Towards **Smart** Road Infrastructure..

Morris De Beer, CSIR Built Environment

RPF November, 12/13, 2018

November, 2018

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35th RPF:

Resolution 3

- That RPF should devote attention to Smart Roads Concept in view of advances being made in:
  - Autonomous Vehicles
  - Intelligent construction equipment and establishment of Mobility Centre for Africa
  - Use of Internet of Things (IoT).

From recent: 14th SA South Africa Systems Engineering Conference, 2018

INCOSE - International Council on Systems Engineering

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Any Q or Comments?

In Summary…

- Smart roads concept is much more than just sensors and feedback loops:
  - Solar roads, Inductive charging roads, innovative load bearing blocks, intelligent, self-healing, pay for themselves ?
- Advanced and alternative and/or intelligent materials/systems for roads:
  - R&D & Industrialization opportunities ?
- Off-site “smart” manufacturing and on-site “smart” assembly;
- Intelligent Compaction (IC): Equipment & Reporting:
  - a paradigm shift for the construction sector ?
- Incorporation of futuristic transport systems needs – time proof roads:
  - be ready for the 4th /5th Industrial Revolution ?
- Development of Road Maps for Smart(er) Roads
  - 10 year strategy for CSIR....?

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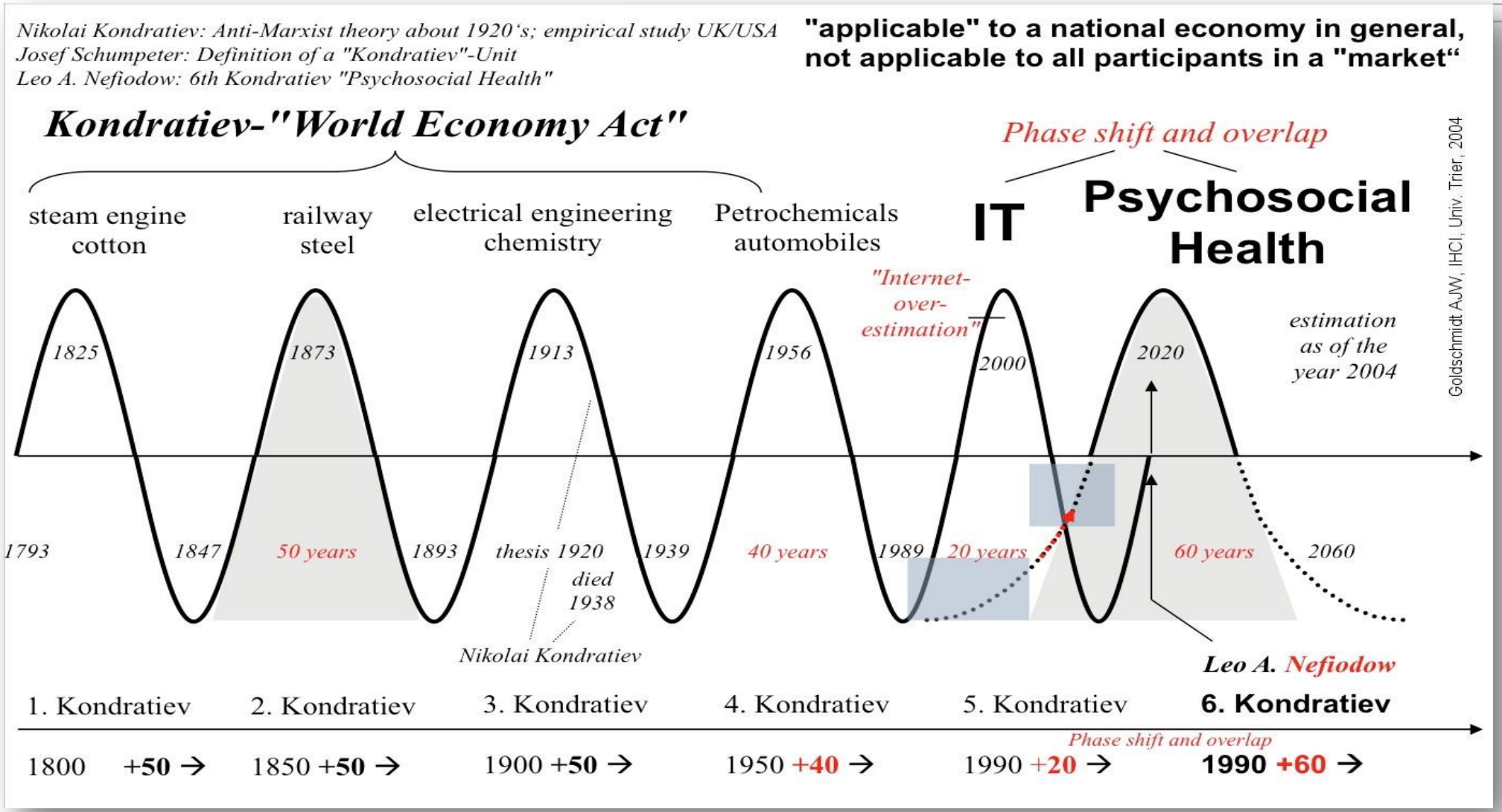
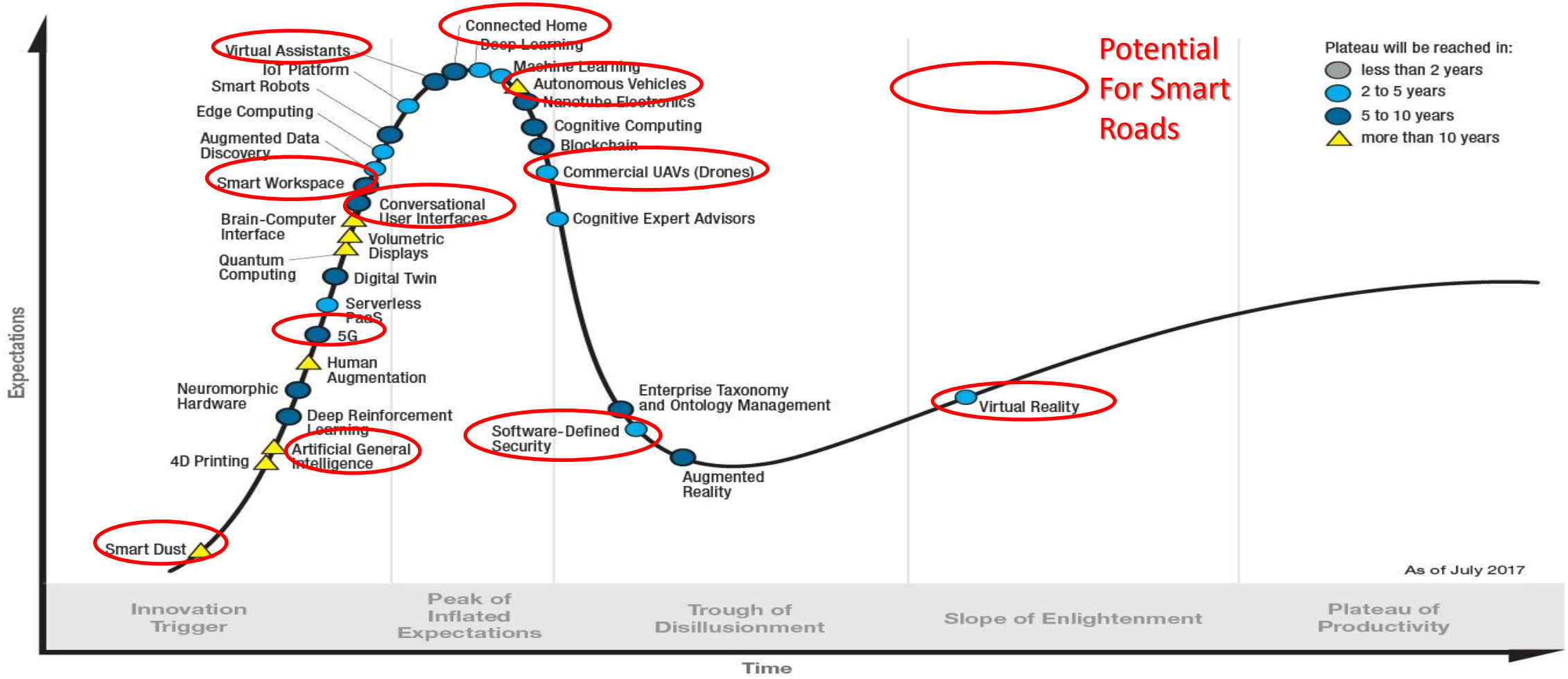
Innovations:- Kondratieff's Wave of development:



