The Future of Mobility – Asia in the driver's seat presentation

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Energy Research Institute @ NTU

The Rise of Autonomous Mobility and Vehicles in Singapore

Shaping the Future Autonomous Landscape

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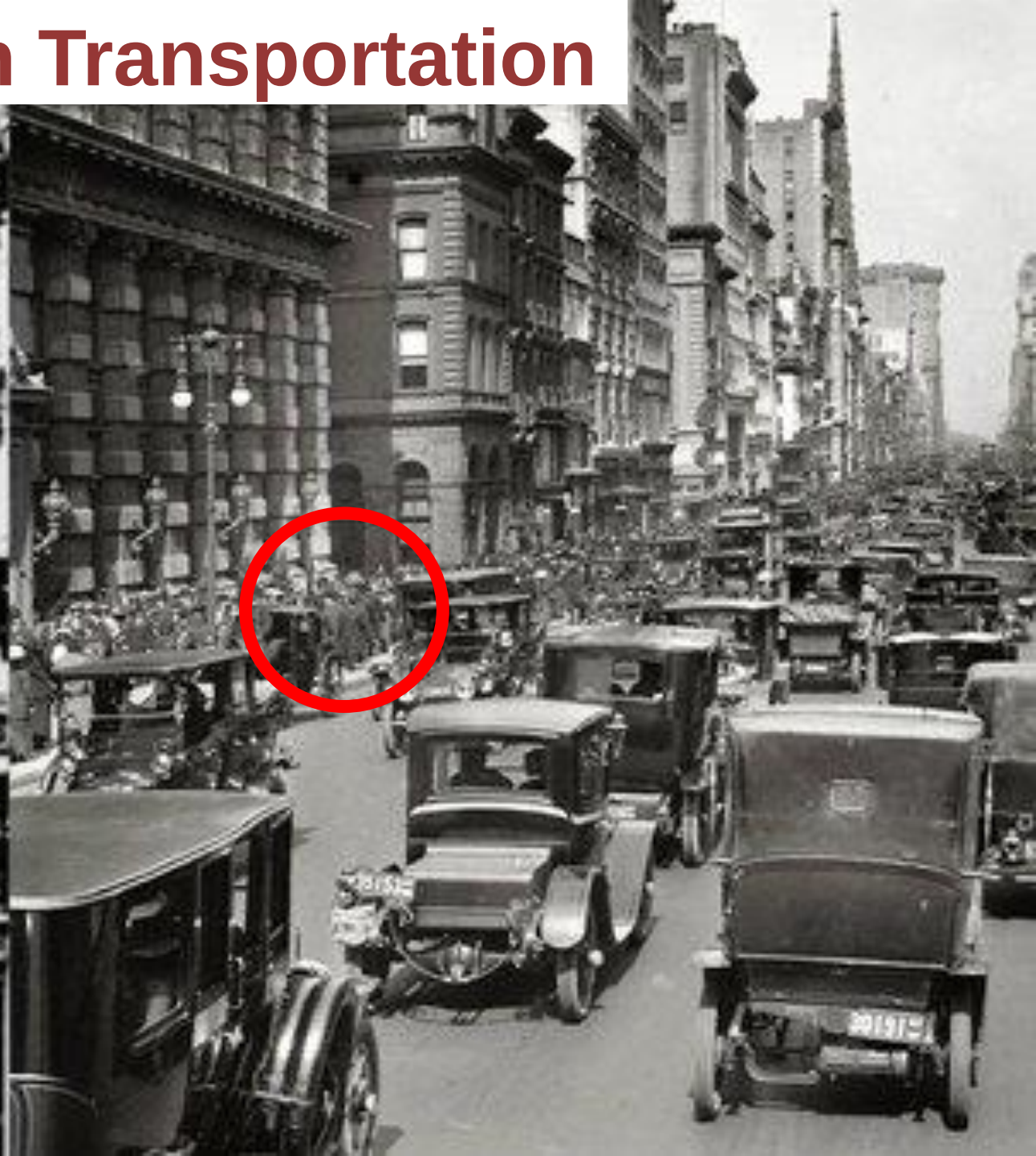
1900: NYC – Where is the Car?

1913: NYC – Where is the Horse?

1900 → 1913: Disruption in Transportation

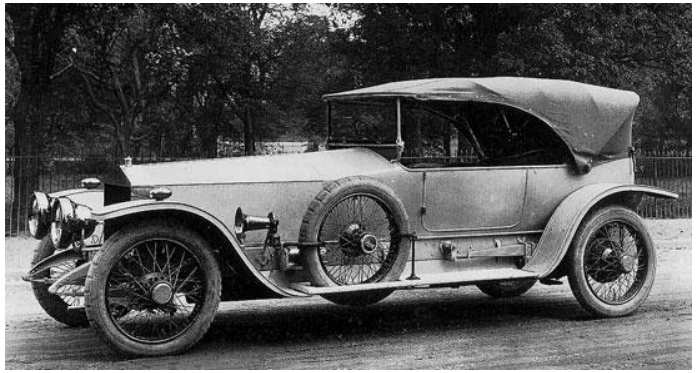


1900 → 1913: Disruption in Transportation

- Driver of this disruption:
  - Technology

1900 Peugeot

1913 Peugeot



1913 Rolls Royce

- Why accepted:
  - Speed
  - Convenience
  - Comfort
  - Pollution (horses are not zero emission transportation)

What do we expect from driving today

6

And what do we experience today

Indian Traffic Intersection - India Crossroads Traffic Busy, https://www.youtube.com/watch?v=_l99w_CKwCU

Are we due for a new set of major disruptions?

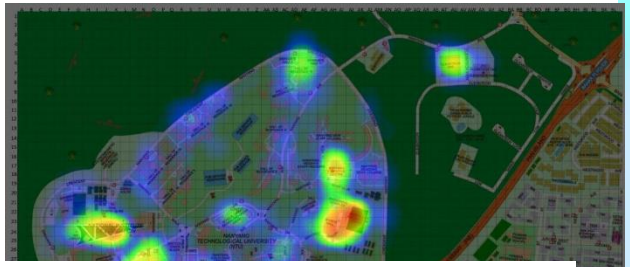
Is happened before – it can happen again

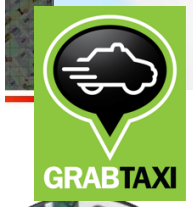
2019 – 2030: Disruption – déjà vu?

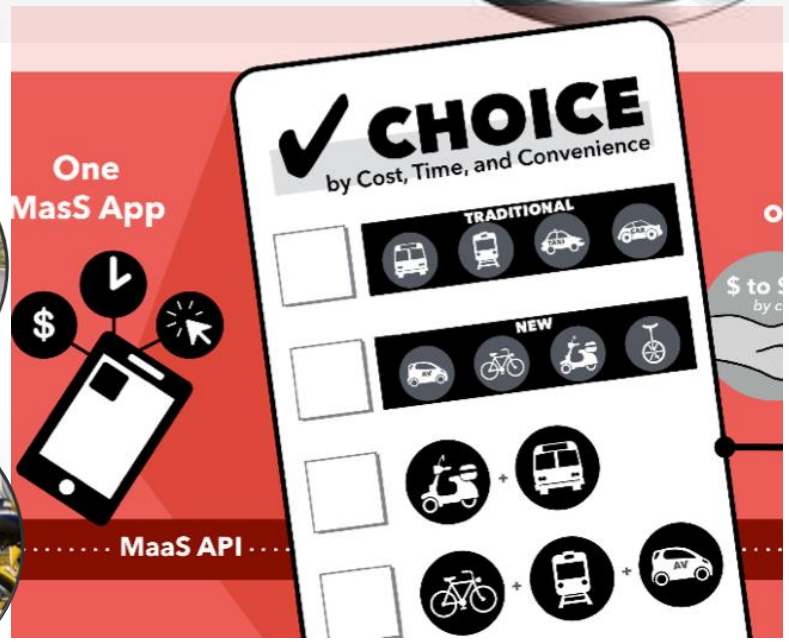
- **#1: Electrification**
  - Costs, Range, Fast Charge
  - Standards, Infrastructure

2019 – 2030: Disruption – déjà vu?

