December 21st, 2022

Nicolas HAUTIERE
Director COSYS Department
R5G Program manager

3rd SIIV International Winter School 2022, Moena (IT)

5TH GENERATION ROAD (R5G) WHAT'S NEXT?

Université Gustave Eiffel

MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE ET DE LA COHÉSION DES TERRITOIRES
Liberté Égalité Fraternité

Nicolas Hautière

ICPEF'13 and Senior Researcher

Université Gustave Eiffel

Education

- Civil engineer (2002)
- M2 and PhD in computer vision (2002 & 2005)
- HDR in signal and image processing (2011)
- MS Public Policies and Actions for Sustainable Development (2013)

Professional Experience

- PhD student (2002-2005)
- Researcher (2006-2009)
- Head of unit (2009-2012)
- R5G Project director (2013-2016)
- Deputy Director of COSYS, in charge of R5G (2017-2021)
- Assistant director of COSYS (2019-2021)
- Director of COSYS (since 2022)

Expertise and affiliations

- Co-pilot of the "Smart Mobility Solutions" strategic domain at the NextMove competitiveness cluster
- Expert of the Operational Committee "Education, Research and Innovation" (IDRRIM- Paris)
- Element Leader "Automated road" (FEHRL- Bruxelles)
- Expert for the JTRC (OCDE/FIT- Paris)
- Member of PIARC France
- Expert member of the Scientific Council of Transpolis
- Co-pilot of the "Shared energy and mobility" Domain (VEDECOM- Versailles)
- Expert member of the scientific council of ITTECOP research program
- Co-pilot of the strategic partnership with CEREMA

Teaching activities

UNIVERSITÉ GUSTAVE EIFFEL | 1

OUR HISTORY

An unique model of national university created January 1st 2020

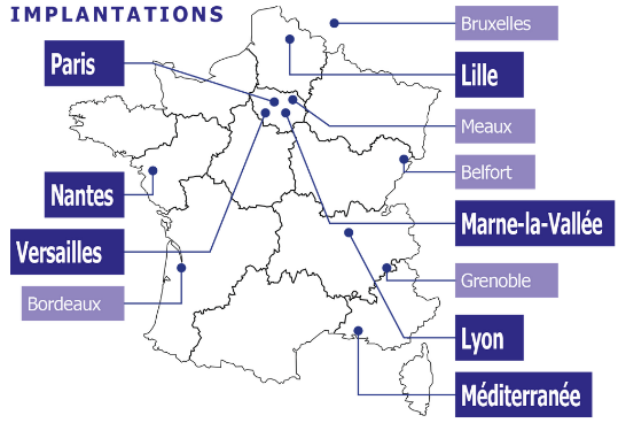
Université **Gustave Eiffel** is a multidisciplinary University, carrying the scientific ambition to prepare transformation and sustainable adaptation of cities and territories.

FOUNDING MEMBERS

A university + *A research institute* + *A school of Architecture* + *3 Engineering schools*

A NATIONAL POSITION

- 7 main campus and 4 antennas in France + 1 office in Brussels



MISSIONS

- Research and innovation
- Expertise for local/national policies and standardisation
- Opening sciences to society
- International cooperation including European Research Area
- Initial and long life education and training, promotion of apprenticeship
- Professional integration of students

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A MAJOR FOCUS

Transformation and sustainable adaptation of cities and territories

¼ of French research and development on the sustainable city

5 main scientific disciplines covered by our researchers and professors :

- Mathematics and computer science (22%)
- Social and Human Sciences (25%)
- Physical and experimental Sciences (20%)
- Arts, Humanities & Language (19%)
- Economics and business administration (14%)

KEY NUMBERS

A « Human scaled » University

- **17 000** students → 3 500 trainees
- **500** PhD students
- **1 200** Researcher/lecturers / Researcher-professors
- **1 300** Administrative and technical staff

Research key figures

- **Xx Peer review publications**
- **240 M€** annual budget
- **More than 50** world-class scientific equipment
- **More than 1 000** PhD defences
- **More than 150 brevets** active patents
- **More than 250 on going research projects (xx in H2020 program)**

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RESEARCH STRUCTURES
Laboratories, teams, departments, institutes

23 RESEARCH STRUCTURES

5 DEPARTMENTS

MAST : Materials and Structures
230 people – 8 laboratories

GERS : Geotechnical, Environment, Natural Hazards and Earth Sciences
120 people - 7 laboratories

COSYS : Components and Systems
280 people - 8 laboratories + 1 emerging team

TS2 : Transport, Health, Safety
150 people - 6 laboratories

AME : Planning, Mobility, Environment
160 people - 9 laboratories

18 THEMATIC LABS

Environnement
1 lab : LGE

City
5 labs : AUSSER, Lab'Urba, LATTS, LISAA, LVMT

Economics and business administration
3 labs : ERUDITE, IRG, DICEN

Social and Human Sciences
3 labs : ACP, LIPHA-PE, LISIS

Modeling and Digital Transition
6 labs : LAMA, LasSTIG, Navier, ESYCOM, LIGM, MSME

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COSYS : COMPONENTS & SYSTEMS

Urban monitoring

•Sensor networks
• Big data analytics
• Urban energy efficiency
• Air quality and soil pollution monitoring
• Urban network monitoring

Transport management

• Safety and security devices
• Railway control and command simulator
• Network operation and maintenance support tools
• Development of dedicated, safe and robust ICTS (antennas, beacons, warning systems, etc.)
• Traffic regulation

Civil Engineering Instrumentation + Innovative Structures

• Auscultation, optical (wireless sensors)
• Inspection by drone
• Structural health check
• Imaging detection
• Ultra-light bridges
• Unballasted railways

Softwares

• Dedicated software development/Software security
• Structural design
• Travel simulation
• Cooperative traffic simulation
• Fluid Reversal

Energy, environment

• Reliability of power electronic components dedicated to electromobility (batteries, super-capacitors, etc.)
• Eco-driving

Cooperative and autonomous mobility

• All-weather vision,
• Perception, simulation, navigation, automation
• Cooperative systems
• Evaluation of technological solutions in real-life situations (Living Labs)

7 LABORATORIES AND 2 UMR

UR or UMR	Name
ESTAS	Évaluation des Systèmes de Transports Automatisés et de leur Sécurité
ERENA	Équipe de Recherche en Émergence Nouveaux usages et pratiques de la mobilité en nouvelle Aquitaine
GRETTIA	Génie des réseaux de transports terrestres et informatique avancée
LEOST	Laboratoire Électronique Ondes et Signaux pour les Transports
PICS-L	laboratoire Perception, Interactions, Comportements & Simulation des usagers de la route et de la rue
IMSE	Laboratoire Instrumentation, Simulation et Informatique Scientifique
SII	Structure et instrumentation intégrée
LICIT-ECO7	UMR UGE/ENTPE Laboratoire d'ingénierie circulation transport
SATIE	UMR 8029 UGE/CNRS/ENSPS/ENSR/CNAMP/UCP/UPS Systèmes et applications des technologies de l'information et de l'énergie Equipe TEMA

COSYS INTERNATIONAL STRATEGY

Ambitions

- Extensive international activity … in-line with the scientific strategy
- IALs (Europe, Australia & Canada) – Low TRL, PhD and/or Masters co-supervised - Triptic Training – Training through Research - Technology & Innovation Transfert …
- Cosys proactively addresses the changing European research landscape (Green Deal, Missions, European Partnerships, EIC …)
- International Benchmarking … (Analysis of written documents, mission reports, European projects or scanning tours and other international benchmarks …)

Current achievements with Italy

- IAL NextRIM (Next Generation Road Infrastructure and Mobility)
- IAL SEnSIN-CT (Smart Sensors, Energy and intelligent Infrastructures for Transport and Cities)
- IAL ASTI (Advanced Sensing laboratory for Transport Infrastructures)
- MOU with UNIPA

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

POLITECNICO
MILANO 1863

istituto per il rilevamento elettromagnetico dell'ambiente

UNIVERSITÀ
DEGLI STUDI
DI PALERMO

OVERVIEW OF THE PRESENTATION

1. STATE OF THE ART
2. THE 5TH GENERATION ROAD PROJECT- R5G
   - R5G CONCEPTUALIZATION
   - THE ADAPTABLE ROAD
   - THE AUTOMATED ROAD
   - THE CLIMATE RESILIENT ROAD
3. NEXT STEP- THE R5G*FAB* : FROM KEY CONCEPTS TO DEPLOYMENT
   - KEY CONCEPTS FOR ROADMAPS
   - BUSINESS CASES UNDER DEVELOPMENT
   - R5G AS PART OF A GLOBAL ENVIRONMENTAL STRATEGY
4. CONCLUSION AND PERSPECTIVES

STATE OF THE ART | 2

STATE OF THE ART

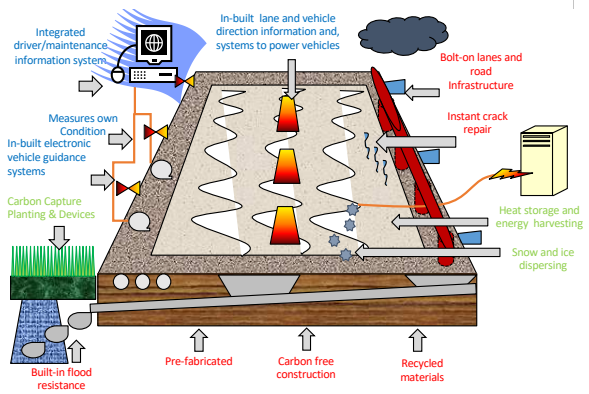
THREE TECHNOLOGICAL PARADIGM SHIFTS AND FOUR GENERATIONS OF ROADS

- 1st road generation: The pathway
- 2nd road generation: The roman road
- 3rd road generation: The smooth road
- 4th road generation: The motorway
  - First development in the early 20th century
  - Full development of freeway from the 60s-70s
  - Mitigation and adaptation since the 80s
- 5th road generation – R5G ©?
  - The Forever Open Road: A road infrastructure that takes the best of existing technologies and the best of those to come.

19th-20th century

End of 20th century

Porzamparc
Atelier Grand Paris



21st century

Lamb, M., Collis,B., Deix, S., Krieger, B. and Hautière, N. The Forever Open Road - Defining the next generation road. In Routes/Roads, 352-353: 120-129, 2012

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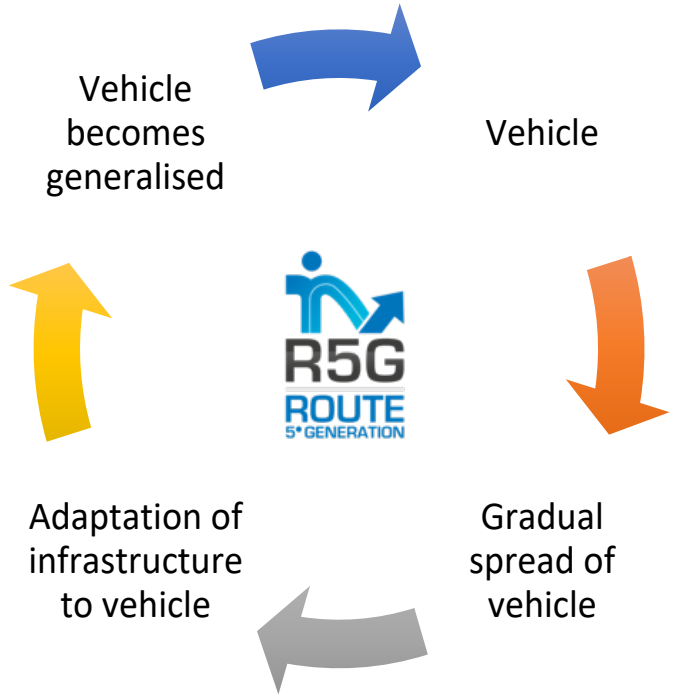
STATE OF THE ART

TECHNOLOGICAL PARADIGM SHIFTS ARE DRIVEN BY NEEDS BUT MAY TAKE DIFFERENT FORMS

- The history of road development shows that the development needs of society generate progress as regards personal transport modes whose development is stimulated by the fact that roads adapt to them.
- Technological paradigm shifts are difficult to foresee, and above all take place relatively slowly.
- In the following of this presentation, we develop the hypothesis that the conditions of a shift to a new generation of road is present and describe the form we expect this to take.
- This hypothesis has been formulated by the research institutes from FEHRL in its flagship "Forever Open Road" programme, of which our R5G program is part.



FOREVER OPEN ROAD
Redefining Road Transport for the 21st Century
FEHRL's Flagship Programme

Hautière, N. Smart roads for tomorrow's cities – A new paradigm of continuous innovation. polisMOBILITY Magazin, pages 72- 75, January 2022

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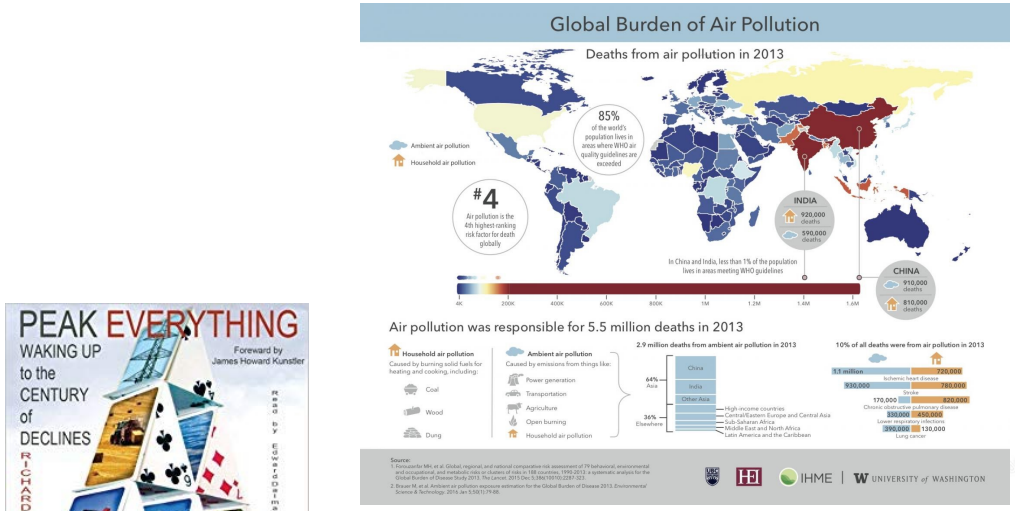
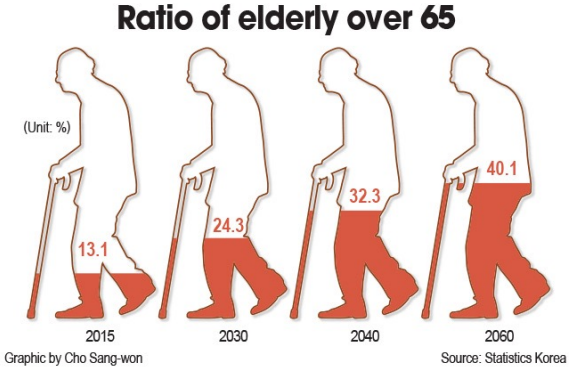
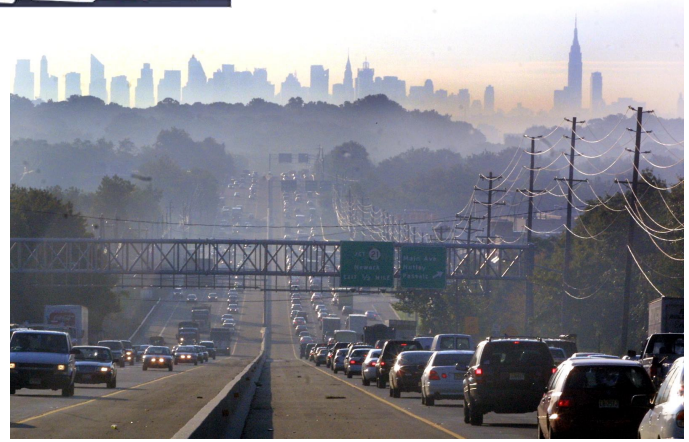
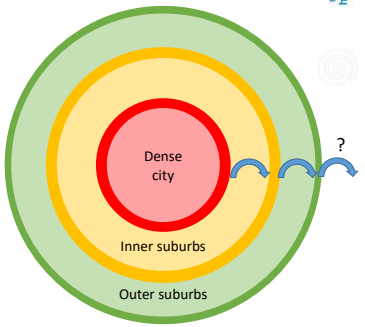
URBAN SOCIETAL ISSUES ARE STILL GROWING (1/2)

- Scarcity of resources
- Aging of population
- Biodiversity loss
- Climate change
- Finance crisis
- Urban sprawl
- Air pollution
- Congestion
- Etc.