Artificial Intelligence (AI)…

https://en.wikipedia.org/wiki/Kondratiev_wave#/media/File:Kondratieff_Wave.svg

Gartner Hype Cycle for Emerging Technologies, 2017



gartner.com/SmarterWithGartner

Source: Gartner (July 2017)

Gartner

Innovation..4th Industrial Development (4IR..):

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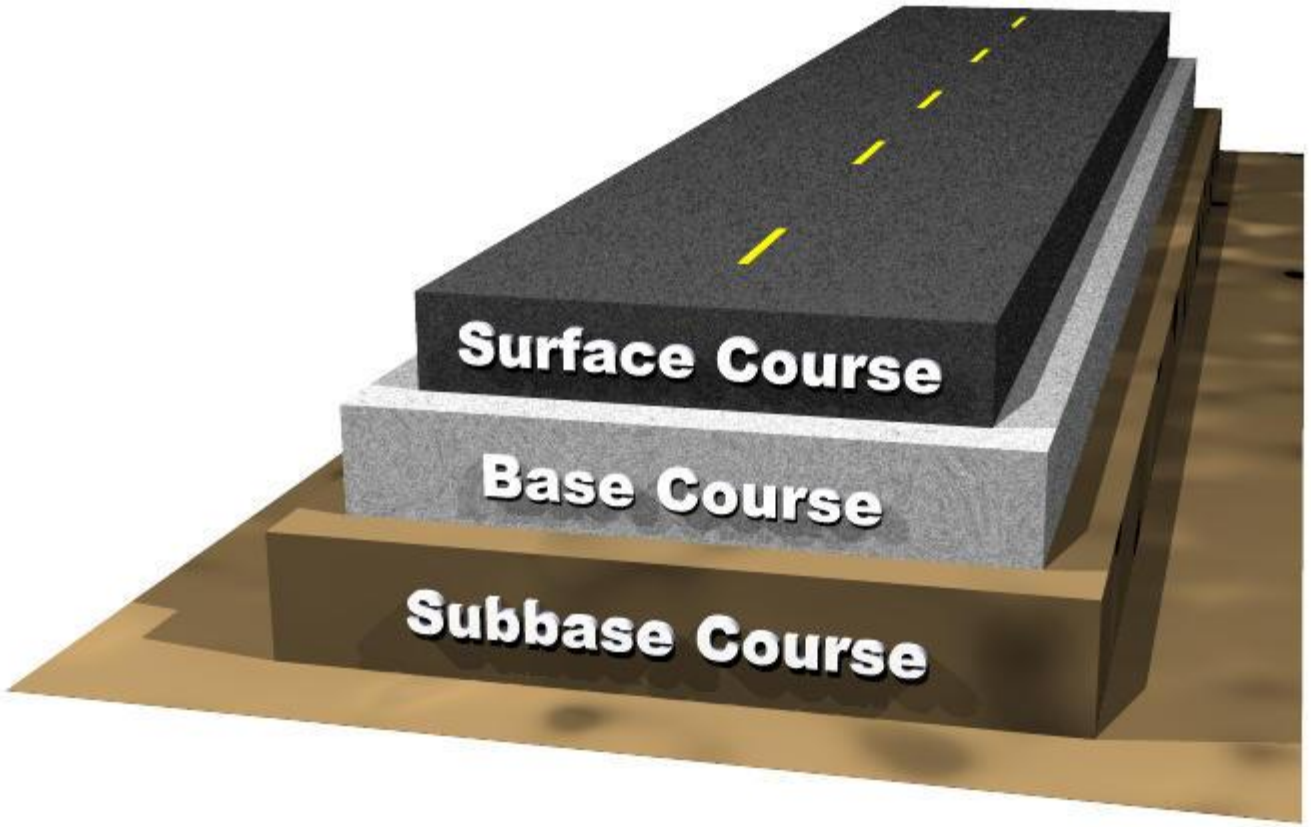
The 5th Generation Road..

