Connected Autonomous Vehicle & Shared Mobility

- *A Singapore Perspective* -

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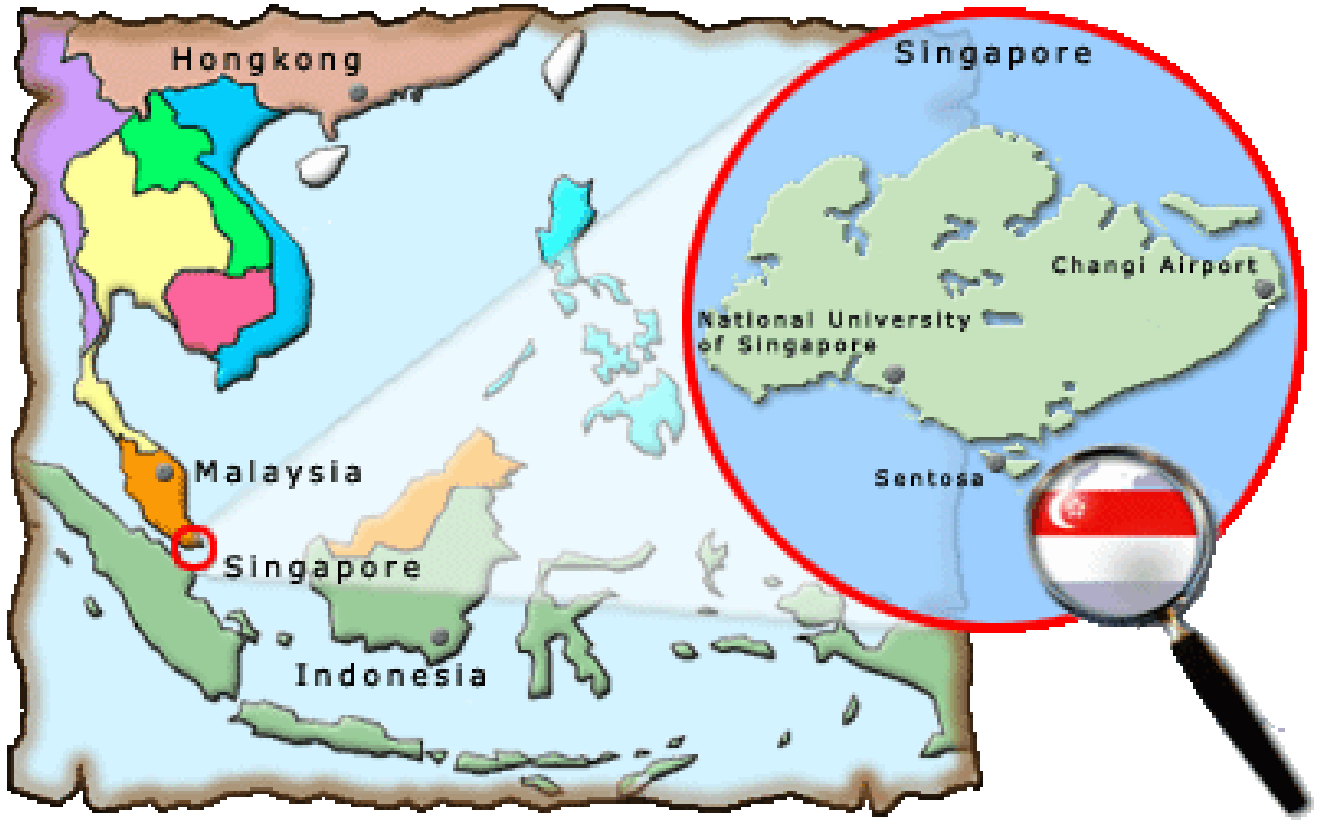
Automotive Summit Bangkok
Jun/2019

Agenda

- History, Background and Singapore's challenges
- Singapore's Smart Nation Initiative and Urban Mobility 2040
- Connected Mobility
- Shared Mobility
- Autonomous Mobility
- Some experience sharing of my own autonomous vehicle project

Some facts about Singapore

- Population: 5.6 Million
- Land area: 719.9 km²



Some facts about Singapore

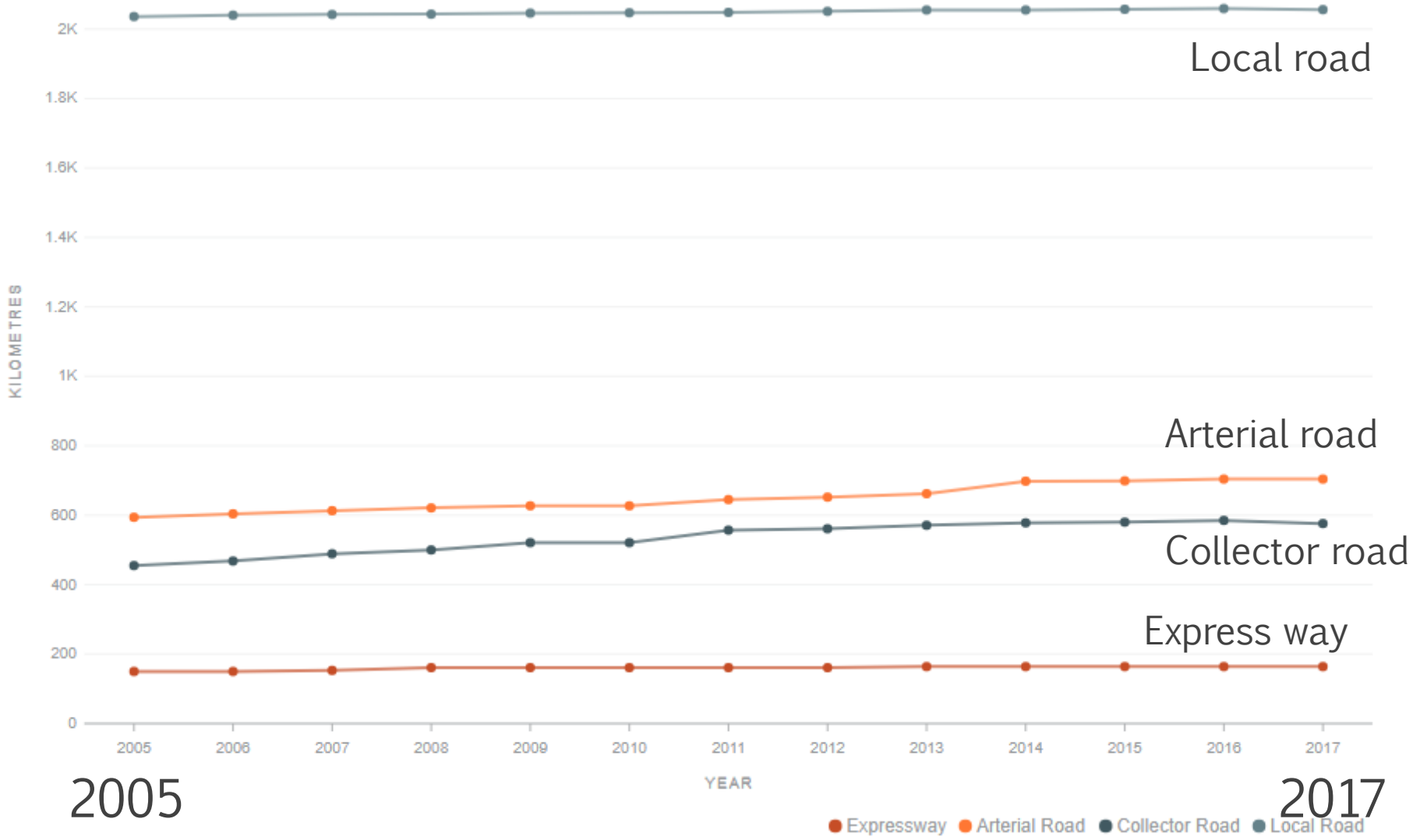
- Population ranking: 114th in the world as of 2017
- Land area ranking: 123rd in the world
- Population density: 3rd in the world

Rank	Country	Population density (Number of people per square kilometer)
1	Macau	21,346.42
2	Monaco	15,322.5
3	Singapore	8,188.16
4	Hong Kong	6,490.53
5	Gaza Strip	4,986.62

Bangkok Metropolitan Region: 5,900 per square kilometer

Some facts about Singapore

- Excellent Infrastructure
- Road network expansion is limited by land area (12%)
- On the other hand, Singapore's GDP per capita grow from 29,869 USD in 2005 to 57,722 USD in 2017
- GDP doubled, how about car ownership?



Can a wealthy society also be a car-lite society?

- China GDP per capita increases more than 4 times from 2005 to 2017.
- New and better infrastructure
- Car ownership: 24/1000 people in 2005
- Car ownership: 173/1000 people in 2018
- Car ownership: increase by 7.2 times

China National Highway 110 traffic jam. The China National Highway 110 traffic jam was a recurring massive traffic jam that began to form on August 13, 2010, The traffic jam is more than 100 kilometres long and lasted for two weeks. Many drivers were able to move their vehicles only 1 km per day, and some drivers reported being stuck in the traffic jam for five days.

MOTOR VEHICLE POPULATION BY VEHICLE TYPE

	End of Period (Year)	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	**Cars & Station-wagons**	**514,685**	**550,455**	**576,988**	**595,185**	**603,723**	**617,570**	**621,345**	**616,609**	**602,311**	**601,257**	**612,256**
	i) Private cars	451,745	476,634	497,116	511,125	520,614	535,233	540,063	536,882	519,645	504,160	502,187
	ii) Company cars	16,954	18,246	18,874	19,733	20,372	21,403	21,756	21,860	21,987	22,382	24,196
	iii) Tuition cars	949	976	1,011	940	919	899	897	874	841	817	843
	(iv) Private Hire (Self-Drive) cars	11,054	12,391	12,763	13,347	13,919	14,862	15,782	17,238	18,884	19,374	21,180
	(v) Private Hire (Chauffeur) cars							614	1,609	10,485	31,962	46,903
	vi) Off peak cars [1]	33,983	42,208	47,224	50,040	47,899	45,173	42,233	38,146	30,469	22,562	16,947
2	**TAXIS**	**24,446**	**24,300**	**24,702**	**26,073**	**27,051**	**28,210**	**27,695**	**28,736**	**28,259**	**27,534**	**23,140**
3	**MOTORCYCLES & SCOOTERS**	**143,482**	**145,288**	**146,337**	**147,282**	**145,680**	**143,286**	**144,307**	**144,404**	**143,279**	**142,439**	**141,304**
4	**GOODS AND OTHER VEHICLES [2]**	**138,604**	**142,966**	**144,802**	**143,613**	**145,158**	**145,046**	**144,202**	**144,507**	**143,972**	**143,966**	**142,857**
	i) Goods-cum-passenger vehicles (GPVs)	5,074	4,941	4,771	4,570	4,402	4,144	3,166	2,868	2,997	2,992	2,972
	ii) Light Goods Vehicles (LGVs)	91,945	94,045	95,185	93,999	94,710	93,914	92,317	92,731	94,016	95,750	94,724
	iii) Heavy Goods Vehicles (HGVs)	30,207	31,383	31,884	31,869	32,297	32,313	32,549	32,196	30,155	28,817	28,641
	iv) Very Heavy Goods Vehicles (VHGVs)	11,378	12,597	12,962	13,175	13,749	14,675	16,170	16,712	16,804	16,407	16,520
5	**BUSES**	**14,192**	**14,976**	**15,659**	**15,936**	**16,652**	**16,768**	**17,065**	**17,109**	**17,740**	**18,338**	**18,814**
	i) Omnibuses	3,761	3,854	4,045	3,981	4,112	4,212	4,552	4,756	5,120	5,470	5,665
	ii) School buses (CB)	1,851	1,852	1,849	1,845	1,844	1,839	1,847	1,845	1,847	1,840	1,844
	iii) Private buses	2,628	2,739	2,795	2,842	3,076	2,968	2,871	2,802	2,717	2,659	2,533
	iv) Private hire buses	3,356	3,548	3,586	3,507	3,332	3,063	2,654	2,152	1,909	1,598	1,255
	v) Excursion buses	2,596	2,983	3,384	3,761	4,288	4,686	5,141	5,554	6,147	6,771	7,517
6	**TAX EXEMPTED VEHICLES [3]**	**15,927**	**16,697**	**17,030**	**17,740**	**18,440**	**19,030**	**19,556**	**20,672**	**21,685**	**22,896**	**23,471**
	i) Cars & Station-wagons	2,356	2,391	2,383	2,561	2,557	2,441	2,343	2,414	2,411	2,506	2,533
	ii) Motorcycles and scooters	858	832	878	878	879	824	627	622	621	613	612
	iii) Buses	338	351	364	373	394	394	444	445	443	466	471
	iv) Goods & Other Vehicles	12,375	13,123	13,405	13,928	14,610	15,371	16,142	17,191	18,210	19,311	19,855
7	**TOTAL MOTOR VEHICLES**											
	Cars & Station-wagons	505,987	540,455	566,608	584,399	592,361	605,149	607,292	600,176	575,353	552,427	546,706
	Private Hire Cars	11,054	12,391	12,763	13,347	13,919	14,862	16,396	18,847	29,369	51,336	68,083
	Taxis	24,446	24,300	24,702	26,073	27,051	28,210	27,695	28,736	28,259	27,534	23,140
	Buses	14,530	15,327	16,023	16,309	17,046	17,162	17,509	17,554	18,183	18,804	19,285
	Goods & Other Vehicles	150,979	156,089	158,207	157,541	159,768	160,417	160,344	161,698	162,182	163,277	162,712
	Motorcycles & Scooters	144,340	146,120	147,215	148,160	146,559	144,110	144,934	145,026	143,900	143,052	141,916
	ALL MOTOR VEHICLES (TOTAL)	**851,336**	**894,682**	**925,518**	**945,829**	**956,704**	**969,910**	**974,170**	**972,037**	**957,246**	**956,430**	**961,842**