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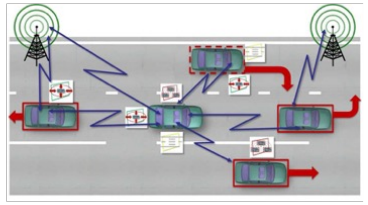
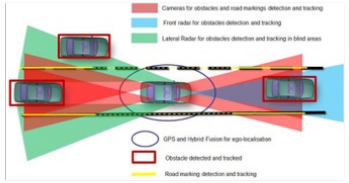
AVAILABILITY OF TRANSFORMATIVE TRANSPORTATION TECHNOLOGIES (2/2)

Connected and Automated Mobility

- Connected mobility

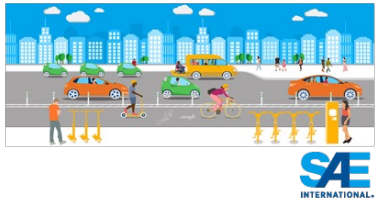



- Automated mobility

Shared Mobility

- Shared fleets



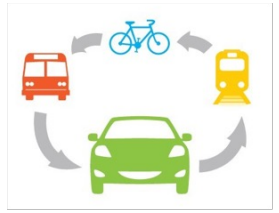
- Carpooling


Zero Emission Mobility

- Electric cars


- E-bikes


Multimodal Mobility



ffel

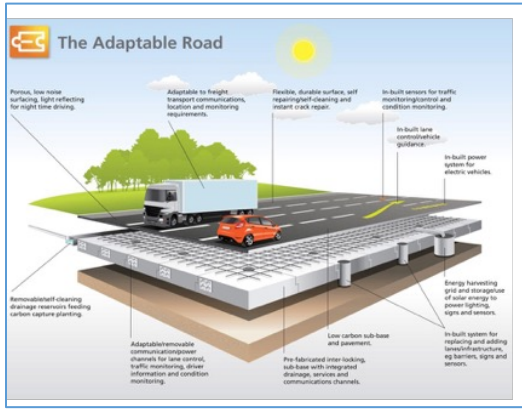
THE 5TH GENERATION ROAD PROJECT – R5G

3

R5G CONCEPTUALIZATION | 3.1

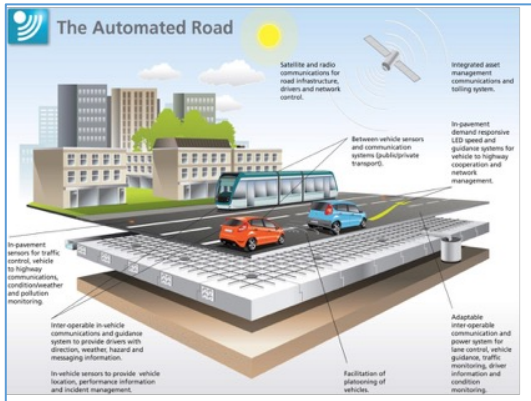
THE 5TH GENERATION ROAD

NEEDS AND REQUIREMENTS



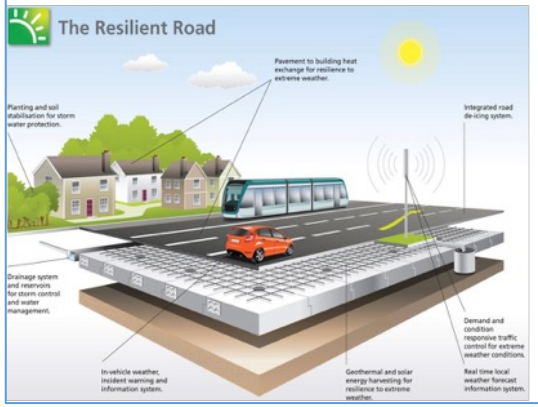
Fully adaptable to changes in demand

- The adaptable road will be based on a pre-fabricated/modular system that can gradually be implemented across Europe's motorway, rural and urban road networks.
- It will adapt to increasing travel volumes and to changes in demand for public transport, cycling and walking.
- It will power vehicles, harvest solar energy, measure its own performance and even repair itself.



Fully integrated with the user, vehicle, services and operations

- Will incorporate a fully integrated information, monitoring and control system;
- Will support a co-cooperative vehicle-highway system that will manage travel demand and traffic movements.
- Will ensure the co-existence of autonomous, connected and conventional vehicles
- Will measure, report and respond to its own condition, providing instant information on weather, incidents and travel information.



Fully adaptable to extreme weather conditions

- The resilient road will adapt itself to the impacts of extreme weather conditions and climate change.
- The road will monitor flooding, snow, ice, wind and temperature change, and mitigate their impacts through integrated storm drainage, automatic heating and cooling, and will be linked to the integrated information system for travellers and operators.
- The climate change resilient road: focuses on ensuring adequate service levels of the road network under extreme weather conditions.
- Innovation themes will address adaptation of road operations and management to the effects of extreme weather to such extent that adequate service levels are ensured.

FOREVER OPEN ROAD

Redefining Road Transport for the 21st Century

FEHRL's Flagship Programme

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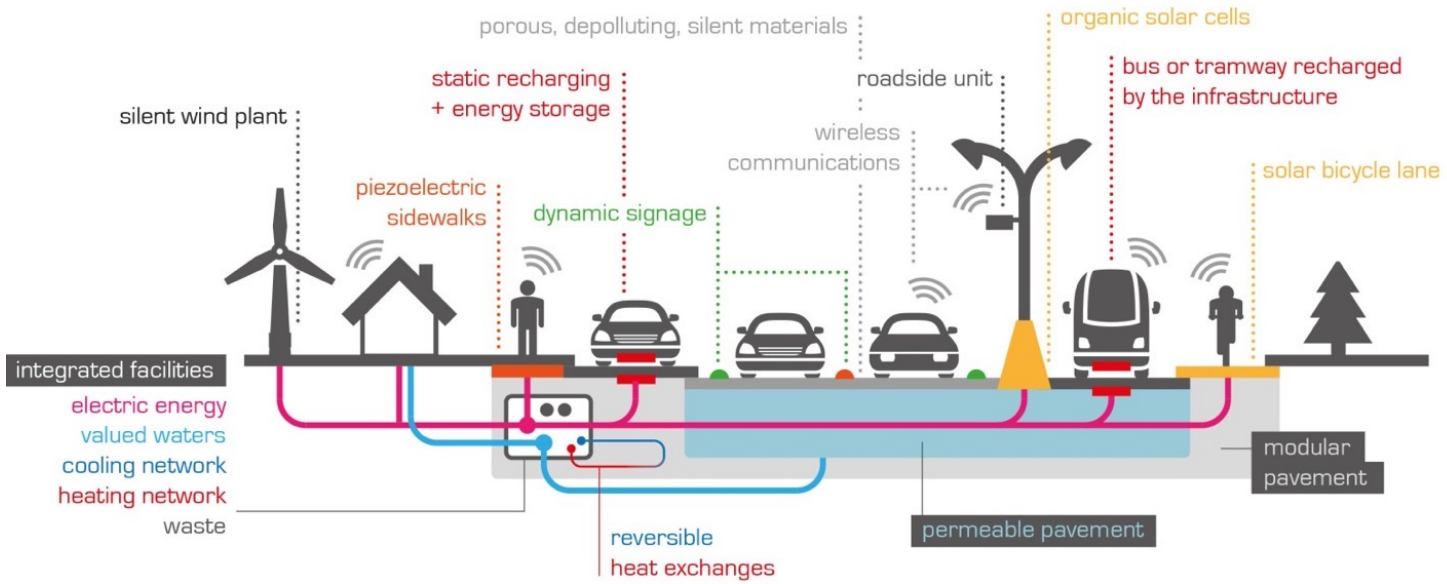
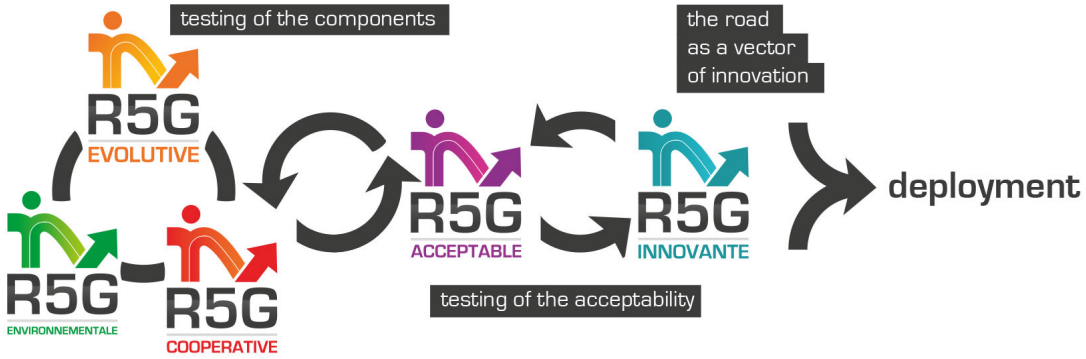
THE 5TH GENERATION ROAD

THE R5G CONCEPT

- R5G project aims at integrating the different components of the Forever Open Road following a systemic approach to design and build full scale demonstrators of the next generation road





La roadmap "évolutions de la route" : route de 5e génération : route communicante / Nicolas Hautière *in Revue générale des routes et de l'aménagement (RGRA), (2018)955 (Juin 2018)*

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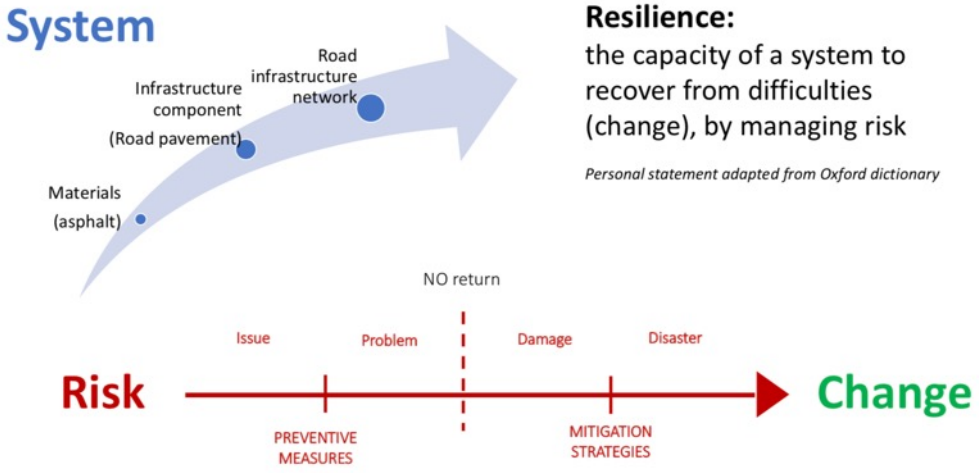
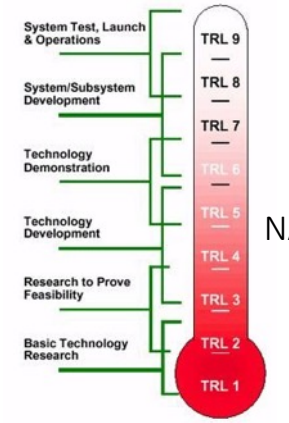
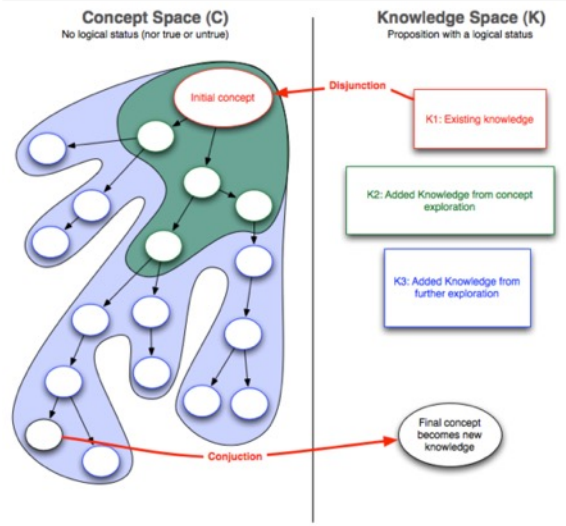
SYSTEMIC APPROACH AND ROAD INNOVATION AS A RESILIENT PROCESS



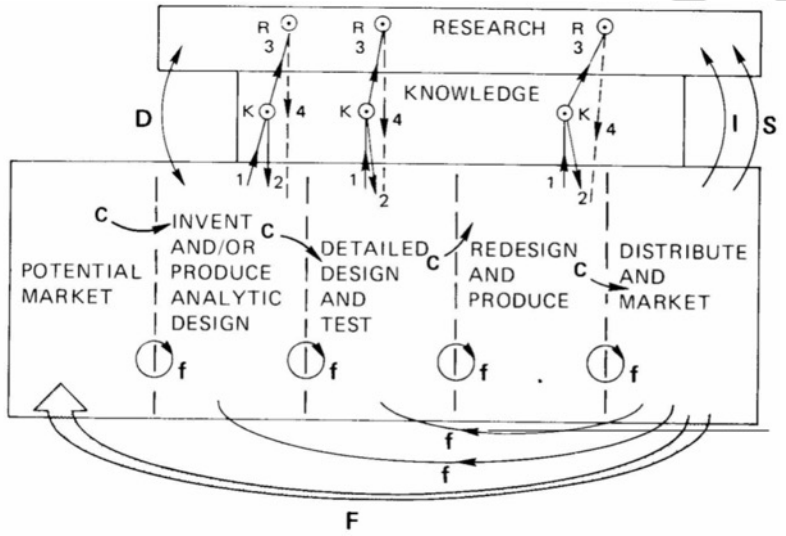
Buttlar & Lo Presti, ISAP (2018)



TRL
Theory
NASA (1968)



C-K theory
Hatchuel (1993)



The chain-linked model
Kline, Rosenberg. An overview of innovation, 1986

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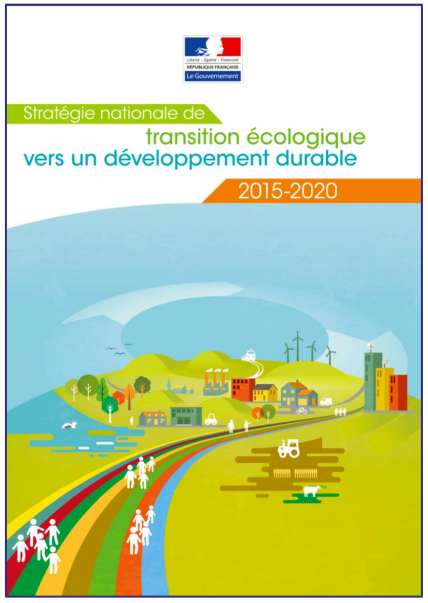
R5G – AN INTEGRATED ROADMAP

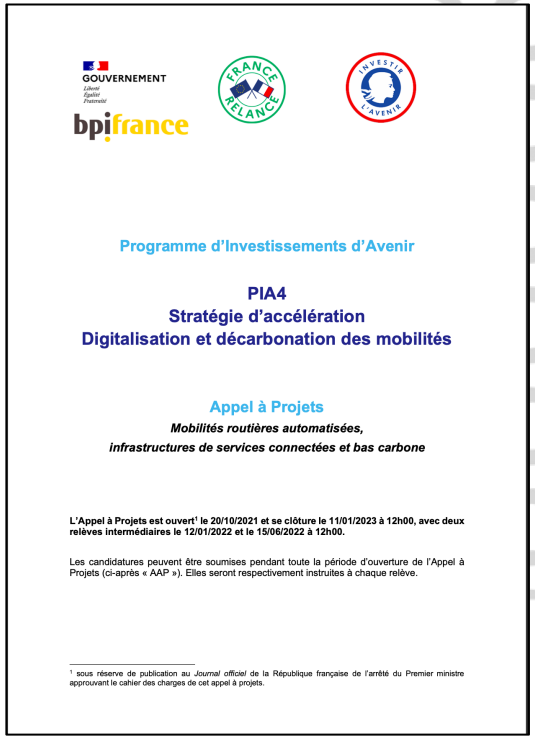
ENLIGHTENING, CATALYSING AND ACCELERATING ROAD INNOVATION

ECLAIR LAB

The R5G project is driven by 4 actions

1. Align the national RDI agenda with that of FOR
2. Inform public policies related to road innovation
3. Catalyse innovative solutions
4. Accelerate territorial development projects





50 M€ cfp - 2015

250 M€ cfp - 2021

Hautière, N. « La route du futur », Annales des Mines – Enjeux numériques, N°7, pages 15-19, 2019