- **Quo Vadis in Road Construction?**
  - 1st generation – the track
  - 2nd generation – the paved road
  - 3rd generation – the smooth road
  - 4th generation – the continuous road/motorways
  - **What will the 5th Generation Road be like?**

Innovation..:



What is a “Smart Road” ?

A Smart Road is a road **able to communicate** with itself and users like a **modern object interconnected** with the **world of information**. (Internet of Things.., IoT)

Road Infrastructures are still not responding to our need to be connected and informed in real time: there is a risk of creating a distance between mobility systems and the surrounding world.

added: Roads are the literal bedrock of future ground base transport…

Luigi Carrarini
Head of Technology Infrastructures and Systems, ANAS SpA (Italian National Roads and Motorways Administration)

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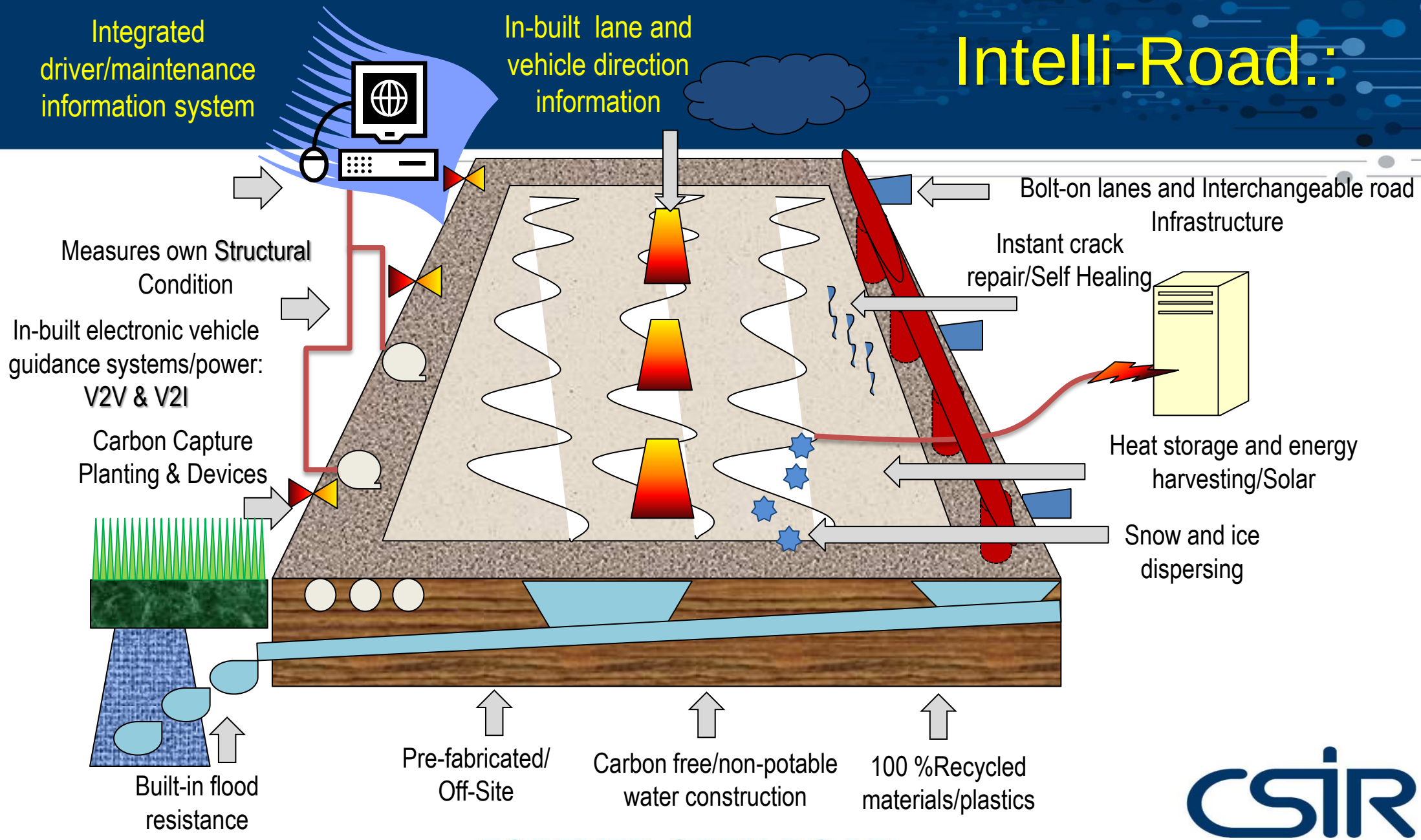
Intelli-Road.:



FOREVER OPEN ROAD
Redefining Highway Transport for the 21st Century

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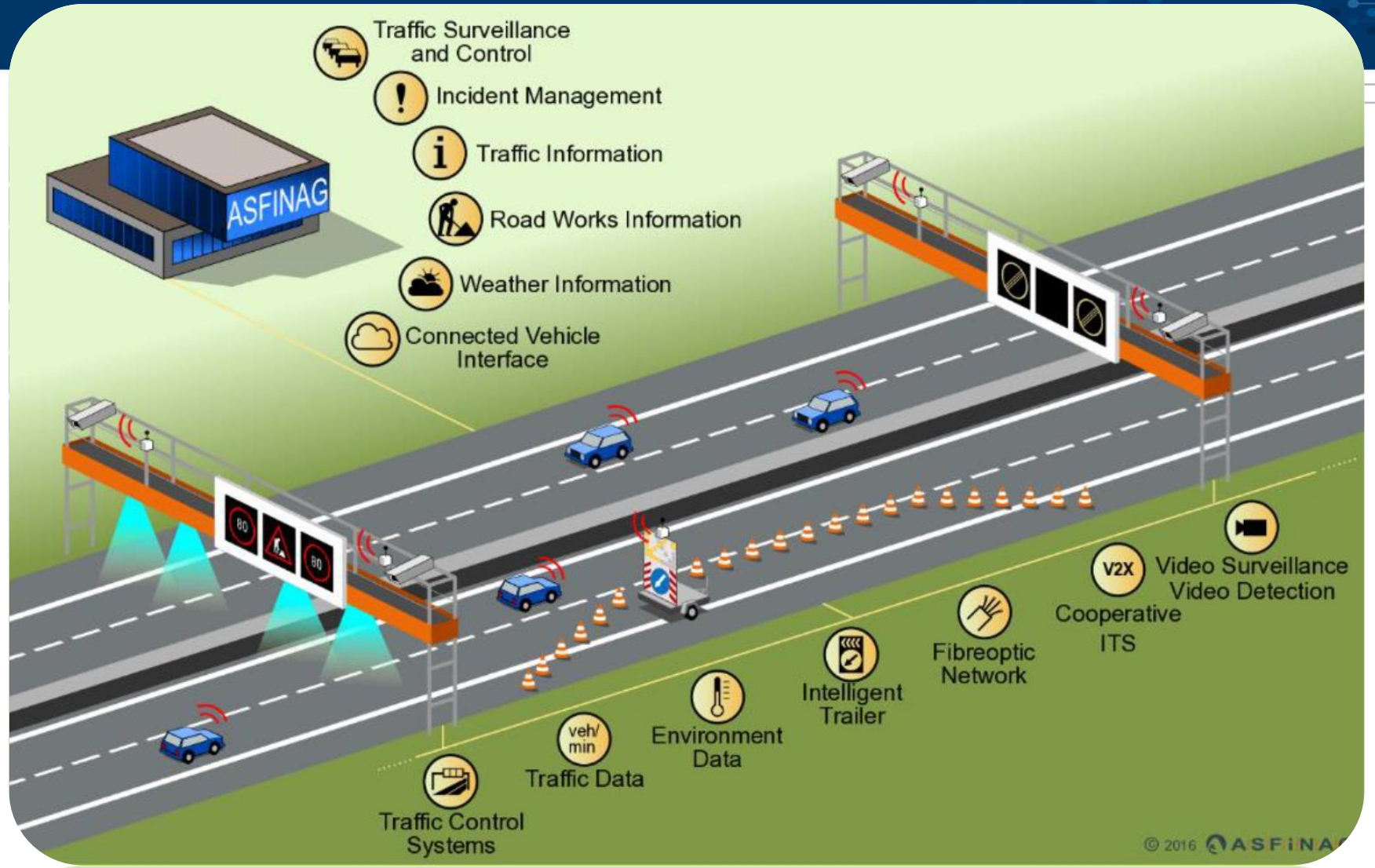
Modified From: Forever Open Road @ TRB.pdf