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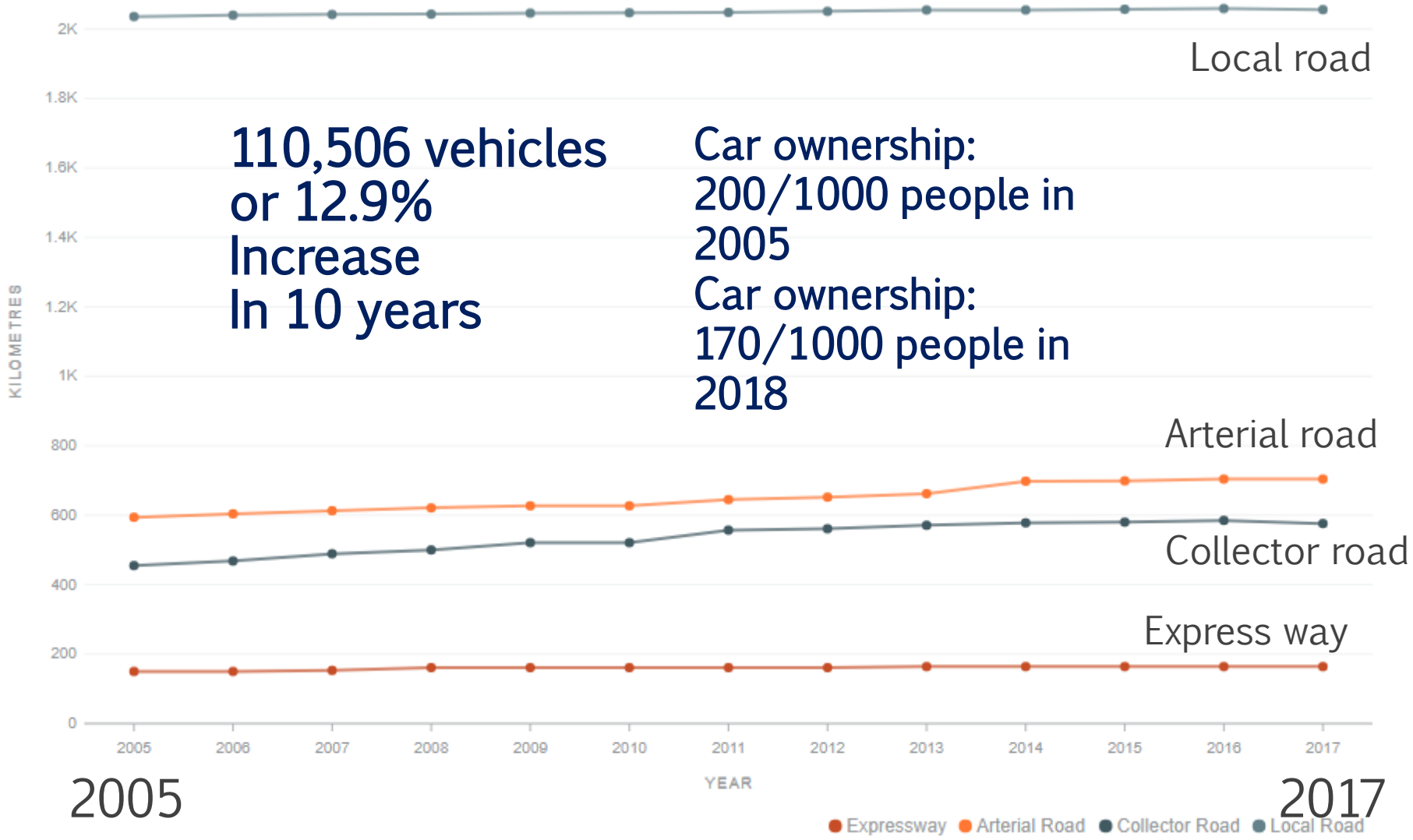
- GDP doubled, how about car ownership?



How did we control the number of cars?

What is a Certificate of Entitlement (COE)?

COE is a certificate that gives you the right to register, own and use a vehicle in Singapore for a period of 10 years.

By bidding 10 years

- Category A – Cars with engine capacity of 1600 CC and below
- Category B – Cars with engine capacity exceeding 1601 CC and above
- Category C – Goods vehicles and buses
- Category D Motorcycles
- Category E – This is an "open category" COE, which can be used for all vehicles

There are five categories of vehicles. You will need a COE of the matching category when registering for your vehicle.

In Thailand

Toyota Corolla Altis

800,000 – 1,000,000 Baht

In Singapore

Toyota Corolla Altis

2,000,000 – 2,400,000 Baht

COE Results

April 2017, 2nd Bidding

motorist.sg

CAT A (CAR UP TO 1600CC & 97KW)			
Quota Premium	$51,600	Change	▼ $400
CAT B (CAR ABOVE 1600CC OR 97KW)			
Quota Premium	$54,406	Change	▲ $1
CAT C (GOODS VEHICLE & BUS)			
Quota Premium	$26,501	Change	▼ $19,405
CAT D (MOTORCYCLE)			
Quota Premium	$6,712	Change	▼ $877
CAT E (OPEN)			
Quota Premium	$54,616	Change	▲ $60

COE price in 2017: 1,200,000 Baht

Moving forward…

- COE itself cannot solve our problem !
- Zero growth policy for motor vehicle in Singapore for now
- Likely negative growth in the future
- LTA (Land Transport Authority) publishes Future Mobility Plan 2040:

1. 8 in 10 households living within 10 minutes' walk of a train station
2. 85% of public transport journeys under 20km completed within 60 minutes
3. 75% of all journeys during peak hours undertaken on public transport

- Singapore's vision: to become a car-Lite society
- Our challenge: *how do we meet the increasing demand in personal mobility with our limited road infrastructure?*

Smart Nation: Smart Urban Mobility Initiative

- Strategic National Projects that drive pervasive adoption of digital and smart technologies throughout Singapore, including healthcare, living, **mobility** and service.

Smart Nation SINGAPORE

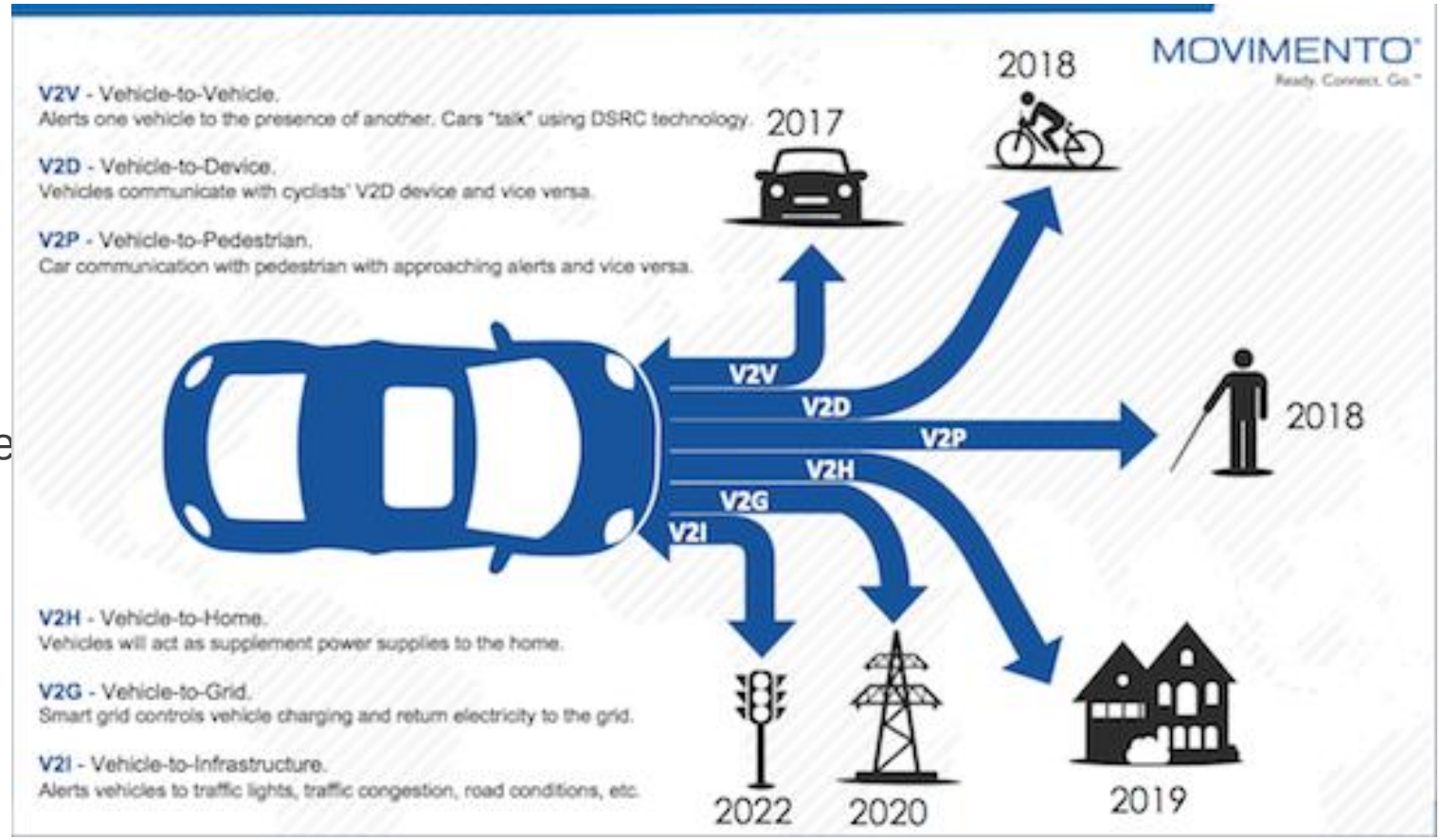
Smart Nation: Smart Urban Mobility Initiative

- Autonomous vehicle technology is the key enabler to realize "Smart Urban Mobility"
- Smart Urban Mobility is not just about autonomous vehicle.
- Connectivity, shared, assistive and green

Connected Mobility

Vehicle-to-everything (V2X) Communications: Passing of information from a vehicle to any entity that may affect the vehicle, and vice versa.

- ✓ V2V (Vehicle-to-Vehicle)
- ✓ V2P (Vehicle-to-Pedestrian)
- ✓ V2D (Vehicle-to-Device)
- ✓ V2H (Vehicle-to-Home)
- ✓ V2G (Vehicle-to-Grid)
- ✓ V2I (Vehicle-to-Infrastructure
- ✓ Etc…



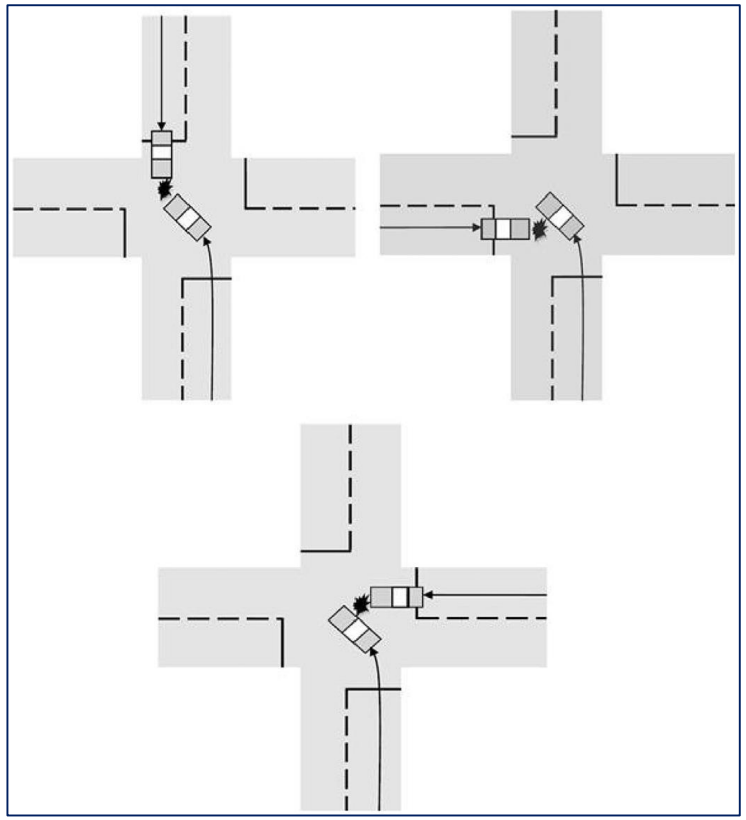
Connected Mobility

Why do we need V2X?