- **#2: Digitalization**
  - Choice, Mobility
  - Pain Points

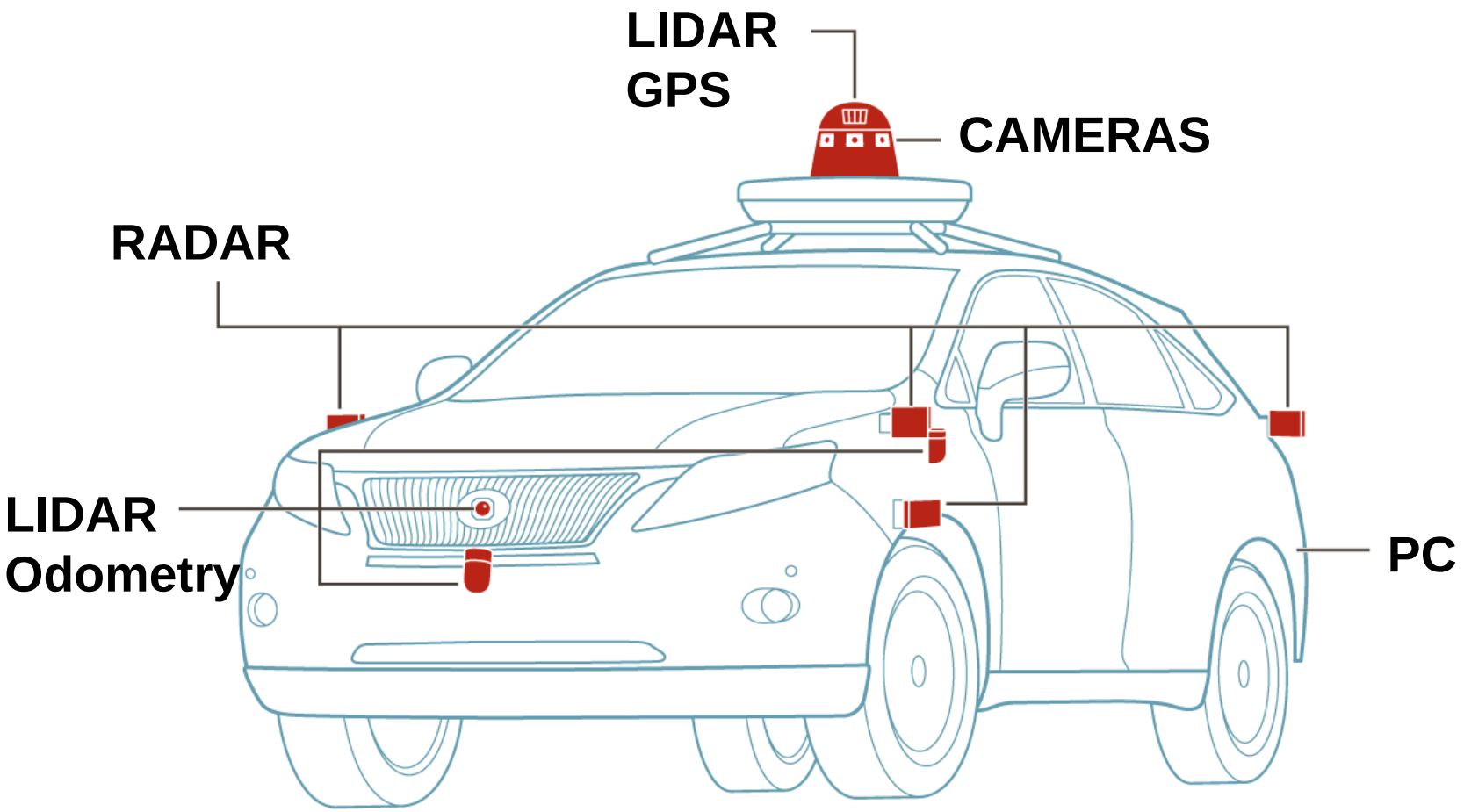






2019 – 2030: Disruption – déjà vu?

- #3: Autonomous Vehicles



Vehicle types: traditional

Vehicle types: small shuttles & buses

Vehicles – The small and the wonderful

As well as very large trucks

And COVID-19 solutions…

A country specific response to these disruptions

SINGAPORE URBAN MOBILITY CHALLENGE

Singapore Urban Mobility Challenge

66%

increase in domestic travel in last 10 years

1/3

of the work force is over 50

55%

of bus drivers are foreigner

12% + **4%** versus **14%**

of land used for roads

of land used for car parks

of land is used to house 5.5M people

There is not enough space to increase the number of vehicles at the same rate as the population growth

Car-lite estates

MINISTRY OF TRANSPORT
CONNECTING SINGAPORE

Concept of a Future Town Centre in Singapore with Self-Driving Vehicles (Day Time)

MINISTRY OF TRANSPORT
CONNECTING SINGAPORE

Concept of a Future Town Centre in Singapore with Self-Driving Vehicles(Night Time)

Singapore‘s Vision for Autonomous Vehicles
Tengah The Forest Town

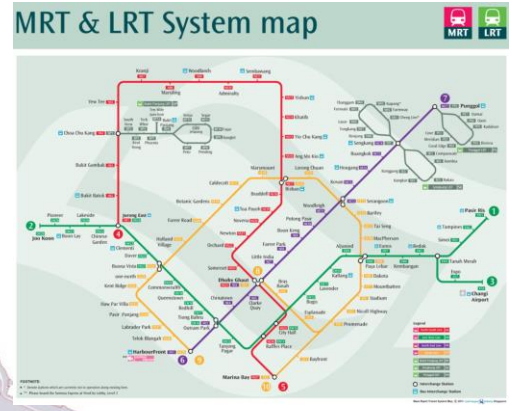
Tengah: First Car-Free Town

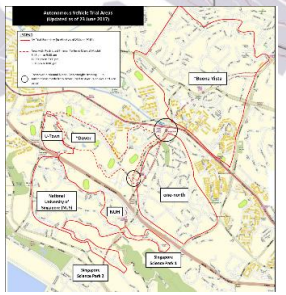
Picture a town centre connected by just paths between your home and the nearby amenities such as food courts, community centres and the train station. At Tengah, Singapore's first car-free town centre, this vision is a reality.

Commuting will be easy in this western town, with public transport networks no further than 300m of residents' doorsteps, providing excellent connectivity to nearby MRT and key destinations such as the Jurong Lake District. Autonomous buses will also be piloted in the town. While there are no roads at ground level, the town centre – named 'The Market Place' – will still be accessible by roads underground. This frees up valuable space on ground level for walking, cycling and other recreational activities.

This exciting development, set to be developed over 20 years, will feature underground crossings, dedicated bus lanes, shaded paths and rest-stops.