Innovation..:



Marko Jandrisits – ASECAP chair of the ITS committee

Some Communication Shortcuts…

- **V2V**: Vehicle-to-Vehicle;
- **V2I**: Vehicle-to-Infrastructure (I);
- **V2X**: Vehicle-to-Anything (X);
- **I2I**: Infrastructure-to-Infrastructure;
- **IoT**: Internet-of-Things…

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Some infrastructure statistics..

- **76% of road network is older than 30 year design life (Rand value of road assets > R2 trillion)**
- **Provincial and local roads have deteriorated in past 5 to 10 years**
- **SAICE Infrastructure Report Card overall rating in 2017 is D+, worse than 5 years ago**
  - **Apart from National Roads at B, rest rated from C- to E**

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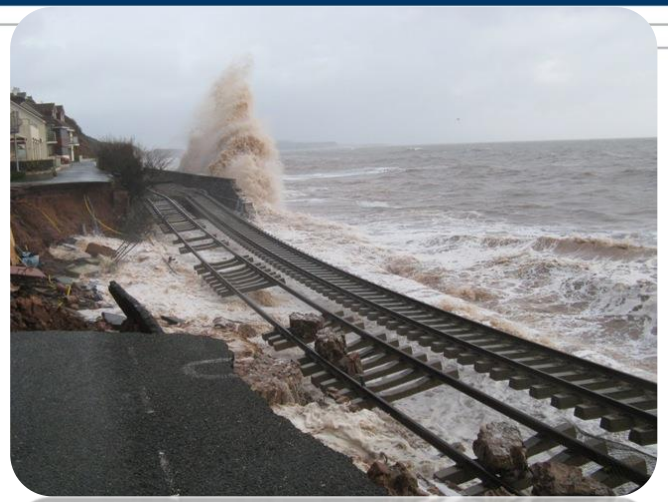
Climate Adaptation..Risks



Morandi bridge, Italy, 2018

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Safer (Smarter..) roads in Developing Africa..

Daniel #209227495, source: fotolia.com 2018

The 5th Generation Road Idea (FEHRL)-Europe

- Takes all existing ideas and produces one solution that will support all our future needs….
  - the Adaptable Road
  - the Automated Road
  - the Climate Change Resilient Road
- A concept that will…
  - provide an integrated system
  - be adaptable to future travel demands
  - provide low-cost automated travel
  - produce sustainable benefits
- Be Forever Open
- Done in Partnership with FEHRL
- (Forum for European Highway Research laboratories)