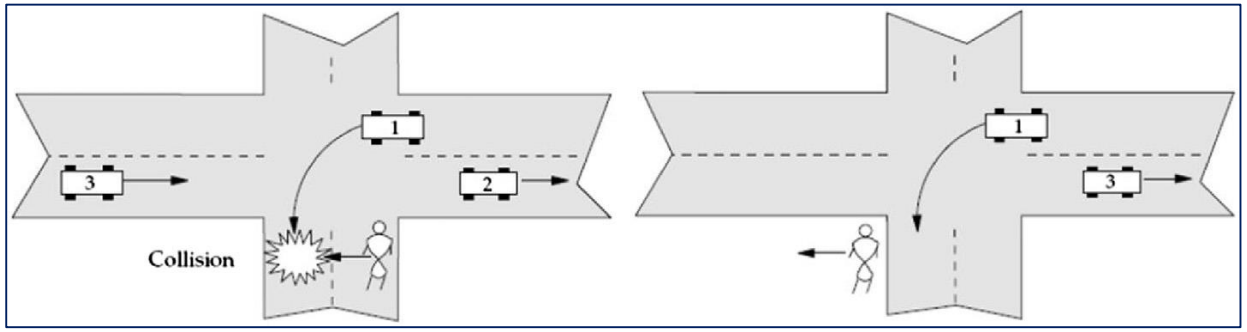
- Improve the safety
  - ✓ Reduce vehicle collisions and crashes
  - ✓ Traffic hazard warnings
- Increase the traffic efficiency
  - ✓ Regulatory/contextual speed limits
  - ✓ Traffic light optimal speed advisory
  - ✓ Traffic information and recommended itinerary
  - ✓ Enhanced route guidance and navigation
- Others
  - ✓ Point of interest notification
  - ✓ Automatic access control/parking access
  - ✓ Local electronic commerce
  - ✓ Car rental/sharing assignment/reporting
  - ✓ Map download and update
  - ✓ Instant messaging

Connected Mobility

Left turn driver assistant

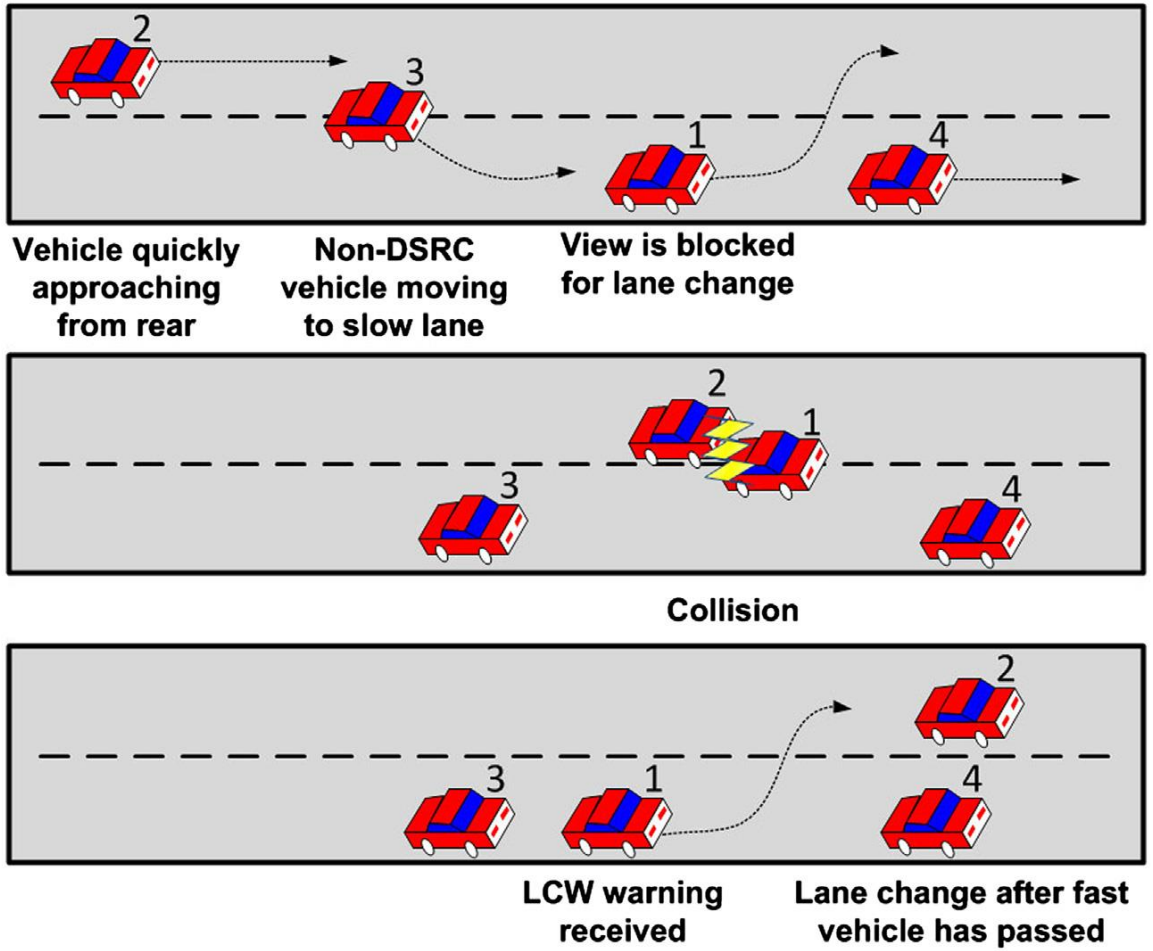


Pedestrian crossing warning

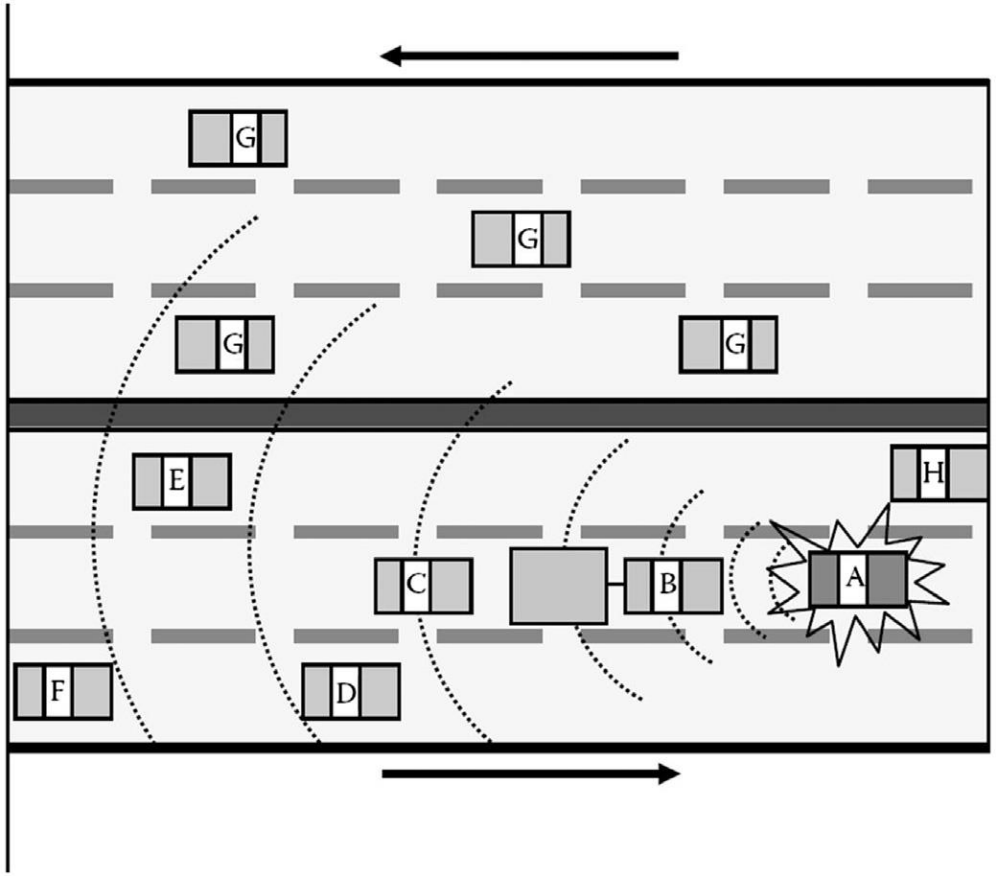


Connected Mobility

Lane Change Warning System



Emergency electronic break light system

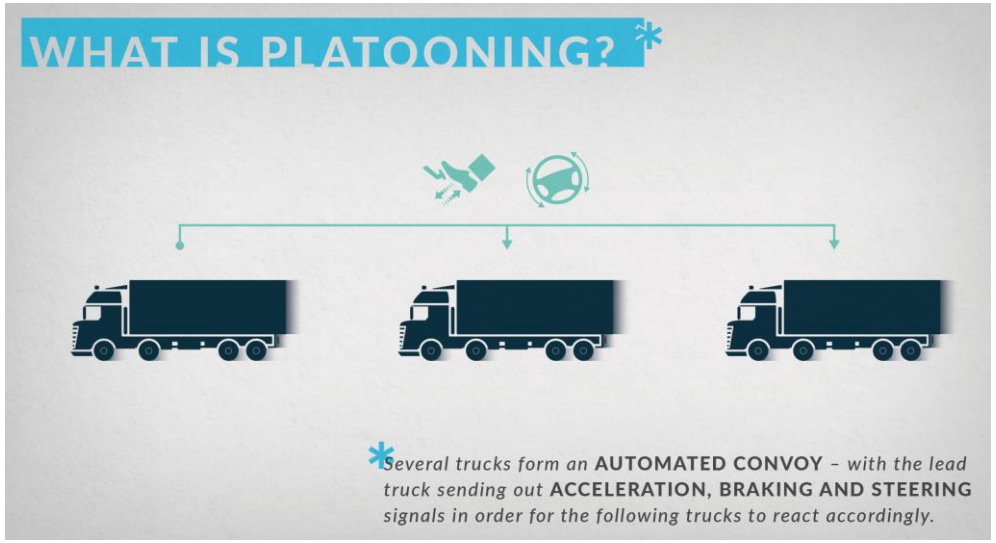


Connected Mobility

V2X allows road safety, efficiency applications such as (non-exhaustive list):

- Forward collision warning
- Lane change warning/blind spot warning
- Emergency Electric Brake Light Warning
- Intersection Movement Assist
- Emergency Vehicle Approaching
- Road Works Warning
- Platooning: Grouping vehicles into **platoons** is a method of increasing the capacity of roads.

V2X is perceived as a *key enabler* for autonomous driving.