Singapore‘s Vision for Autonomous Vehicles
Car-lite Precincts





Woodlands

Punggol

Tengah

Jurong

Kallang River

Bayshore

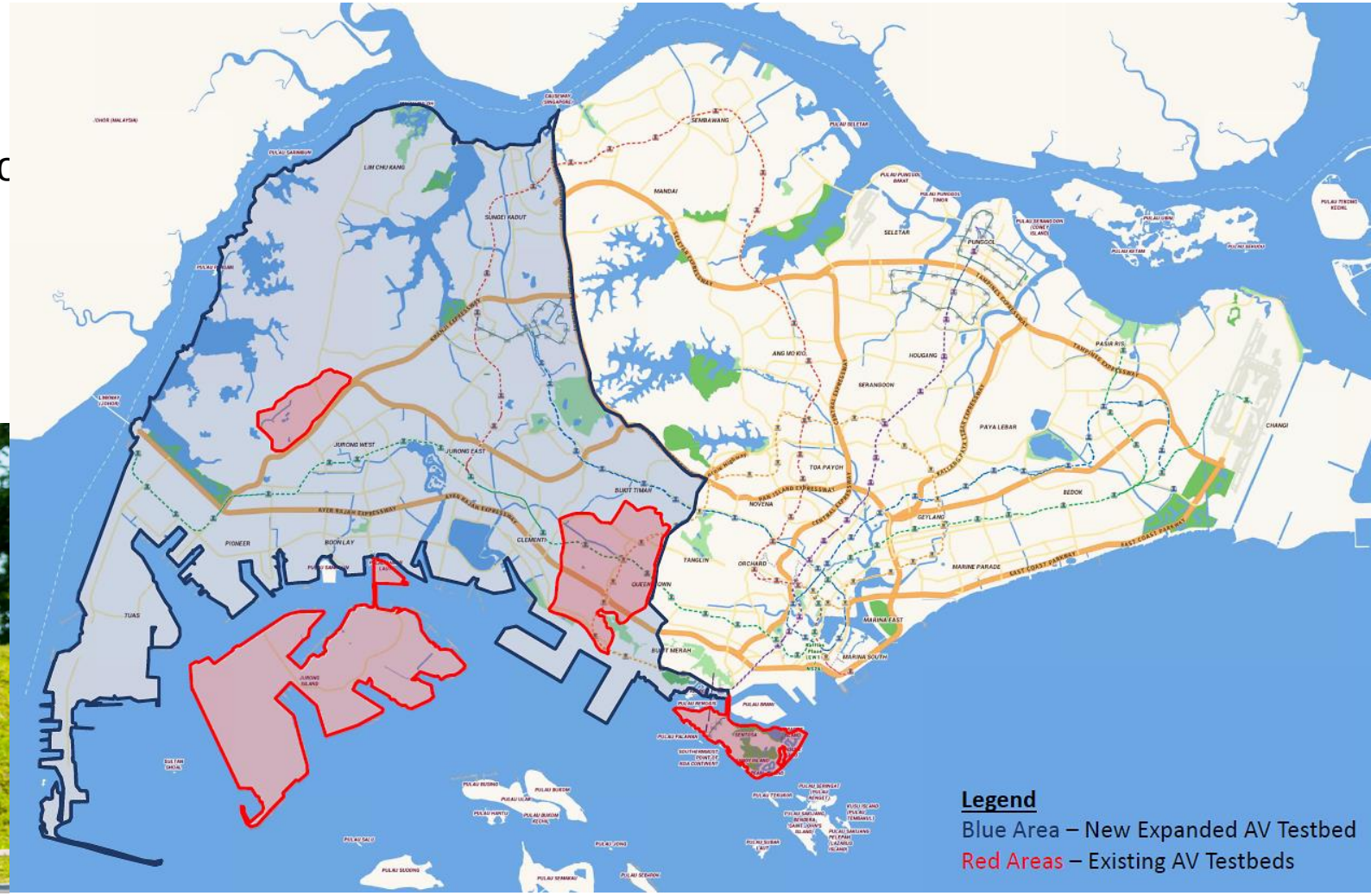
One-north

Gardens by the Bay

Bus Interchange/
Integrated Transport Hub
Car-lite Precinct (Announced)
Car-lite Precinct (Proposed)
Cycling Network
MRT/ LRT Line
MRT/ LRT Station
Transit Priority Corridor

Singapore‘s Vision for Autonomous Vehicles Trial Areas

- Test bed at One North for AV testing
  - Infrastructure to support trials
  - CCTV
  - 5.9 GHz Dedicated Short Range Co testing
  - Backend system



Autonomous mobility – Testbed programs

Enablers

- Fixed and Scheduled services
- Point-to-point Mobility on Demand
- Freight
- Utility

Technology, Public Acceptance and Regulations

Vision

- Reduce demand for car ownership
- Reduce road congestion during peak hours
- Reduce manpower reliance

CETRAN

MINISTRY OF TRANSPORT
CONNECTING SINGAPORE

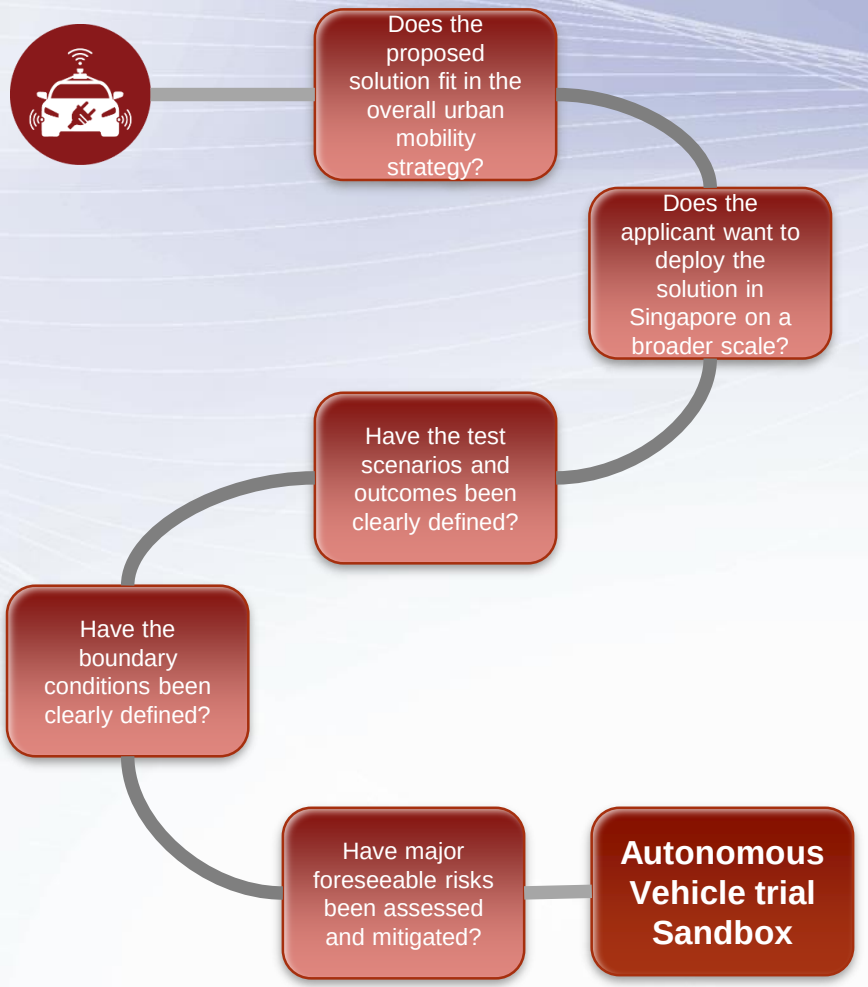
CETRAN

CETRAN Centre of Excellence for Testing & Research of AVs – NTU

- **Centre of Excellence to support Singapore AV community**
  - Standards development
    - Developing AV testing procedures
    - Perform AV testing on behalf of LTA to support issue of AV Authorization
    - Technical lead in development of AV Technical Reference
  - Operator of CETRAN AV Test Centre
  - Linking with other countries to align on standards and testing
  - Supporting skills development for Industry
  - AV Developer support

Regulatory Sandbox

- Autonomous Vehicle regulatory sandbox has the same structure as other regulatory sandboxes deployed in Singapore (e.g. FinTech)
  - A regulatory sandbox has been implemented and could be extended at the end of 5 years, before enacting more permanent legislation
  - Caters for trials without safety driver on public roads – if the risks have been mitigated
  - Advantage of the sandbox is Threefold:
    - Development of legislation without having to go to parliament for every incremental change
    - Be able to tailor requirements to a specific solution if required
    - Being able to trial regulations before rolling them out as law



Milestone Framework

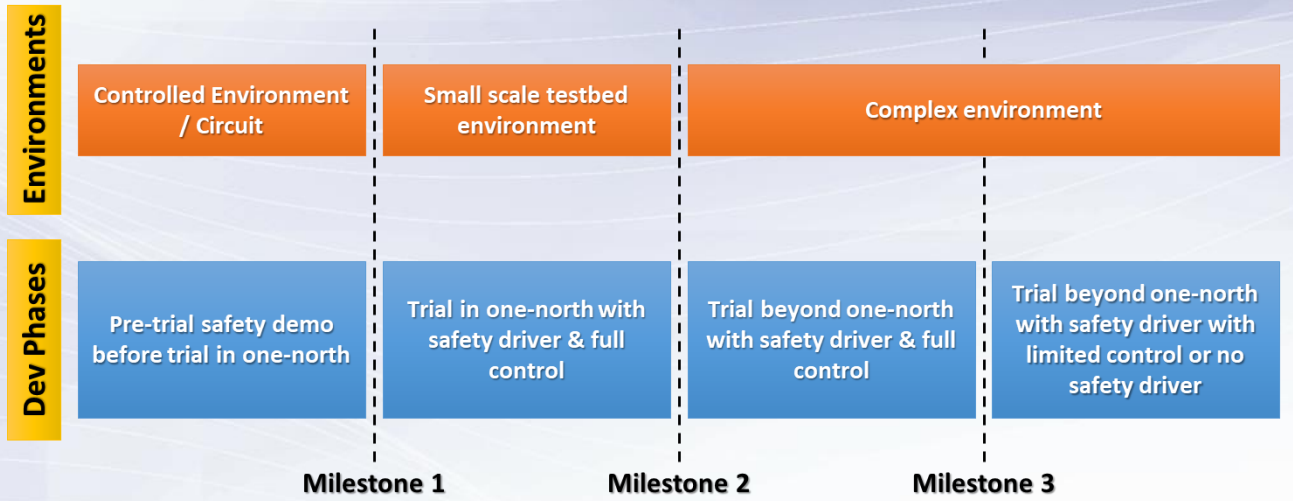
- Assumption:
  - Vehicles are SAE Level 4 in automation
  - Will have an increase in technical maturity as trials progress