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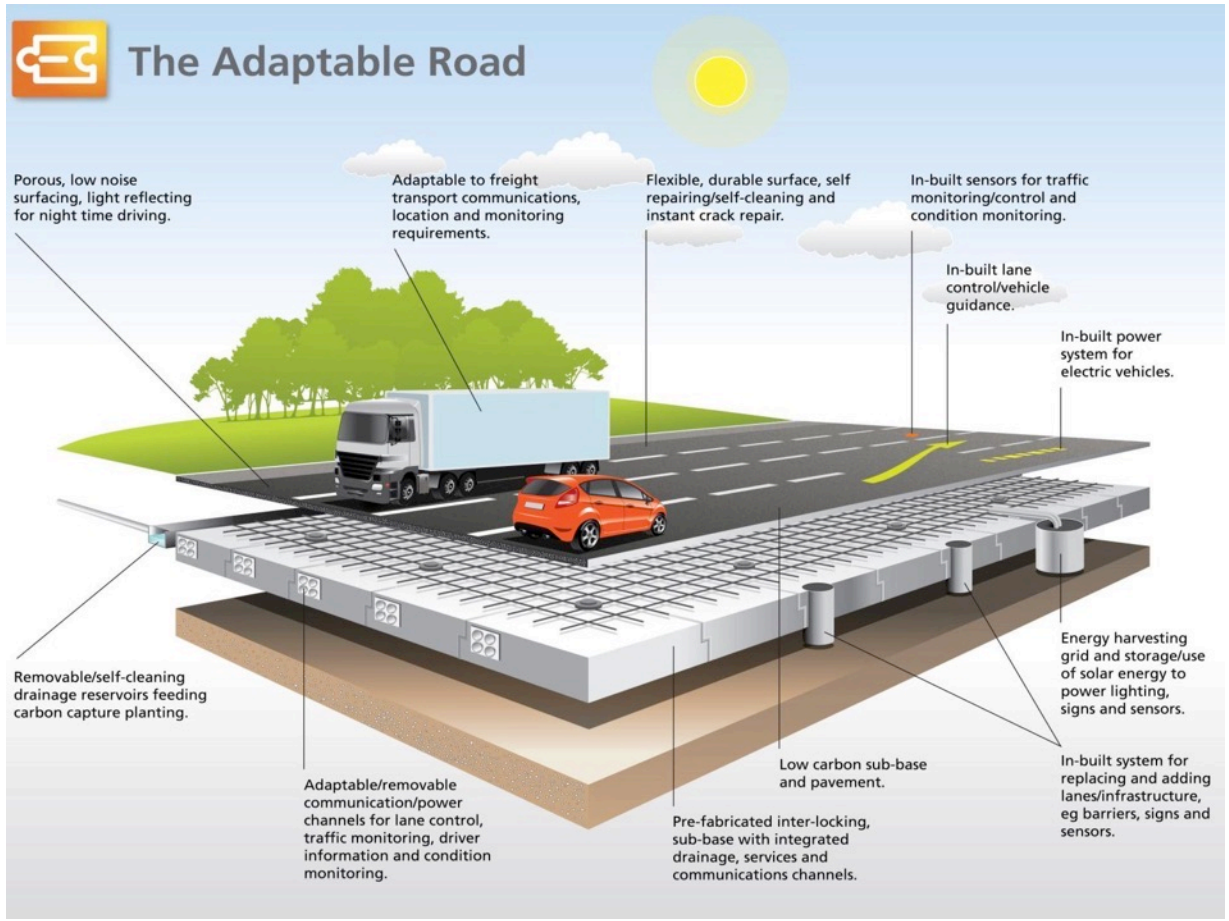
THE ADAPTABLE ROAD | 3.2

THE ADAPTABLE ROAD



- Fully adaptable to changes in demand
  - The adaptable road will be based on a pre-fabricated/modular system that can gradually be implemented across Europe's motorway, rural and urban road networks.
  - It will adapt to increasing travel volumes and to changes in demand for public transport, cycling and walking.
  - It will power vehicles, harvest solar energy, measure its own performance and even repair itself.

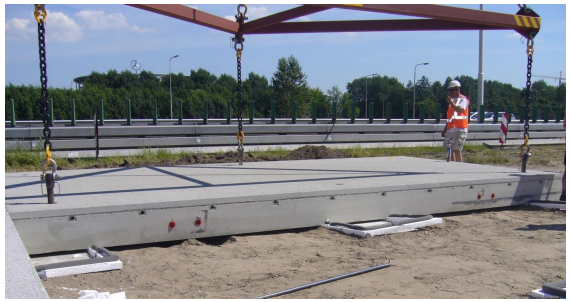
THE PRE-FABRICATED ROAD

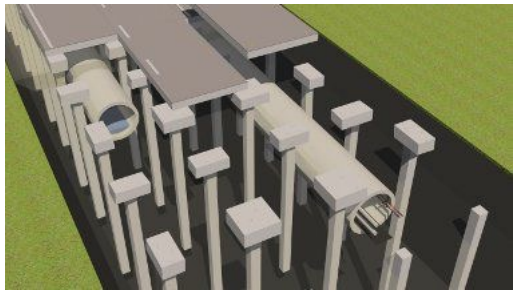
CUD-FR

- Urban pavement for smart city planning

MODIESLAB - NL

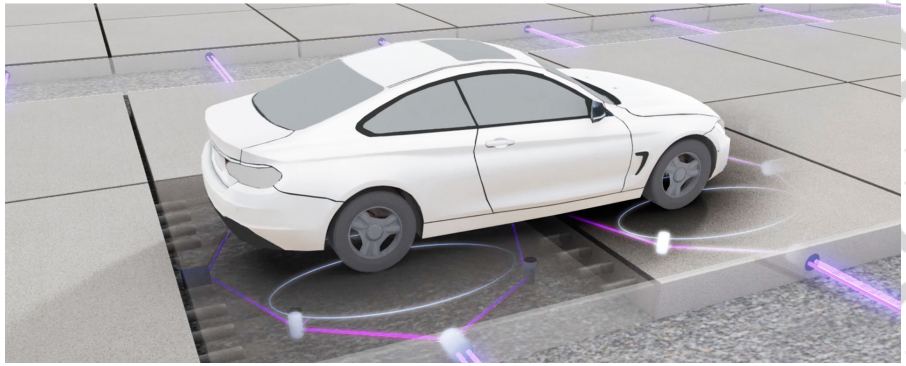
- Integrated motorway pavement





INTEGRATED ROADWAYS - USA

- Durable, precast concrete sections embedded with digital technology and fiber optic connectivity to transform ordinary roads into smart roads.



Geisler, F., Olard, F., Moglia, O., Létard, J.-F., Hautière, N. Les avancées du projet « Route du Futur » I-STREET. Revue Travaux n° 973 « Ouvrage d'Art » - Novembre 2021

TOWARDS 100% RECYCLED ASPHALT PAVEMENTS

- Algoroute (FR) aims at developing a bio-binder issued from the micro-algae industry.
- Biorepavation (EU) project aims at demonstrating that the reuse of asphalt pavement materials can be facilitated by the use of bio-sourced materials.

Pavement caroussel Nantes – Summer 2017
Biorepavation demonstrator

- Eurovia (FR) built in 2018 the first 100% recyled motorway pavement.

- Plastic road (NL) aims at building roads from recycled plastics.

- Next **challenge**: how many times a road can be recycled?

ANR IMPROVMURE
PN MURE

Chailleux, Emmanuel, et al. "BioRePavation: innovation in bio-recycling of old asphalt pavements, comparison between EU and US mix design specification systems." *13th ISAP conference, Fortaleza, Brazil*. 2018.

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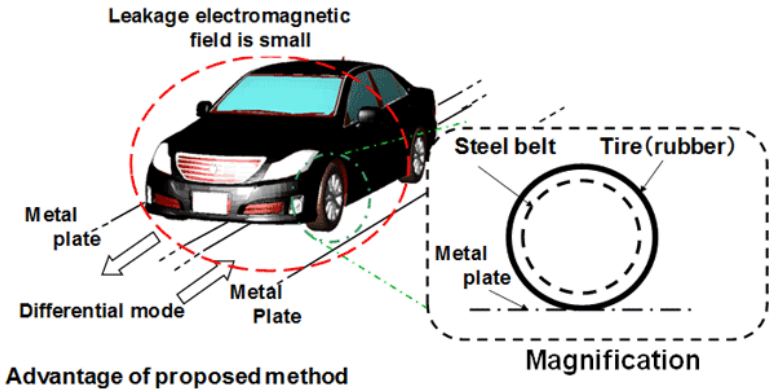
ELECTRIC VEHICLES POWERING
DIFFERENT COMPETING TECHNOLOGIES

ALSTOM
vti
IFSTTAR

INCIT-EV
FABRIC
RENAULT
INSTITUT VEDECOM
IFSTTAR

SIEMENS
bast
Federal Highway Research Institute

- Different technologies for energy transfer are being developed worldwide: three of them are more mature, but other may come



Advantage of proposed method
- ✓Leakage electromagnetic field is small
- ✓Infrastructure can be set up at a low cost compared with a coils
- ✓Influence of a shake of a car is not received easily

- An alliance between Germany-Sweden and France is being built to develop electric motorways.

FR_SE 2018
INNOVATION
PARTNERSHIP

Laporte, S.; Coquery, G.; Deniau, V.; De Bernardinis, A.; Hautière, N. Dynamic Wireless Power Transfer Charging Infrastructure for Future EVs: From Experimental Track to Real Circulated Roads Demonstrations. *World Electr. Veh. J.* **2019**, *10*, 84. https://doi.org/10.3390/wevj10040084

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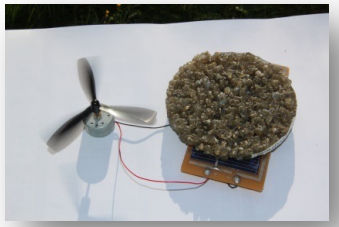
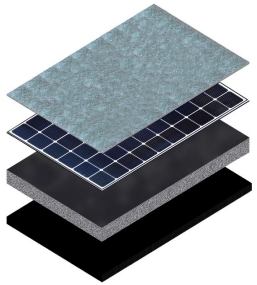
SOLAR ENERGY HARVESTING

SMART
European Training Network

PV road





Small scale prototype

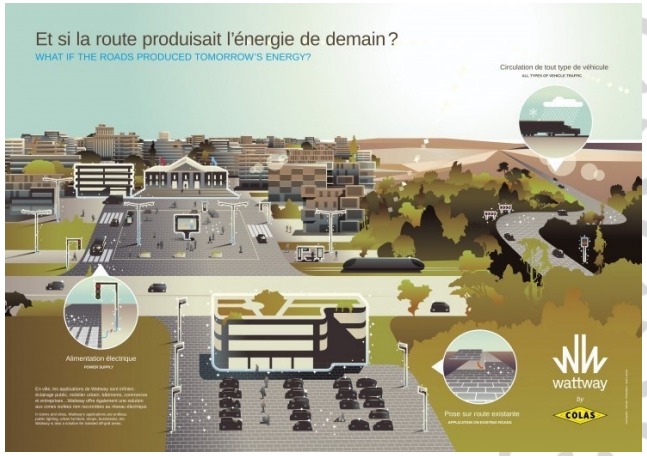
sense CITY

Research directions
- PV cells selection
- Materials properties
- Surface characteristics
- Electrical architecture

Towards a modular solution

Hybrid solar road
PV + fluid circulation

Tourouvre, December 2016



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RÉPUBLIQUE FRANÇAISE
Ministère de l'Environnement, de l'Énergie et de la Mer

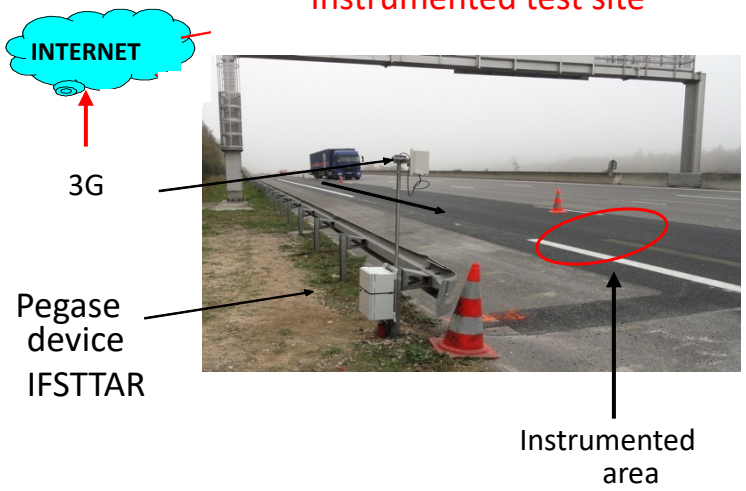
wattway by COLAS

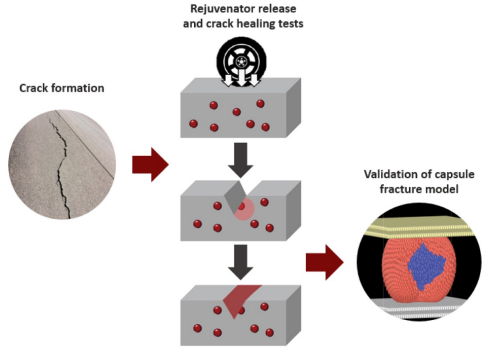
COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

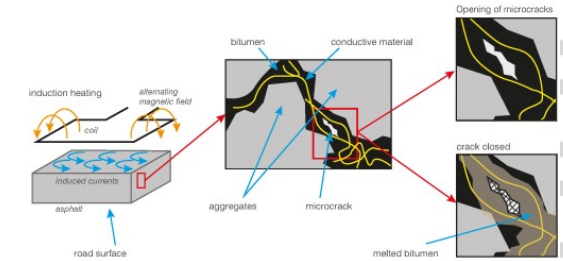
Nicolas Le Touz , Jean Dumoulin, J.M. Piau. Solar hybrid road: from numerical model to an energy balance in France, ICOME 2018 - International Conference on MATERIALS & ENERGY, Apr 2018, San Sebastian, France
Hu, H., Vizzari, D., Zha, X., & Roberts, R. (2021). Solar pavements: A critical review. *Renewable and Sustainable Energy Reviews*, *152*, 111712.

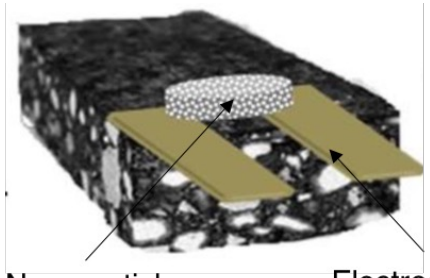
SELF-DIAGNOSIS OF ROAD NETWORKS
SELF-REPAIRING MATERIALS

Instrumented test site

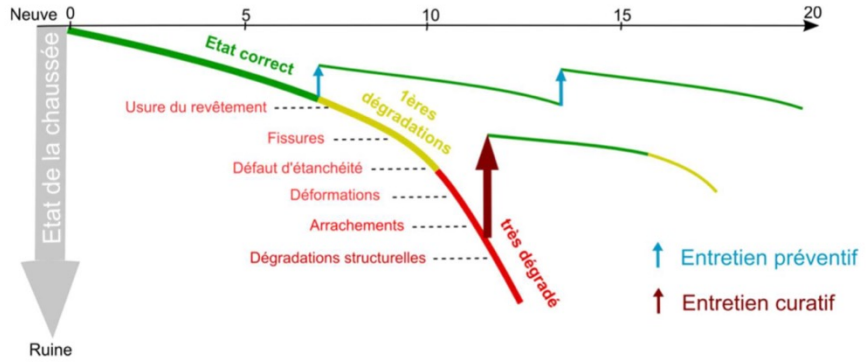








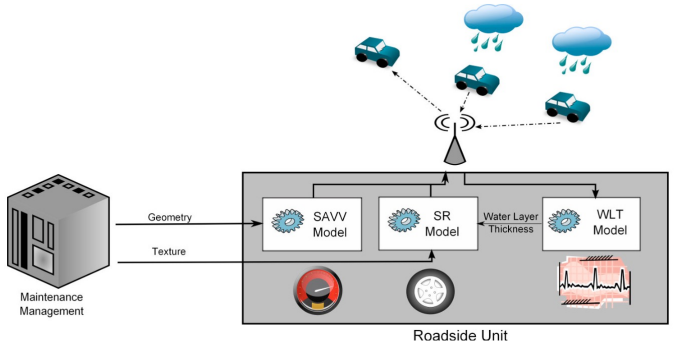
ALTAROAD



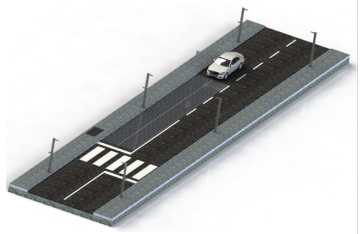
Barriera, M.; Pouget, S.; Lebental, B.; Van Rompu, J. In Situ Pavement Monitoring: A Review. *Infrastructures* **2020**, *5*, 18. https://doi.org/10.3390/infrastructures5020018

SMART ASPHALT PAVEMENTS AND COATINGS

- Smart tires will incorporate new functions
  - Pavement characterization including skid resistance measurement