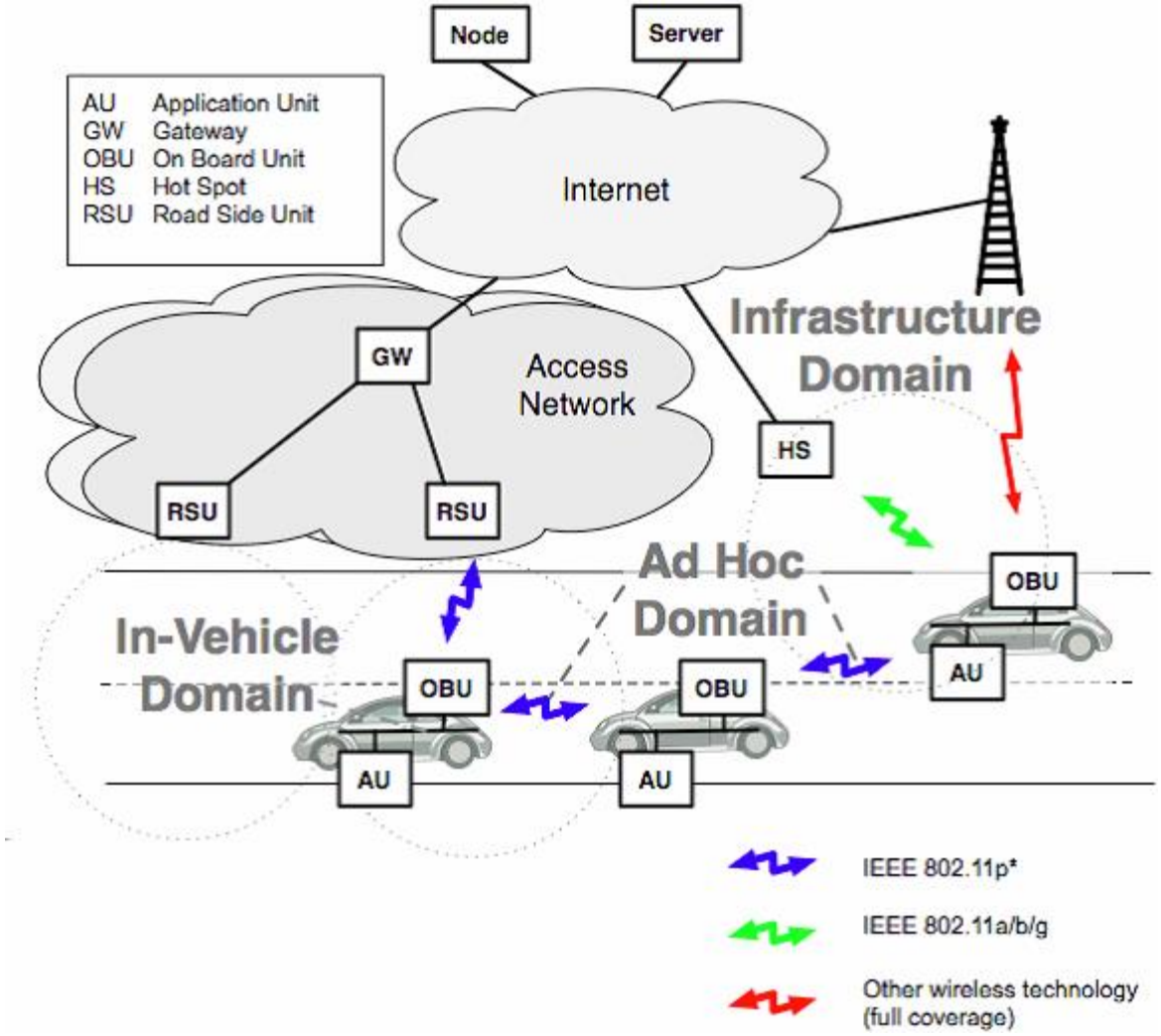


Connected Mobility

Connected Mobility

The basic main components of VANET (Vehicle Ad-hoc Network)

- **On Board Unit (OBU)** Communication units mounted on vehicles.
- **Road Side Unit (RSU)** Communication units located on the roadsides
- **Application Unit (AU)** The application reside in vehicles.

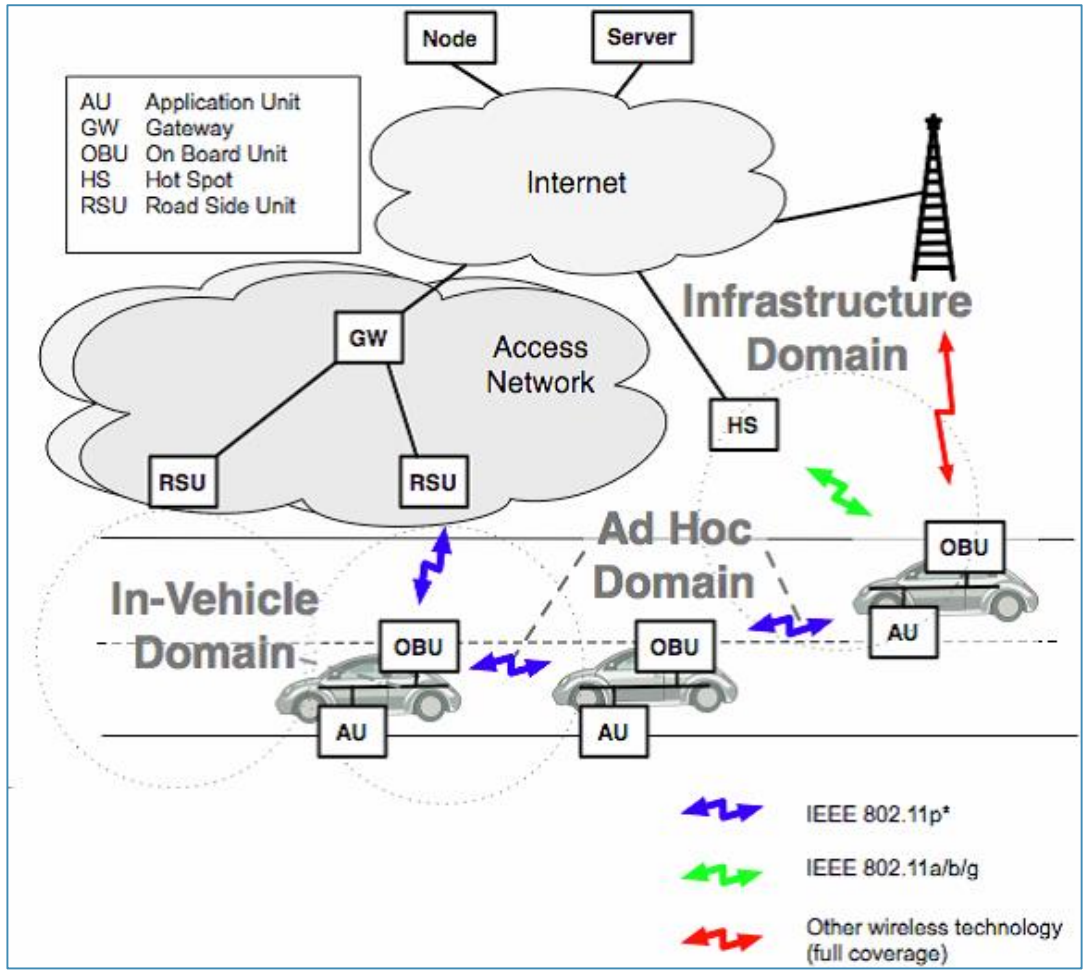


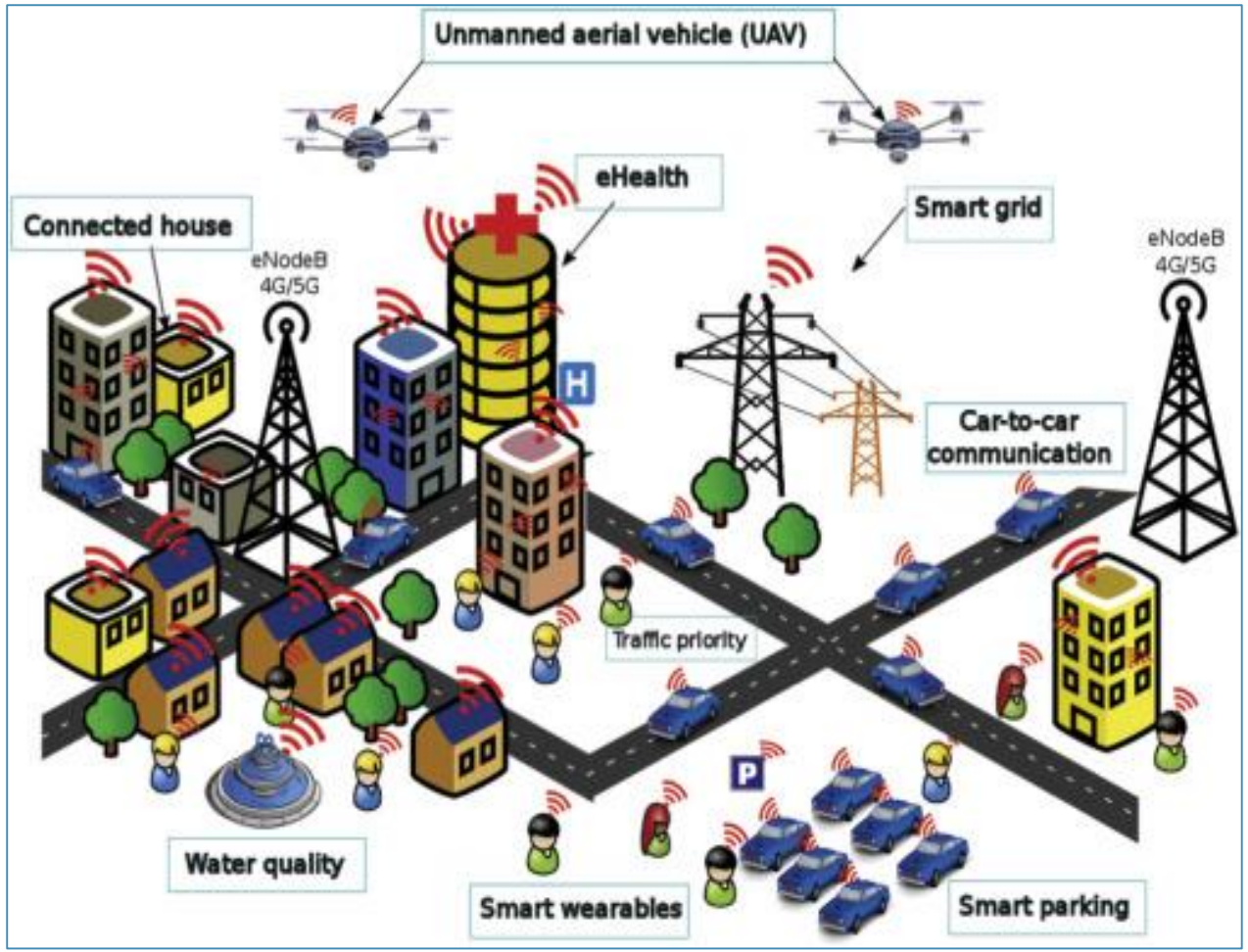
Connected Mobility

Challenges (uncertainty):

1. Infrastructure Cost: RSU (Road Side Unit)
2. Vehicle cost: OBU (On-board Unit)
3. Use cases and applications can be realized using alternative technologies:
    - Forward collision warning: radar-based ADAS
    - Road and traffic conditions: apps
    - Traffic light, speed camera: apps
    - Traffic monitoring: satellite-based, camera-network, highway induction loop detector, etc.
4. Standard — US: WAVE ("Wireless Access for Vehicular Environments"); Europe: ETSI ITS-G5
5. VANET vs. 5G