- Effectively a Stage-Gate R&D process applied to AV trials
  - Stages are trials with increasing levels of complexity and increasing levels of risk
  - Gates are readiness assessments to determine
    - The level of maturity has sufficiently increased that the risk is acceptable for trial in an increased complexity environment
    - The vehicle has developed sufficient maturity that an increase in complexity of the environment is justified

Milestones for AV Trials

Milestones are used to assess AVs before they are allowed to proceed to their next phase of trial

- Each milestone test will produce a test report with recommendation which is used by the Land Transport Authority as one of the decision criteria to “pass” the AVs



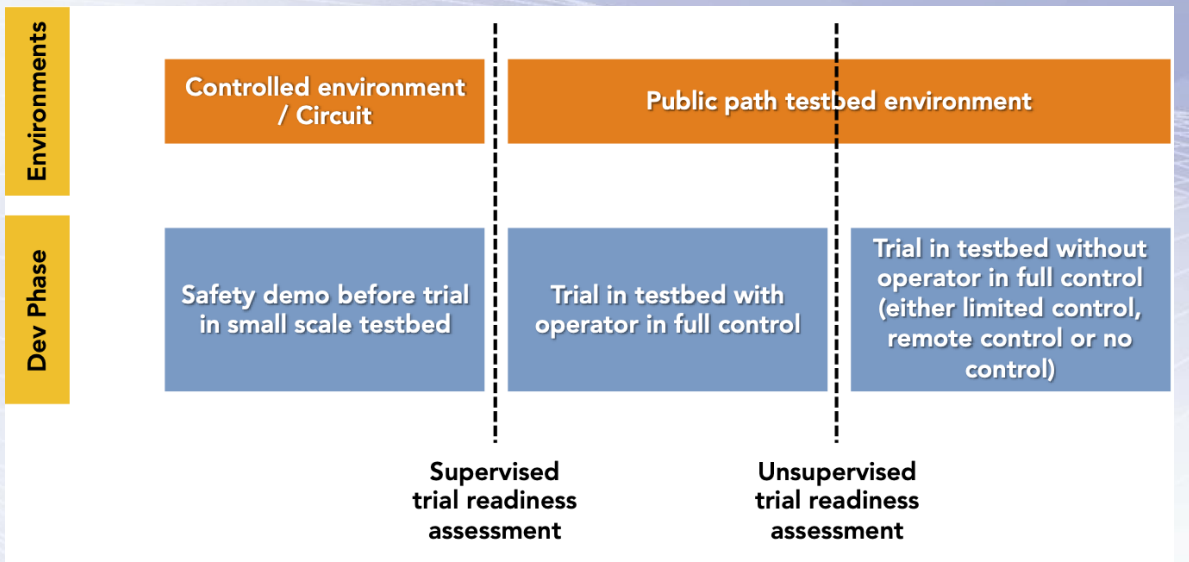
- **Milestone 1**
  - Ability to safely conduct testing of autonomous vehicles with safety driver in a small scale testbed.
- **Milestone 2**
  - Ability to safely conduct testing of autonomous vehicles with safety driver in a complex environment.
- **Milestone 3**
  - Ability to safely conduct testing of autonomous vehicles without or with a safety driver (with limited control) in a complex environment. This implies high technical maturity.

Extension to AMR

Milestones for AV Trials on Public Paths

Adaption of Public Road Milestone Framework to facilitate trails on public paths:

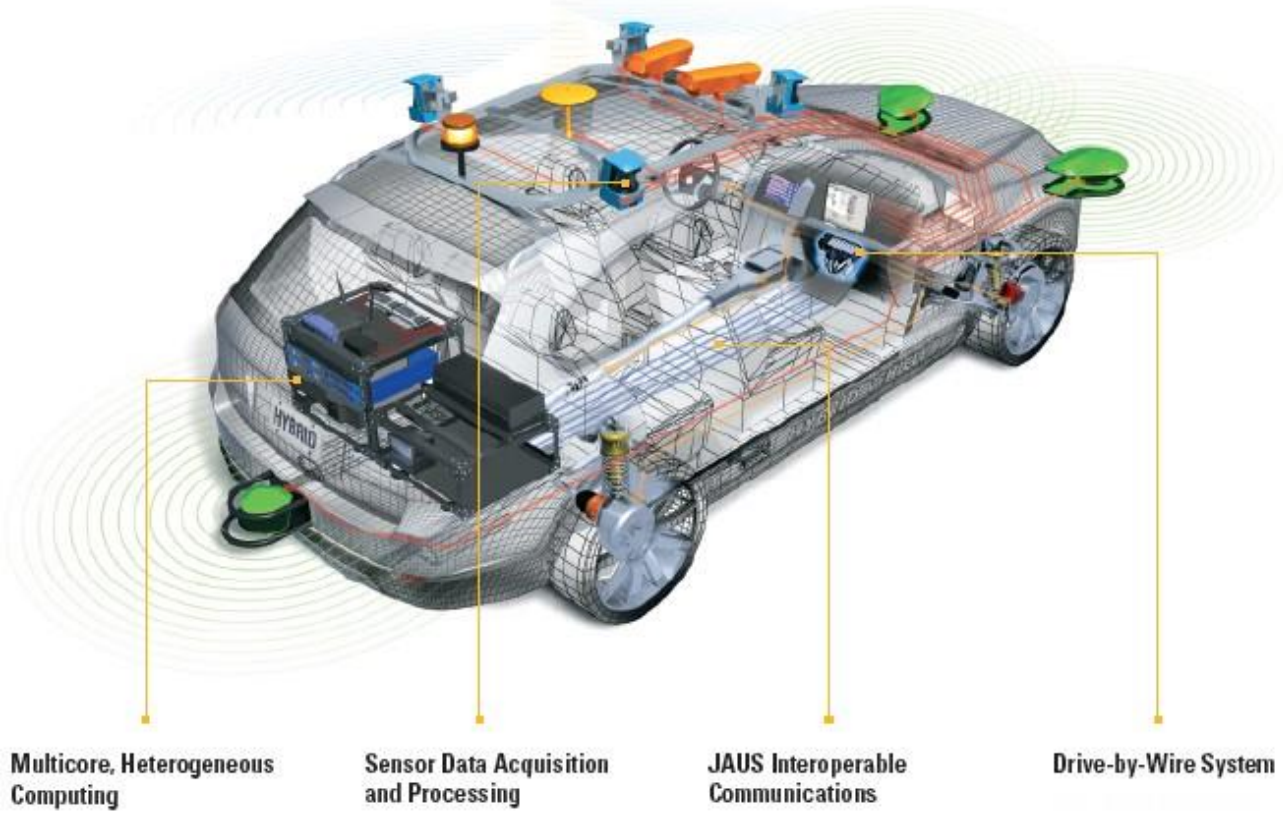
- 3 categories of vehicle defined:
  - Cat-A1: Vehicles not carrying passengers with a width of less than 70cm.
  - Cat-A2: Vehicles not carrying passengers with a width of less than 70cm.
  - Cat-B1: Vehicles not carrying passengers with a width of more than 70cm.
  - Cat-B2: Vehicles carrying passengers with a width of more than 70cm.