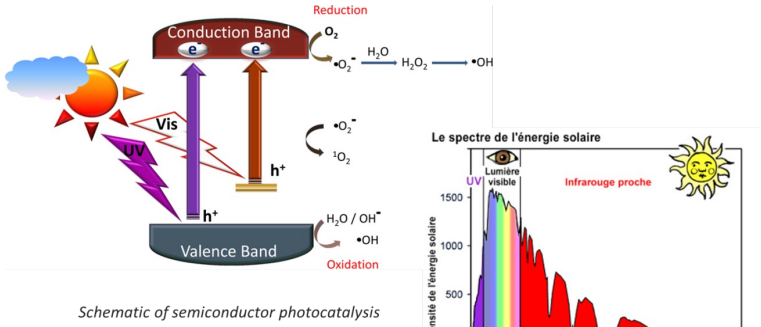
  - Energy production by harvesting energy losses due to pavement-tire interactions



- Next generation pavements will have a reduced rolling resistance while still being safe

Test track dedicated to skid resistance isssues, Ifsttar-Nantes

- Next pavement will harvest energy for road lighting or even improve air quality using smart materials



Schematic of semiconductor photocatalysis

Basset, Philippe, et al. "Roadmap on nanogenerators and piezotronics." *APL Materials* 10.10 (2022): 109201.
Villa, Céline & Brémond, Roland & Eymond, François & Saint-Jacques, Enoch. (2021). Caracterisation of luminescent road markings. 10.25039/x48.2021.OP02.
Le Pivert, M., Hautière, N., Geisler, F., Pouget, S., Leprince, Y. Les nanomatériaux au service des routes dépolluantes, Revue Générale des Routes et leur Aménagement (RGRA), N°987 – « Matériaux de la route et de la voirie », pages 26-29, Janvier 2022

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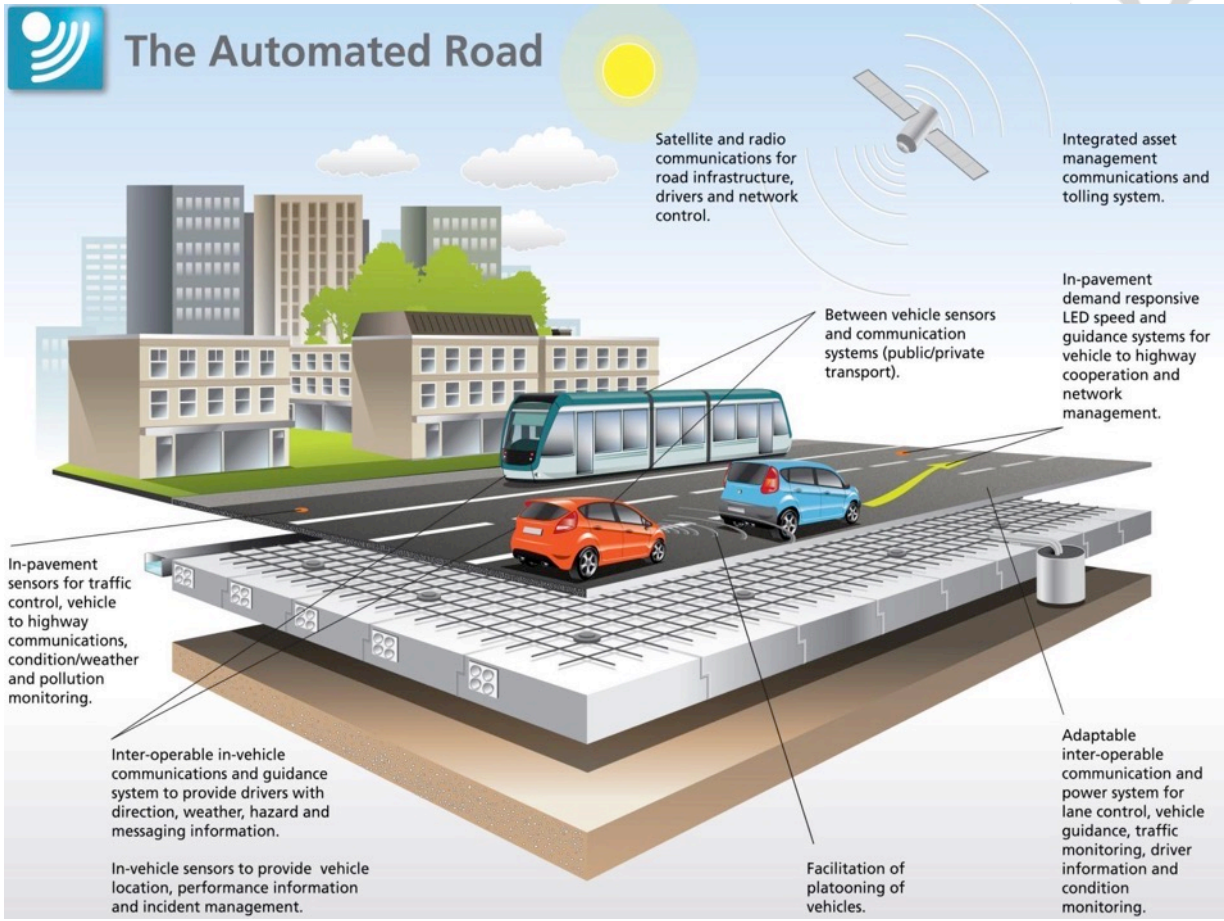
TURBO
LA ROUTE DE DEMAIN, un avenir pas si lointain !

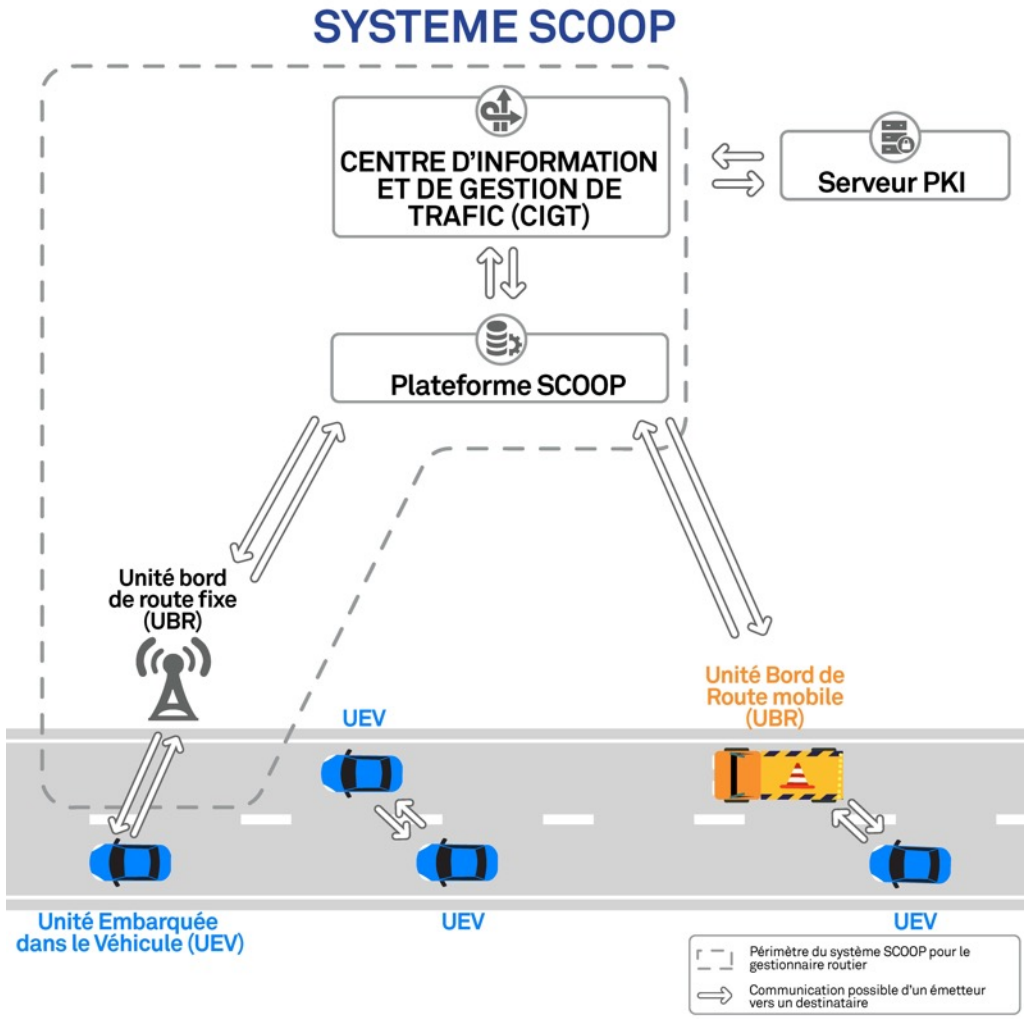
THE AUTOMATED ROAD | 3.3

THE AUTOMATED ROAD

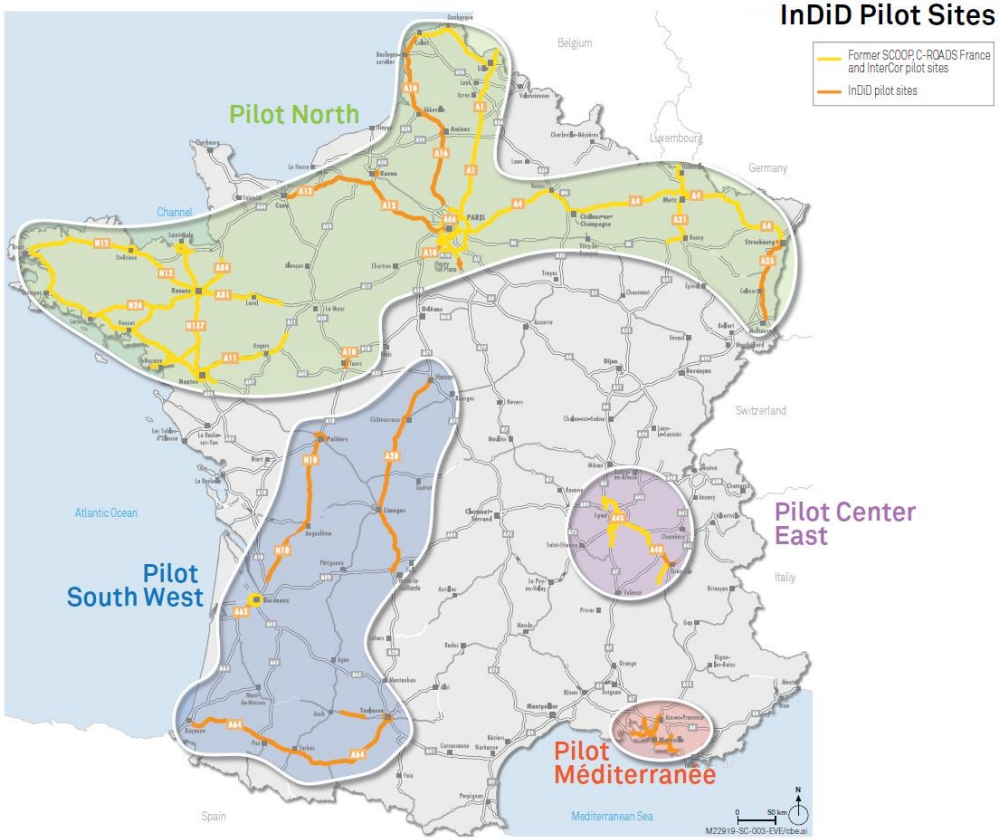
- Fully integrated with the user, vehicle and operations:
  - The automated road will incorporate a fully integrated information, monitoring and control system; communicating between road users, vehicles and operators.
  - It will support a cooperative vehicle-road system that will manage travel demand and traffic movements.
  - It will measure, report and respond to its own condition, providing instant information on weather, incidents and travel information.



HIGHWAY USE CASE #1: IMPROVED TRAFIC SAFETY AND EFFICIENCY THROUGH CONNECTIVITY



C-ROADS



InDiD Infrastructure Digitale de Demain

InterCor

Projet SCOOP véhicules et routes connectés connected vehicles and roads

Ladino, Andres, Pierre-Antoine Laharotte, and Nour-Eddin El Faouzi. "System Level Impacts of V2I-based Speed Control Strategies: the SCOOP@ F project deployment scenarios." *International Symposium on Transportation and Data Modeling*. 2021.

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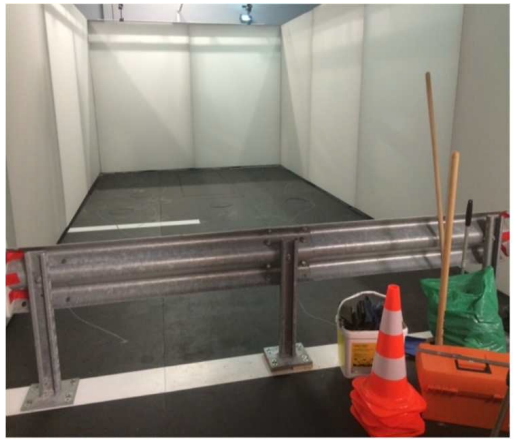
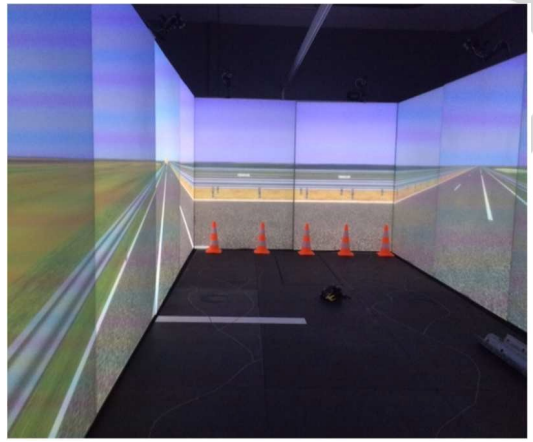
HIGHWAY USE CASE #2: SMART ROADWORKS

- The YELLOW project aims to:
  - design and validate smart devices to improve the safety of workers in construction sites via:
    - The optimization of intrusion detection by image processing alerts in case of intrusion
    - A better identification of sites by road users.
  - Reduce the risk of intrusion of a road user (VL, PL, 2RM ...) in the area of activity of the site and collision with on-site personnel.

- Displacement simulators have been used to assess the acceptability of the tools by road workers and assess their efficiency





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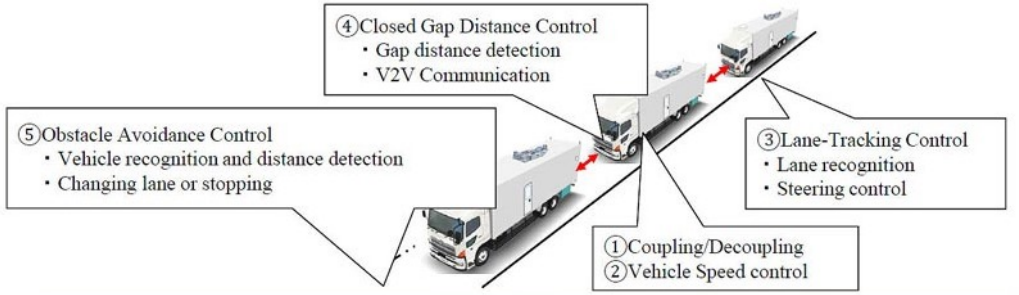
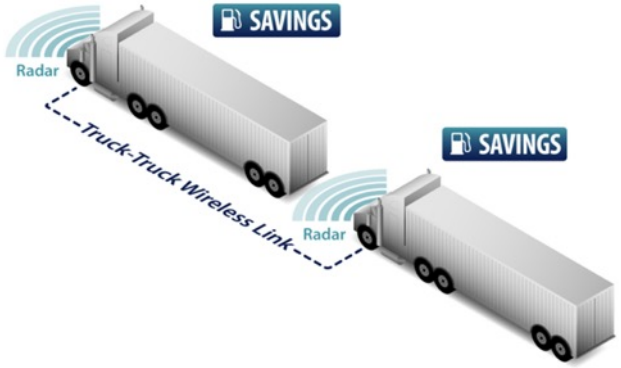
HIGHWAY USE CASE #3: TRUCK PLATOONING FOR FREIGHT MOVEMENT

ENSEMBLE

- Truck platooning:
  - 2-3 trucks connected using V2V solution are following at close distances (<10m)
  - Stabilized and uniform speeds, no overtaking manoeuvres
- Benefits
  - Reduction of costs and delays,
  - Improvement of productivity
  - Reduction of drivers anxiety
  - Increased safety thanks to less human faults
  - Reduced emissions and oil consumption (10%)
  - Increasing of road capacity, reduction of congestion



		Ahead Vehicle	Following Vehicle
Coupling/decoupling		Semi-auto	Semi-auto
Gap distance within platoon			10m
Control	Lane-keeping	Machine vision	Machine vision
	Vehicle speed	ACC ・Laser ・Radar(76GHz)	CACC ・Laser ・Radar(76GHz) ・5.8GHz V2V Communication
	Gap distance		
	Obstacle avoidance	Emergency Braking	



- Remaining challenges:
- Impact on infrastructures
- Reliability and interoperability of the technology
- Labour law
- Formation of convoys, management centres
- Business model
- Liability, insurance, etc.