Connected Mobility: VANET vs. 5G

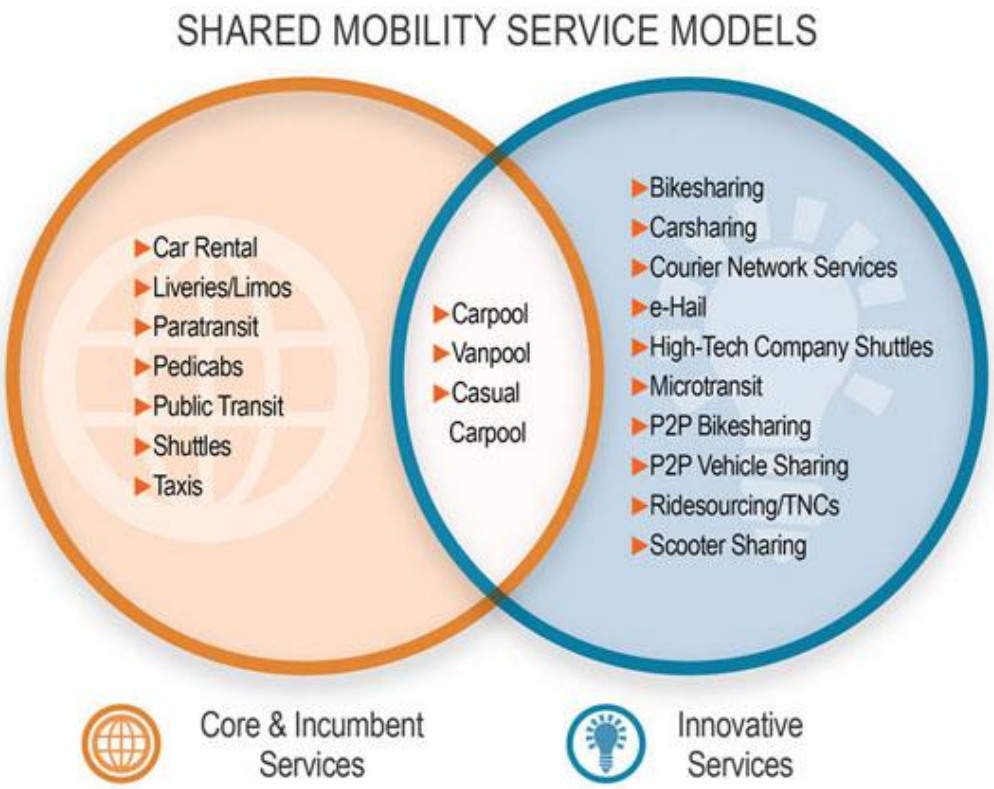


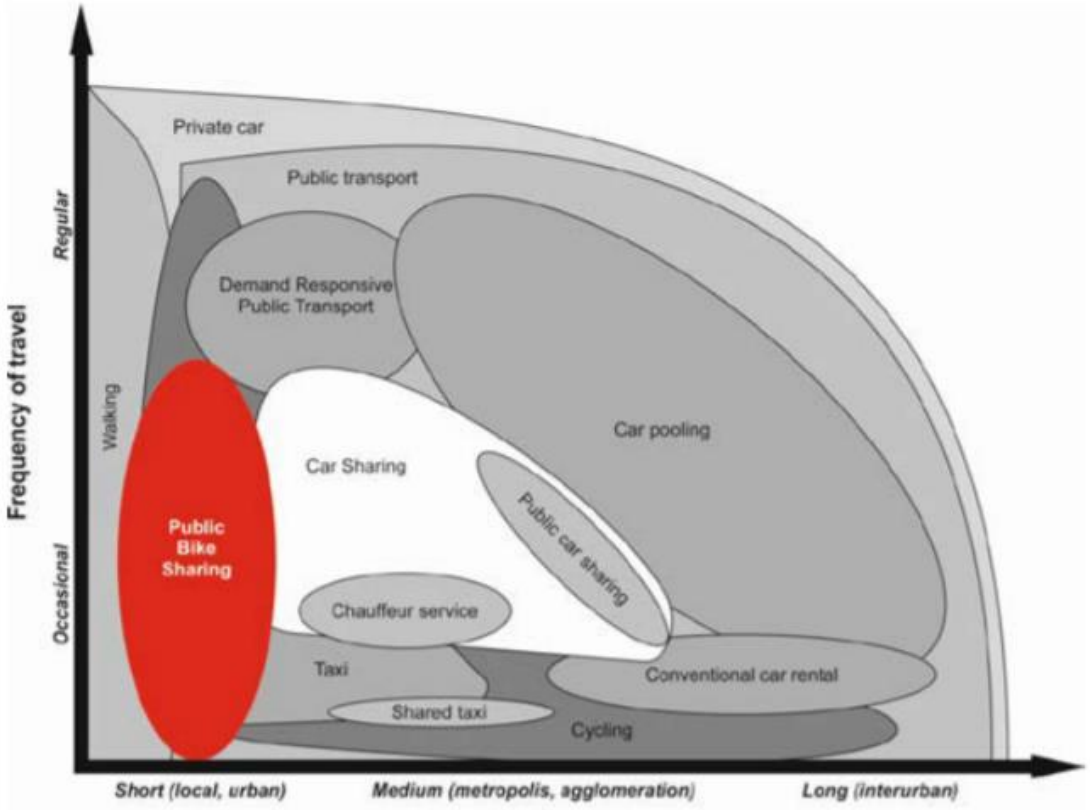


Shared Mobility

Shared mobility refers to the shared used of a vehicle, bicycle, or other transportation mode

It is a transportation strategy that allows users to access transportation services on an as-needed basis.





Comparison of travel alternatives based on frequency and length.

Shared Mobility

Impacts of shared mobility:

- Enhanced transportation accessibility as well as reduced driving and decreased personal vehicle ownership.
- Environmental, social, and transportation system benefits
- Expand the reach of public transportation by addressing gaps in existing public transportation systems.
- Cost savings

Shared Mobility Service Models				
Membership-Based Self-Service Models	Peer-to-Peer Self-Service Models	Non-Membership Self-Service Models	For-Hire Service Models	Mass Transit Systems
• Bikesharing • Carsharing • Carpooling • On-Demand Ridesharing • Scooter Sharing • Vanpooling	• Bikesharing • Carsharing	• Bikesharing • Car Rental • Casual Carpooling	• Courier Network Services (CNS) • Liveries/ Limousines/ Pedicabs • Ridesourcing/ TNCs • Taxis/E-Hail	• Public Trans-portation • Micro and Alternative Transit Services (including Microtransit, Paratransit, and Shuttles)

Shared Mobility Service Models

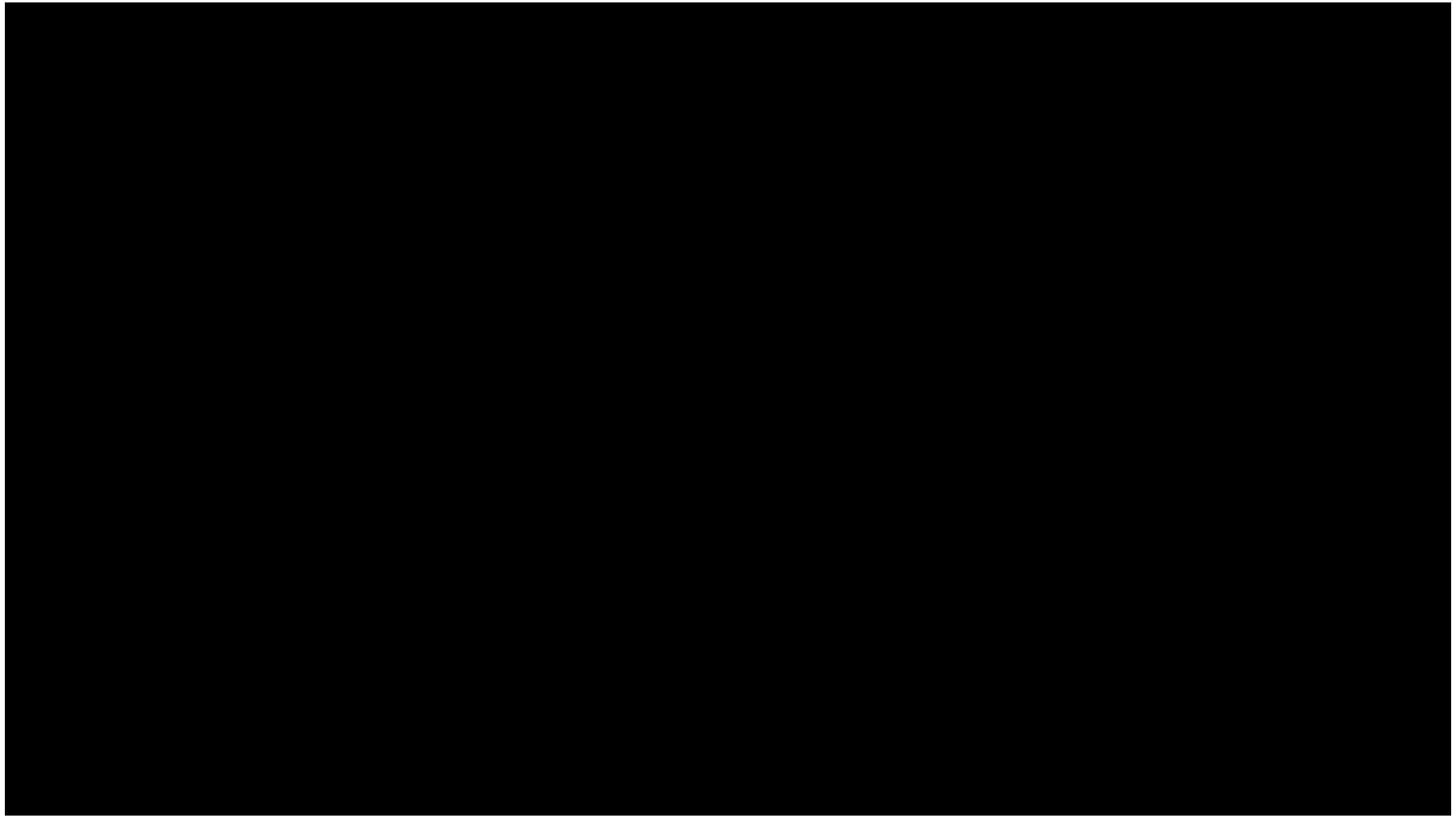
Shared Mobility: E-hailing

Ride-hailing (E-hailing) is a process of ordering a car, taxi, limousine, or any other form of transportation pick up via a computer or mobile device. The E stands for electronic and hail refers to the traditional process of signalling an approaching taxi/cab to stop.

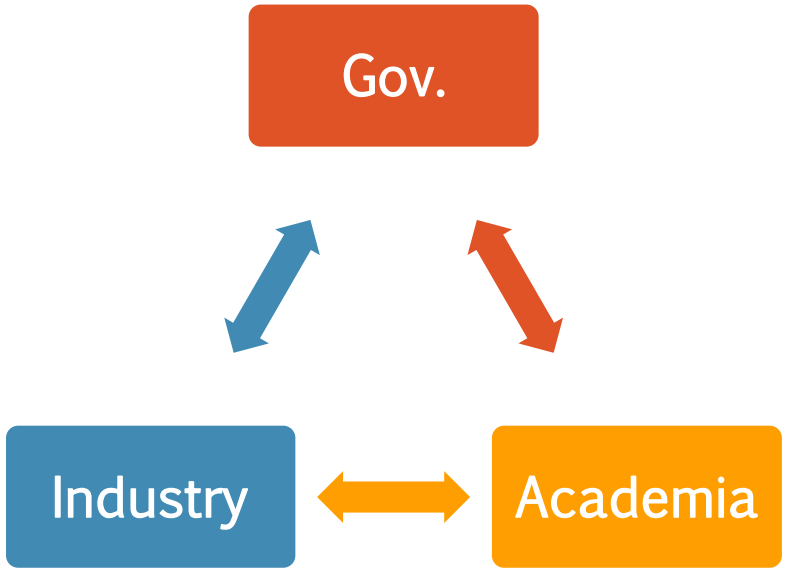
Shared Mobility: rental car

BlueSG

Shared Mobility: rental car



Autonomous Mobility Initiative



Self-Driving Vehicles (SDVs): Future of Mobility in Singapore

Find out how self driving vehicle technology can support mobility on demand and provide efficient transportation in the face of existential constraints.

Spearheading Research in Standards for Self-Driving Vehicles (SDVs)

Singapore will spearhead research in standards for self-driving vehicles (SDVs) and provide an environment to test them before introducing to public roads.

Autonomous Vehicle in Singapore

NUS National University of Singapore

NANYANG TECHNOLOGICAL UNIVERSITY

nuTonomy

ST Kinetics
A company of ST Engineering

Institute for Infocomm Research
A*STAR

Singapore Autonomous Vehicle Initiative (SAVI)

Joint partnership between LTA, JTC and A*STAR to provide a technical platform for industry partners and stakeholders to conduct research and development (R&D) and test-bedding of AV technology, applications and solutions.

National University of Singapore

- The 1st AV program in Singapore.
- Joint collaboration between NUS and MIT (Singapore-MIT Alliance)
- Started with golf buggy and deployed at Chinese Garden
- ROS-based

NUS: autonomous golf buggy

NUS: Nissan Autonomous Vehicle

Nanyang Technological University

- Started with electric vehicle research by ERI@N (Energy Research Institute)
- Many intelligent transportation testbeds & initiatives

1. CETRAN (Centre of Excellence for Testing & Research of AVs)
2. Autonomous guided shuttle

Centre of Excellence for Testing & Research of AVs

1. CETRAN

- World's **biggest test track** for AVs, dedicated to supporting the Singapore's efforts in the introduction of these vehicles on public roads.
- Furthermore, ERI@N (CETRAN's host institute) has partnered with LTA to develop an **electromobility roadmap** for Singapore in 2015. ERI@N is also involved in the R&D process of Singapore's **first large-scale electric-vehicle (EV) sharing** programme by Blue SG, and is responsible for designing and testing high power (150kW) charging of their vehicles.

Centre of Excellence for Testing & Research of AVs

1. CETRAN AV testbed: 1.8-ha CETRAN Test Circuit provides a simulated road environment for the testing of AVs prior to their deployment on public roads, and it complements the AV testbed in one-north.