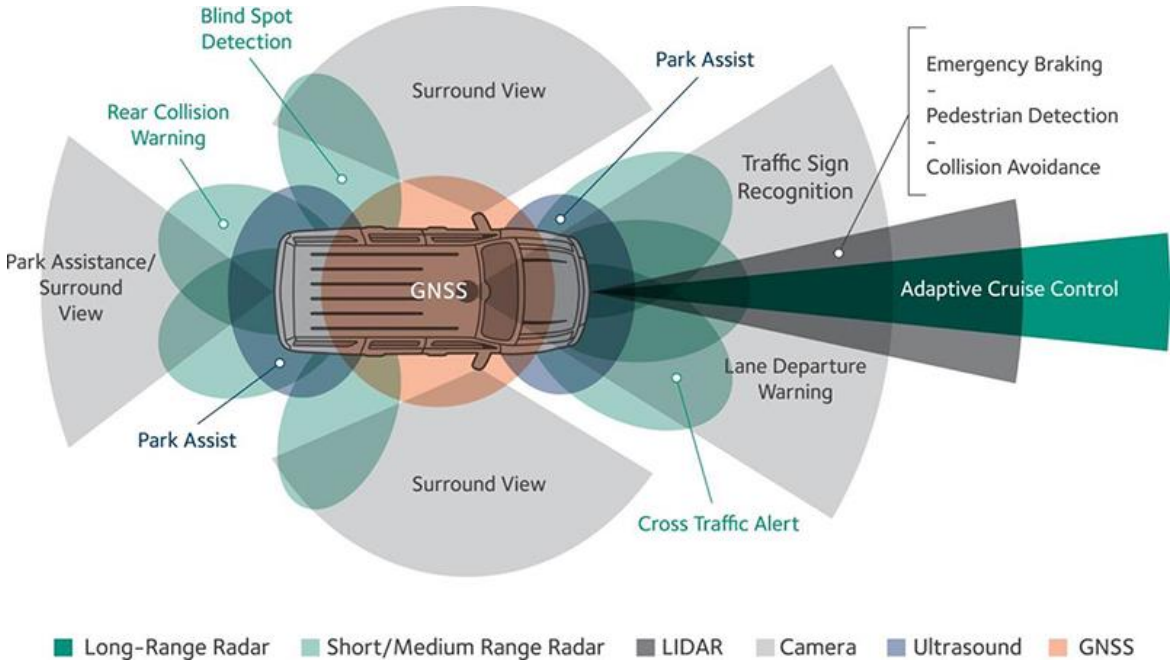


- **Supervised trial readiness assessment (T1)**
  - Derived from Milestone 1
  - Changes in safety operator requirements and safety controls
  - Test routes adapted to reflect trial environments
- **Unsupervised trial readiness assessment (T2)**
  - To be derived from Milestone 3
  - Development will start Q3 2021

REPLACING HUMAN DRIVERS WITH TECHNOLOGY

Basic sensors of an Autonomous Vehicle





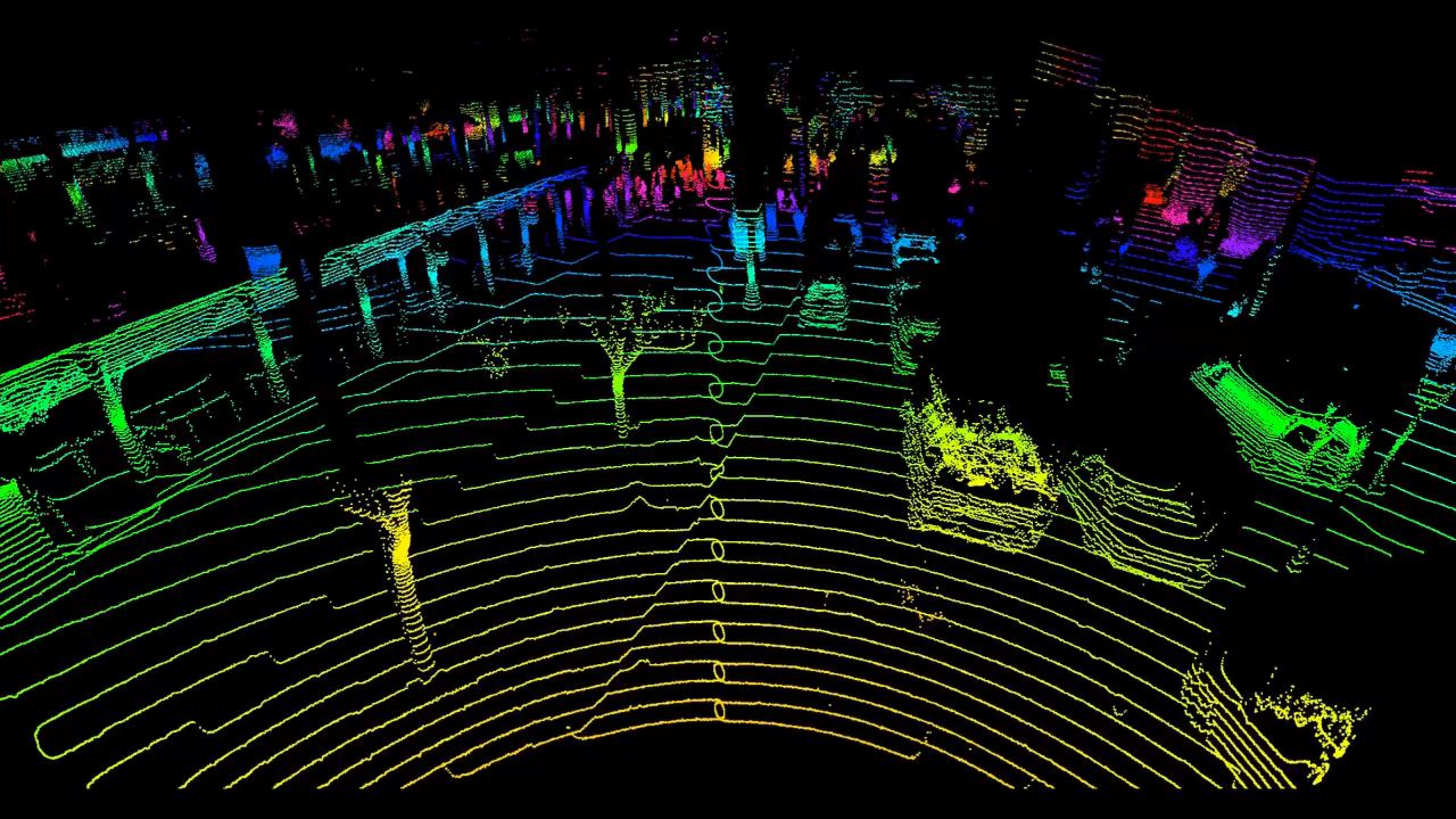


Image recognition benchmark

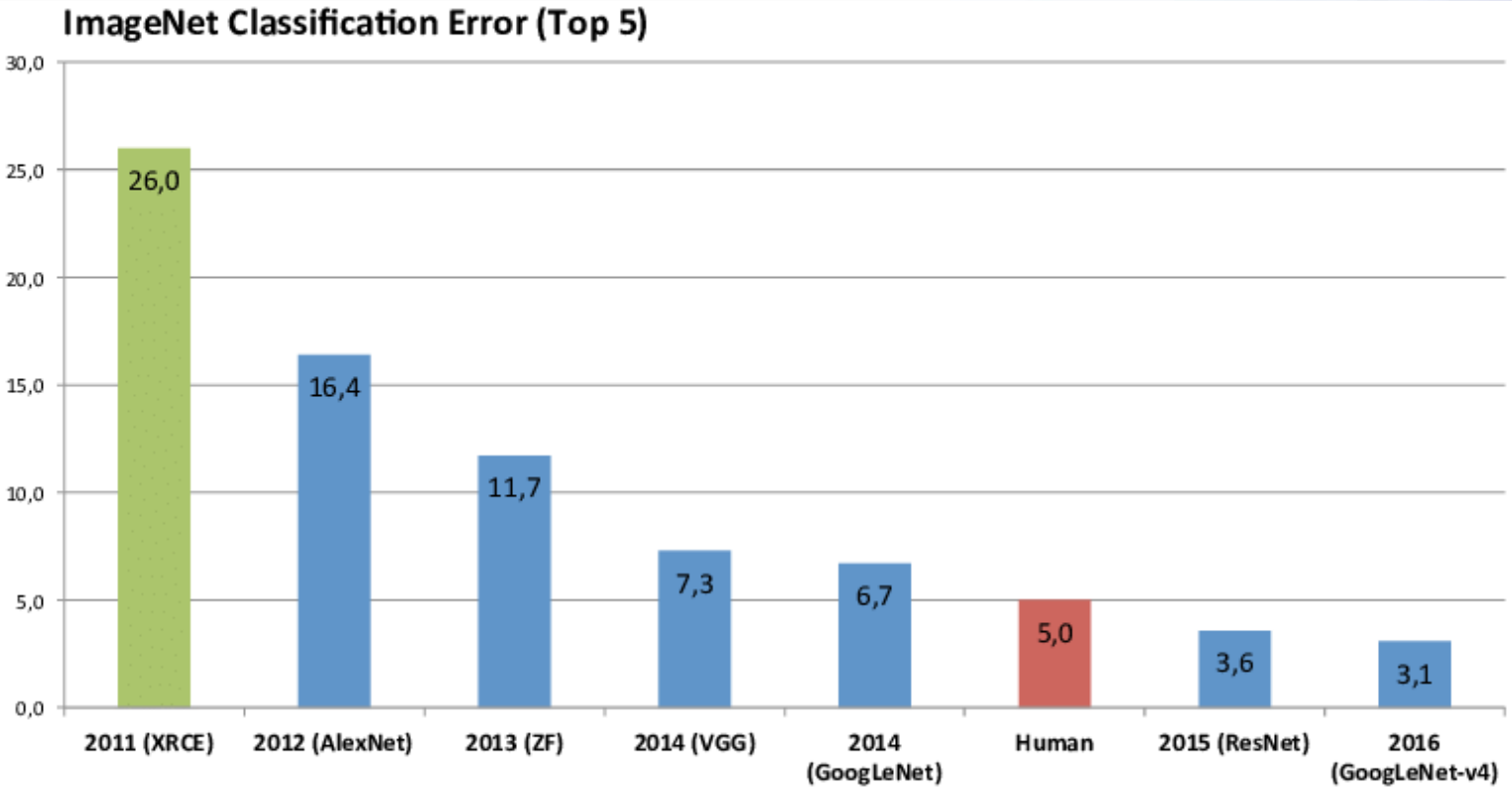


Fig.3. Image recognition algorithm benchmark.

