PH.D. in INDUSTRIAL ENGINEERING
Curriculum: Electronic Engineering
XXXIV CYCLE – N.S.

Università di Salerno
Dipartimento di
Ingegneria Industriale

PH.D DEFENSE

Advanced Driver Assistance Systems for Active Safety of Modern Tram

In partnership with Hitachi Rail STS SpA

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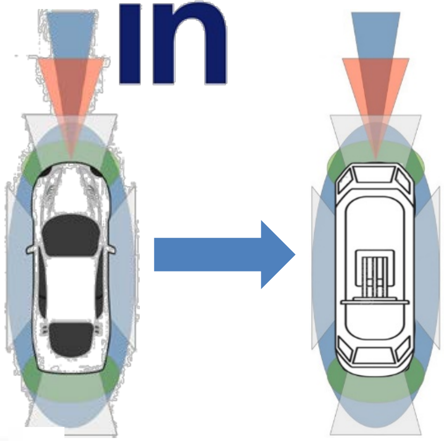
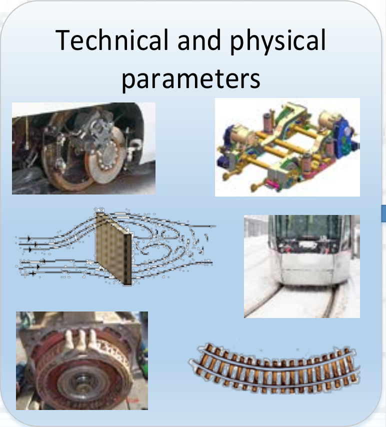
HITACHI
Inspire the Next

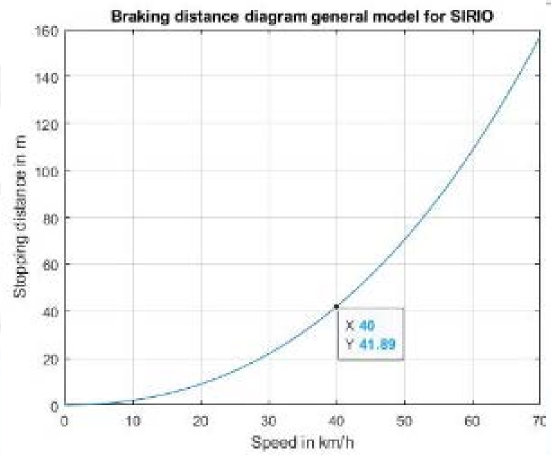
RESEARCH AIM

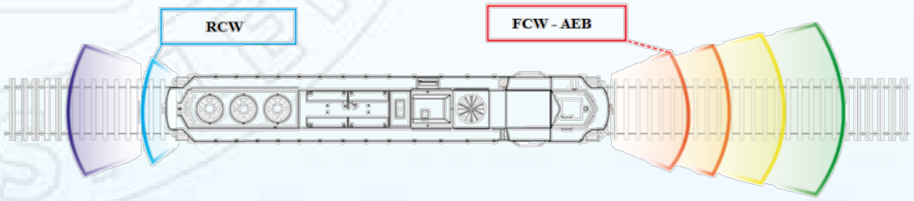


Starting from an automotive **ADAS**, to develop an **implementation** approach to ensure the **active safety of a tram** that takes into account the different **physical** and **dynamic** aspects and real-time adaptation data



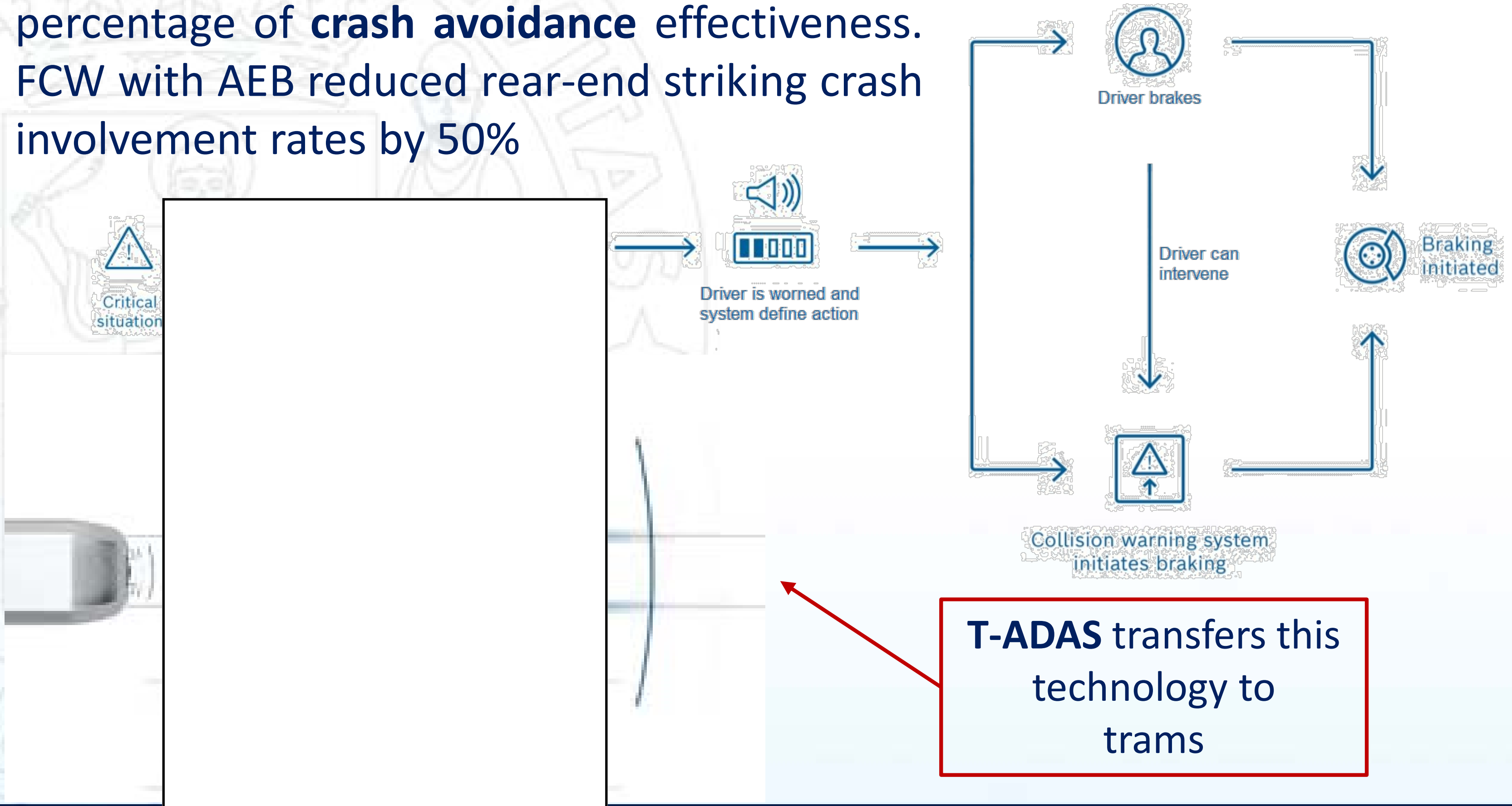
MODEL





RESEARCH AIM

Among the **automotive ADAS, FCW-AEB** represents the one with the highest percentage of **crash avoidance** effectiveness. FCW with AEB reduced rear-end striking crash involvement rates by 50%



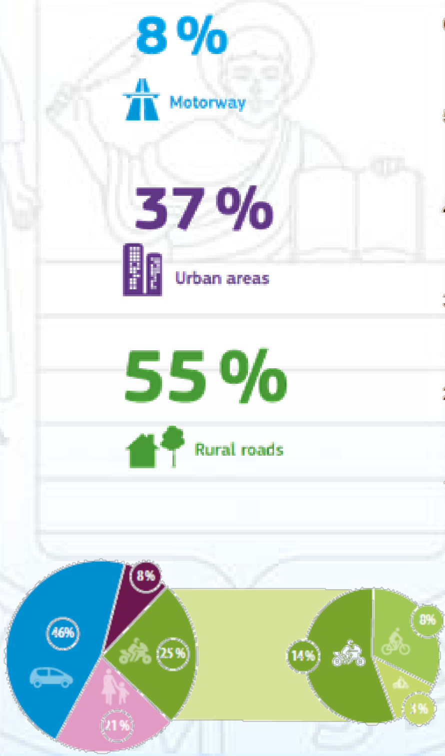
T-ADAS transfers this technology to trams

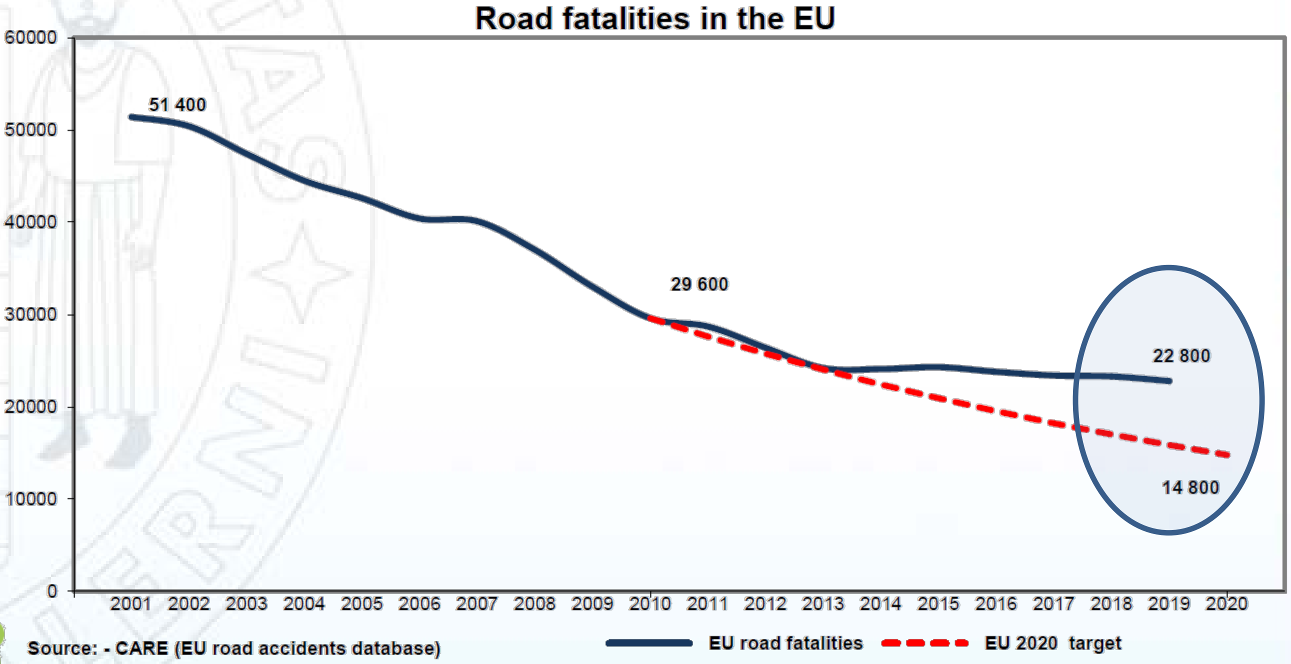
OUTLINE

- ❖ REFERENCE CONTEXT
- ❖ PROBLEM ANALYSIS
- ❖ SATE OF ART
- ❖ SPREAD ANALYSIS
- ❖ DCE MODEL
- ❖ CASE STUDY & RESULTS

REFERENCE CONTEXT

The **accident situation in Europe** is declining, but still far from EU objectives. More than 3/4th of these accidents are caused due to the driver's inability to judge the driving conditions



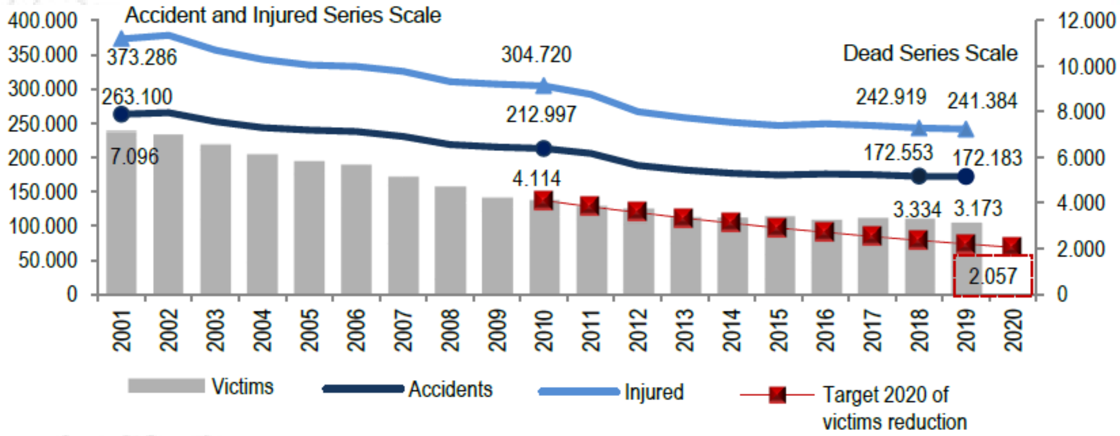

Road fatalities in the EU

Source: - CARE (EU road accidents database)

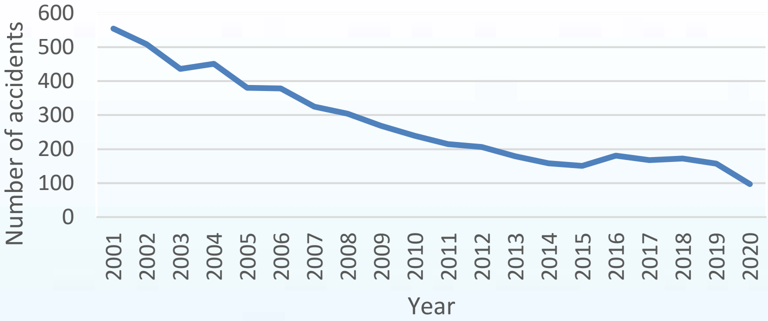
Source: CARE (EU road accidents database)

REFERENCE CONTEXT

The **Italian situation** follows the European trend. Here too the target set in 2020 was missed