1. Bus stop with bay
2. Rain simulator
3. Slope
4. Signalled intersection
5. S-course
6. Signalled intersection
7. V2X communication
8. Charging station for vehicle and AutOnomous VehicLe MonItoring and EValuation SystEm (OLIVE)
9. Urban canyon
10. Pedestrian crossing
11. Crank course
12. Bus stop
13. Flash flood area

CETRAN AV Testbed

Autonomous Guided Shuttle

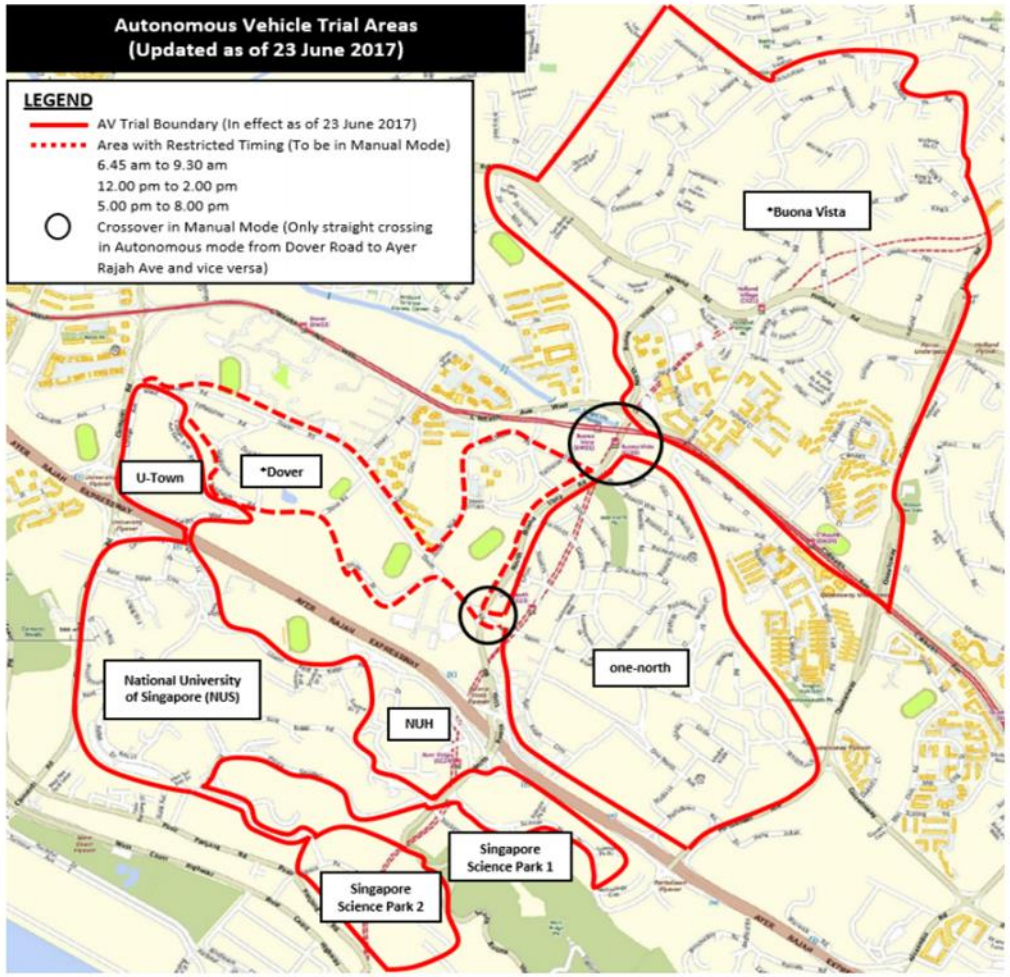
1. Group Rapid Transit autonomous vehicles (Dutch autonomous vehicle technology company **2getthere**)
2. Campus Shuttle

Institute of Infocomm Research (I2R)
Agency of Science, Technology And Research (A*STAR)

- **A*STAR** is Singapore's national research institute, I2R covers many areas including wireless, robotics, AI and machine learning, network, information security, etc.
- I2R started AV program by its robotics department in 2014
- Many spin-offs later on.

Industry players: Start-ups, MNCs and GLCs

- Start-ups
- Government Linked Company
- Multinational company



**AV trial participants will be required to undergo further demonstration and qualification tests before conducting trials in mixed-use, residential estates in Dover and Buona Vista.*

MIT Autonomous Vehicle Spin-off

- nuTonomy, founded in 2013. based in Boston, Zurich and Singapore
- Launched a pilot robo-taxi service in Singapore
- Acquired by Delphi for 450 M$ in 2017

A*STAR Autonomous Vehicle Spin-off

- Moovita: inherited most of the technologies/capabilities from A*STAR AV team. Working on general purpose AV, AI, first/last-mile AV
- SingPilot: by-wire conversion/retrofitting of AV
- IIM (International Intelligent Machine), headquarter in ShenZhen, China, R&D office in Singapore: AI and robotics
- Red Dot Robotics: autonomous utility/service vehicle

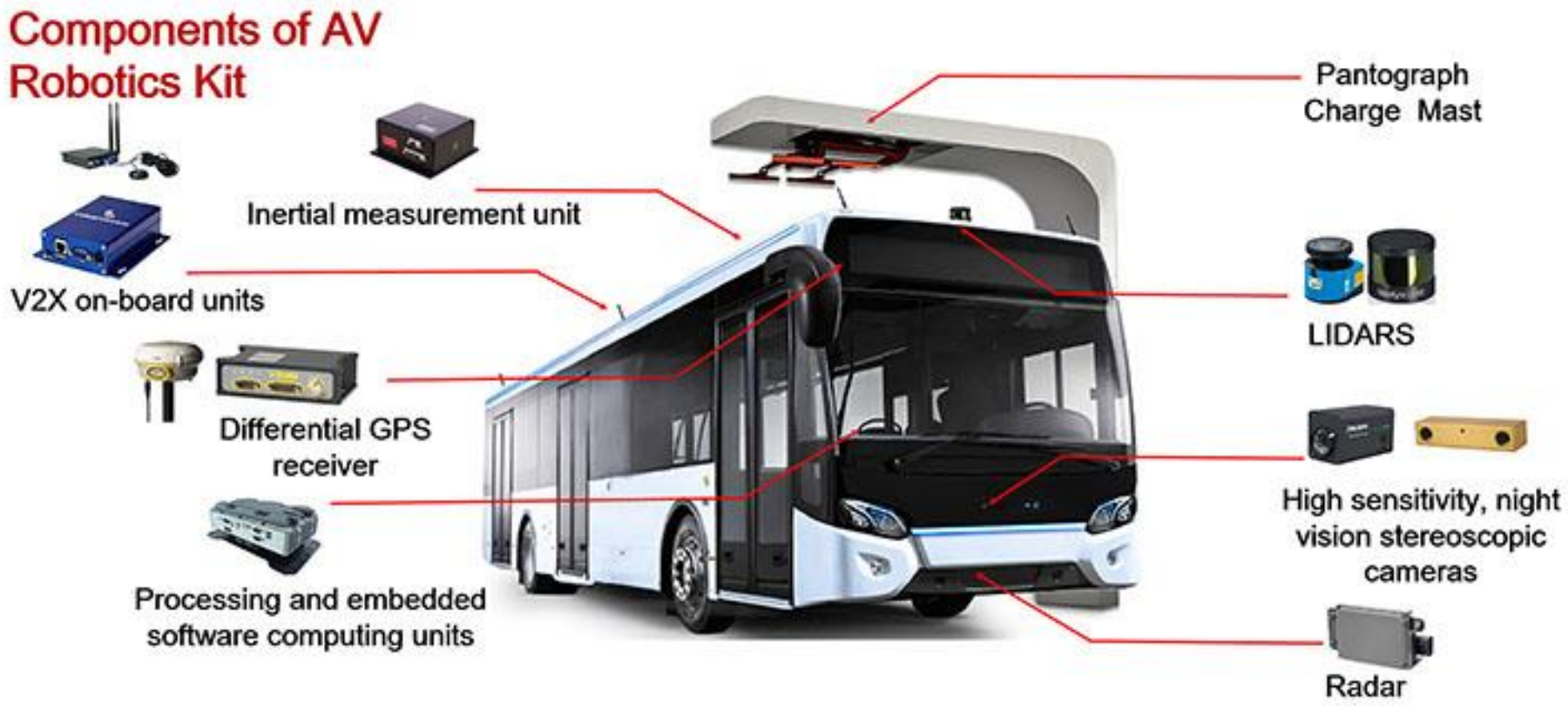
A*STAR Autonomous Vehicle Spin-off

MooVita

DRIVING AUTONOMOUS
MOVER SOLUTIONS

ST (Singapore Technology) Engineering

1. Autonomous bus: ERI@N in partnership with LTA (Lad Transport Authority) will test and develop their self-driving vehicle technology with two electric hybrid buses.



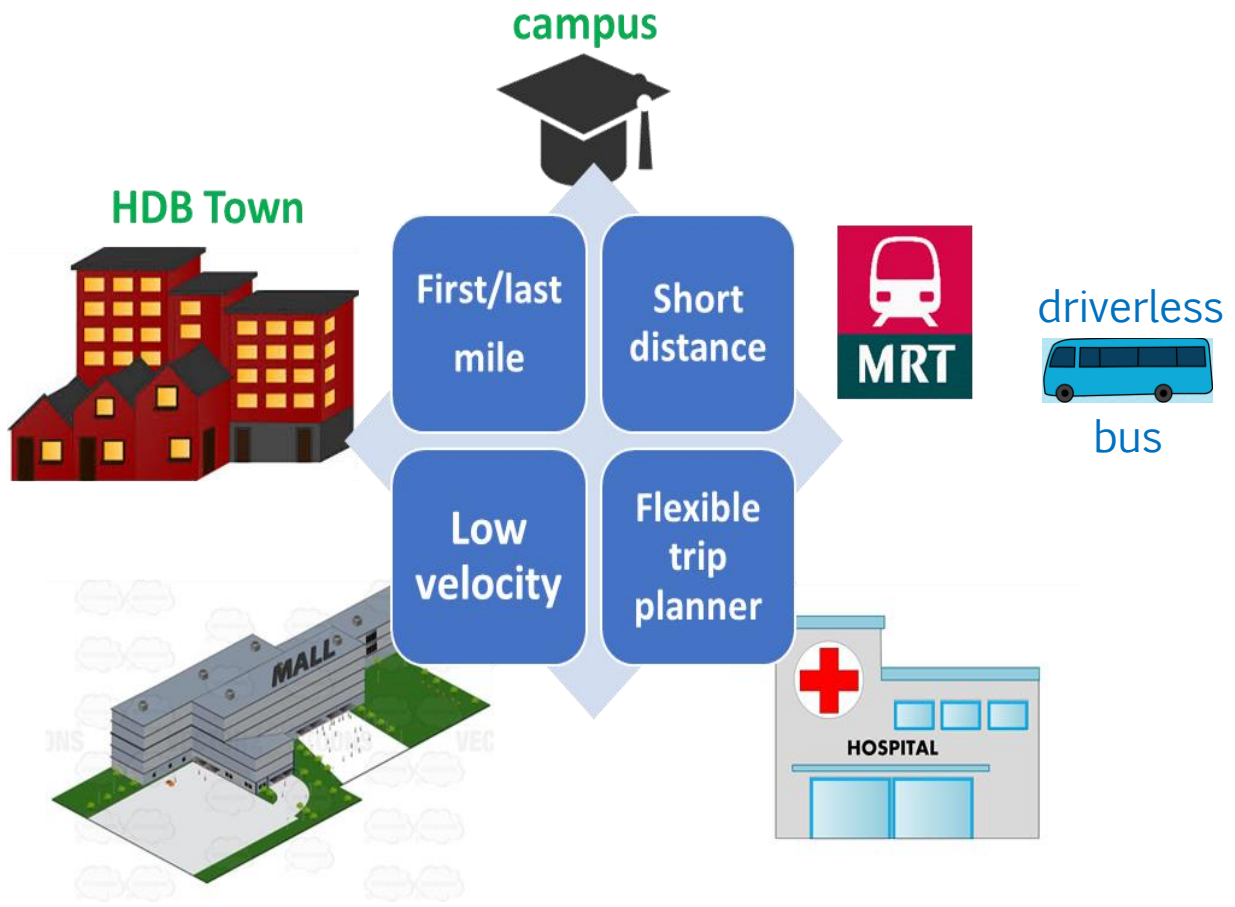
ST (Singapore Technology) Engineering

ST-Kinetics (Singapore Technology Kinetics)

- Singapore Technology is one of the biggest engineering company in Singapore. ST groups consists of ST Electronics, Marine, Aerospace and Kinetics.
- Deployed mini AV shuttle at Garden by the Bay.
- Trial of ST AutoBus in Sentosa Island

My Experience in Autonomous Vehicle

- Started an R&D program in 2014
- Focus on first/last-mile vehicle, campus shuttle, community transport, etc.
- Major achievements: autonomous campus navigation, auto-parking, etc.
- Successful translation of IP to commercial product
- Local and international events and activities