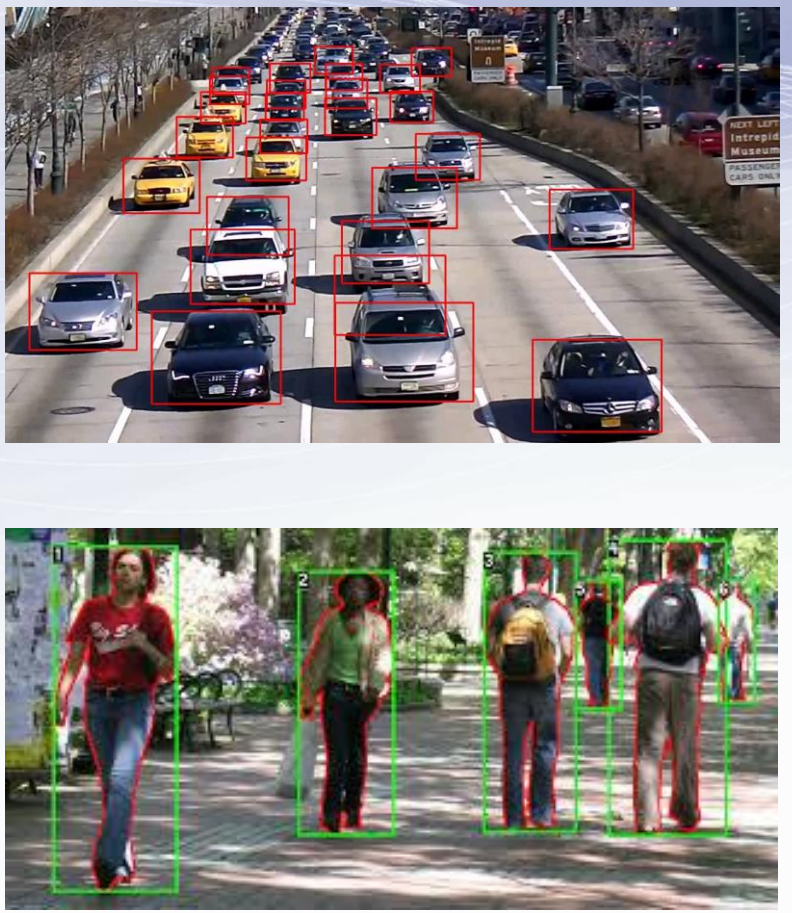


Fig.4. Image recognition algorithm performance.

Source: Prof Justin Dauwels

Adversarial example

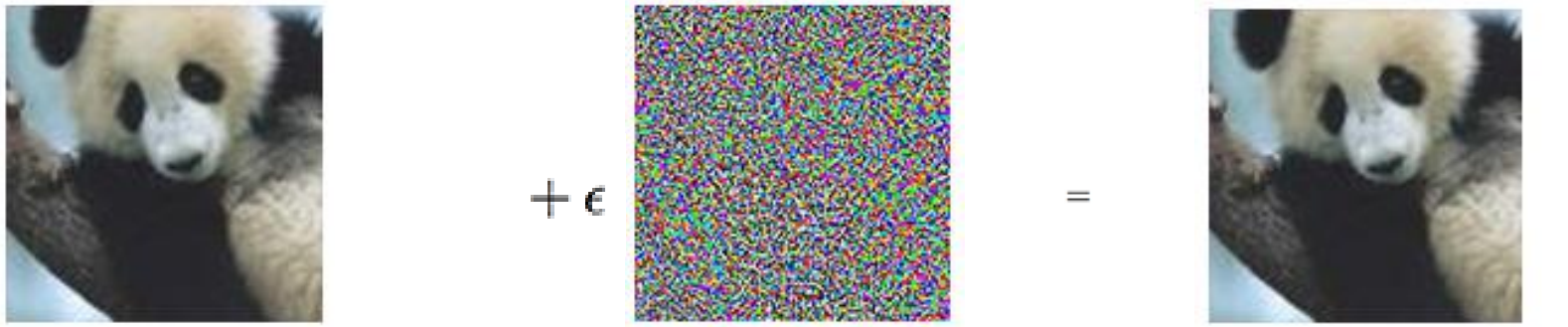


Fig.5. Adversarial example illustration.

Observation:

- Deep Learning is fragile in some sense
- There is perception gap between deep learning and human

Source: Prof Justin Dauwels

Training database quality – example 1

- One developer had a problem that they could not detect road construction workers:

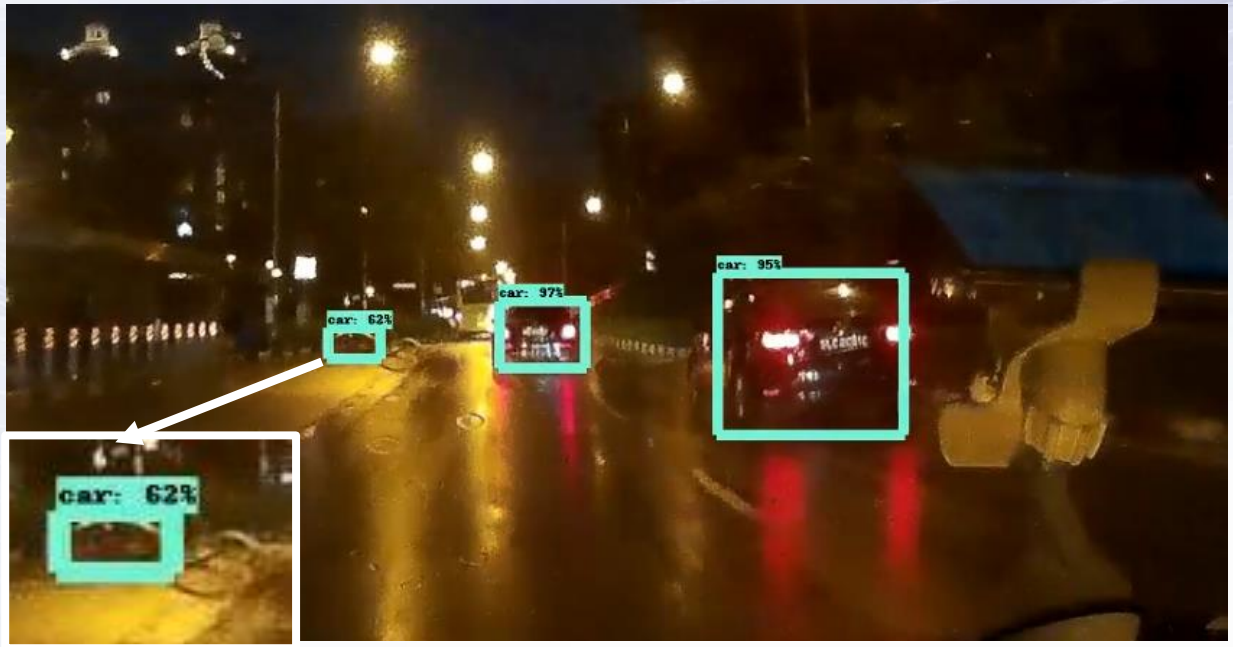
Cause:
Their training database did not include a single image of someone wearing a yellow shirt. Yellow shirts are very uncommon in the general population.