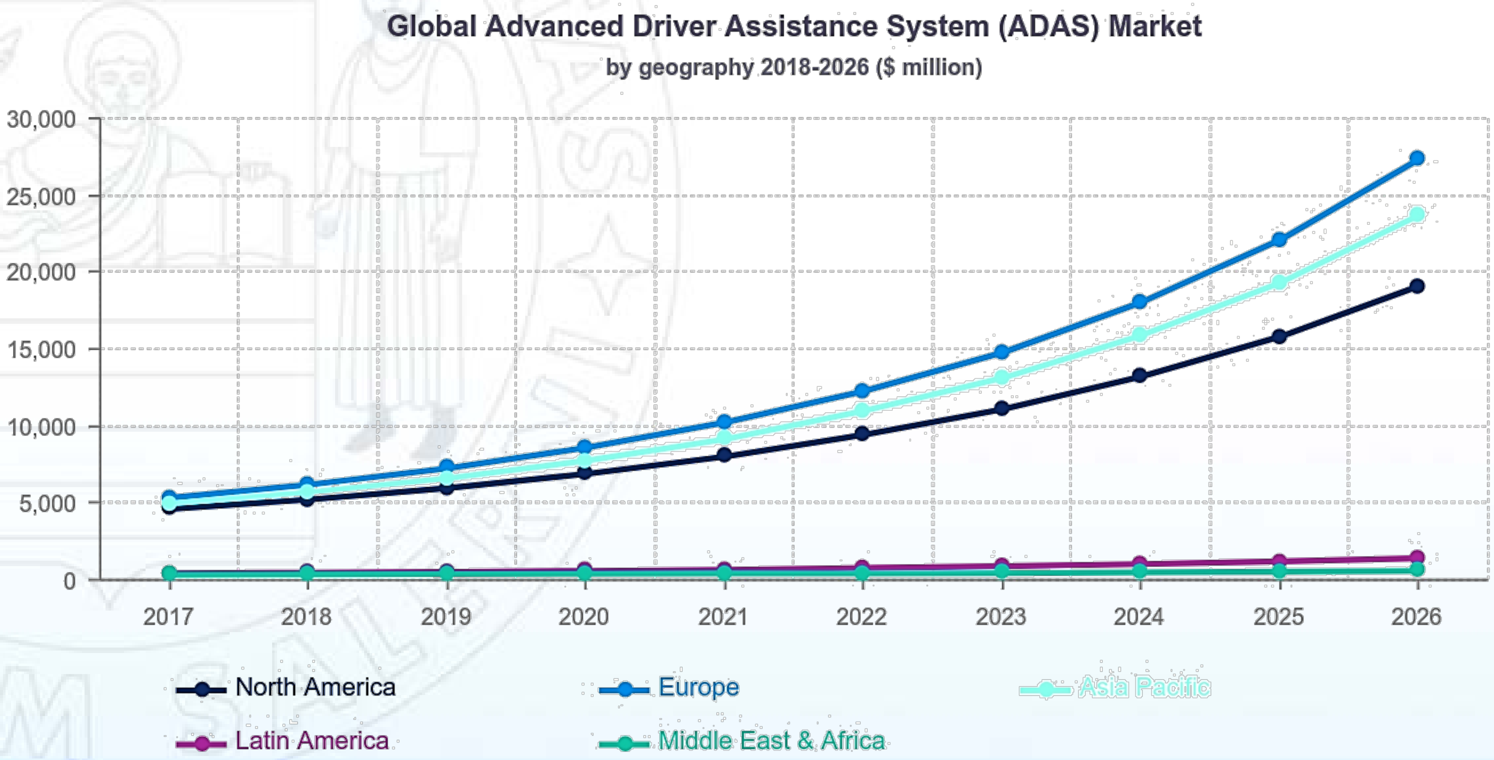


With focus on the Italian scenario that involves the tram, trend accidents has dropped by about 70%. The contribution lies in the investments for the increase of reserved lanes and the replacement of the fleet with more modern means.



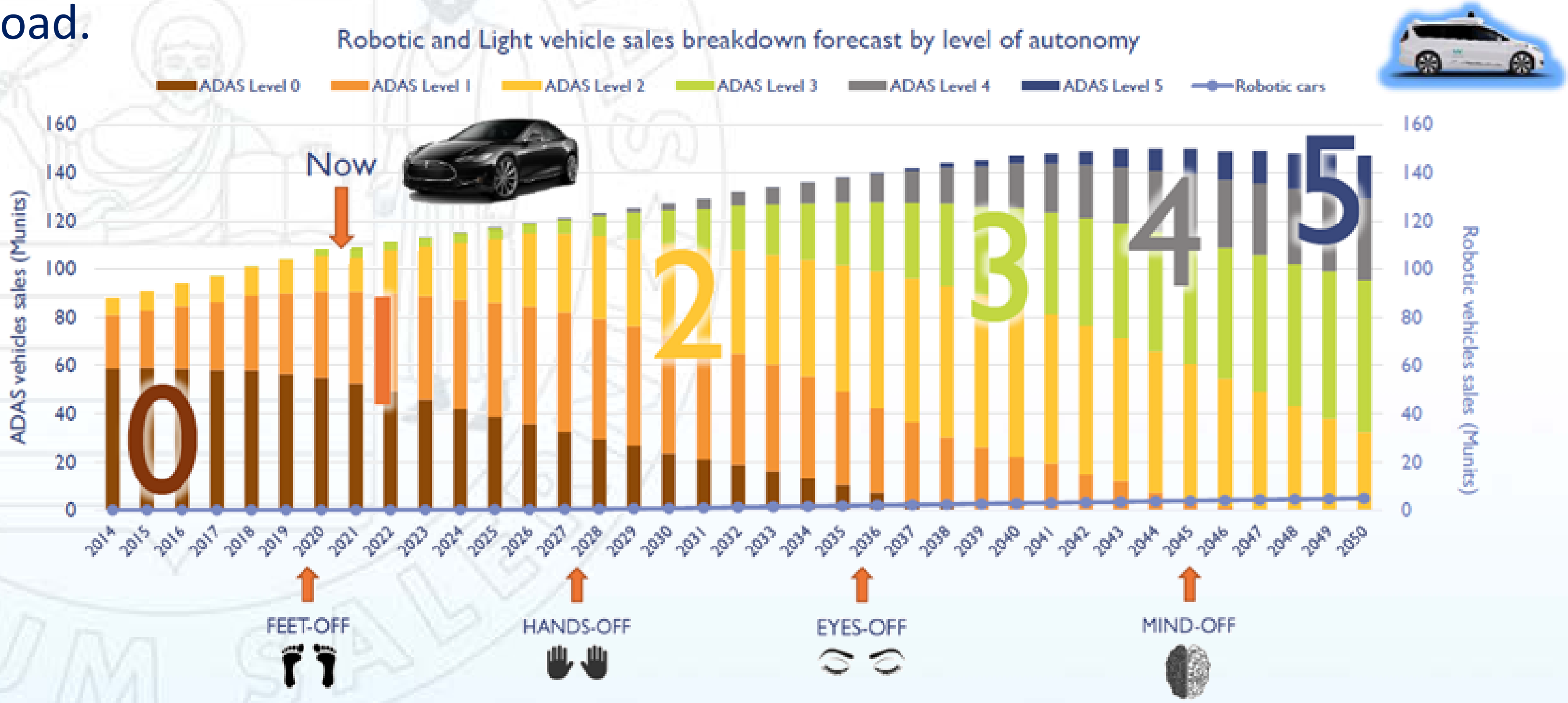
REFERENCE CONTEXT

The **European committees**, more than others in the world, are **pushing for** technological solutions to **increase road safety**. The focal point are **ADAS as a key to avoid** any spontaneous **error** by the **driver**



REFERENCE CONTEXT

SAE International defines six Levels of Driving Automation: from SAE Level 0 (no automation) to SAE Level 5 (full vehicle autonomy). In a global context, more than 20% of the cars today are sold with SAE Level 2. Compared to 2014, in 2050 there will be about 40% more cars on the road.



PROBLEM ANALYSIS

Urban travel by mode group

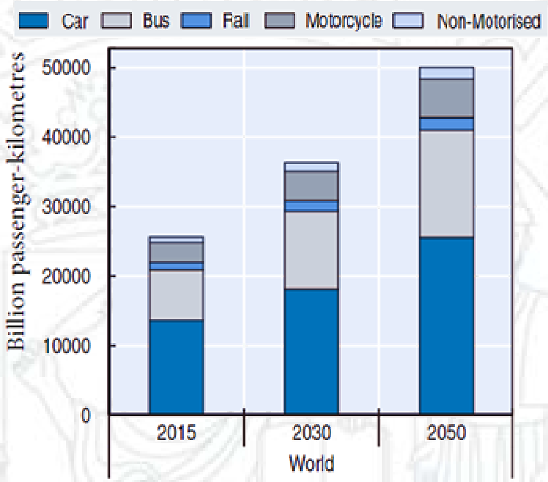
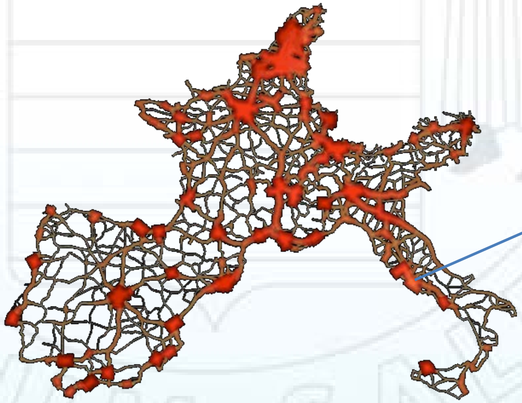


Image Source : OCSE

Private vehicles are currently the preferred mode of travel worldwide. The additional cars will be driving on already congested roads **increasing the levels of pollution** and infrastructure maintenance. Public transport systems as **trams** can improve accessibility and **reduce CO_2 emissions** responding to growing passenger transport demand in urban regions.

An average of 1.3 passengers travels per car	
If 48 people moved by car	If 124 people moved by SIRIO Tram (20,2 m long)*
	



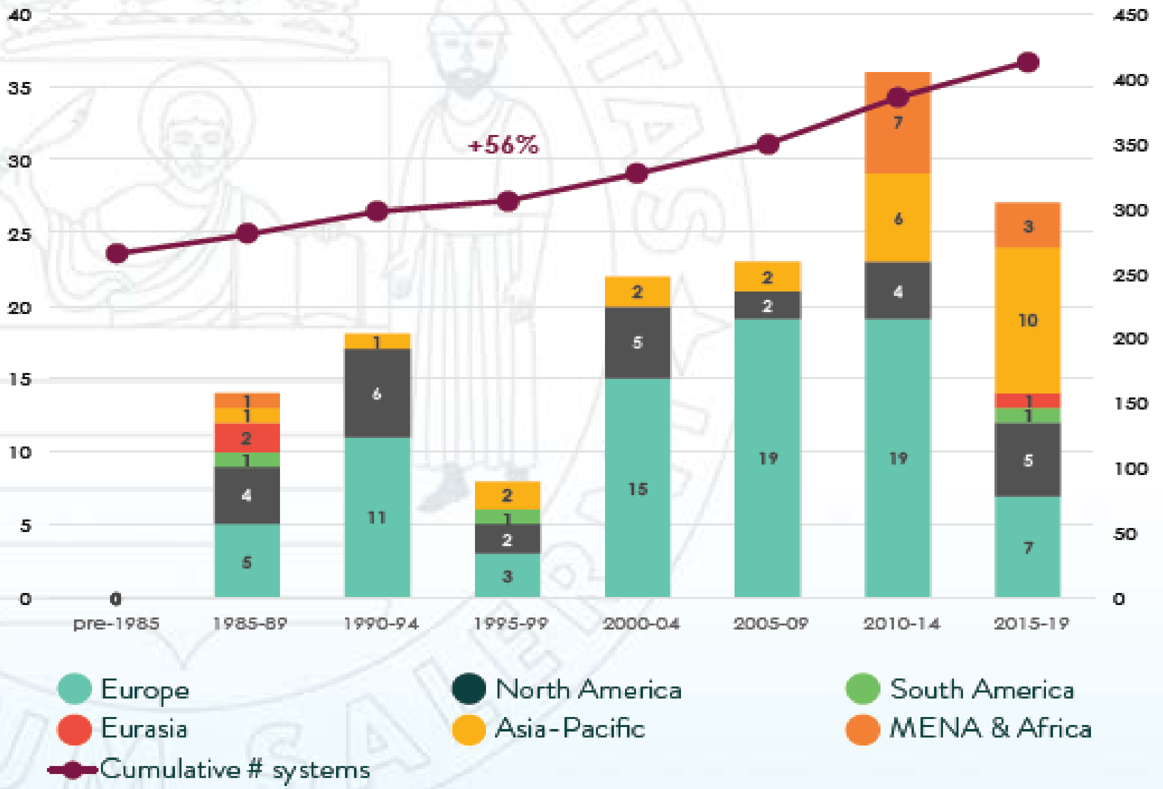
Traffic flow in western Europe

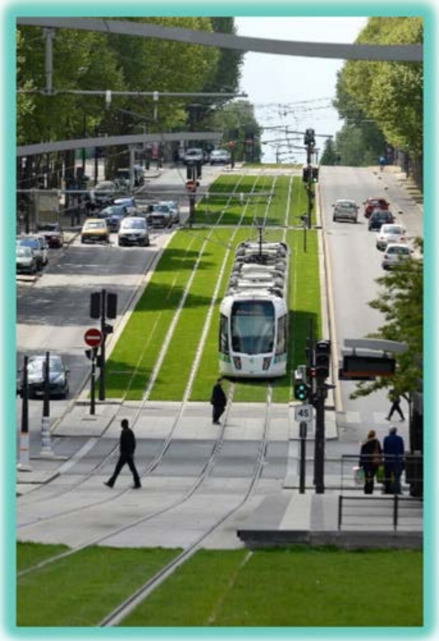
Rome: by car it takes 40% more time to travel the same stretch without traffic.