Leiva-Padilla, Paulina, et al. "Fatigue Life Predictions for a European Pavement Test Section Subjected to Individual and Platoon Truck Configurations." *Transportation Research Record*2676.4 (2022): 746-762.

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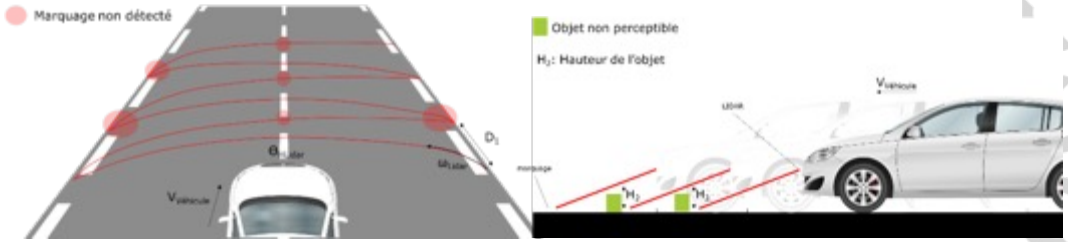
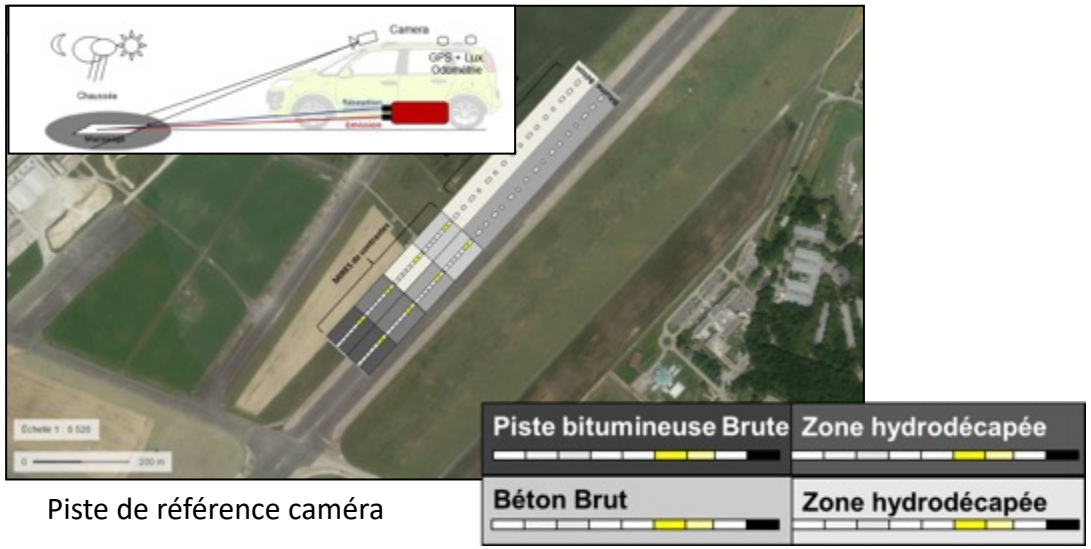
HIGHWAY USE CASE
SIGNS & SENSOR CROSS-SPECIFICATION ISSUE

- Establish a correlation between the detection of the signs by a vehicle sensor and the measurements made by a reference device
- Develop new smart paintings which are adapted to the needs of ADS and able to self-diagnose and to feed predictive maintenance schemes.



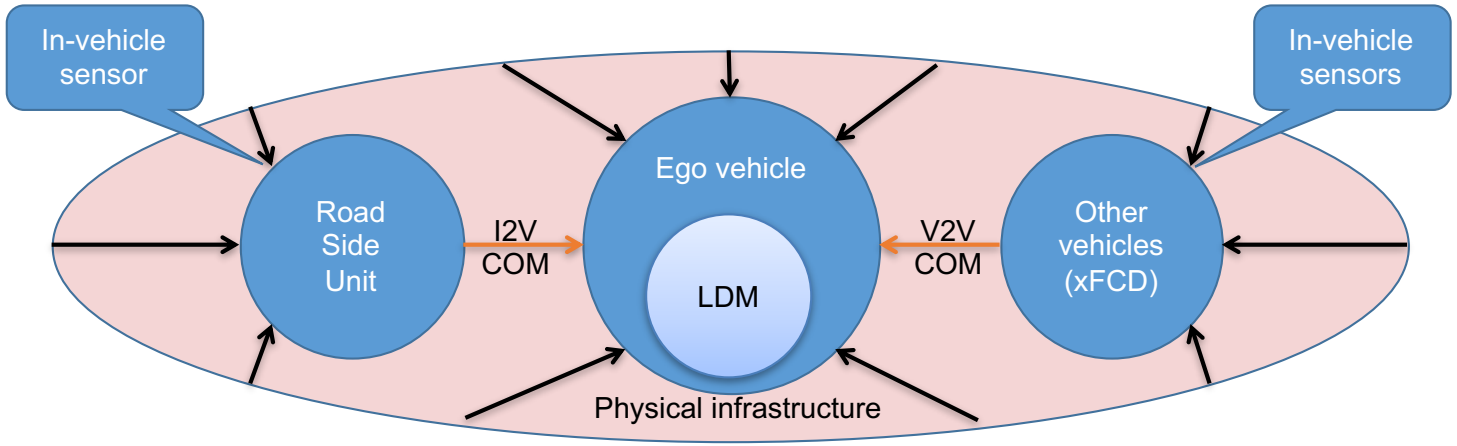
Lidar reference track

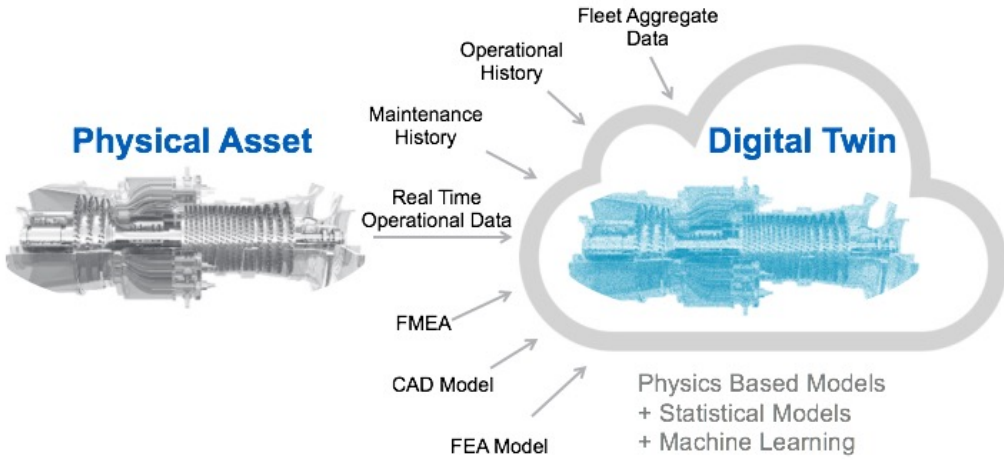


Piste de référence caméra

Hautière, N., Muzet, V., Franchineau, J.-L. Signalisation horizontale : Quels enjeux de recherche ? Revue TEC, N°240 - Dossier : Nouvelles mobilités : quel impact sur les infrastructures ? pages 38-39, Janvier 2019

DIGITAL TRANSFORMATION OF HIGHWAYS IS A MUST FOR CONNECTED AND AUTOMATED VEHICLES





Autonomous Vehicle: The Concept of High Quality of Service Highway. J. Ehrlich,. D. Gruyer, O. Orfila, N. Hautière, FISITA World Automotive Congress, Busan, Korea, 2016

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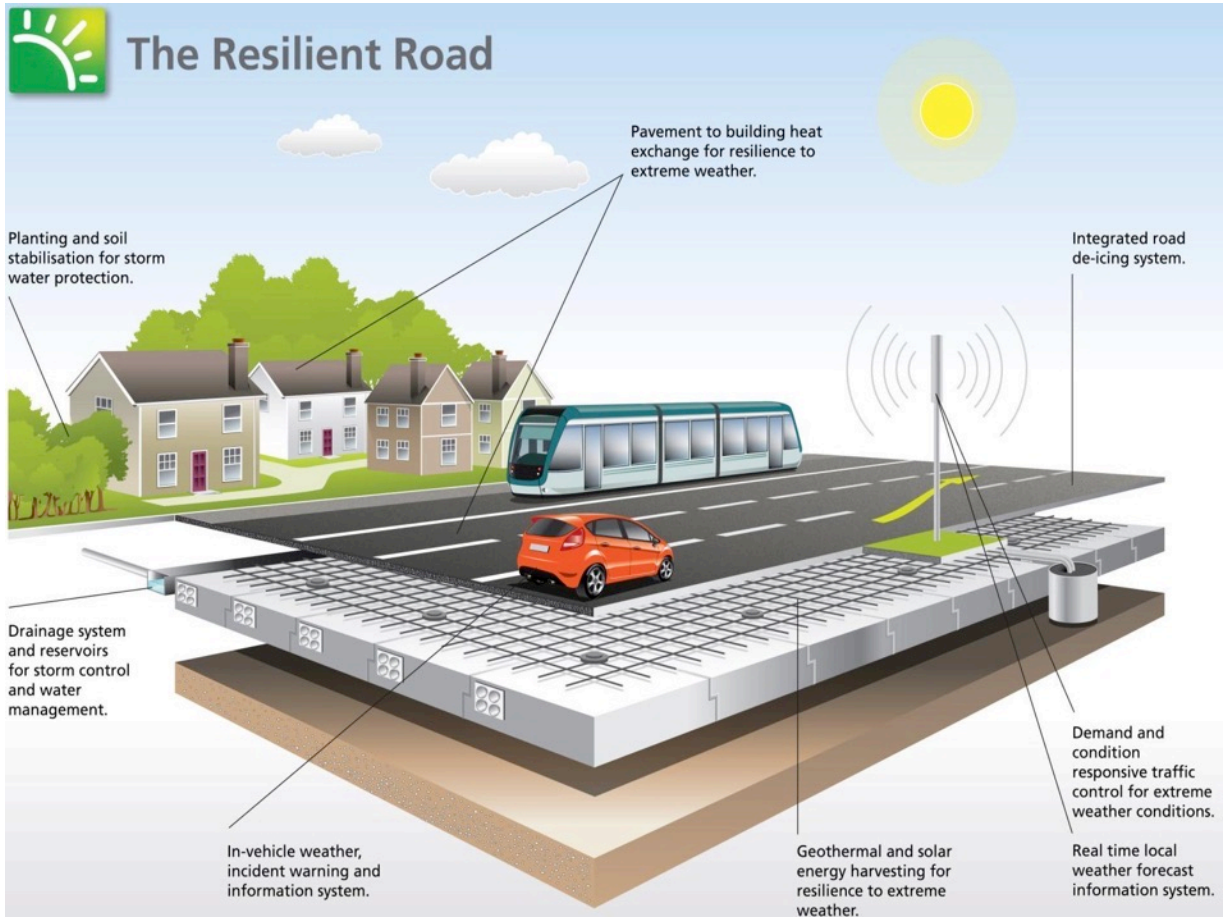
THE RESILIENT ROAD | 3.4

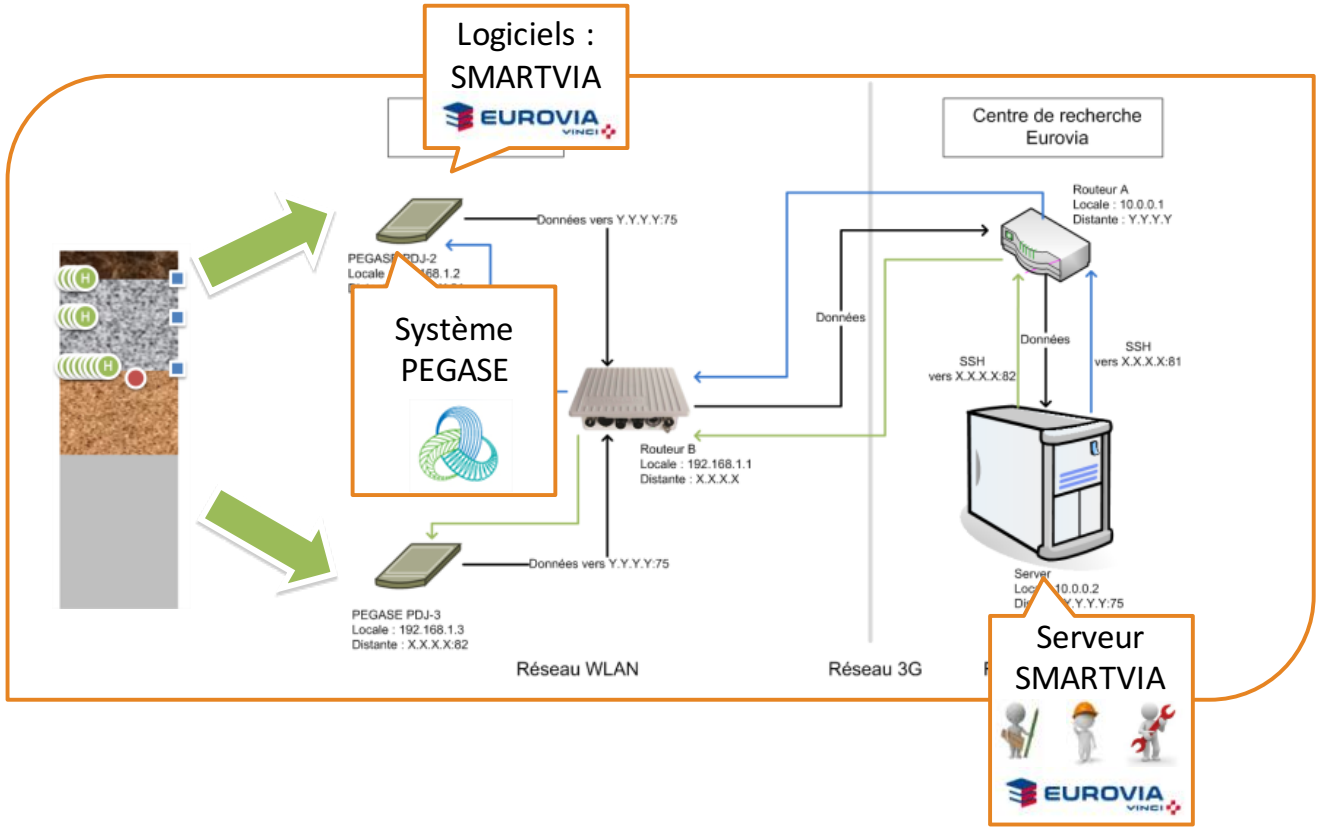
THE RESILIENT ROAD



- Fully adaptable to extreme weather conditions:
  - The resilient road will adapt itself to the impacts of extreme weather conditions and climate change.
  - The road will monitor flooding, snow, ice, wind and temperature change, and mitigate their impacts through integrated storm drainage, automatic heating and cooling, and will be linked to the integrated information system for travellers and operators.
  - The climate change resilient road: focuses on ensuring adequate service levels of the road network under extreme weather conditions.
  - Innovation themes will address adaptation of road operations and management to the effects of extreme weather to such extent that adequate service levels are ensured.