Training database quality – example 2

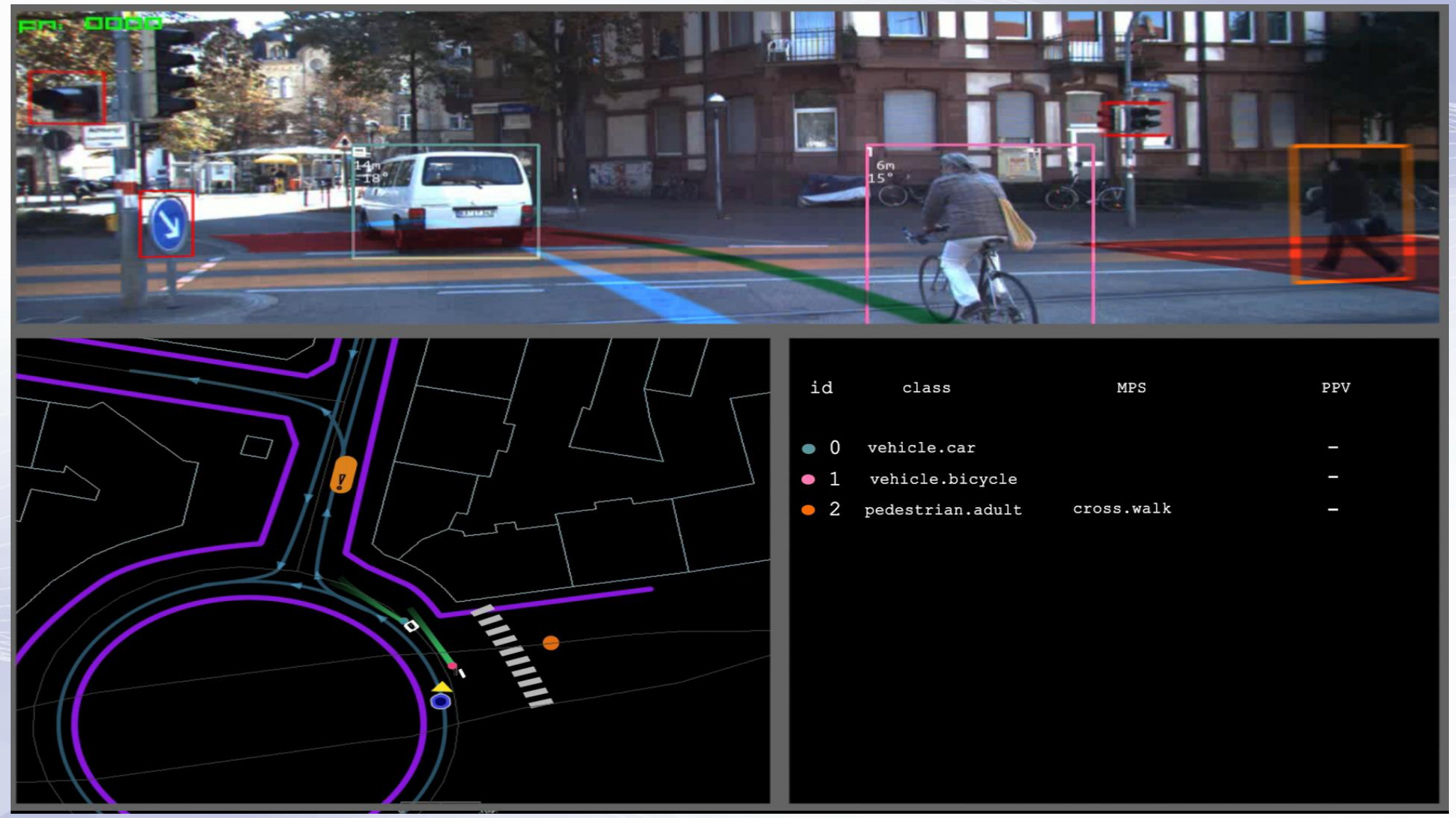
- Another developer had a problem where they could not detect women wearing short skirts.

Cause:
Their training database did not include images of women wearing short skirts as the database was generated in the middle of winter using data recorded by the vehicle during that time.