* Before art. 1 of the Dpcm of 8 March 2020

PROBLEM ANALYSIS

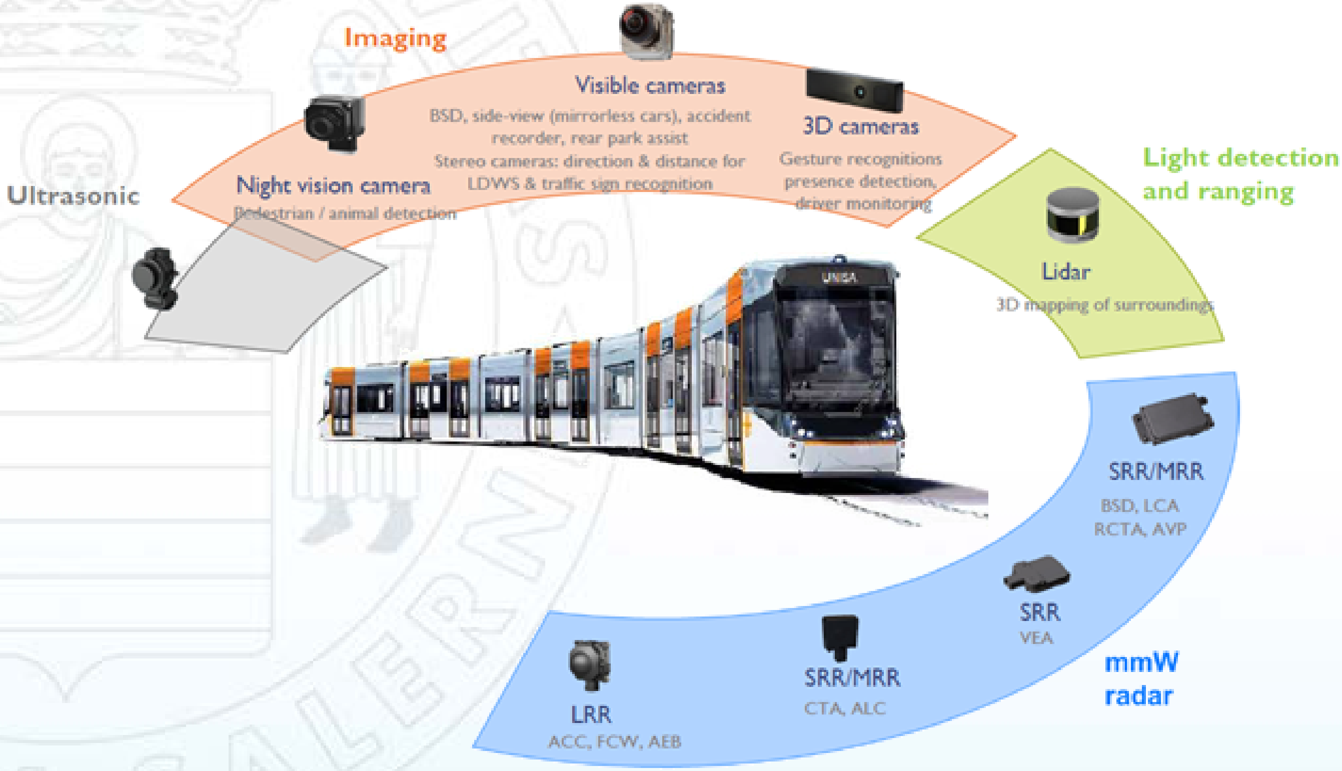
LRT and trams have enjoyed a renaissance since the new millennium, with more than 108 new cities (re)opening their first line. Europe is a leader in LRT and trams development with 60 ex novo systems





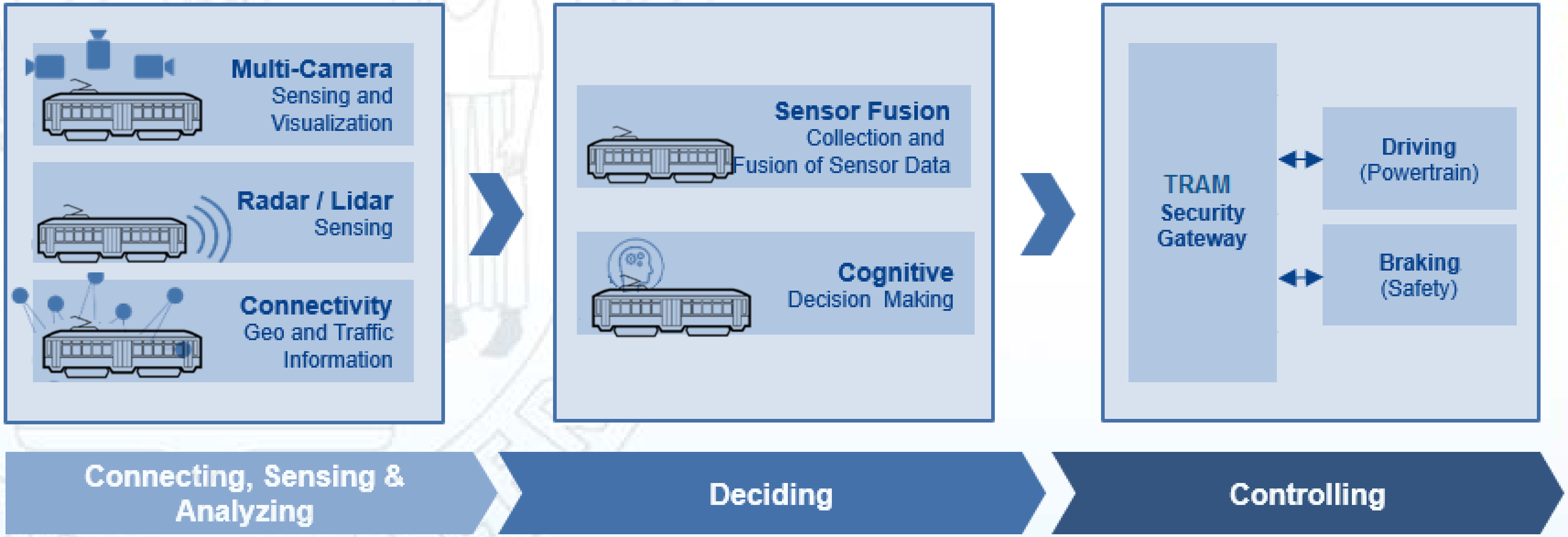
PROBLEM ANALYSIS

It is possible to imagine **a new generation** (or revamping) of trams that **exploits** the existing **ADAS** sensors and technologies



PROBLEM ANALYSIS

An adjustment of the **algorithms** must occur in order to design and to develop a Common Perception Platform which **considers** the **different parameters** of the tram allows an easy and flexible adaptation of the different sets of sensors that from the car can be installed on the tram.



Multi-Camera Sensing and Visualization

Radar / Lidar Sensing

Connectivity Geo and Traffic Information

Sensor Fusion Collection and Fusion of Sensor Data

Cognitive Decision Making

TRAM Security Gateway

Driving (Powertrain)

Braking (Safety)

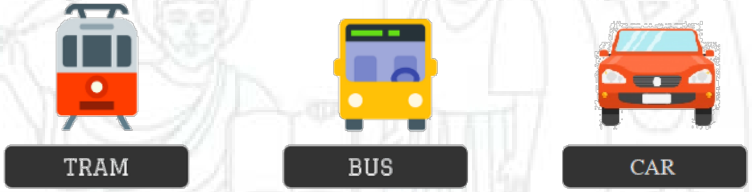
Connecting, Sensing & Analyzing

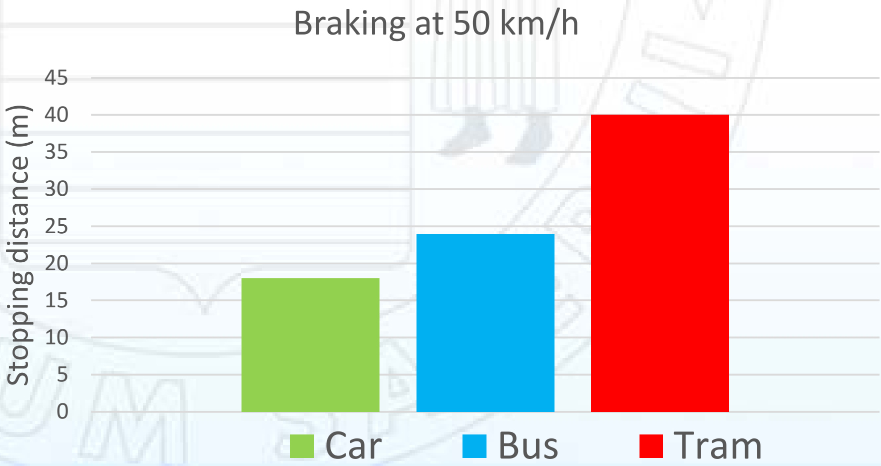
Deciding

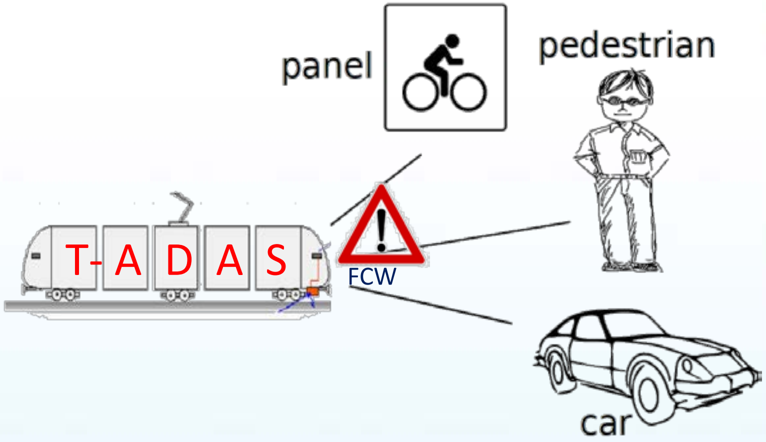
Controlling

PROBLEM ANALYSIS

When the ego vehicle has much **longer braking distances** the **FCW** system **warns** the driver too **late** and the risk of rear-end collision increases. The FCW system must be **re-parameterized** according to the characteristics of each vehicle

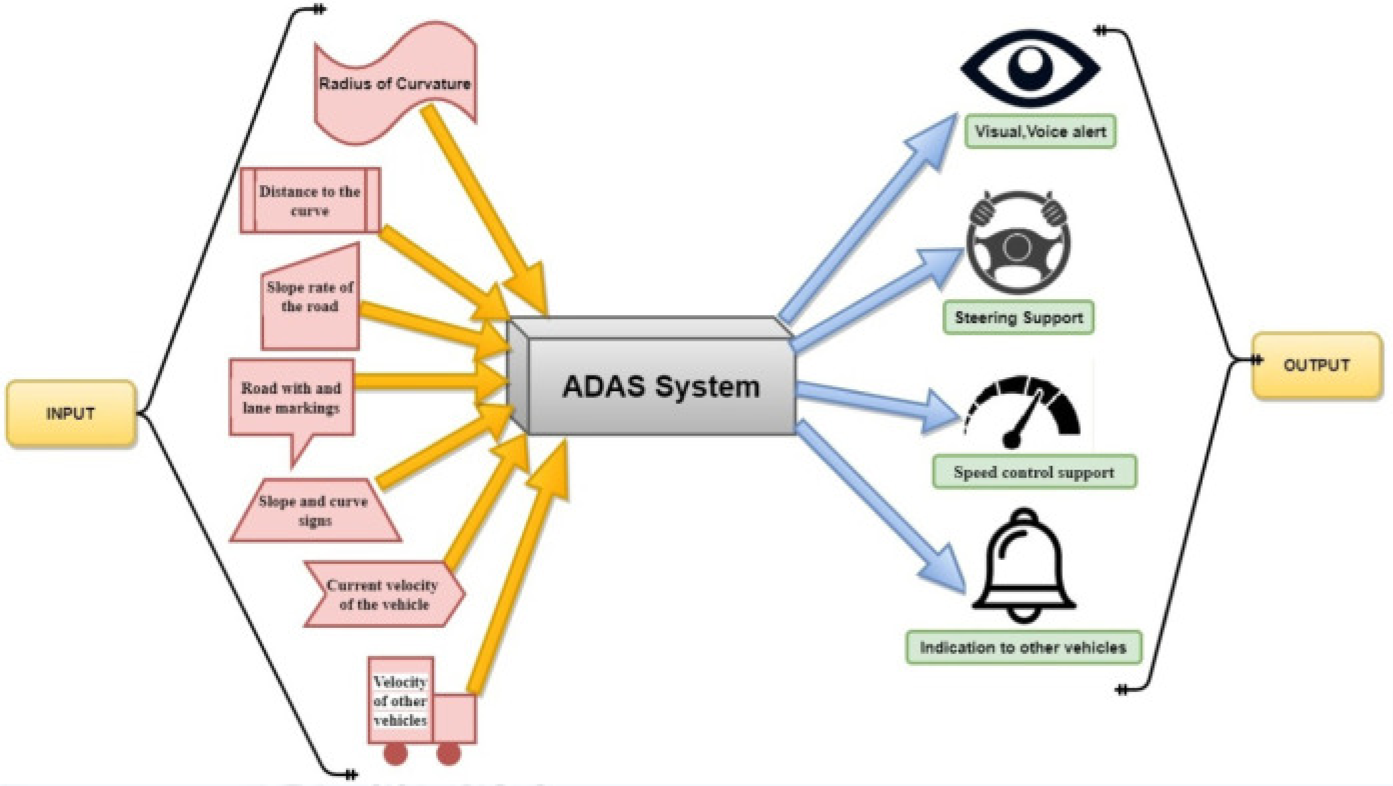






STATE OF ART

When



INPUT

Radius of Curvature

Distance to the curve

Slope rate of the road

Road with and lane markings

Slope and curve signs

Current velocity of the vehicle

Velocity of other vehicles

ADAS System

Visual,Voice alert

Steering Support

Speed control support

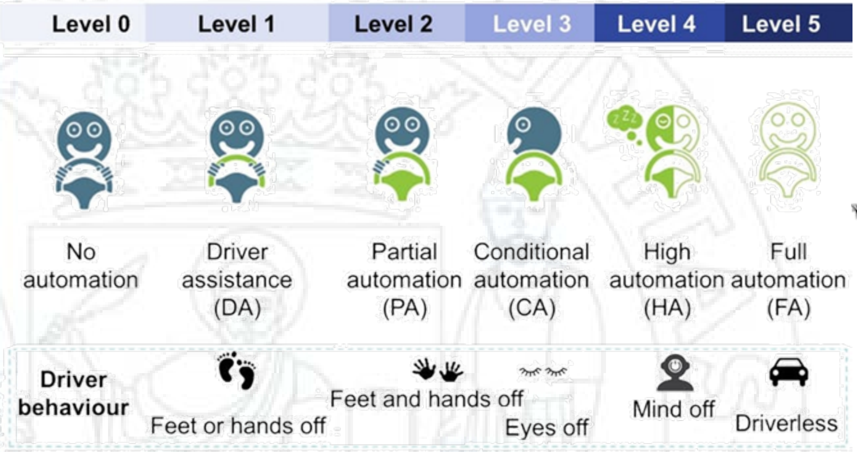
Indication to other vehicles

OUTPUT

STATE OF ART

When

WORK IDEA



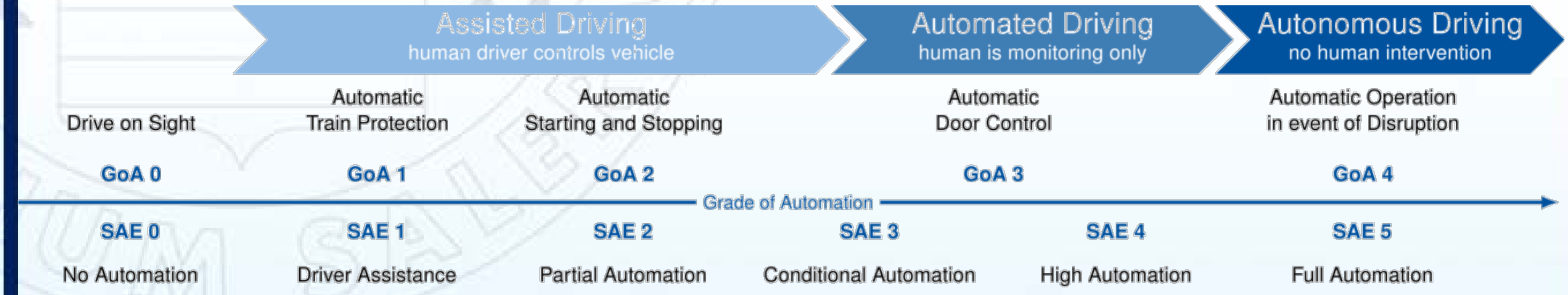
Automotive

VS

No automation	Manual	GoA 0
ATP	ATP Manual	GoA 1
ATO	STO	GoA 2
	DTO	GoA 3
	UTO	GoA 4