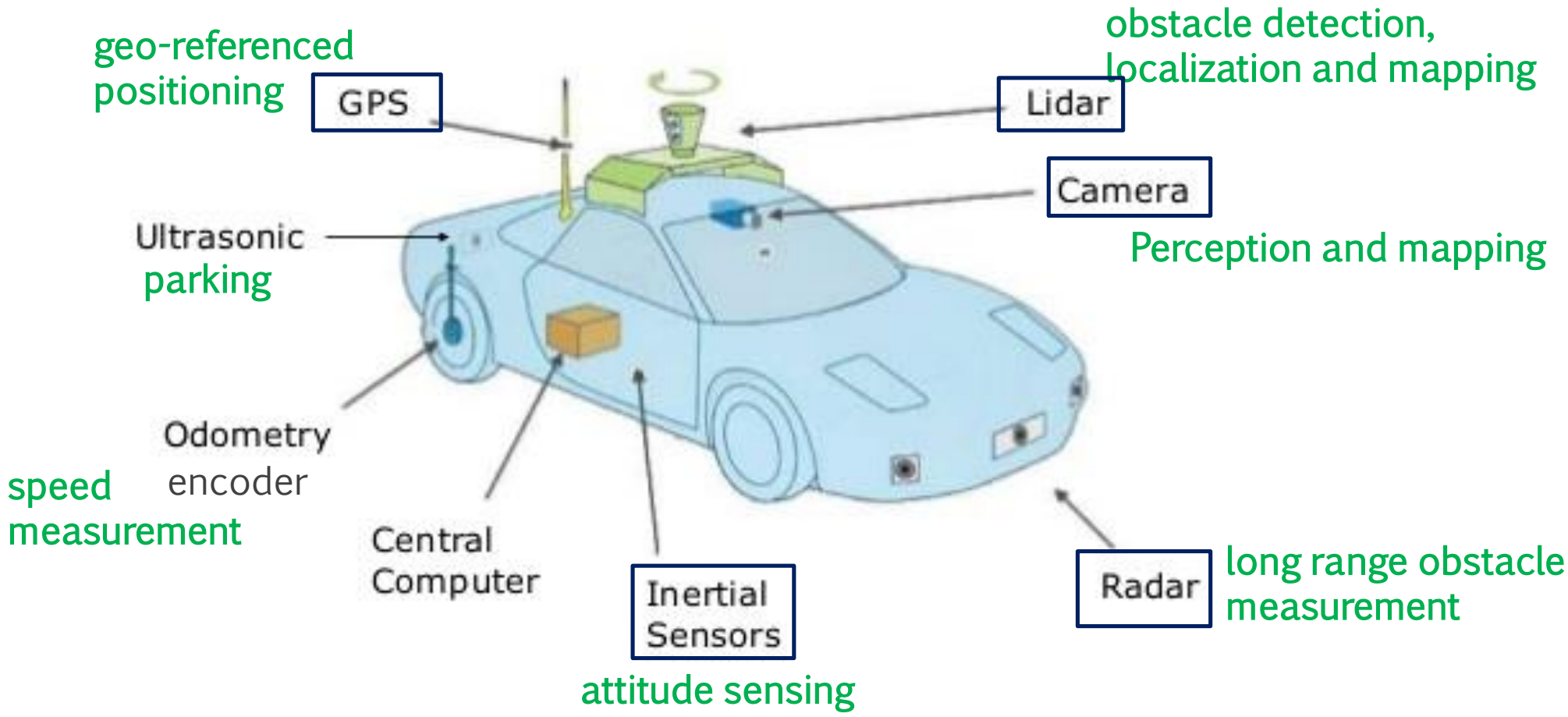


Hardware Architecture: vehicle platform

- *Toyota COMS* Electric Vehicle
- Modified for drive-by-wire/steer-by-wire

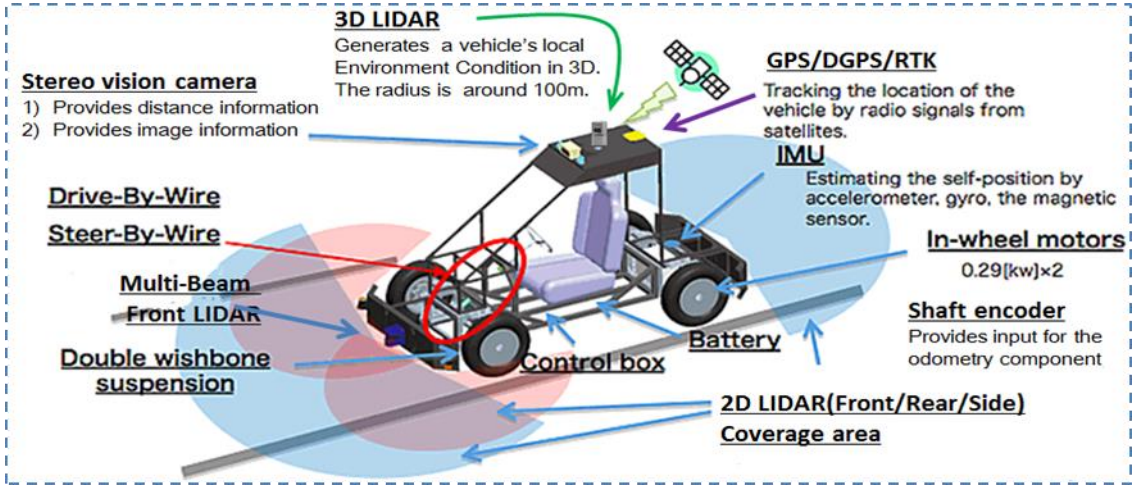
Capacity	1	Maximum speed	60 km/h
Loading weight	100 kg	Maximum torque	250 Nm
Dimension	2.4(H)x1.1(W)x 1.5(L) m	Battery	Lead-acid or lithium-ion
Weight of vehicle	410 kg	Charging mileage	50 km
Drive system	Rear-wheel drive	Charging time	6 hours
Output power	5 kw	Communic ation	CAN

Hardware Architecture: Sensors



System Integration

System Integration: 6 months



Some experience sharing:

- Computing power
- Battery capacity
- Power management
- Automotive inspection

Software

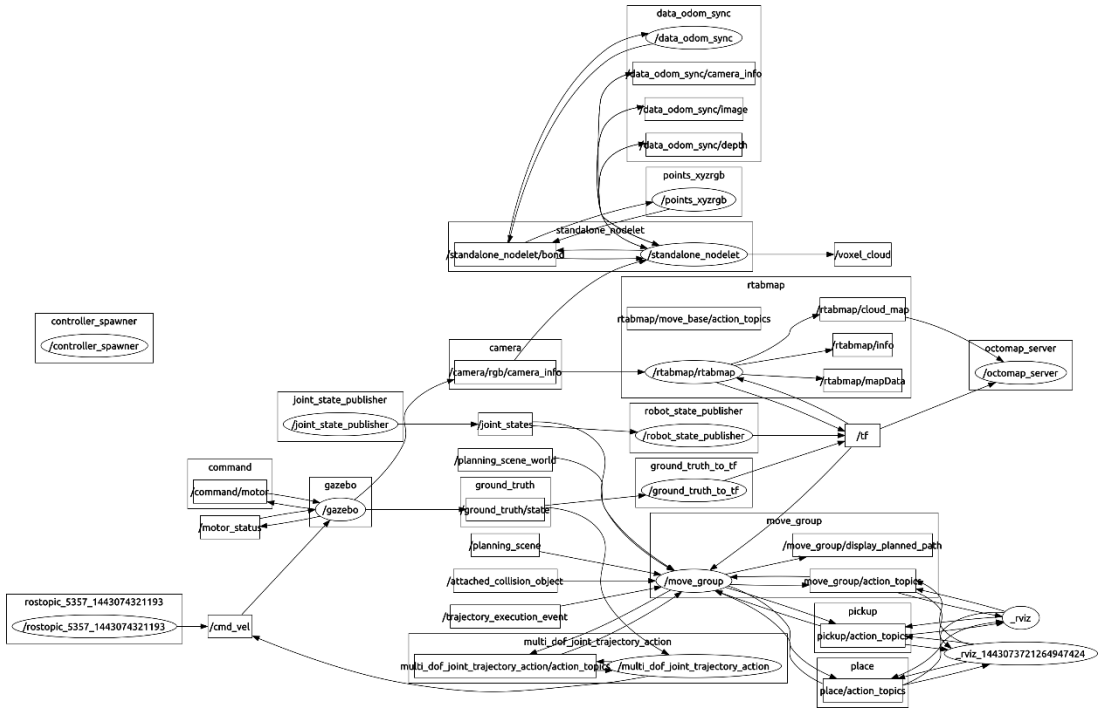
- Inter-process communication (IPC) framework
- SLAM: Simultaneous Localization And Mapping for vehicle localization
- Control: throttle, brake and steering control
- Navigation and Path Planning: driving and parking scenarios
- Perception: Deep learning

Software: Inter-process communication framework

- Autonomous vehicle has many software components.
- Failure of one software component should not result in catastrophic system failure.
- Inter-process communication framework allows processes (software components) to synchronize, manage shared data, exchange information, etc.

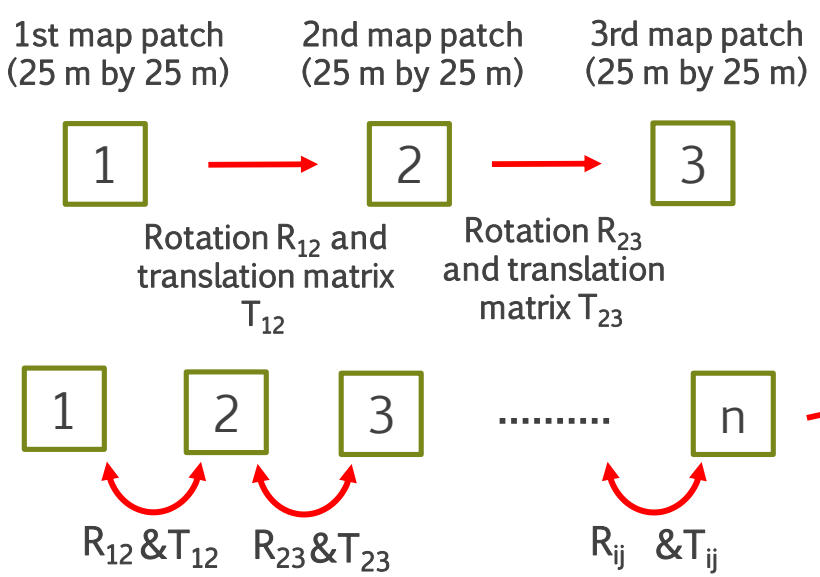
ROS
Robot Operating System

- Message passing interface (IPC) middleware
- Remote procedure calls
- Distributed systems
- Robot-specific features/libraries
- Debugging tools

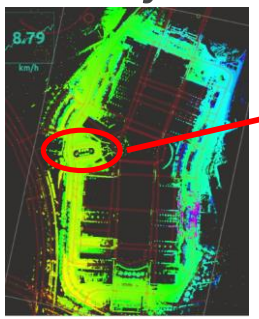


Software: SLAM

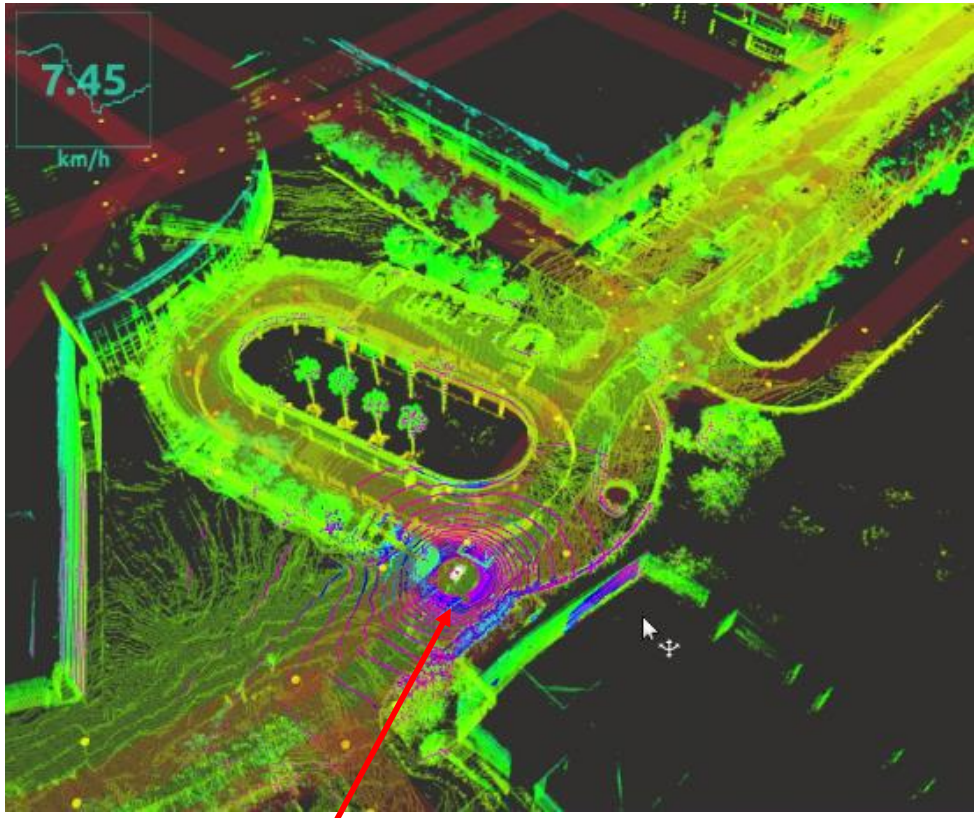
- Challenges:
  1. High-resolution, large-scale map's memory footprint is large. Construction of map is slow. Loading regional map data to a vehicle is slow.
  2. Long-term map maintenance. (removing temporal objects)
  3. Tedious data collection process.