RESILIENCE OF PAVEMENTS TO CLIMATE CHANGE

- CCLEAR Project (FR) aimed at developing design models taking into account climate change



Sudden potholes formation on A75 in Winter 2012

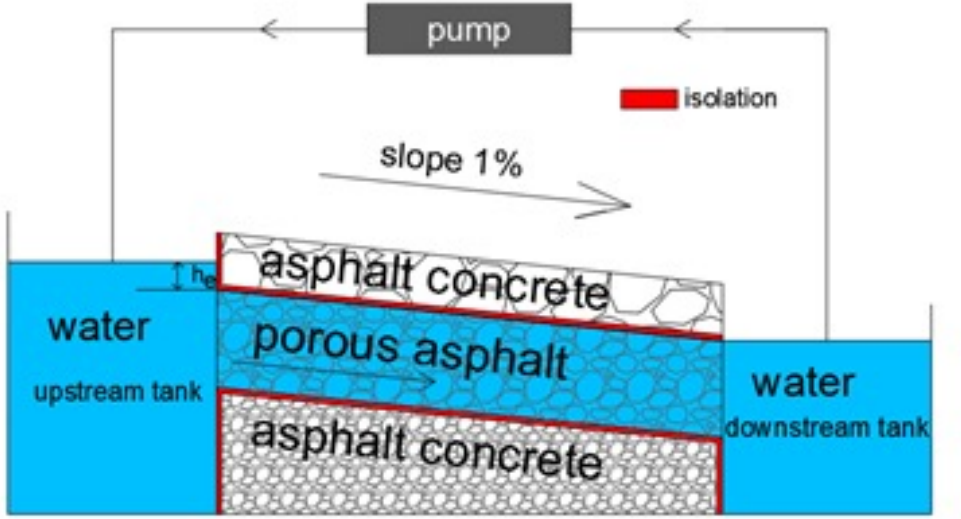
Instrumentation of pavement section on A75 in CCLEAR Project (2012)

C. Mauduit, Ph. Nguyen, V. Mauduit, N. Venries, J.-P. Kerzreho, B. Pouteau, F. Hammoum Instrumented site on motorway A75 - Impact of climatic conditions on road infrastructures, RGRA | N° 907-908 • December 2012 - January 2013

SOLAR ROAD

HEATING AND COOLING PAVEMENTS

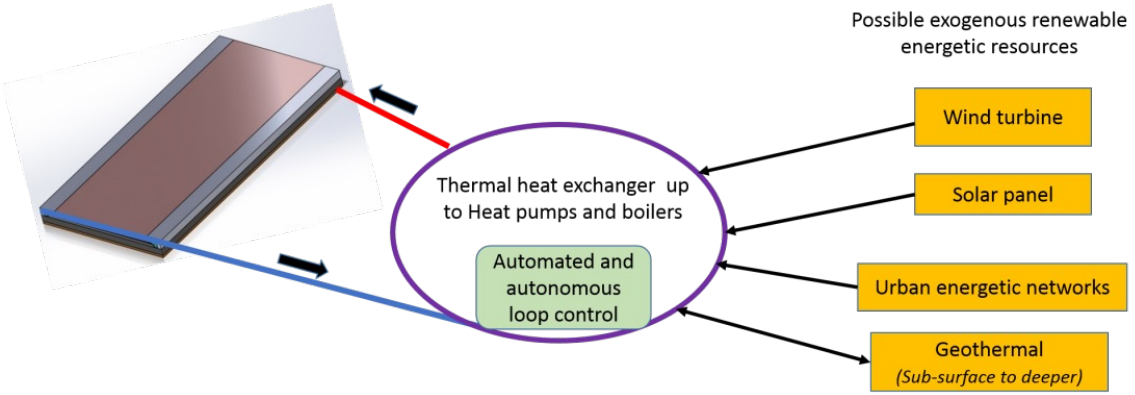
Principle

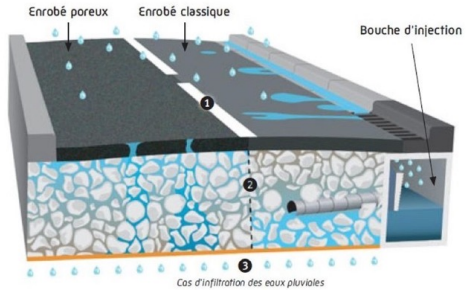


Demonstrator

Cerema

Energy supply system





Asfour, Sarah, Frédéric Bernardin, and Evelyne Toussaint. "Experimental validation of 2D hydrothermal modelling of porous pavement for heating and solar energy retrieving applications." *Road Materials and Pavement Design* 21.3 (2020): 666-682.

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RESILIENCE OF TRANSPORT NETWORKS

Characterization and modelling of network resilience

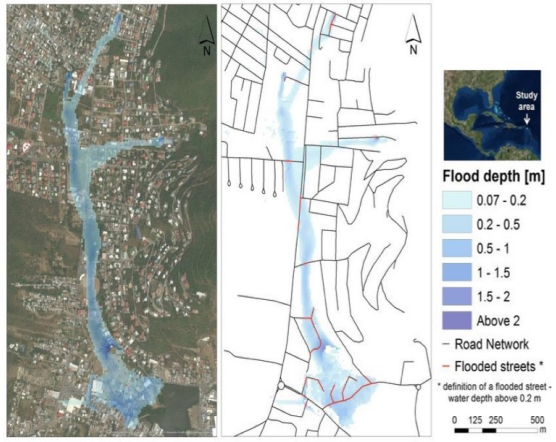
- Resilience metrics: topological, dynamic
- Stress testing and traffic simulation
- Cascade effects and propagation in a multimodal context

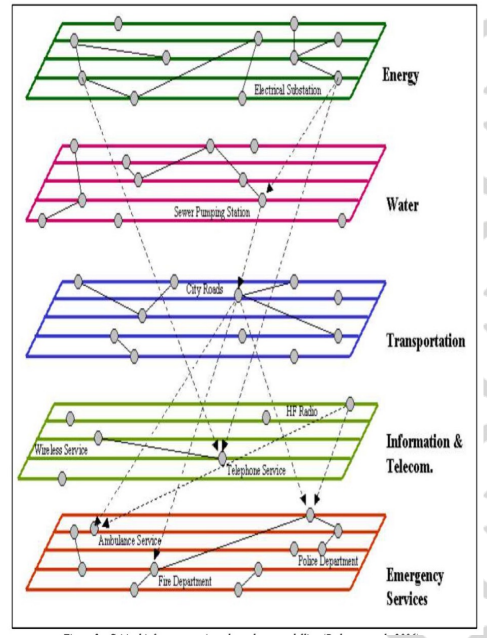
Multi-physics simulation of networks

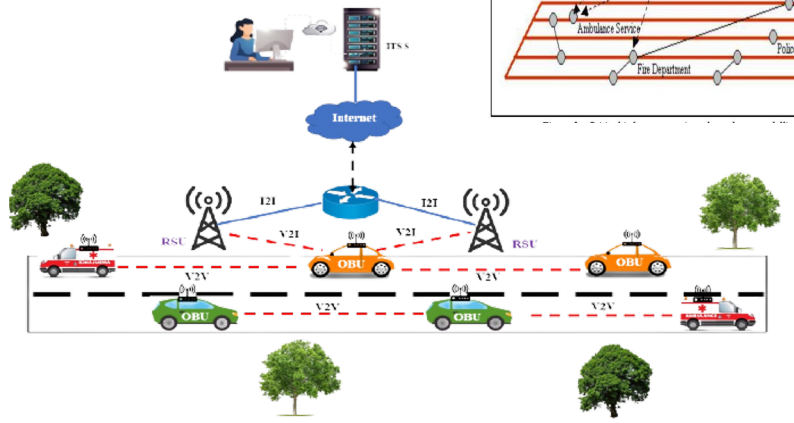
- Coupling of different dynamics, e.g. flash floods vs. road networks
- Towards a multi-network approach, including utilities

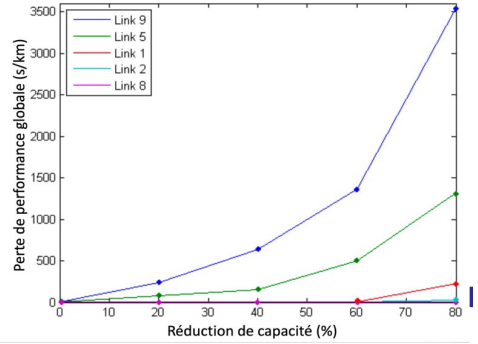
Dynamic reconfiguration of networks in case of crisis

Dynamic population evacuation strategies using connected vehicles









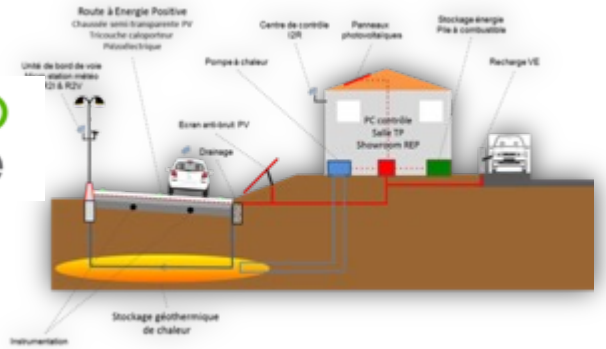
Furno, Angelo, et al. "Graph-based ahead monitoring of vulnerabilities in large dynamic transportation networks." *PloS one* 16.3 (2021): e0248764.

NEXT STEP - THE R5G*fab* : FROM KEY CONCEPTS TO DEPLOYMENT

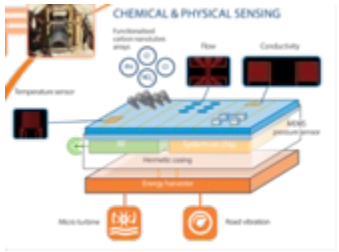
4

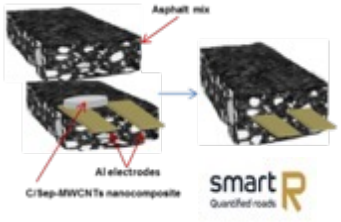
KEY CONCEPTS FOR ROADMAPS | 4.1

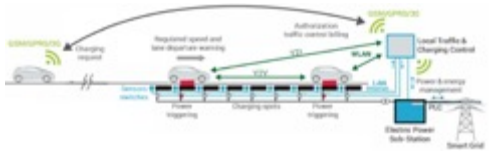
CONCEPT#1: ENERGY INTEGRATED ROADS

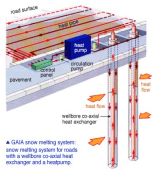


Transforming the 17 000 km² of the French road networks into photovoltaic surfaces makes it possible to produce 5 times the electricity consumption.









Urban & Transport Planning

Energy Harvesting

Energy Storage

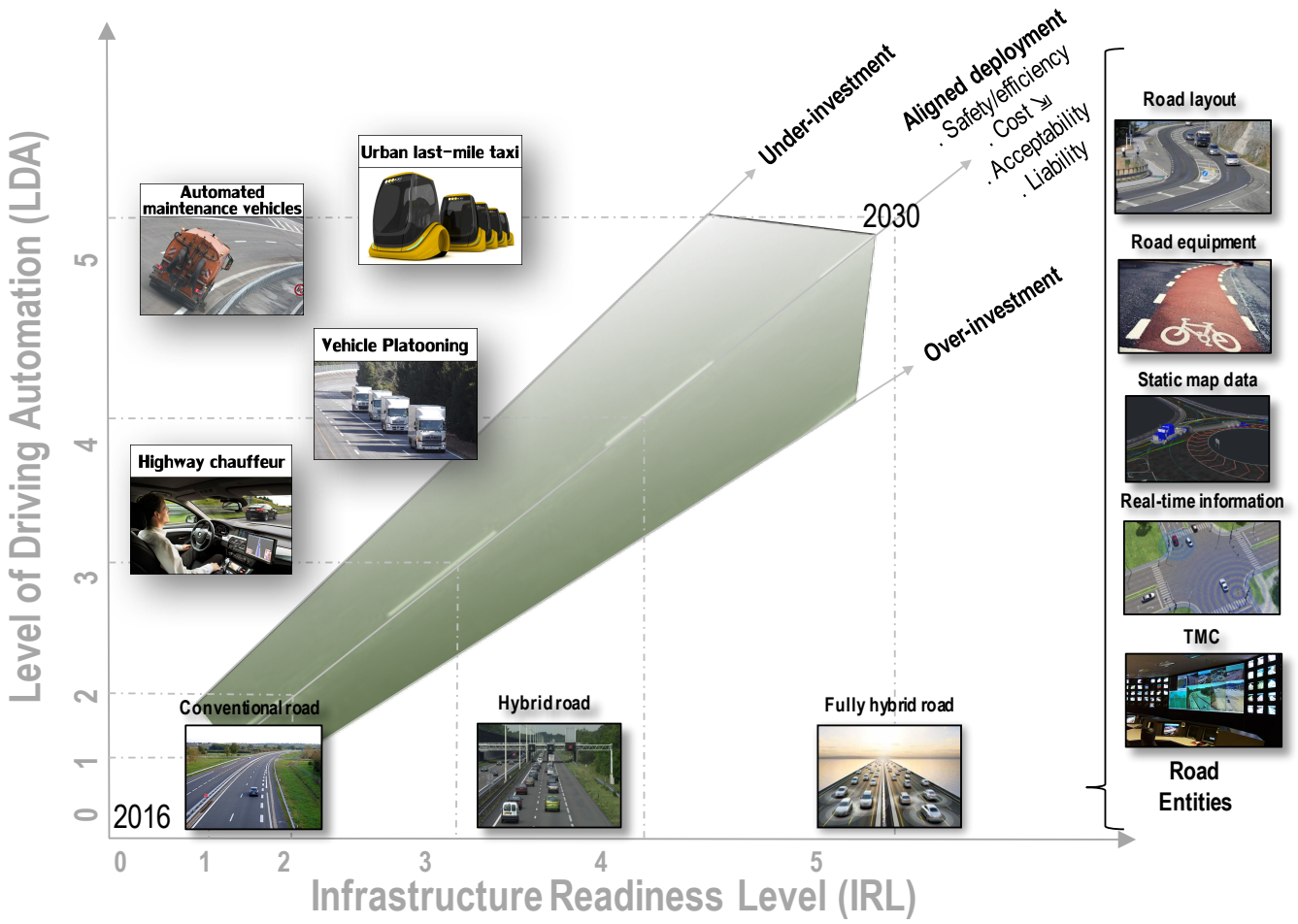
Energy Transfer

SHM

PARIS2015 COP21·CMP11

Hautière, N. De la route électrique à la route énergétiquement intégrée. Revue Générale des Routes et de l'Aménagement (RGRA), N°962, pages 38-42, Avril 2019

CONCEPT #2: HYBRID ROAD DESIGN FOR CAD



	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Conventional infrastructure	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				
	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs.	X			
Digital infrastructure	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	X	X		
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time.	X	X	X	
	A	Cooperative driving	Based on the real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow.	X	X	X	X

Figure 3 – Levels of the Infrastructure Support for Automated Driving (ISA Levels)

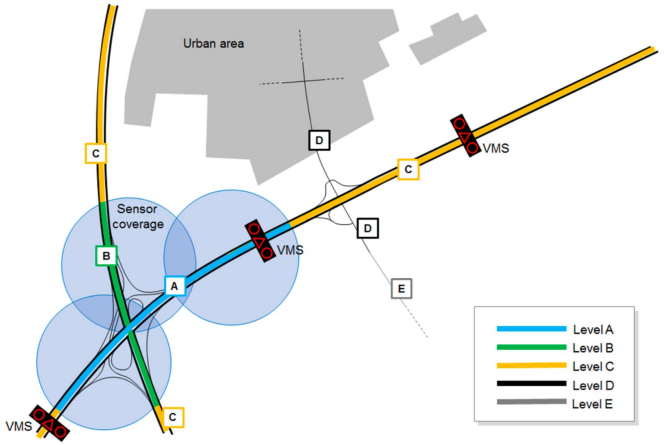
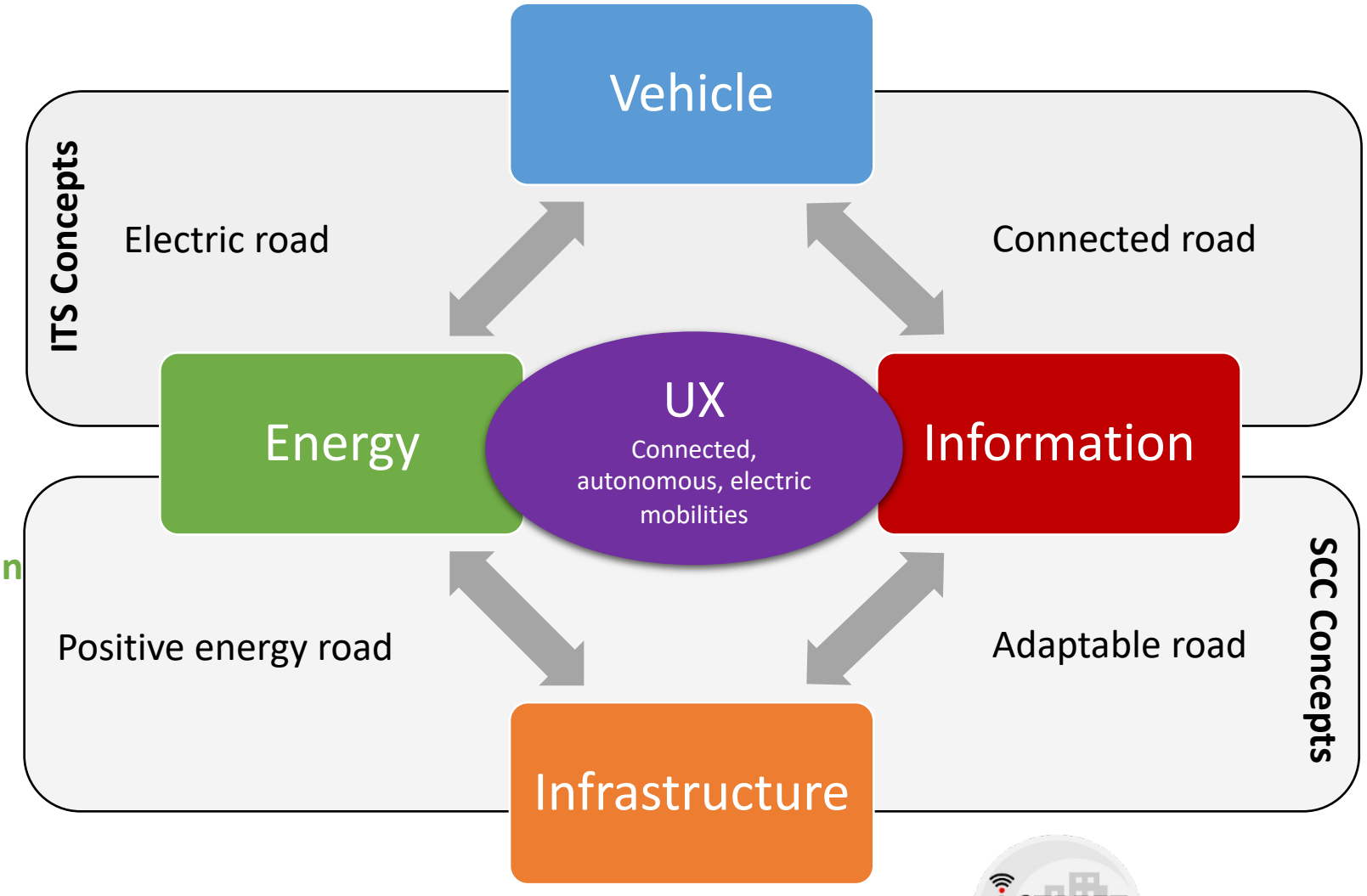


Figure 4 – Examples of ISA Levels assigned to a road network

Gruyer, D., Orfila, O., Glaser, S., Hedhli, A., Hautière, N. and Rakotonirain, A. “Are Connected and Autonomous Vehicles the silver bullet for future transportation issues? Benefits and weaknesses on Safety, Consumption, and Traffic congestion.”, in Frontiers in Sustainable Cities, Special Collection "Advances in Road Safety Planning", 8th January 2021.