Rail

It is not possible to define a one-to-one correlation between SAE e GoA levels



	Assisted Driving human driver controls vehicle		Automated Driving human is monitoring only		Autonomous Driving no human intervention
Drive on Sight	Automatic Train Protection	Automatic Starting and Stopping	Automatic Door Control		Automatic Operation in event of Disruption
GoA 0	GoA 1	GoA 2	GoA 3		GoA 4

Grade of Automation

SAE 0	SAE 1	SAE 2	SAE 3	SAE 4	SAE 5
No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation

SPREAD ANALYSIS

Grade of Automation improvement for trams

Tram now

Grade of Automation (GoA)	Type of train operation	Manipulator	TSR	FCW/ AEB	ACC	Smart Vigilance (DMS)	Door side control	Overspeed control	Dead man's switch
GoA 0	Driver without **ADAS** and ATP	Driver	Driver	Driver	Driver	Driver	Driver	Driver	On
GoA 1	Driver with **ADAS** (replace ATP)	Driver	T-ADAS	Driver	Driver	Driver	Driver	T-ADAS	On
GoA 2	Driver with **ADAS** (replace ATP and ATO)	Driver	T-ADAS	T-ADAS	Driver	Driver	Driver	T-ADAS	On
GoA 2.1	Driver with **ADAS** (replace ATP and ATO)	Driver	T-ADAS	T-ADAS	Driver	Driver	T-ADAS	T-ADAS	On
GoA 2.2	Driver with **ADAS** (replace ATP and ATO)	Driver/T-ADAS	T-ADAS	T-ADAS	T-ADAS	Driver	T-ADAS	T-ADAS	On
GoA 2.3	Driver with **ADAS** (replace ATP and ATO)	Driver/T-ADAS	T-ADAS	T-ADAS	T-ADAS	T-ADAS	T-ADAS	T-ADAS	Off

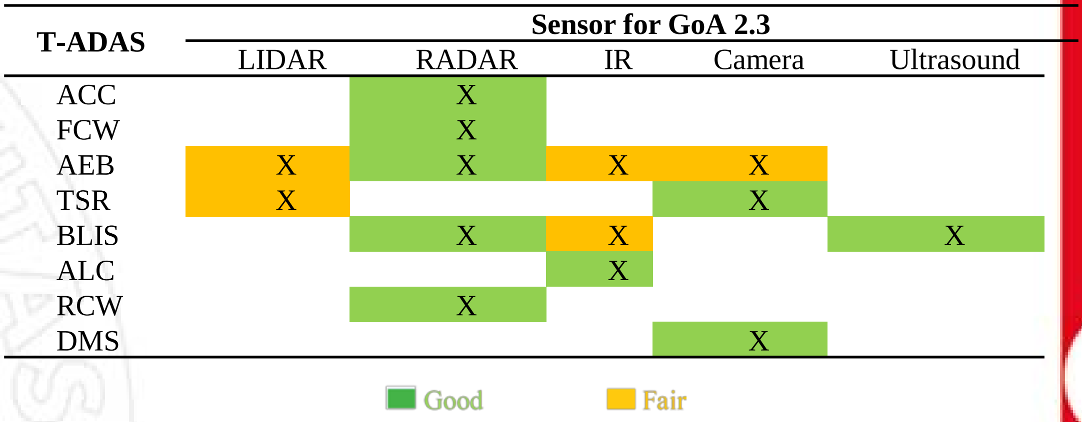
🟩 Automation

🟨 Manual

SPREAD ANALYSIS

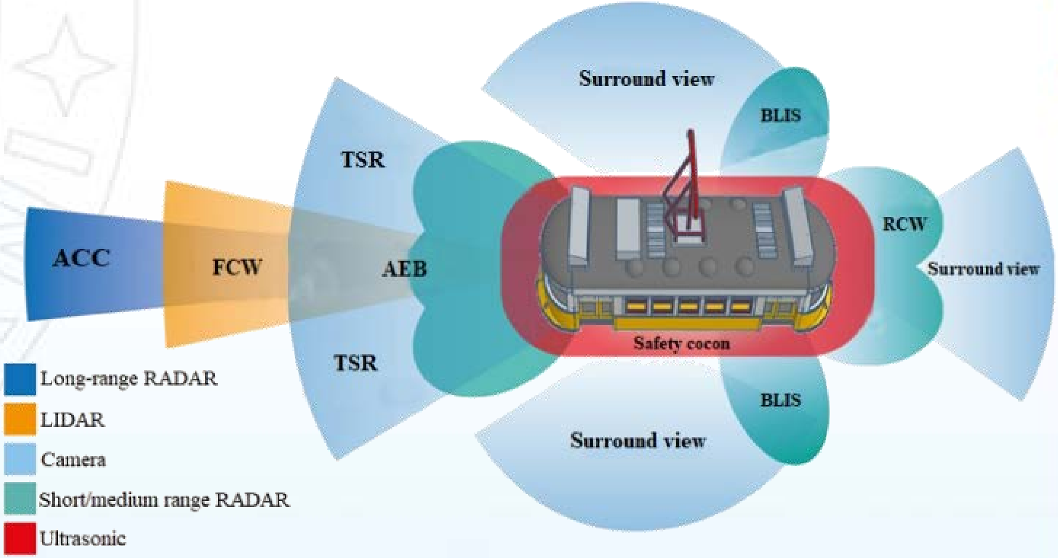
From the analysis of the technological porting, it emerges that only a part of the automotive ADAS is reasonably transferable to the tram.

Key sensors used in perception platforms for ADAS applications allows tram perception security cocoons formation.



T-ADAS	Sensor for GoA 2.3				
	LIDAR	RADAR	IR	Camera	Ultrasound
ACC		X 🟩			
FCW		X 🟩			
AEB	X 🟨	X 🟩	X 🟨	X 🟨	
TSR	X 🟨			X 🟩	
BLIS		X 🟩	X 🟨		X 🟩
ALC			X 🟩		
RCW		X 🟩			
DMS				X 🟩	

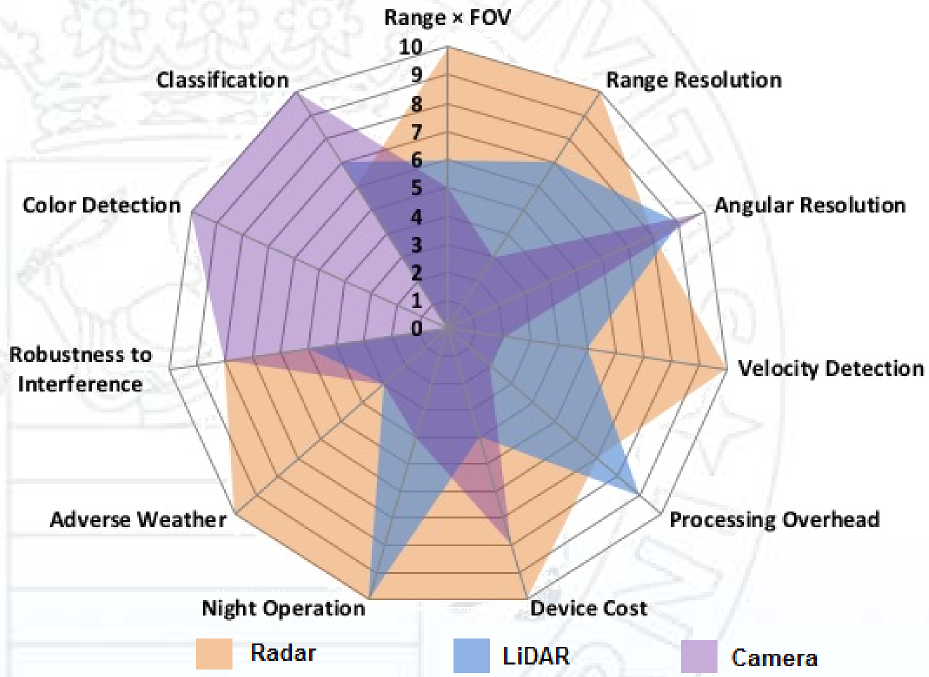
🟩 Good 🟨 Fair



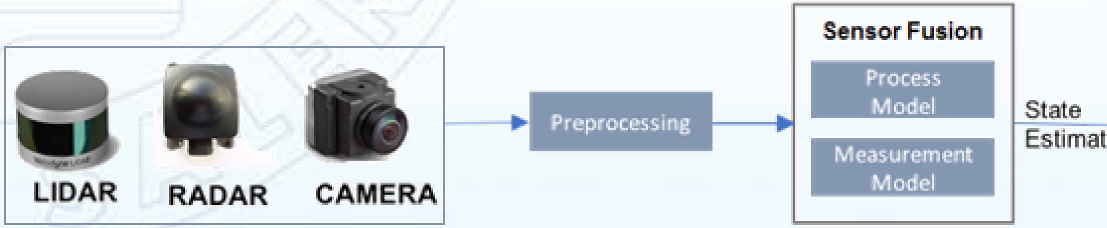
SPREAD ANALYSIS

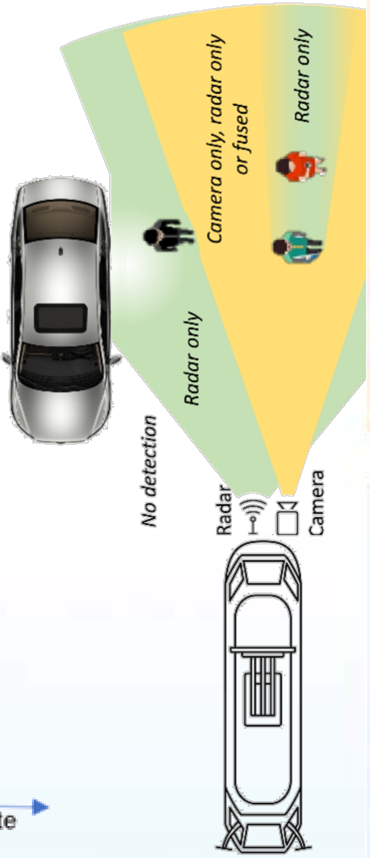
VALUTA SE TOGLIERE

In order to best perform all ADAS functions, a sensor fusion is necessary



- The camera can see where the radar does not see and vice versa
- Sensor fusion is needed

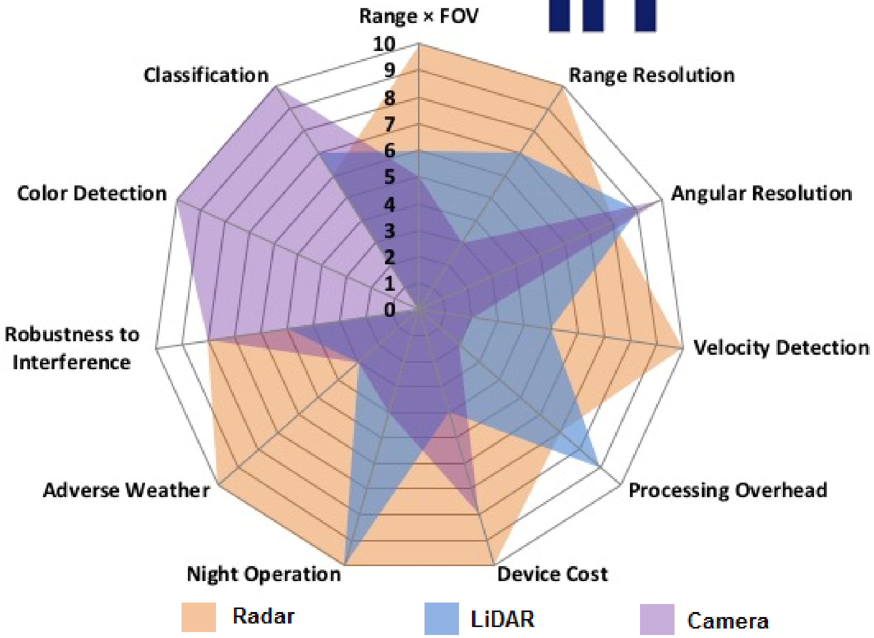


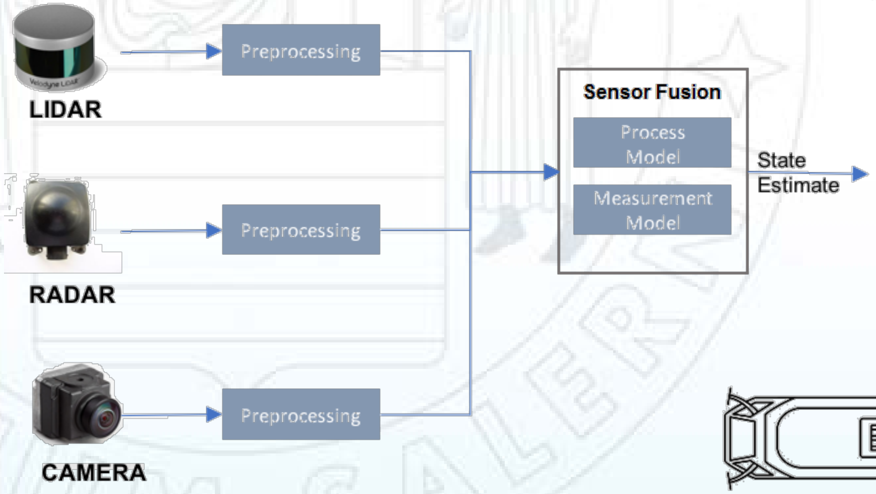


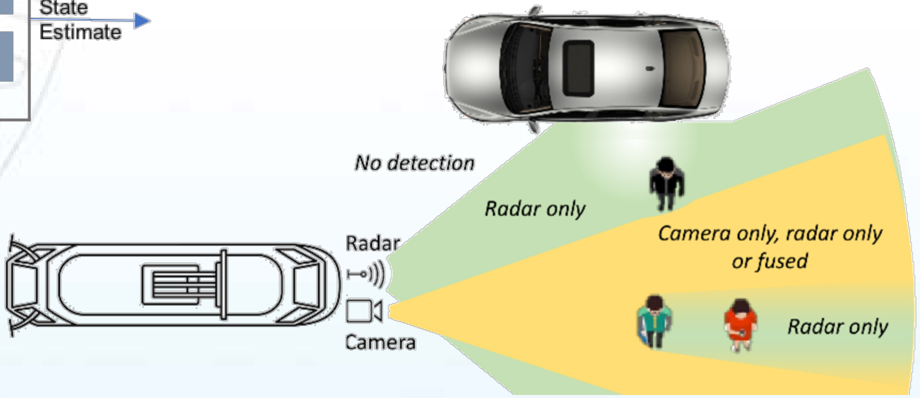
SPREAD ANALYSIS

VALUTA SE TOGLIERE

- To best perform all ADAS functions, a **sensor fusion** is necessary
- The **camera** and **lidar** can see where the **radar** does not see and vice versa