Perception for Visually Challenging Situations



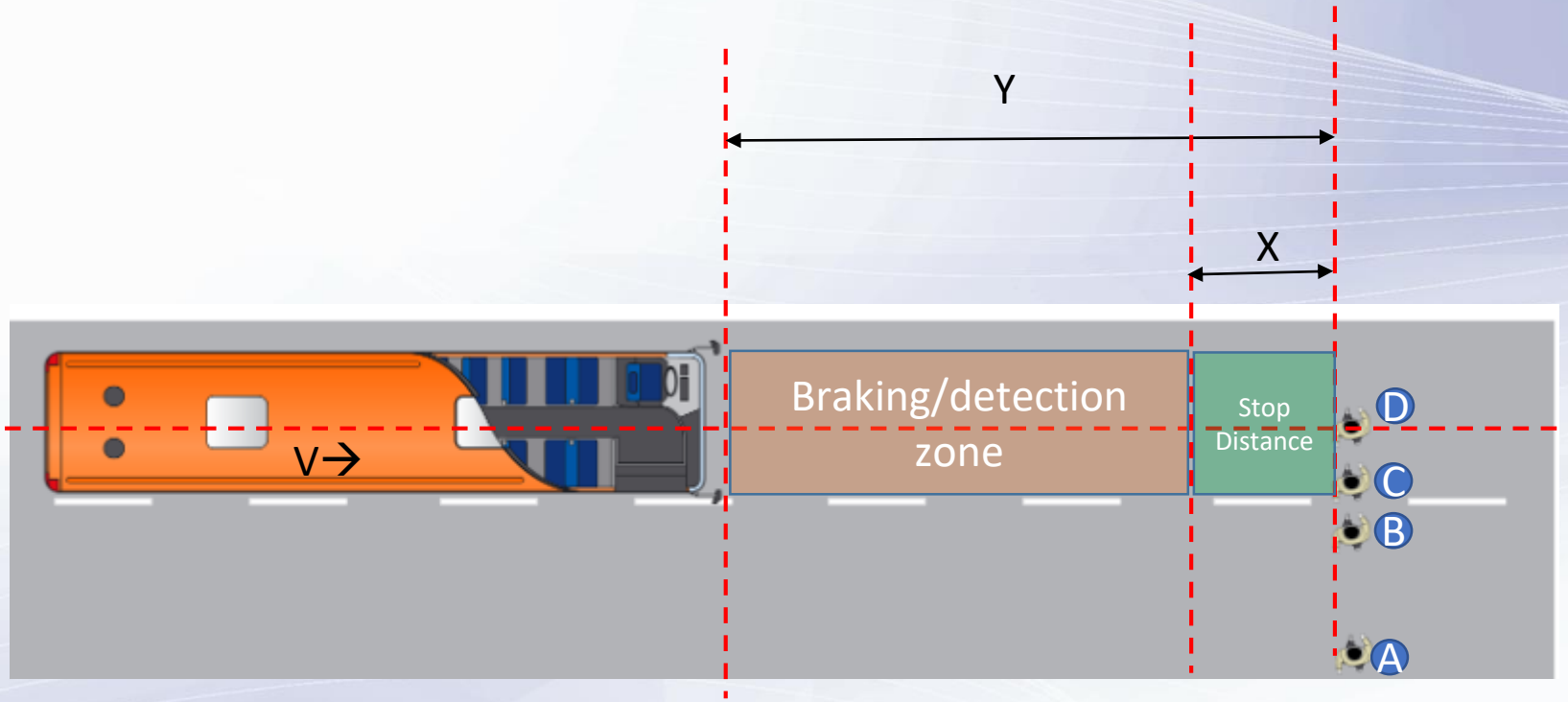
Path prediction



Basic Behavioural Guidelines

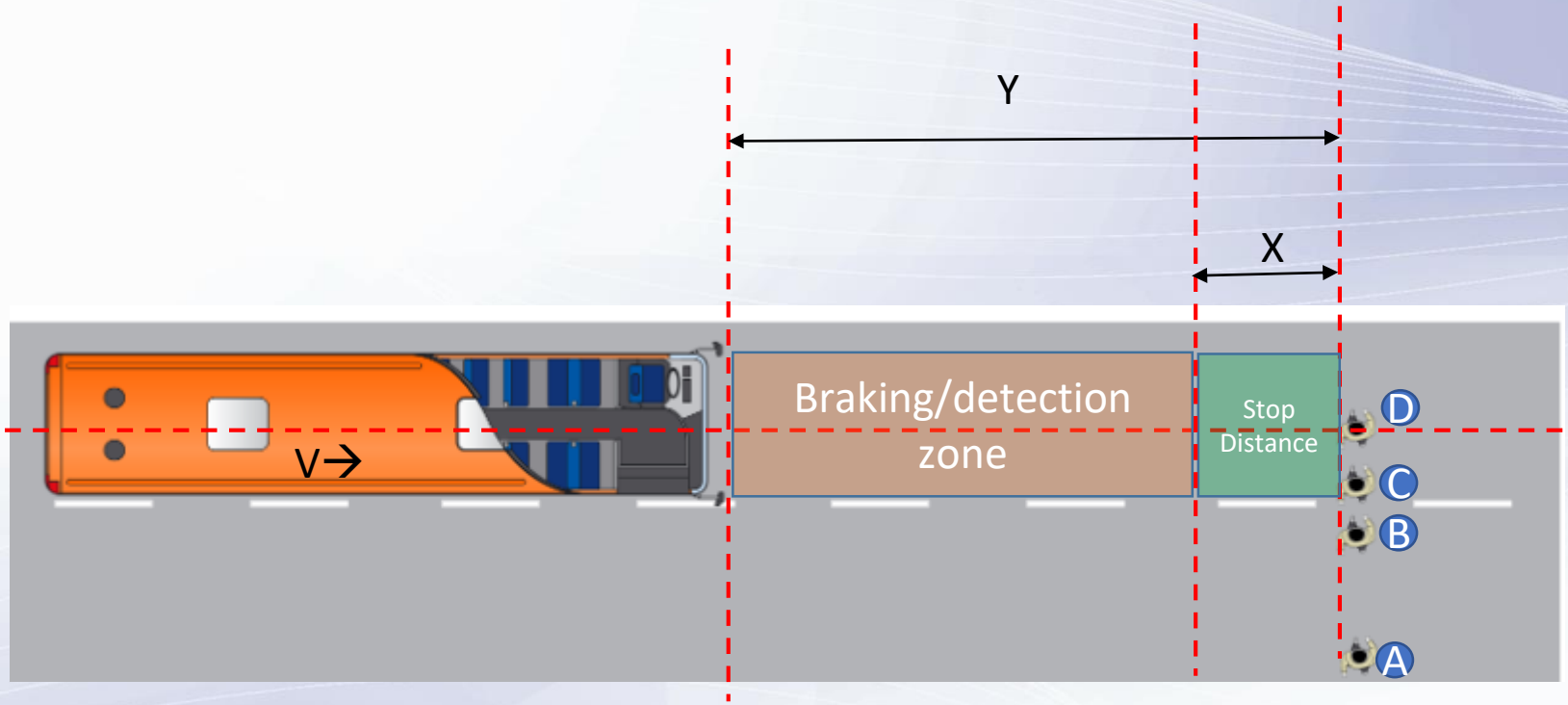
- What are they?
  - Rules and clarification to the driving license requirements as described in the Basic Theory of Driving and the Final Theory of Driving
- Why are they needed?
  - The driving license rules are written for human drivers, not engineers
  - Because desired driving behaviour is context sensitive, they driving license rules are not black or white.
    - “The driver shall indicate *in time* when changing lanes” (what is “in time”?)
    - “The driver shall pass a stationary object on the road with a gap of minimum 1.5m” (So if the 1.5 m gap is not feasible, do you stop and just wait till something makes it feasible?)
  - Some driving license rules can not be complied to with the current state of technology. Waiting till the technology is matured might not be a realistic option.
    - “The driver shall follow the hand signals of an authorised officer” (if AI can recognise all hand signals, can it differentiate between an authorised officer and a random person? And what if this random person is a citizen taking necessary action at an accident site until the police has arrived?)

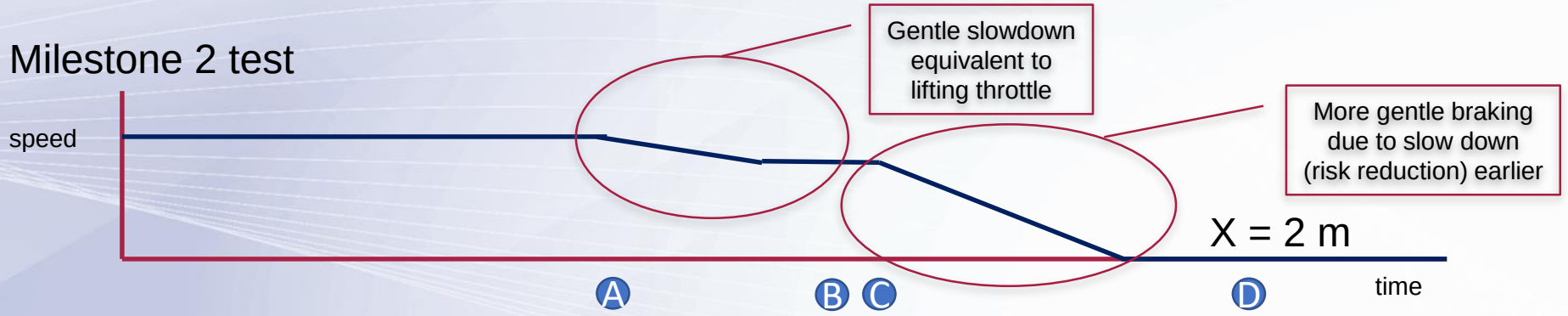
Challenges: what is the desired behaviour?



Milestone 1 test

Challenges: what is the desired behaviour?



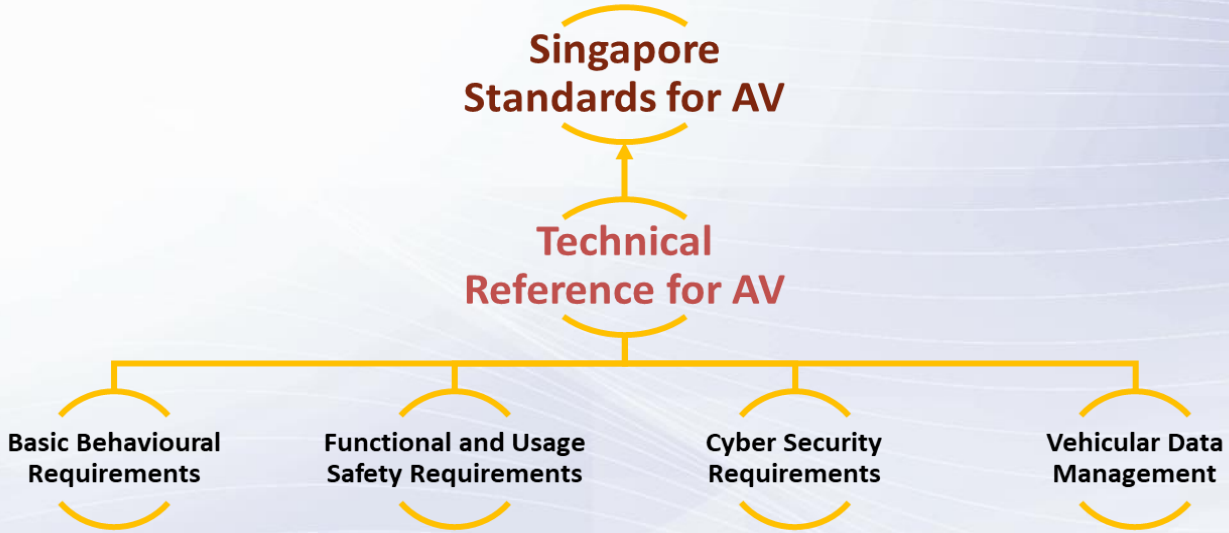


TECHNICAL REFERENCE

TR Development Timeline (subject to change)

- The Technical Reference will be adapted in legislation to regulate AV testing
- The Singapore Standard will be the basis of the technical legal requirements for future commercial deployment

Technical Reference



- Conduct of autonomous driving, including vehicle-to-vehicle interactions (AV-AV, AV-MV)
- Management of non-transferable rules, e.g. hand signs
- Aids to autonomous driving (e.g. special road signs and markings to augment AV ops)

- Functional safety for vehicular systems [e.g. Risk of wrong situation interpretation]
- Functional safety for occupants
- Usage safety (e.g. by misuse, by abuse, during ambiguity)
- Failure Handling (both functional and usage safety)
- In operation
- At standstill
- Singapore specific use cases (local environment customisation)

- Requirements/guidelines for security against unauthorised access to vehicle and AV-augmenting infrastructure
- Also to address the needs for operational functions like OTA updates, tele-operations, remote access, etc.
- Acceptable security protocols for V2X communication

- The necessity and the possibilities of an Event Data Recorder (EDR, 'black box')
- The ownership and how to avoid usage and manipulation of personal data
- The role of data for investigation and reporting of accidents and claim disputes
- How to use AV data reasonable and adequate, i.e. to continuously improve safety
- Management of dynamic content (e.g. HD mapping, road traffic info)

NTU-LTA-Volvo Autonomous Bus

Thank you