CONCEPT #3: FROM VIC TO VI$_2$E DESIGN MODEL



Less CO_2
Less emissions

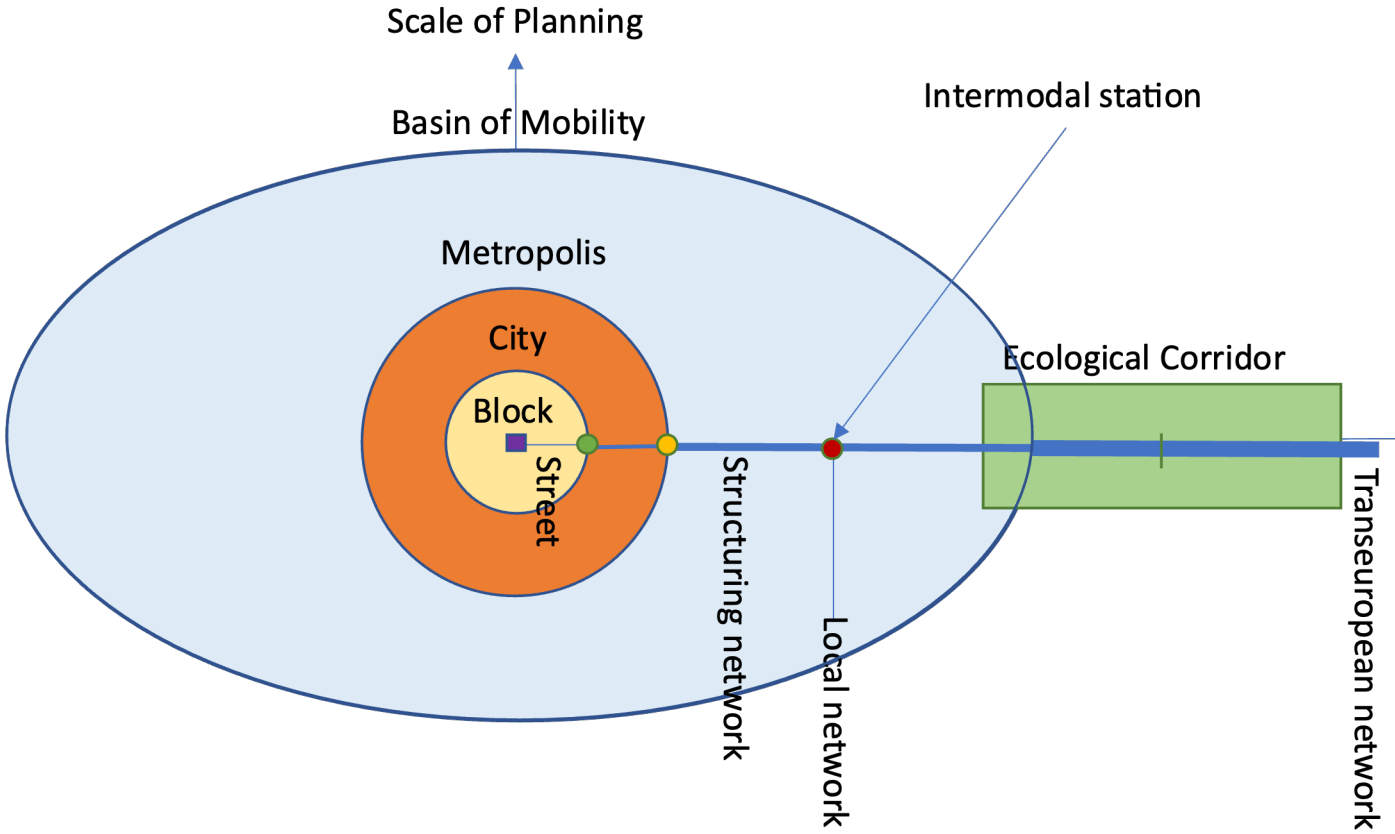
Mastered congestion
Increased safety

Smart and clean energy

Optimized use and maintenance

New services
Optimisation of public space

THE R5G *fab* AIMS TO ACCELERATE THE PROJECTS OF TERRITORIES



- The main reason for the requests for intervention are the metropolitan thromboses: Bordeaux, Nantes, Lyon, Lille, Paris, Strasbourg, Marseille...
- The transformation of VSAs into a new type of urban boulevard, the adaptation of networks to new forms of mobility or positive health streets are the main requests.

Hautière, N., Décarbonation des mobilités et infrastructures de transport. Trajectoire(s), novembre 2022, pages 82-84

BUSINESS CASES UNDER DEVELOPMENT | 4.2

URBAN NETWORKS: GLOBAL PERFORMANCE PUBLIC MARKETS AT THE SERVICE OF NETWORK HYBRIDIZATION

Adaptive lighting

- Light grid: pedestrian safety and reduced consumption
- Variations in light intensities (traffic, safety, consumption)
- Variations in the spectrum and the intensity solid (biodiversity)

Pavement and light

- Visibility = luminance
- Lighting + reflection => road luminance
- Evolution of the reflection properties of pavements
- Intelligent lighting that optimizes consumption and visibility

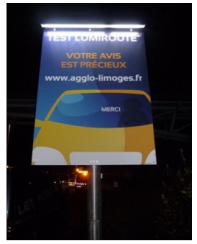
Cerema

spie batignolles

Spie batignolles énergie

THORN

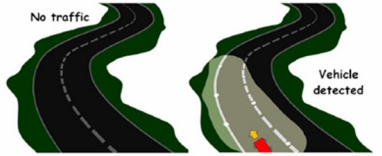
MALET



Reinforcement of guidance in unlit areas

- Luminescent marking
- LED light studs

inroads



Schematic of Active Lane Delineation Application

Projet SUSHIS
Piste cyclable luminescente (Pessac 33)
Olikrom – Eiffage - IFSTTAR

The lighting pole (90 million in France) becomes an RSU including in particular the V2X, but also the recharging of electric vehicles

Consequently, the street lighting markets are transformed into MPGP and become vectors of hybridization of road infrastructures.

CiELiS
I light Paris

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BAYARD, Victor. *Participation du réseau d'éclairage public aux processus de mutations urbaines: Étude des trajectoires historiques du réseau d'éclairage public sur le territoire parisien et réflexions sur son intégration contemporaine à la politique de construction de la «Ville Intelligente»*. 2022. Thèse de doctorat. Université Paris-Est.

PERI-URBAN NETWORKS: FROM MULTIMODAL MOTORWAYS TO ROAD TRAINS

- On peri-urban motorway networks, the challenge is to develop the infrastructure to enable them to accommodate means of transport with higher occupancy rates
- As automation progresses, it is possible to envisage the transformation of dedicated lanes into real road trains, probably decarbonised

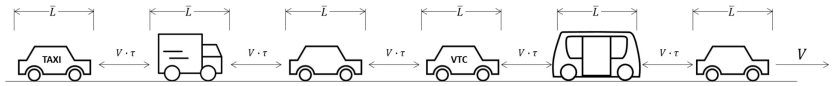
Current situation

Coach on auxiliary lane

Carpool lane

Future situation

TRAINS ROUTIERS…



φ_{max} Débit maximum de véhicules par heure et par voie

Vitesse	500	1 000	1 500	2 000	2 500	3 000	3 500	4 000	4 500	5 000
130 km/h	7,0s	3,4s	2,2s	1,63s	1,27s	1,03s	0,86s	0,73s	0,63s	0,55s
120 km/h	7,0s	3,4s	2,2s	1,62s	1,26s	1,02s	0,85s	0,72s	0,62s	0,54s
110 km/h	7,0s	3,4s	2,2s	1,60s	1,24s	1,00s	0,83s	0,70s	0,60s	0,52s
100 km/h	7,0s	3,4s	2,2s	1,58s	1,22s	0,98s	0,81s	0,68s	0,58s	0,50s
90 km/h	7,0s	3,4s	2,2s	1,56s	1,20s	0,96s	0,79s	0,66s	0,56s	0,48s
80 km/h	6,9s	3,3s	2,1s	1,53s	1,17s	0,93s	0,76s	0,63s	0,53s	0,45s
70 km/h	6,9s	3,3s	2,1s	1,49s	1,13s	0,89s	0,72s	0,59s	0,49s	0,41s
60 km/h	6,8s	3,2s	2,0s	1,44s	1,08s	0,84s	0,67s	0,54s	0,44s	0,36s
50 km/h	6,8s	3,2s	1,97s	1,37s	1,01s	0,77s	0,60s	0,47s	0,37s	0,29s
40 km/h	6,7s	3,1s	1,86s	1,26s	0,90s	0,66s	0,49s	0,36s	0,26s	0,18s
30 km/h	6,5s	2,9s	1,68s	1,08s	0,72s	0,49s	0,31s	0,18s	0,08s	-
20 km/h	6,1s	2,5s	1,35s	0,78s	0,50s	0,12s	-	-	-	-
10 km/h	5,6s	1,44s	0,24s	-	-	-	-	-	-	-

Limite humaine / Limite machine perceptive / Limite machine communicante

$\tau = \frac{1}{\varphi} - \frac{\bar{L}}{V}$

Distance moyenne inter-véhicules

Manuel
VA
V2V / V2I
Impossible

Nb de passagers par véhicule	500	1 000	1 500	2 000	2 500	3 000	3 500	4 000	4 500	5 000
1,0	0,5k	1,0k	1,5k	2,0k	3k	3k	4k	4k	5k	5k
2,0	1,0k	2,0k	3k	4k	5k	6k	7k	8k	9k	10k
3,0	1,5k	3k	5k	6k	8k	9k	11k	12k	14k	15k
4,0	2,0k	4k	6k	8k	10k	12k	14k	16k	18k	20k
5,0	3k	5k	8k	10k	13k	15k	18k	20k	23k	25k
6,0	3k	6k	9k	12k	15k	18k	21k	24k	27k	30k
7,0	4k	7k	11k	14k	18k	21k	25k	28k	32k	35k
8,0	4k	8k	12k	16k	20k	24k	28k	32k	36k	40k
9,0	5k	9k	14k	18k	23k	27k	32k	36k	41k	45k
10,0	5k	10k	15k	20k	25k	30k	35k	40k	45k	50k

$\Phi = \bar{N}\varphi$

Débit de passagers par heure

≈ Route
≈ Bus
≈ Tramway
≈ métro/RER

TRAPEZE

Source : Laurent Taupin - ECOV

Potential
-6,4 Mt/an

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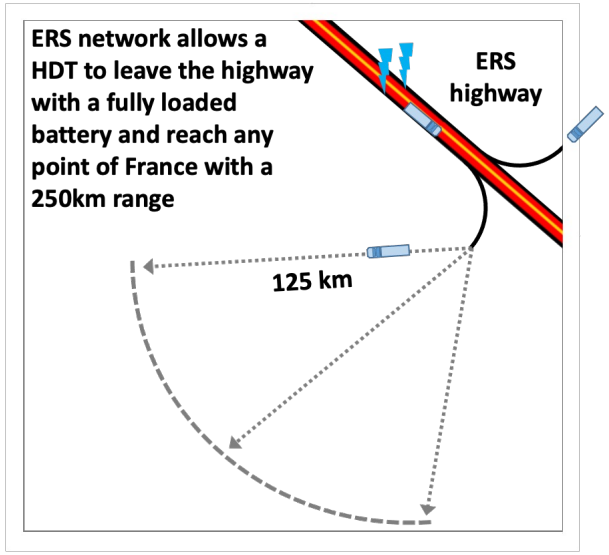
LONG-DISTANCE NETWORKS: AUTOMATION AND DECARBONISATION OF FREIGHT TRANSPORT

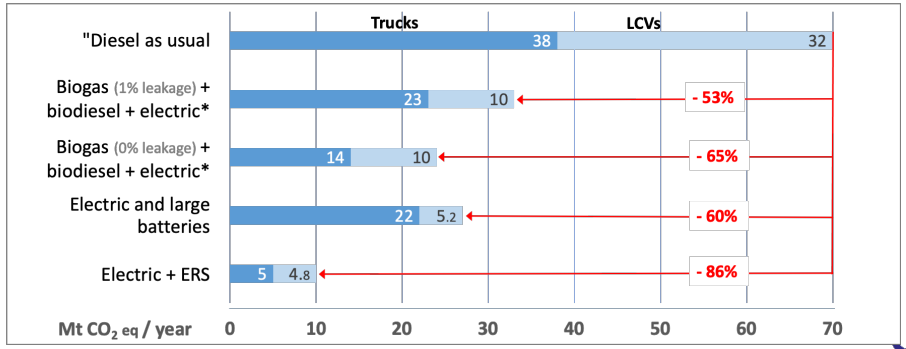
TRUCK PLATOONING

- Reduction of costs and delays
- Improved productivity
- Reduced driver anxiety
- Increased safety through fewer human errors
- Reduced emissions and fuel consumption (10%)
- Increased road capacity, reduced congestion

ELECTRIC ROAD SYSTEMS



GHG emission gaps /year in Life Cycle Analysis (2040) France data



Source : Pelata et al., 2021

Jacob, B., Hautière, N., Levesque, S., Rossigny, P. Solutions technologiques et conditions de déploiement des ERS, Revue Générale des Routes et leur Aménagement (RGRA), N°989 – « Les routes électriques (ERS) », pages 12-21, Avril 2022

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LOCAL NETWORKS: IMPROVING TERRITORIAL SUPPLY

Autonomous shuttles

Ultralight trains

Take advantage of autonomous mobility solutions to decarbonise everyday mobility and adapt at least the existing infrastructures in a cross modal way.

Cœur de Brenne – ENA Project

Rambouillet –TORNADO Project

FLEXMOVE Project – AKKA/ALSTOM

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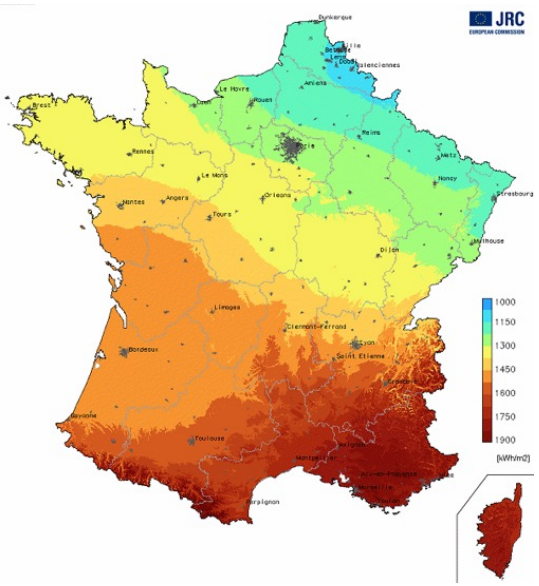
R5G AS PART OF A GLOBAL ENVIRONMENTAL STRATEGY | 4.3

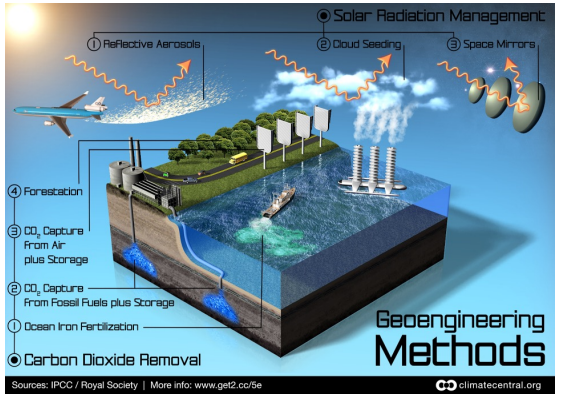
INTERURBAN NETWORKS: TOWARDS SHORT CIRCUIT GEO-ENGINEERING?