SPREAD ANALYSIS

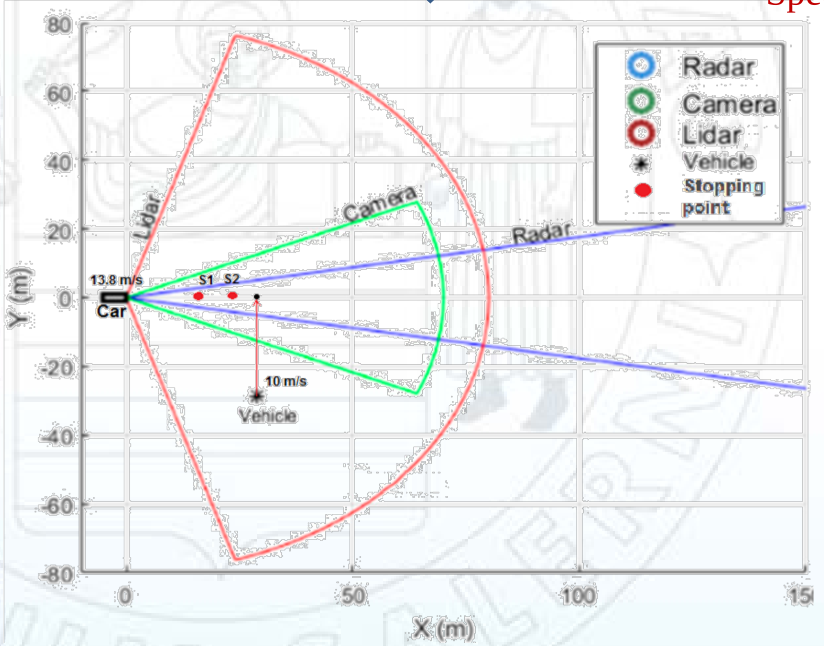
Euro NCAP, 2020

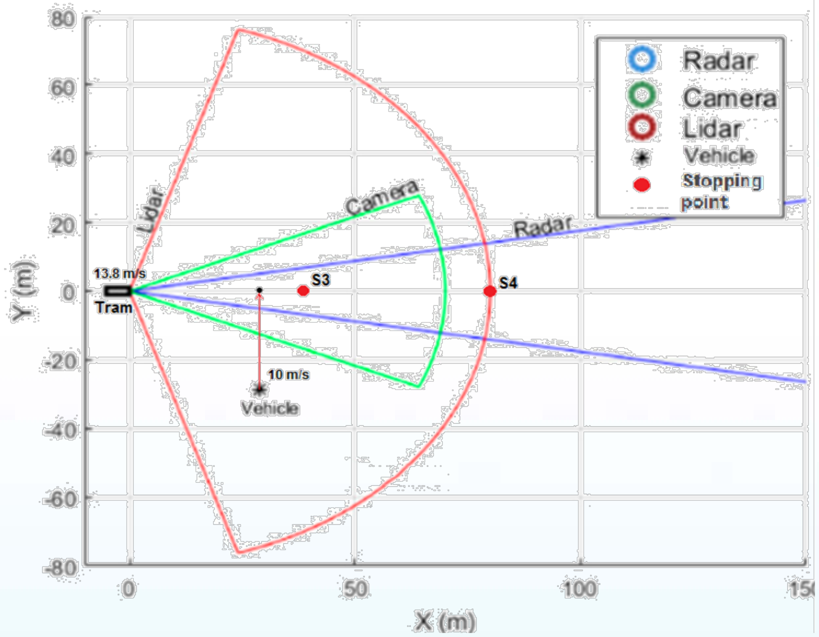
Car–vehicle dangerous simulation scenario for service (S2) and emergency (S1) braking

EN 13452-1, 2003

Tram–vehicle dangerous simulation scenario for service (S4) and emergency (S3) braking

Speed 13 m/s

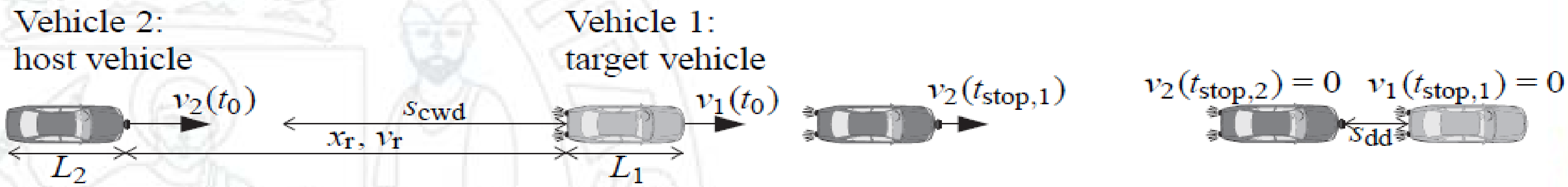




At the same speed, the dynamics of the tram require sensors with higher FOV an range

TYPICAL FCW ALGORITHMS

Forward vehicle collision warning systems (ISO 15623:2013) requirements for cars can be based on acceleration, braking distance, or Time to Collision



$$a_{dec} = \frac{a_t v_{host}^2}{2\, a_t (t_{man}\, v_{host} - x_{head} + s_{dd}) + v_t^2} \qquad if\ t_{t,stop} \leq t_{host,stop}$$

$$s_{cwd} = v_{host}\, t_{man} + \frac{1}{2} a_{host}\, t_{man}^2 - \frac{(v_{host} + a_{host} t_{man})^2}{2\, a_{host,max}} + \frac{{v_t}^2}{2\, a_t} + s_{dd} \qquad if\ t_{t,stop} \leq t_{host,stop}$$

$$t_{TTC} = \frac{-v_{head}(t) \pm \sqrt{v(t)_{head}^2 - 2 x_{head}(t) a_{head}(t)}}{a_{head}(t)}$$

Time to Collision is the most widely used algorithm for FCW-AEB systems

RAILWAY BRAKING MODELS

In the railway literature, several models make it possible to calculate the stopping distance for trains and light trains such as trams. However, the sector regulations must always be followed, in the case of trams the reference is EN 13452-1

EN 13452-1

$$S_{EN} = v_0 t_e + \frac{{v_0}^2}{2a_e}$$

Light rail

Pedeluc model

$$S_P = \frac{{v_0}^2}{\frac{1.09375\lambda_c}{\varphi(v_0)} + \frac{0.127}{\varphi(v_0)} \pm 0.235 i_{‰}}$$

General rail

The RFI braking model

$$S_{RF} = (h + t_f)V_i + \frac{(V_i - V_0)^2}{2(d_p + d_i)}$$

General rail

Converges to →

Semi empirical model

$$S_E = (h + t_f)V_i + \frac{(V_i - V_0)^2}{2 f_a g}$$

General rail

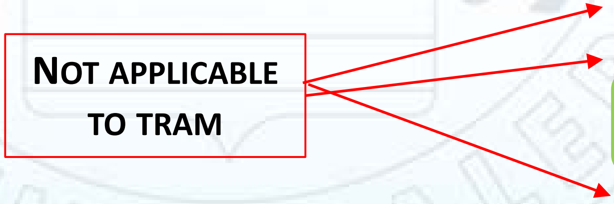
RAILWAY BRAKING MODELS

EN 13452-1

$$S_{EN} = v_0 t_e + \frac{{v_0}^2}{2a_e}$$

In the specific case of the tram, the **operating**, **security** and **emergency braking** with the aid of a magnetic track brake (Emergency 3) must be considered

Parameter	Service	Em. 1	Em. 2	Em. 3	Em. 4	Security
Minimum deceleration a_e	0 ÷ 1.2	1.2	1.2	2.8	2.8	1
Maximum equivalent response time t_e	1.5	1.5	1.5	0.85	0.87	2



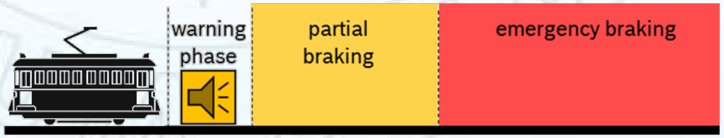
NOT APPLICABLE TO TRAM

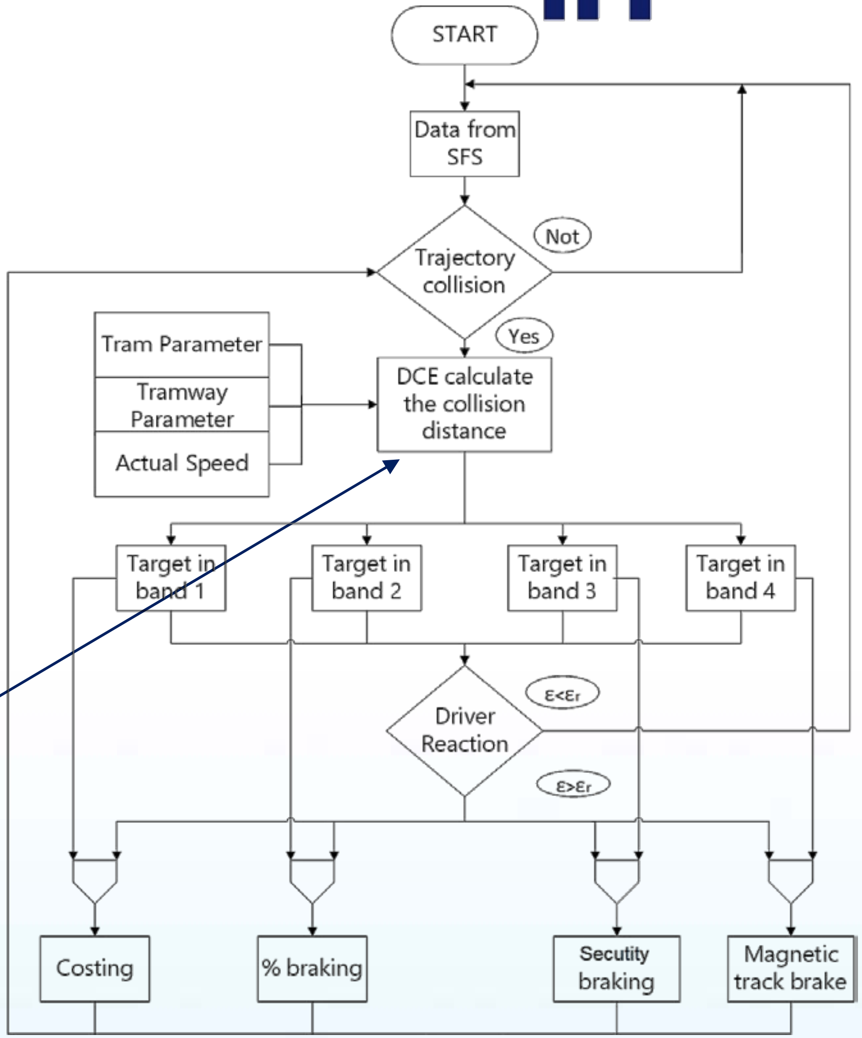
EMERGENCY BRAKING TYPE	PRINCIPAL MEANS OF INITIATION
Emergency 1	Driver vigilance, or ATO
Emergency 2	Passenger alarm
Emergency 3	Driver, via dedicated position on brake controller, or ATP system
Emergency 4	Authorised person via control separate from brake controller

DCE MODEL

- Sensor Fusion System collect environment data and analyse potential trajectory of collision
- Dynamic tram and tramway parameter are collected
- DCE model calculates safety distance classifying the target in a safety band
- Evaluation of driver reaction occurs
- System perform braking action

$$S_{DCE} = S_r + S_f + S_w$$





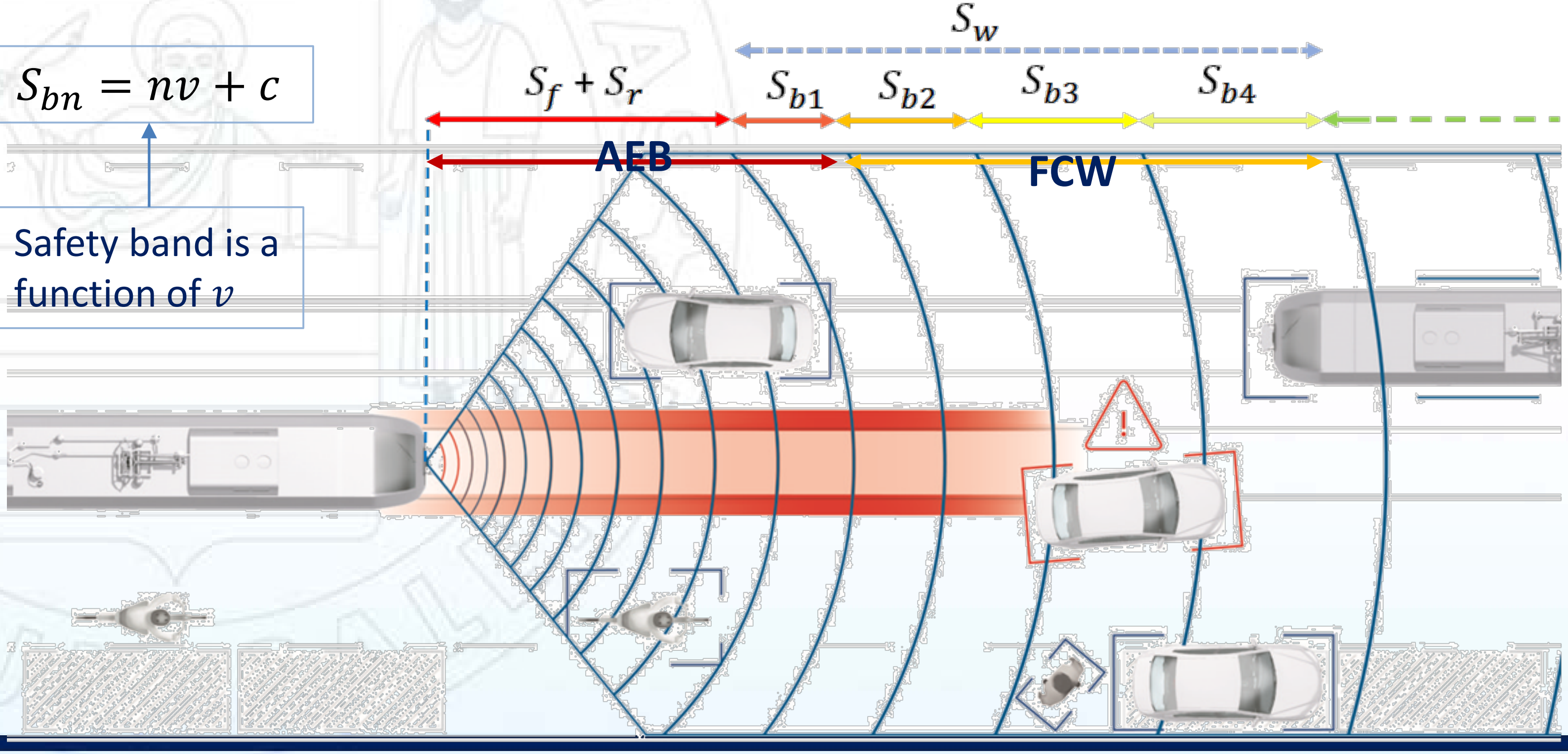
DCE MODEL

Warning distance is the space where the system provides warnings and corrective actions but does not trigger emergency braking

$$S_{DCE} = S_r + S_f + S_w$$

$$n = \frac{S_{bmax} - S_{bmin}}{v}$$

The maximum value of S_w is linked to the range of the sensors.