Top-down view
3D Map
(0.5 km by 2 km)



Orbital view of part of 3D Map



Localized Vehicle in Map

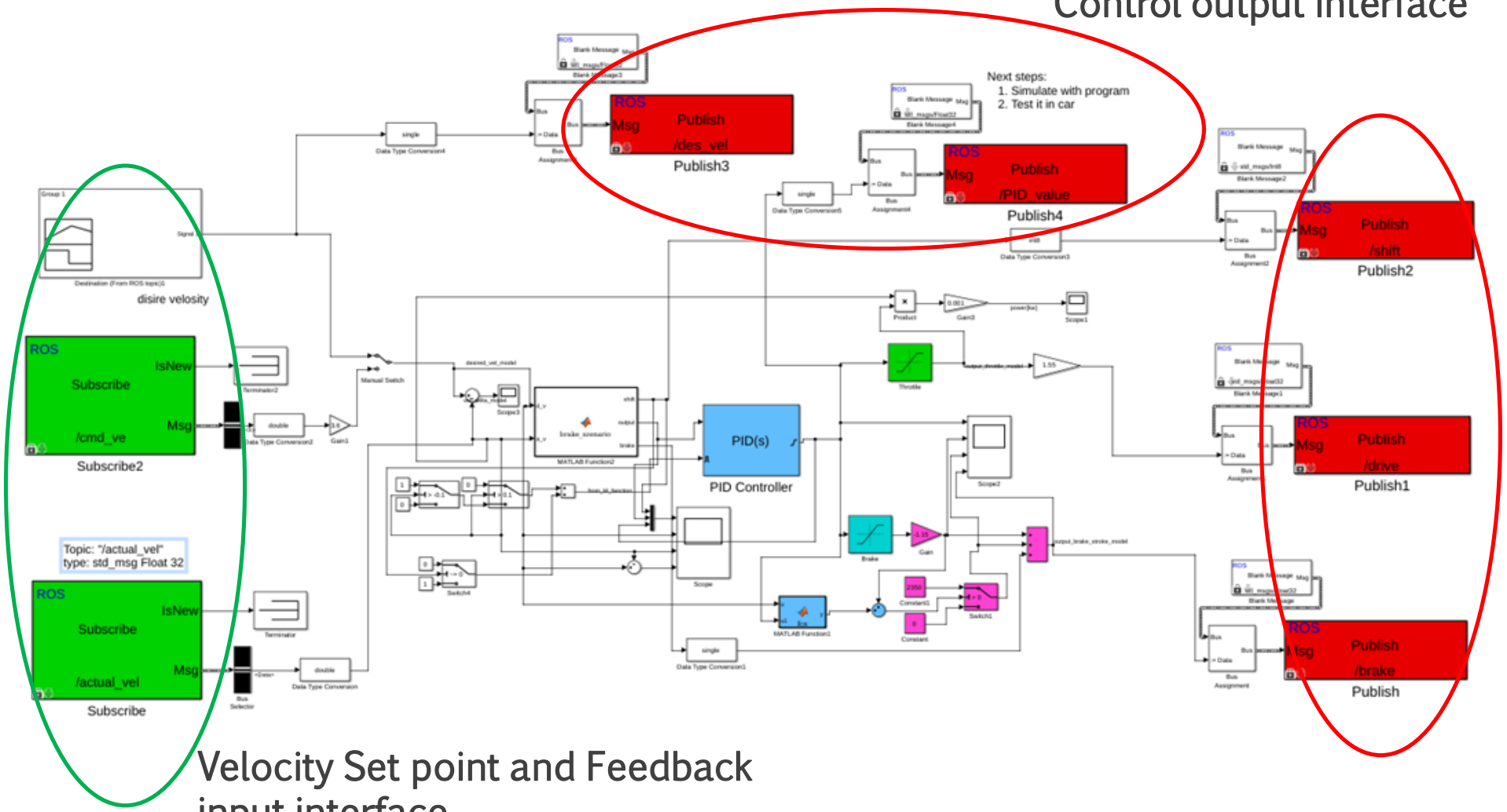
Software: Vehicle Control

- Vehicle Control: throttle, brake and steering control (Velocity and steering control)
- Throttle and brake (velocity control):

1. First attempt: implemented PID controller in C++ and tune parameters on the real car. It works (up to 15 km/hr)!
2. Cons: difficult to compare with other types of controller such as LQR, MPC, etc.
3. Cons: difficult to reproduce on other types of vehicle.
4. Current approach: modelling, identification, simulation and deployment.

Software: Vehicle Control

- MATLAB model
- Design controller in MATLAB
- Tune gains in MATLAB
- Compile into ROS-compatible C code
- Seamless transition from Design to Deployment

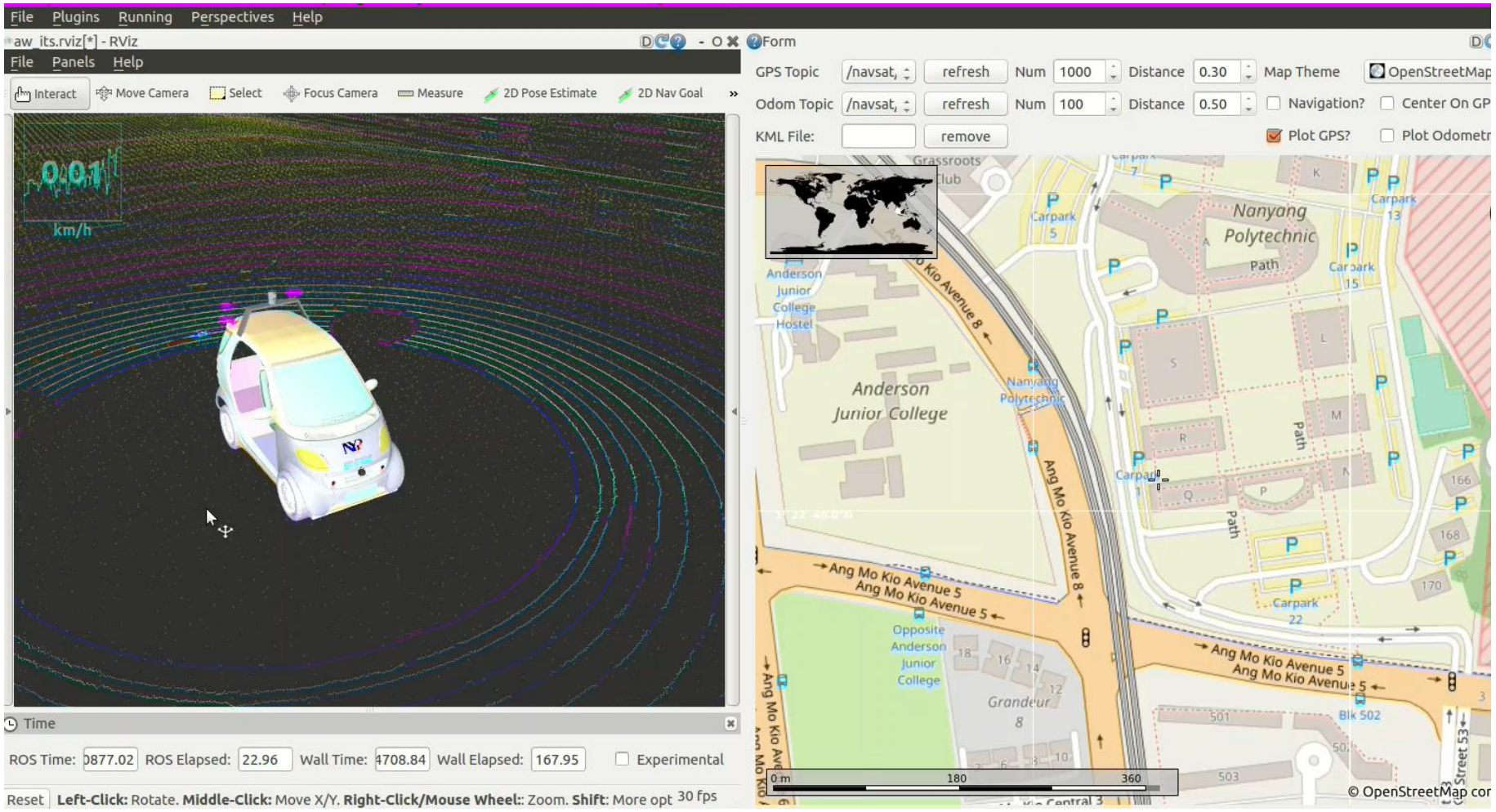


Background: Simulator

- Vehicle Simulator
- ROS
- VREP
- Physics engine
- Standard control algorithm interface
- Gazebo (currently used)

Demonstration

- 3D mapping and localization
- Planning
- Perception
- Vehicle control
- Sensor fusion
- Campus navigation

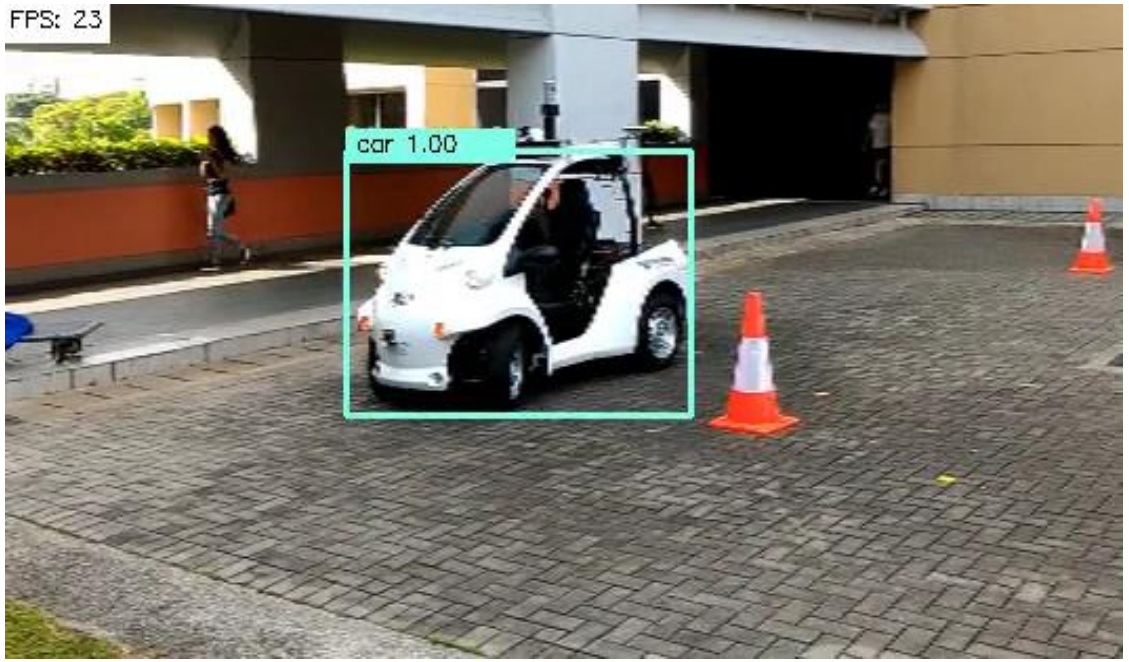


Simulation result:

Simulation of three auto-parking scenarios

Software: Deep learning based Perception

- Detection/recognition of road users: car, bike, pedestrian, traffic police, etc.
- Detection/recognition of traffic signs.
- Situation awareness: sensor-fusion or AI-based?
- Decision making: rule-based or AI-based?



Deep learning model: VGG 16
Detector: SSD
Data set: Pascal VOC 2012

Autonomous driving: Logic vs AI?

- Detection/recognition of road users: car, bike, pedestrian, traffic police, etc.
- Detection/recognition of traffic signs.
- Situation awareness: sensor-fusion or AI-based?
- Decision making: rule-based or AI-based?

AI-based autonomous driving
Sensor used: camera
Deep learning model: ResNet-50
Dataset: human driving inputs and image recording of lanes

Thank you.