- Roads are "pervasive" networks. France has 1 million km and 12,000 km2 (1-2% of the country's area) and this is still growing



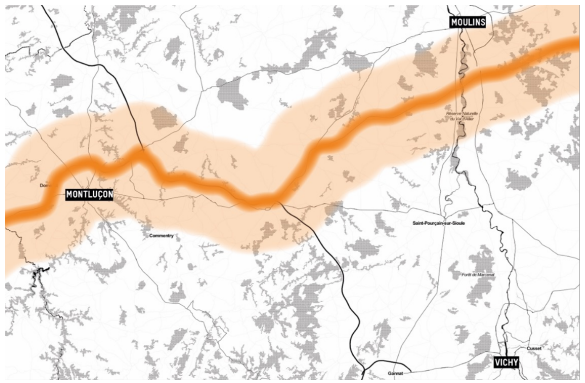
- For example, converting these pavements into photovoltaic pavements can produce the equivalent of four times the current electricity consumption in France.

- Timely monitoring combined with large-scale deployment of intelligent road materials can have a positive impact on the climate



- So, should we see the road as a problem or as a solution?

Projet A79- Allier



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CHALLENGE: MOVING FROM HIGHWAY INNOVATION TO THE SUSTAINABLE DEVELOPMENT GOALS

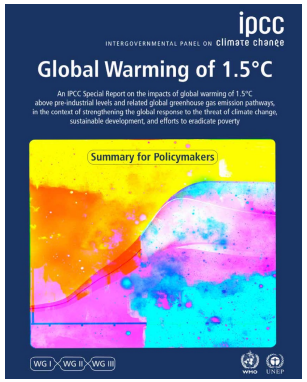
The emergence of the SDGs implies a change in the way RDI is practiced in the linear transport infrastructure sector

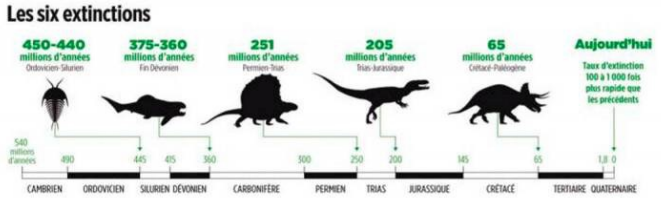
Among the new issues to be addressed:

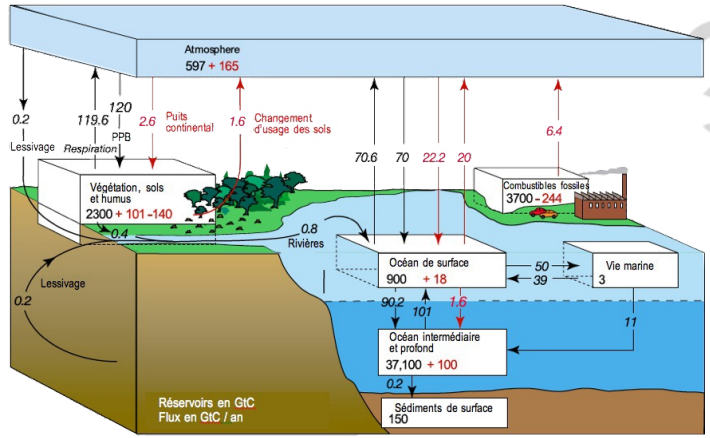
- Developing a new energy mix
- Preserving biodiversity
- Limiting climate change to 1.5°C
- Preserving water resources
- Contributing to the agro-ecological transition
- Sanctuarizing agricultural and forest lands
- Develop citizen involvement

Dual issue

- How can Linear Transport Infrastructures and their rights-of-way (ILTr) contribute to these objectives?
- How can LTIs be transformed into research infrastructures?







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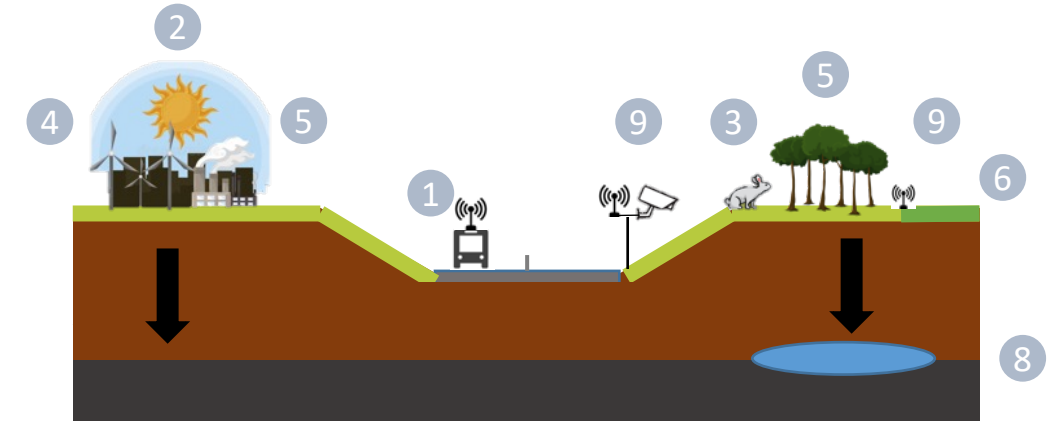
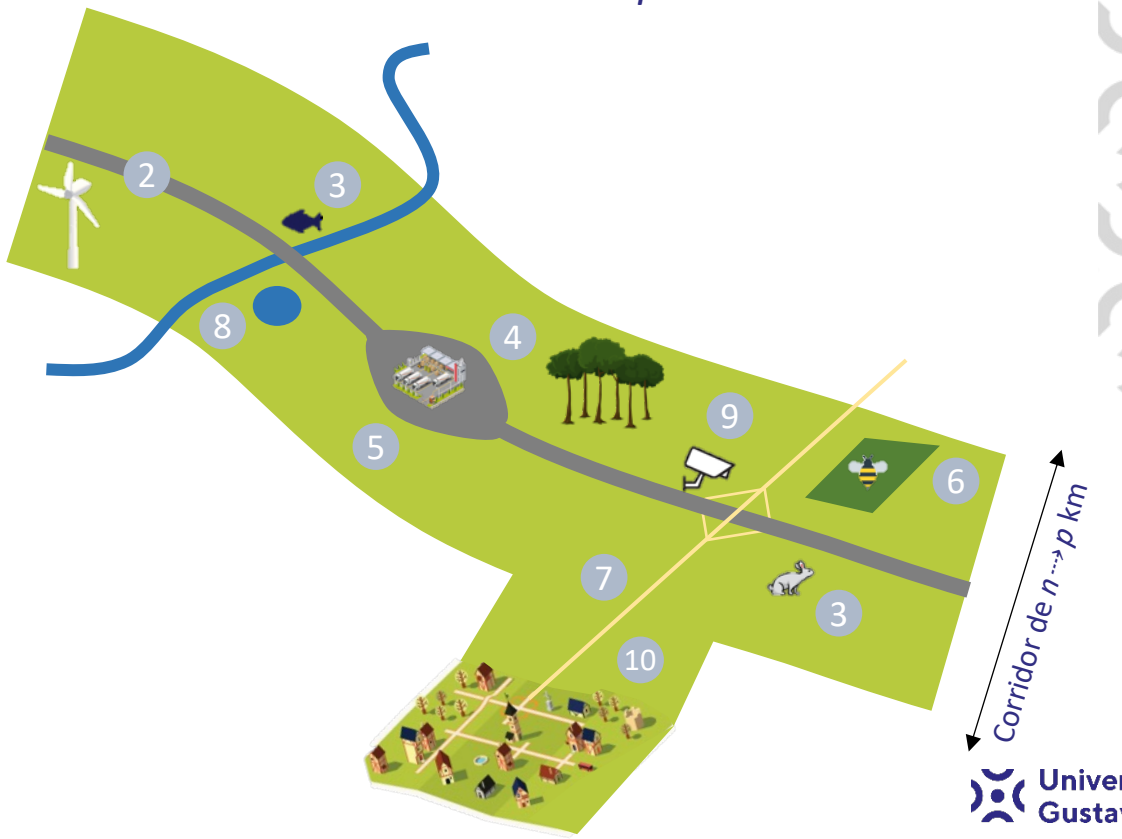
10 INTERDEPENDENT RDI THEMES

1. Rethink and adapt infrastructures to robomobility and electromobility
2. Develop a new energy mix
3. Transform ILTe into a corridor for biodiversity
4. Capture, store and valorize CO_2 on ILTe
5. Develop bioenergy associated with carbon capture and storage on ILTe
6. Contribute to the agroecological transition
7. Develop a local circular economy of carbon-free and bio-based materials
8. Preserve water resources
9. Observe the territory in an opportunitic way
10. Co-construct a local governance



Corridor de *n* ⇢ *p* km



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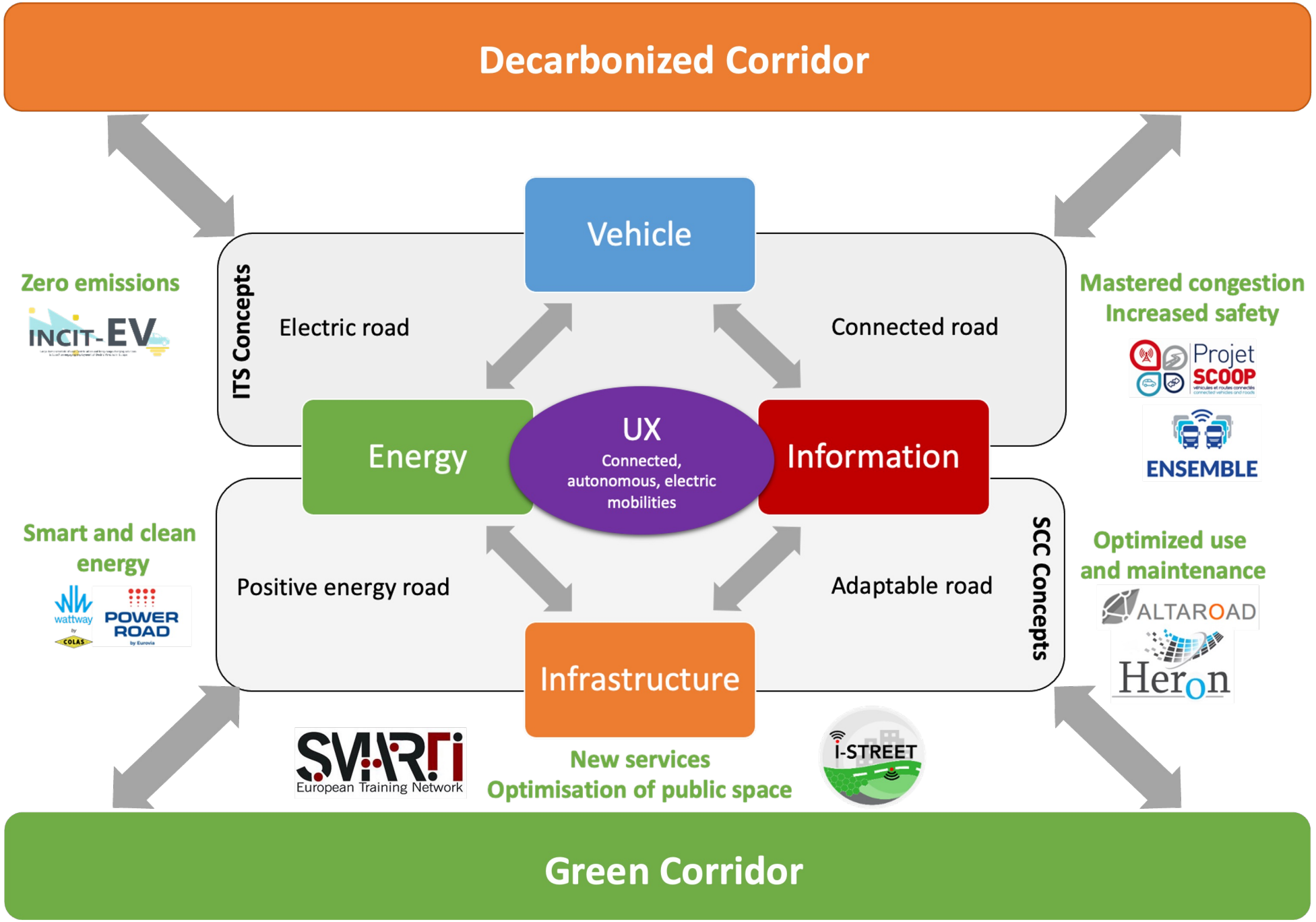
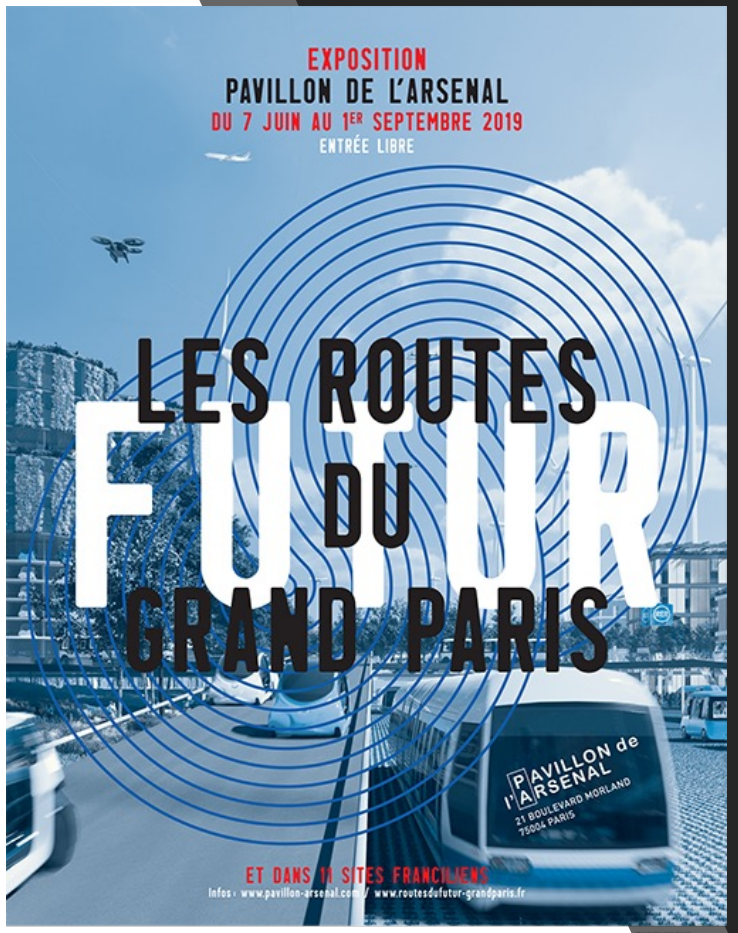

Decarbonized Corridor
Vehicle
ITS Concepts
Electric road
Connected road
Energy
UX
Connected, autonomous, electric mobilities
Information
Positive energy road
Adaptable road
SCC Concepts
Infrastructure
Green Corridor
Zero emissions
INCIT-EV
Mastered congestion
Increased safety
Projet SCOOP
ENSEMBLE
Smart and clean energy
wattway
POWER ROAD
Optimized use and maintenance
ALTAROAD
Heron
SMARTI
European Training Network
New services
Optimisation of public space
i-STREET

CONCLUSION AND PERSPECTIVES | 5



CONCLUSION AND PERSPECTIVES

- Roads and mobility are at the heart of society's challenges, particularly in urban areas.
- Solving urban mobility on a metropolitan scale requires the transformation of road infrastructure.
- These new generation roads and streets must be adaptable, automated and resilient to support the changing transport technologies that are about to emerge.
- The R5G project aims to design demonstrators of the roads of the future on the national territory and to evaluate their capacity to respond to the current challenges of society.
- The various French territories are working in this direction, as shown by the "Roads of the Future of Greater Paris" competition organised by the Greater Paris Metropolitan Forum.
- In the interurban environment, the challenge is to rethink the relationship between motorways and territories and to propose a "closed" approach between town and country that allows the achievement of the SDGs.