$$S_{bn} = nv + c$$

Safety band is a function of v

DCE MODEL

Braking distance formulation

$$\boxed{-F_f - R = m_e \frac{dv}{dt}}$$

$$m_e = m \cdot (1+\beta)$$

$$\beta = 0.04 + (0.7 \div 0.8)\frac{N}{M} r^2$$

The coefficient of the rotating masses $\boldsymbol{\beta}$ depends on the vehicle

$$ds = -m_e \frac{v}{F_f + R} dv \Rightarrow S_f = \int_0^{S_f} ds = -m_e \int_{v_0}^{0} \frac{v}{F_f + R} dv = m_e \int_0^{v_0} \frac{v}{F_f + R} dv$$

$$S_f = (1+\beta)\frac{P}{g}\int_0^{v_0} \frac{v}{F_f + R_p + R_c + R_{ae} + R_{rr} + R_{bp} + R_{wg}} dv$$

Shown all the resistance to motion

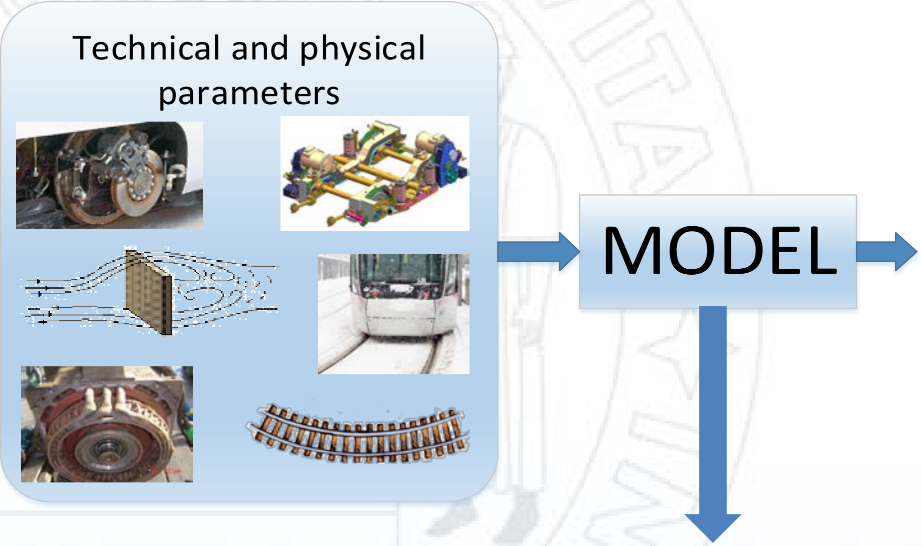
Negligible

$$\Downarrow$$

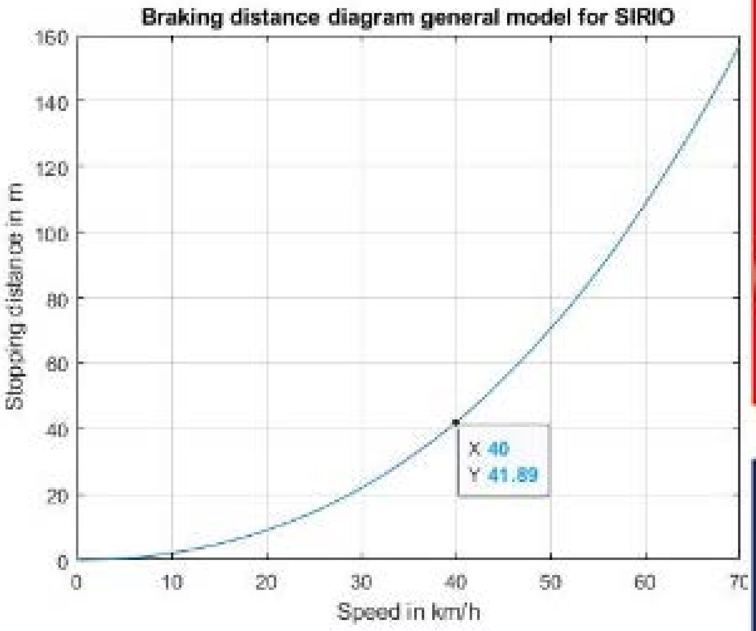
$$\boxed{S_f = \frac{(1+\beta)}{g}\int_0^{v_0} \frac{v}{f'0.7\lambda_c + \left(\frac{0.675 + \frac{125}{P_a} + 0.009v}{10^3} + \frac{\frac{a}{\mathcal{R} - b}}{10^3} + \frac{kSv^2}{P} \pm \frac{i_{‰}}{10^3}\right)} dv}$$

DCE MODEL

Setting technical and physical parameters of Sirio™ tram we obtain a braking curve.


Technical and physical parameters

MODEL



$$S_f = \frac{(1+\beta)}{g}\int_0^{v_0} \frac{v}{f'0.7\lambda_c + \left(\frac{0.675 + \frac{125}{P_a} + 0.009v}{10^3} + \frac{\frac{a}{\mathcal{R}-b}}{10^3} + \frac{kSv^2}{P} \pm \frac{i_{‰}}{10^3}\right)}\,dv$$

MODELS COMPARISON

Theoretical braking performance comparison on dry and wet tramways in the plains

EN 13452-1

$$S_f = v_0 t_e + \frac{{v_0}^2}{2a_e}$$

Pedeluc model

$$S_c = \frac{{v_0}^2}{\frac{1.09375\lambda_c}{\varphi(v_0)} \quad (v_0) \pm 0.235 i_{‰}}$$

Overestimates

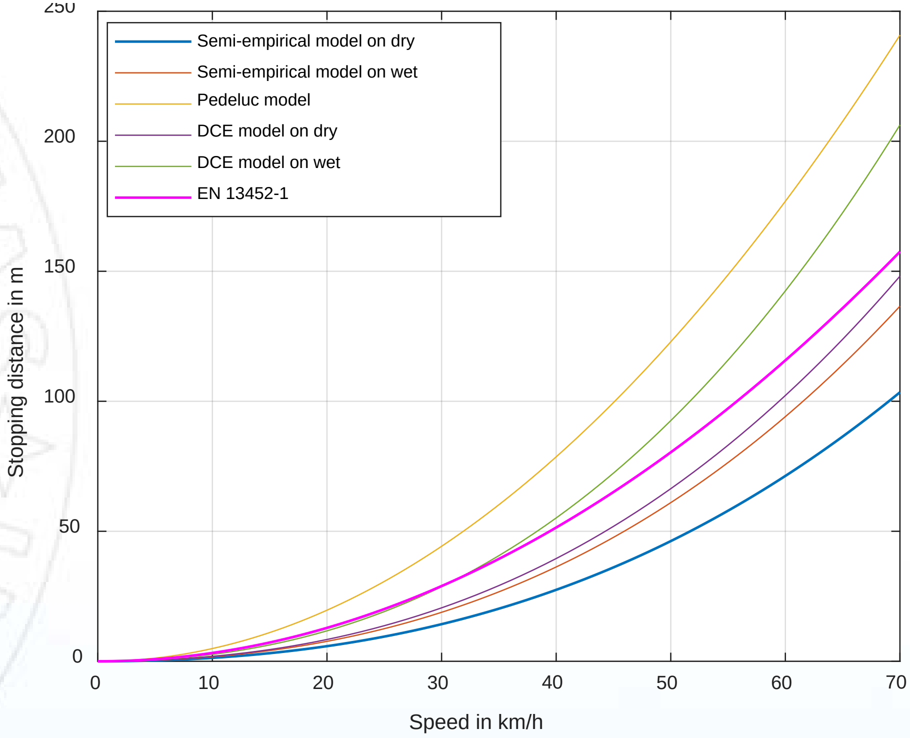
Semi empirical model

$$S_c = (h + t_f)V_i + \frac{(V}{\quad ag} -$$

Underestimate

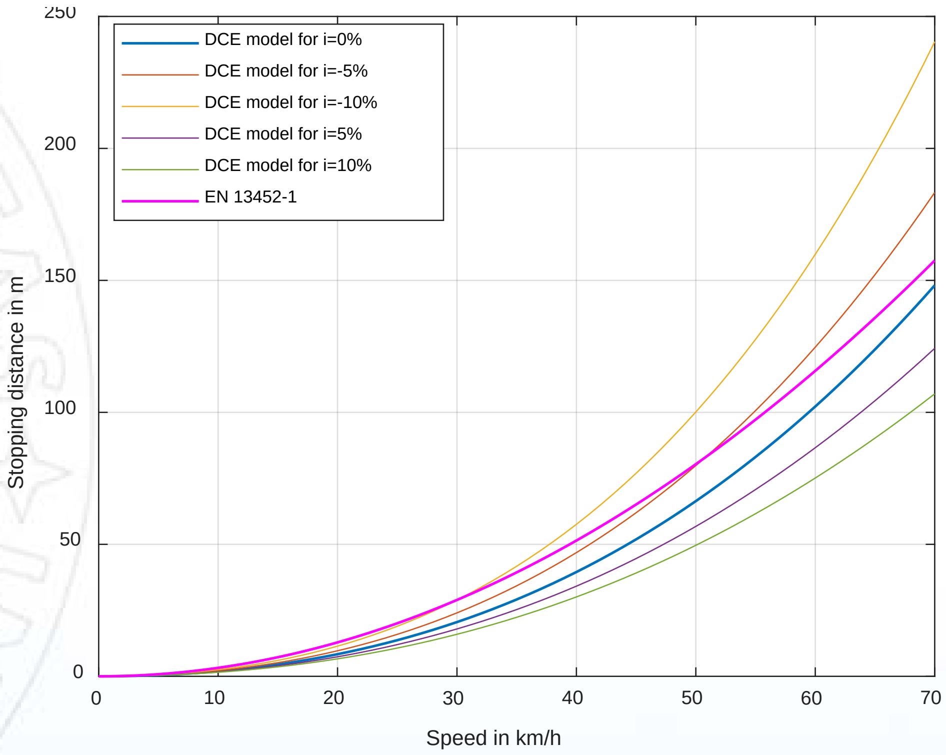
DCE model

$$S_f = \frac{(1+\beta)}{g} \int_0^{v_0} \frac{v}{f'0.7\lambda_c + \left(\frac{0.675 + \frac{125}{P_a} + 0.009v}{10^3} + \frac{\frac{a}{\mathcal{R} - b}}{10^3} + \frac{kSv^2}{P} \pm \frac{i_{‰}}{10^3} \right)} dv$$



MODELS COMPARISON

Theoretical braking performance comparison on slope and dry tramways



EN 13452-1

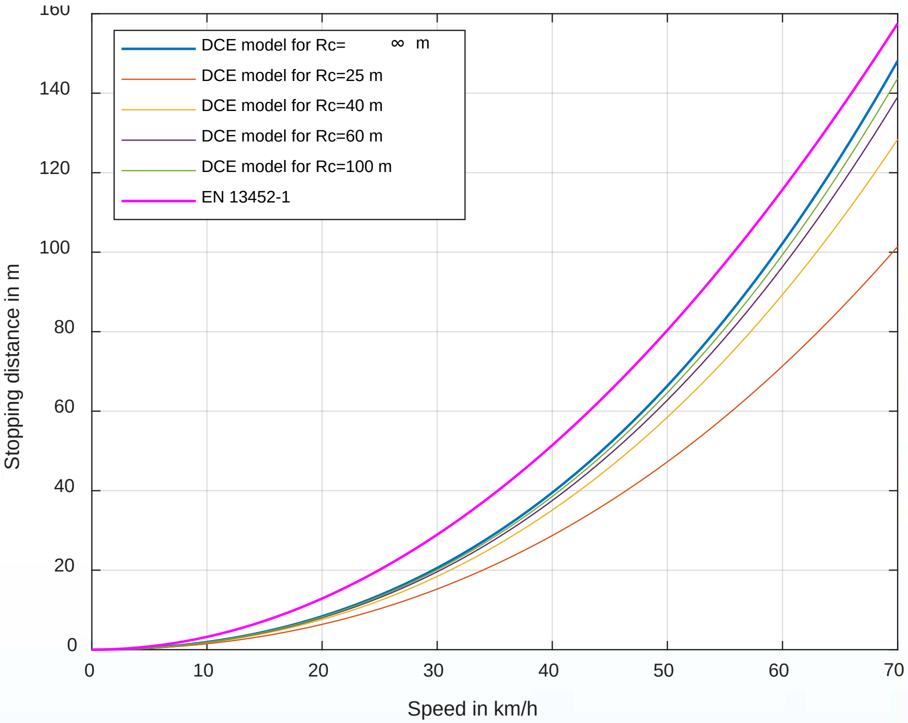
$$S_f = v_0 t_e + \frac{{v_0}^2}{2a_e}$$

DCE model

$$S_f = \frac{(1+\beta)}{g}\int_0^{v_0} \frac{v}{f'0.7\lambda_c + \left(\frac{0.675+\frac{125}{P_a}+0.009v}{10^3} + \frac{\frac{a}{\mathcal{R}-b}}{10^3} + \frac{kSv^2}{P} \pm \frac{i_{\text{‰}}}{10^3}\right)}dv$$

