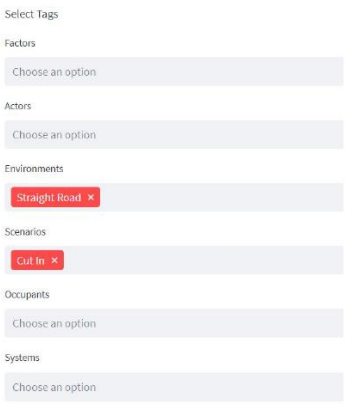
Data visualization

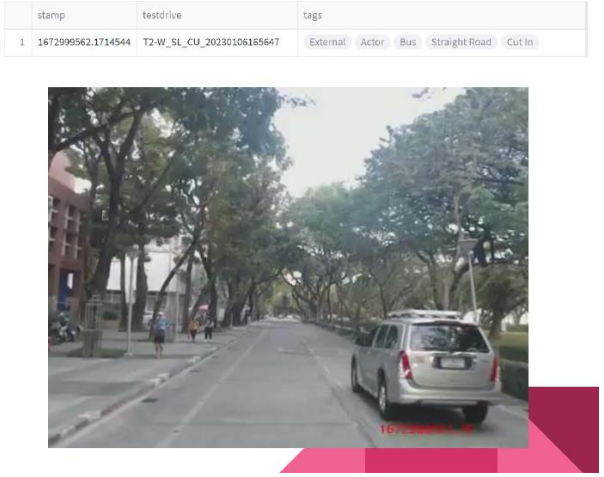
Viewing: T2-B_SL_NBTC_20230125202407





Incident Query System





Summary and Recommendations

Summary:

- "Experiments in 5G Communication for Autonomous Vehicles and Development of Use Cases in Thailand" has been undertaken by Thai researchers.
- The project involves the development of autonomous passenger shuttle vehicles equipped with 5G communication systems. Three prototype vehicles have been created, each fitted with sensor devices for vehicle control, 5G communication systems, and various use case functionalities.
- The autonomous passenger shuttle vehicles have shown promising results during test runs, including successful trials of the 5G communication system using C-V2X (cellular vehicle-to-everything) applications. The experimentation with different use case modules has also yielded positive outcomes.
- This marks a significant advancement in the utilization of 5G communication systems for modern vehicles, particularly in enabling automated vehicle control and interactions with external entities."

Summary and Recommendations

Recommendations:

1. **Utilize 5G V2X technology:** Implement 5G V2X technology to enable safe and efficient autonomous shuttle services, including remote monitoring, control, and data exchange.
2. **Infrastructure:** Consider dedicated lanes and control measures to handle complex traffic conditions and enhance safety in the operating area.
3. **Direct communication:** Establish direct communication channels between autonomous shuttles and the public to create a more inclusive user experience and promote understanding of autonomous driving technology.
4. **Inform and educate:** Provide information and education to the public about the capabilities, limitations, and societal benefits of autonomous driving technology.
5. **Continual improvement:** Continuously analyze operational data and incidents to improve the ODD and enhance safety and performance in autonomous shuttle services.

ROAD 2023 The 5th Round Table on the Purpose of Autonomous Driving, 3-4 July 2023, Bangkok Thailand

Workshop topics:

- Does Autonomous Driving ready for treacherous road conditions from climate change.
- Future implementation in 5G era: smart vehicle and/or smart roads?
- Role of government and Industry on AD supply chain development & social penetration
- Social implementation of Autonomous Driving in Megacity under different cultures & economies.
- Ways forward for Autonomous Driving to make society happy.

Department of Science Service (DSS)
Ministry of Higher Education, Science, Research and Innovation (MHESI)

Thank you.

Nuksit Noomwongs, D.Eng

Nuksit.N@chula.ac.th