MODELS COMPARISON

Theoretical braking performance comparison on curve and dry tramways



EN 13452-1

$$\boxed{S_f = v_0 t_e + \frac{{v_0}^2}{2a_e}}$$

DCE model

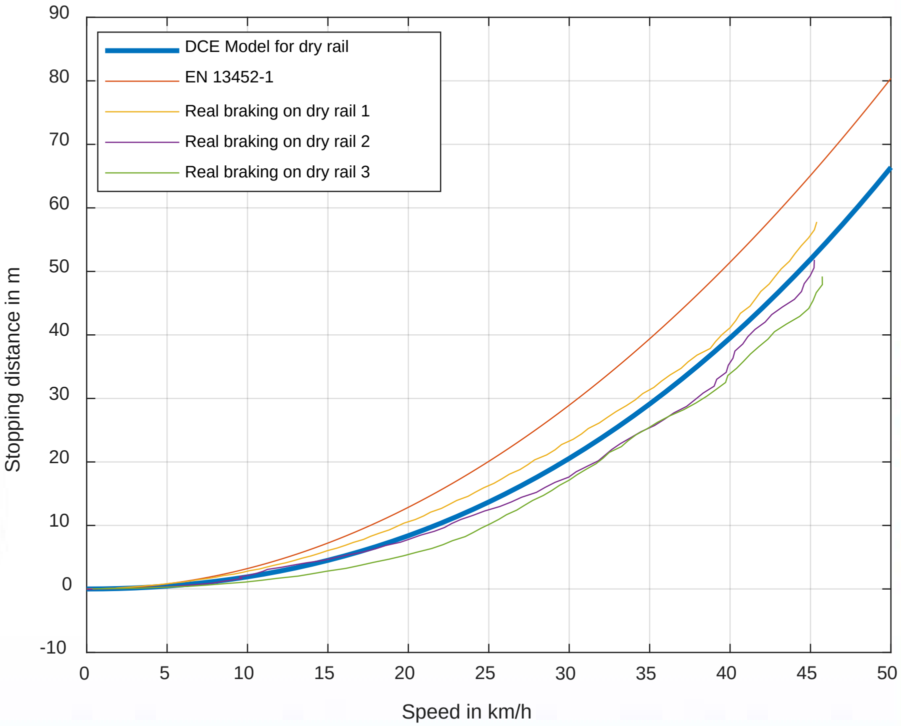
$$\boxed{S_f = \frac{(1+\beta)}{g}\int_0^{v_0} \frac{v}{f'0.7\lambda_c + \left(\frac{0.675 + \frac{125}{P_a} + 0.009v}{10^3} + \frac{\frac{a}{\mathcal{R}-b}}{10^3} + \frac{kSv^2}{P} \pm \frac{i_{‰}}{10^3}\right)}\,dv}$$

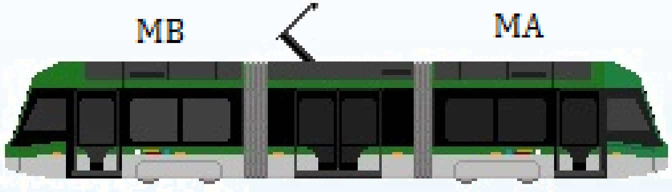
MODELS COMPARISON

In collaboration with the Neapolitan Company for Mobility (**ANM**) and **Hitachi Rail STS SpA**, a **braking test campaign** was conducted in the two main weather conditions to verify the robustness of the model

Both the EN 13452-1 and DCE models are powered with real speeds

In **dry rail conditions** the SIRIO™ model is able to achieve better tracking accuracy than the legislation model



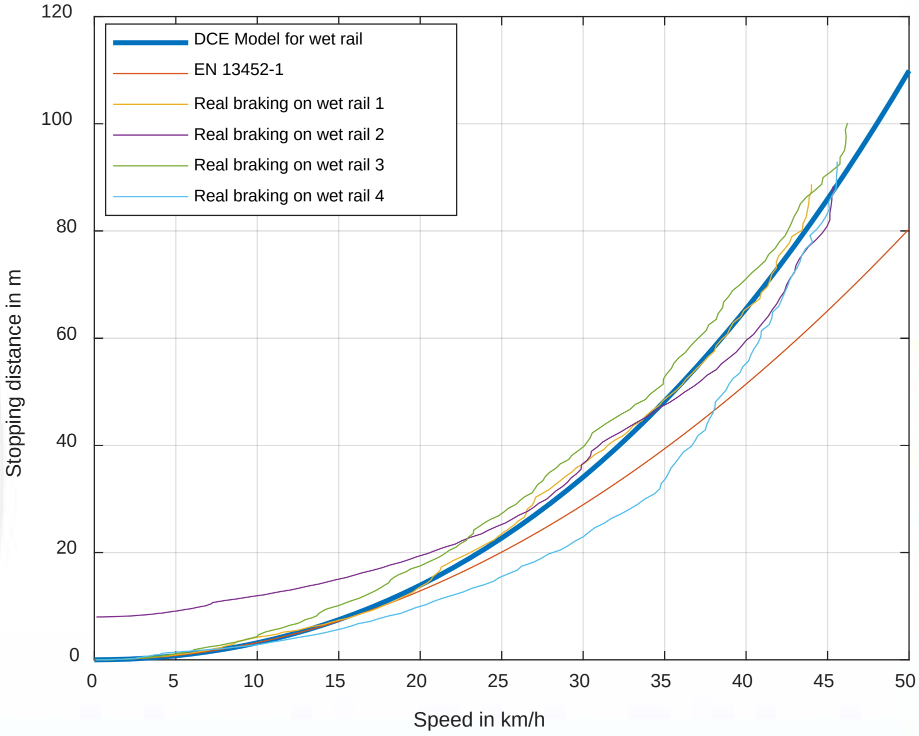


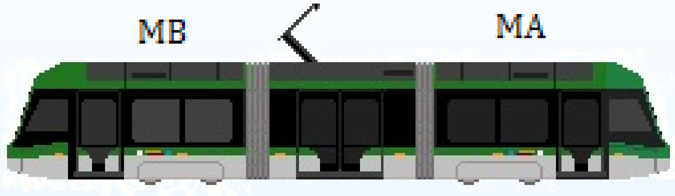
MODELS COMPARISON

A **wet rail test** campaign was carried out on the same route. By adjusting the model parameters with adequate **adhesion coefficients** for the wet rail, DCE model able to achieve better tracking accuracy than the legislation model.

Both the EN 13452-1 and DCE models are powered with real speeds.

Similar test campaigns will be conducted for other parameters (slope, curvature, weight, etc.).





MODELS COMPARISON

The **good performance**, in terms of **RMSE**, **confirm** the effectiveness of the **proposed approach** in all water condition with respect to existent models and legislation and the main commercial tools for ADAS applications

REAL BRAKING DISTANCE	MODEL	
	DCE	EN 13452-1
	RMSE	RMSE
ON DRY RAIL 1	2.08	5.59
ON DRY RAIL 2	2.32	10.02
ON DRY RAIL 3	3.9	12.41
ON WET RAIL 1	1.55	9.28
ON WET RAIL 2	5.9	9.43
ON WET RAIL 3	4.06	12.44

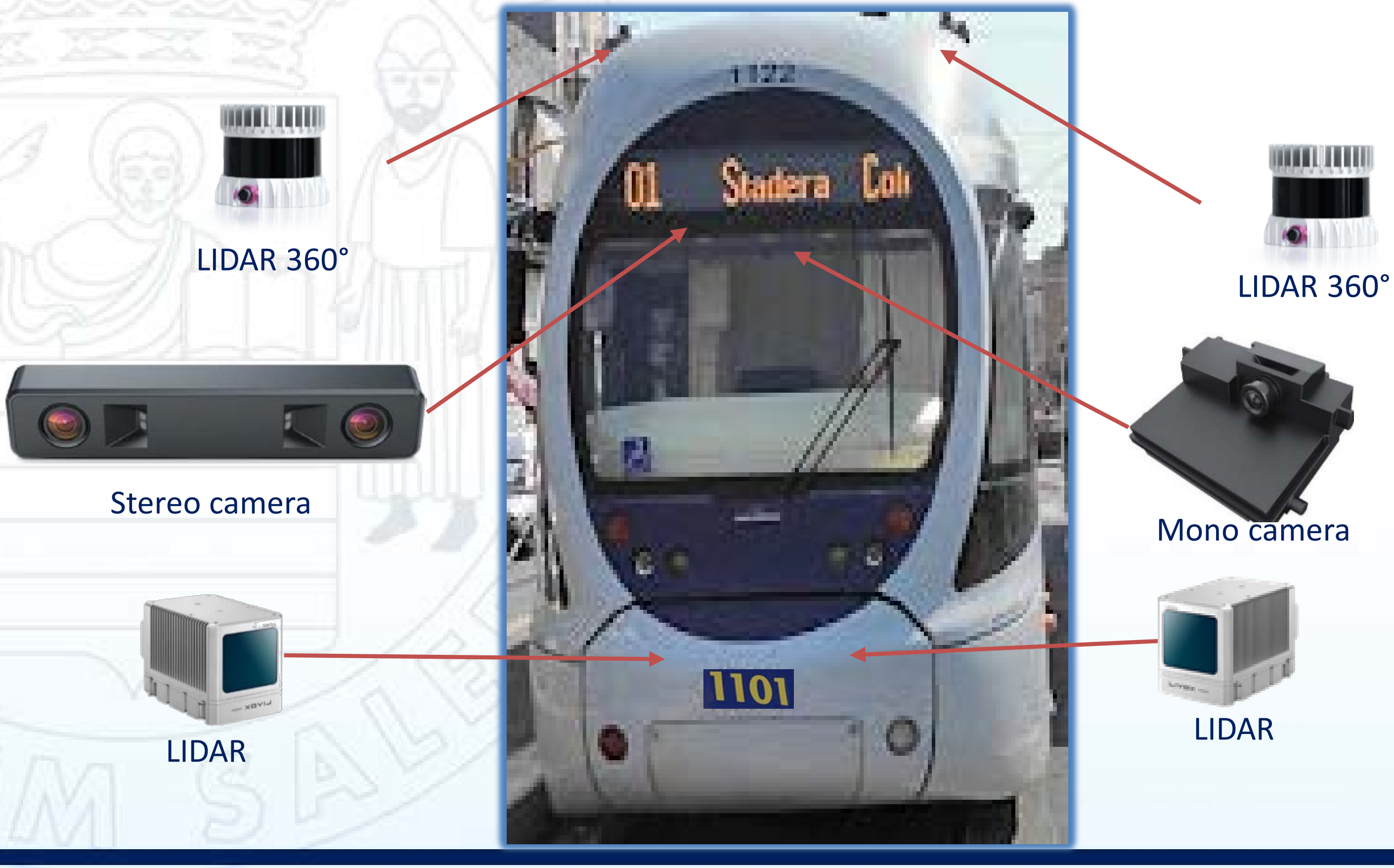
$$\mathbf{RMSE} = \sqrt{\sum_{i=0}^{n} \frac{\left(\widehat{S}_i - S_i\right)^2}{n}}$$

SIMULATION SCENARIO

Simulation of realistic scenarios with real sensors parameter (LIDAR and camera), road actors (pedestrians, cyclists, motorcyclists and cars), tram and tramway characteristics are performed.

T-ADAS IMPLEMENTATION

In collaboration with ANM, Hitachi rai and Hitachi R&D, the sensors are being set up on the SIRIO tram currently operating in Naples.



LIDAR 360°

LIDAR 360°

Stereo camera

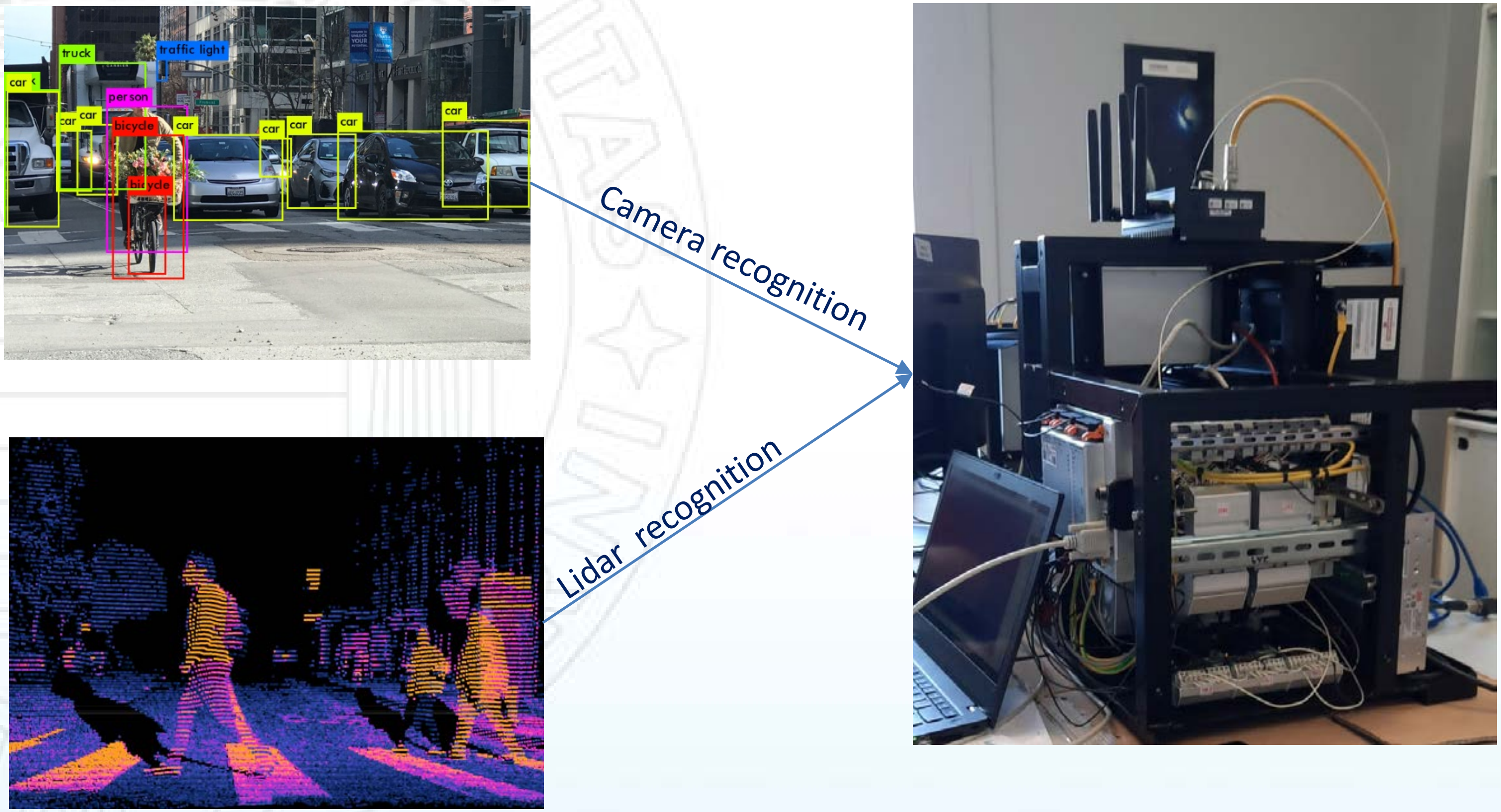
Mono camera

LIDAR

LIDAR

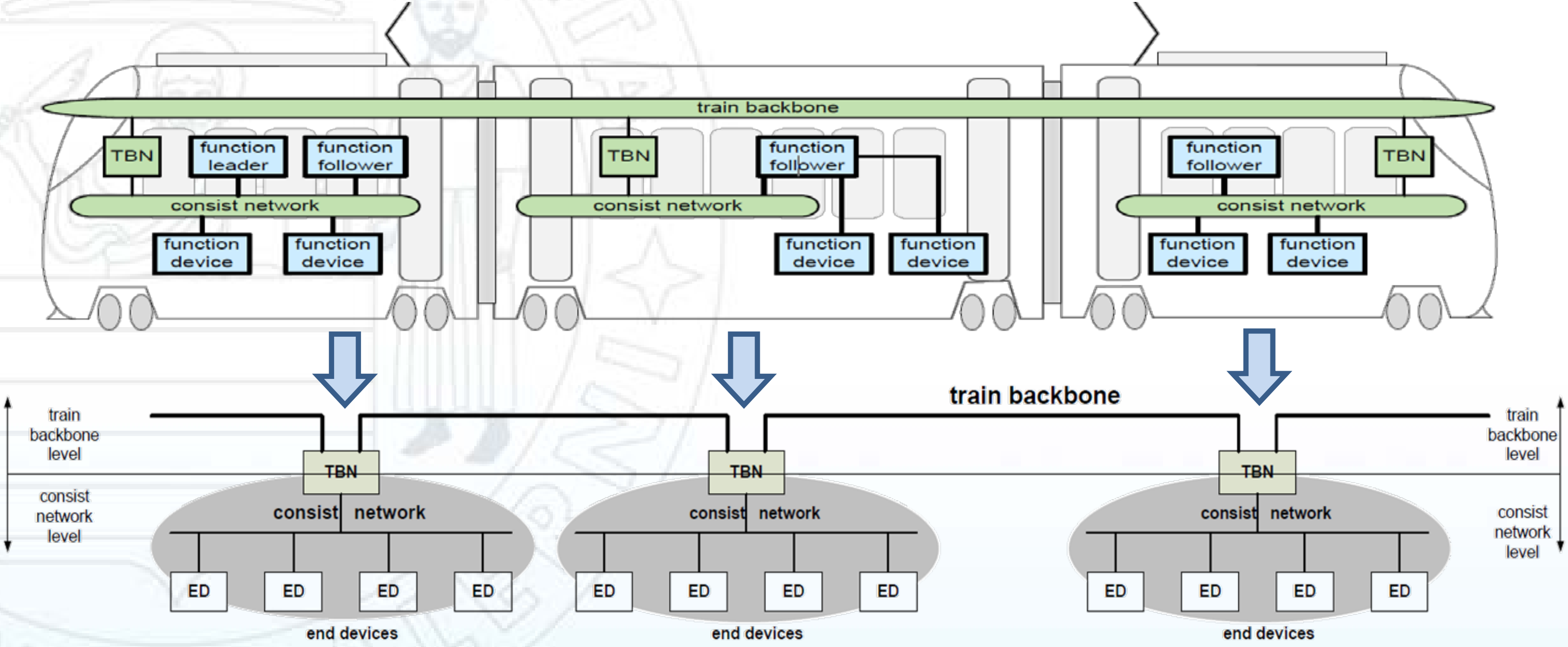
T-ADAS IMPLEMENTATION

Hitachi Rail and Hitachi Rail-R&D developing a sensor fusion platform that houses the T-ADAS. The acquired data is ready to send via the 5G network.



T-ADAS IMPLEMENTATION

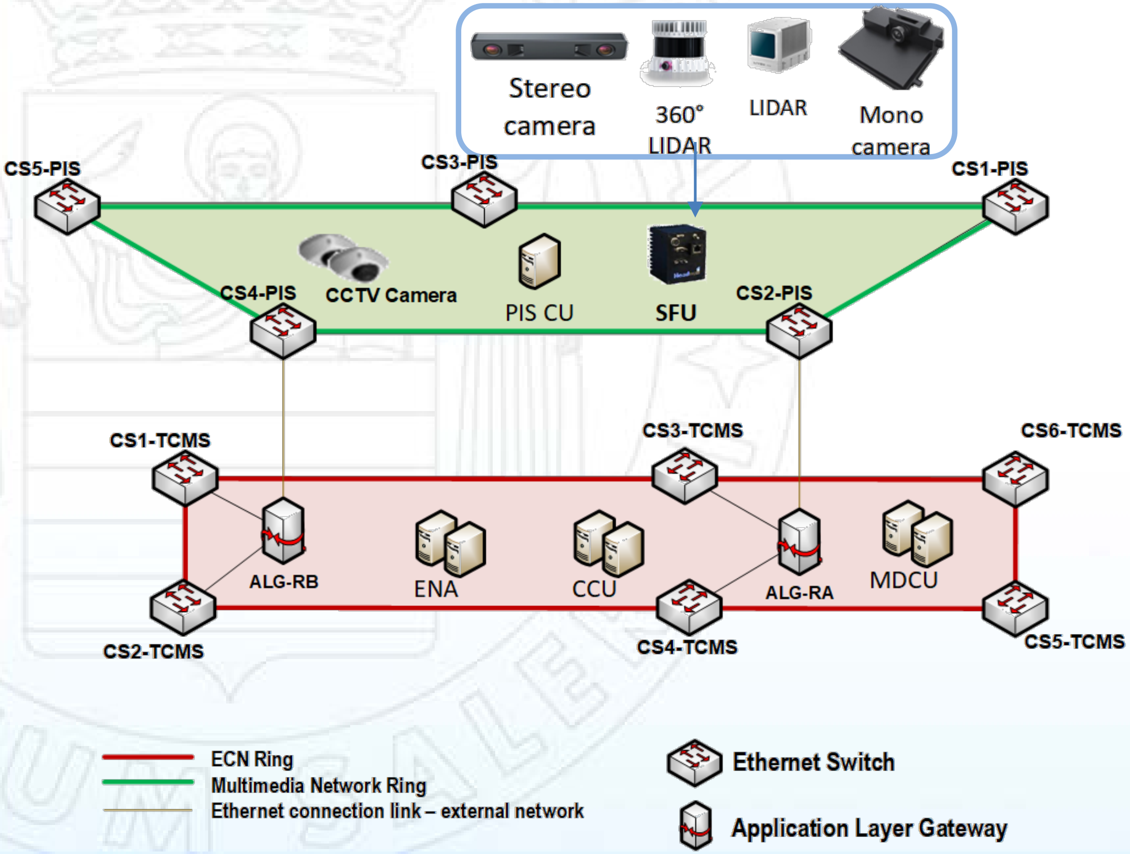
A Train Communication Network (TCN) is the infrastructure enabling the exchange of information throughout the train. The general architecture of TCN consists of two separate network: Consist Networks (CN) and Train Backbones (TB)



Communication between CN and TB can only take place via the Application Layer Gateway (ALG)

T-ADAS IMPLEMENTATION

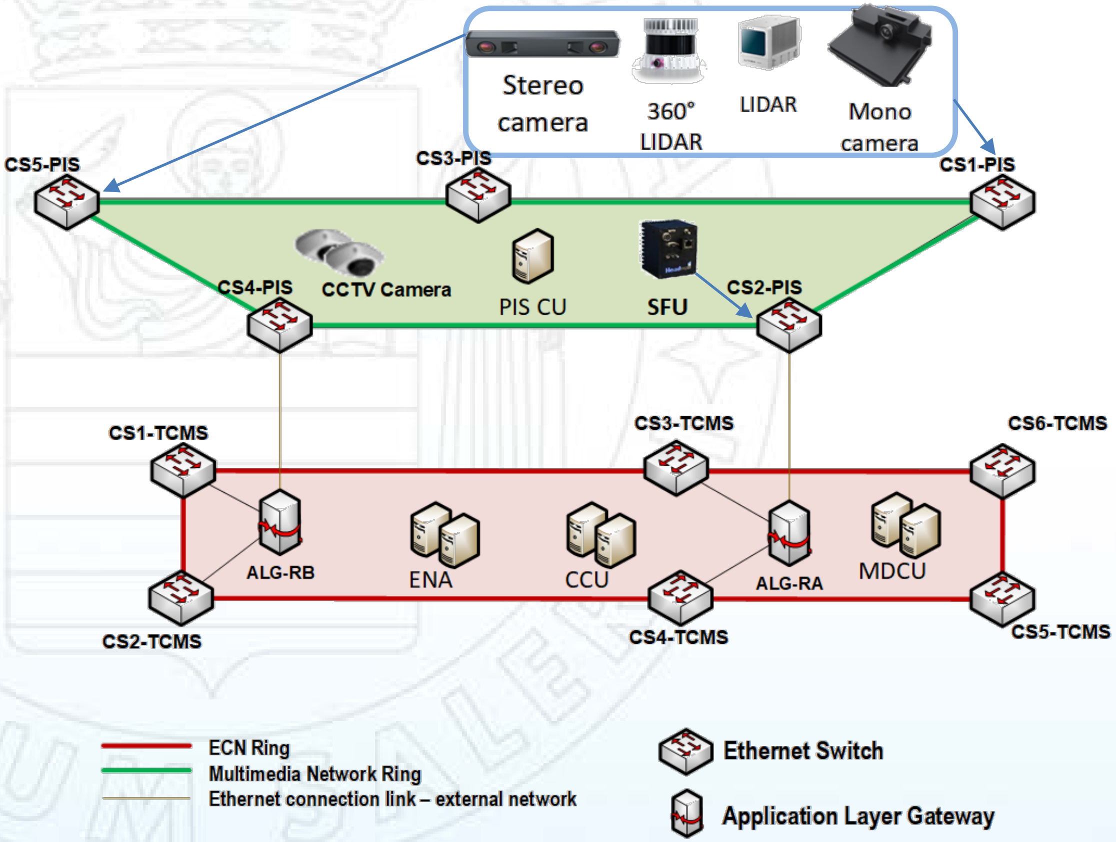
T-ADAS implementation to on-board network could take place in two ways: in a concentrated logic all the sensors are connected to the SFU



Sensor	Data rate required
Mono Camera	50 Mbps
Stereo Camera	145 Mbps
Livox Lidar	100 Mbps
Ouster 360° Lidar	254 Mbps

T-ADAS IMPLEMENTATION

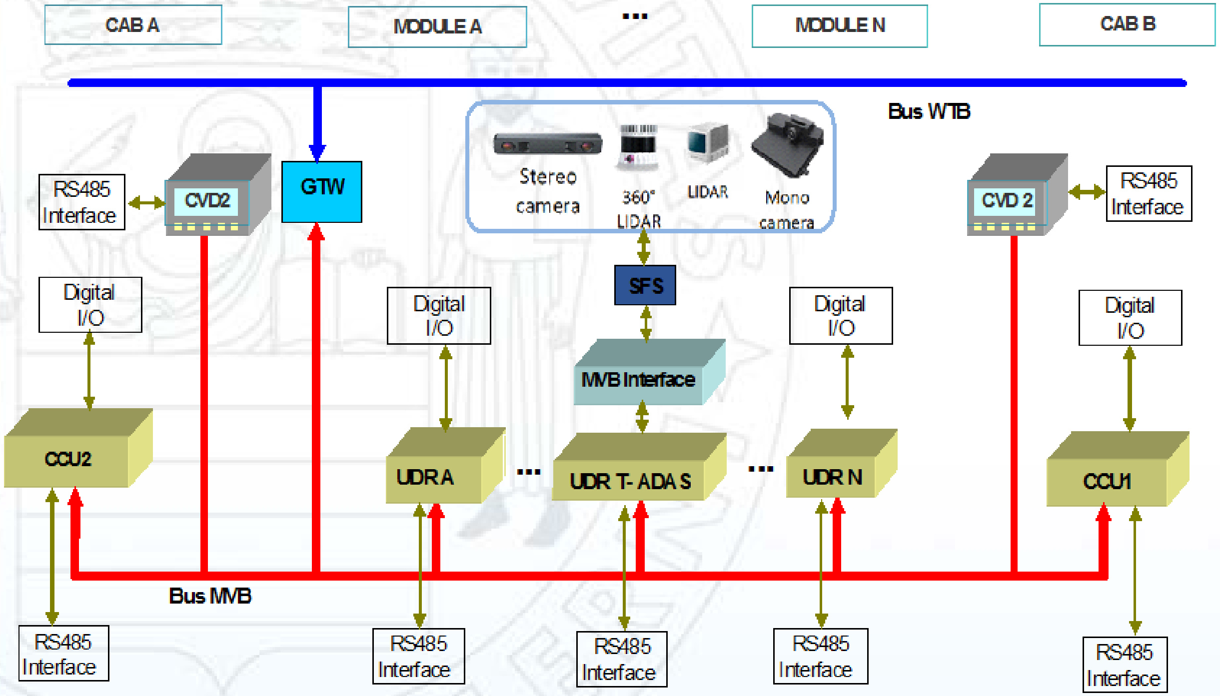
In a distributed logic of the T-ADAS, the sensors can be connected to the various Consist Switches (CS) installed along the ECN. In this case, a bandwidth problem must be considered



Sensor	**Data rate required**
Mono Camera	50 Mbps
Stereo Camera	145 Mbps
Livox Lidar	100 Mbps
Ouster 360° Lidar	254 Mbps

T-ADAS IMPLEMENTATION

In a MVB technology



Sensor	Data rate required
Mono Camera	50 Mbps
Stereo Camera	145 Mbps
Livox Lidar	100 Mbps
Ouster 360° Lidar	254 Mbps

COLLABORATIONS & PUBLICATIONS OF THIRD YEAR

The research activities were carried out in collaboration with:

HITACHI Inspire the Next

anm azienda napoletana mobilità s.p.a.

- C. Di Palma, V. Galdi, V. Calderaro, "Driver Assistance System for Trams: Smart Tram in Smart Cities", 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe, 10 June 2020, Madrid.
- C. Di Palma, V. Galdi, V. Calderaro, "Communication Infrastructure Requirements to include ADAS Technologies in New Generation Trams", WCRR-22, Birmingham. (**UNDER REVIEW**)
- C. Di Palma, V. Galdi, V. Calderaro, "Integration of ADAS technologies in on-board communication systems for Smart Tram", Melecon-2022, Palermo. (**UNDER REVIEW**)
- C. Di Palma, V. Galdi, V. Calderaro, P. De Fazio, L. Carrarini, G.Rizzano, "Weigh-In-Motion based on FBG sensors for Smart Road Applications", Calgary2022, Birmingham. (**UNDER REVIEW**)

PH.D DEFENSE

THANKS FOR YOUR ATTENTION

Questions?

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