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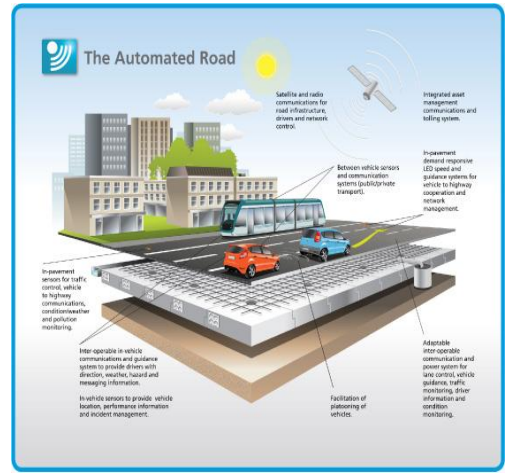
Potential Smart Solutions

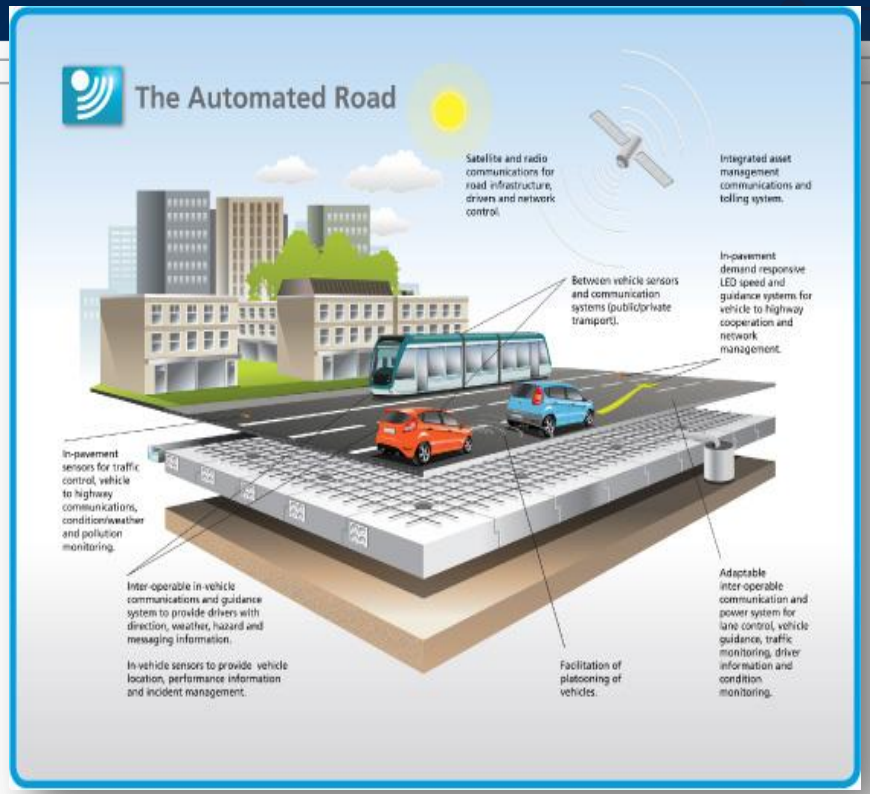
- **Broad thematic focus areas:**
  - Safe and reliable roads
  - Intelligent roads
  - Energy-efficient, low-emission roads
  - Roads as part of people's living environment
  - Sustainable roads
- **The Automated Road**
  - Integration of road-side intelligence with ICT
  - Intelligent systems to optimise road usage & monitor asset condition
- **The Adaptable Road**
  - Allows road owner to respond in a flexible manner to changes in road users' demands and constraints
  - Could include:
    - Pre-fabricated, modular systems
    - Self-healing materials
    - Adaptation to increasing traffic volumes and changes in demand



Innovation Themes and Topics (1)

FOREVER OPEN ROAD
Redefining Highway Transport for the 21st Century

	Automated Road Element	
Innovation theme	**Intelligent Traffic Management**	**Advanced Roadside System Theme**
Innovation topics	Cooperative systems automated transport	**Built-in and wireless sensors**
	Optimisation of network utilisation	Open standard interfaces
	Traffic management for extreme weather conditions and maintenance	**Vehicle recharging systems**
	Incident and disaster management systems and processes	**Low energy lighting and signage**
	Remote operation concept	**Automated asset condition monitoring and forecasting**
	User orientated multi-model traffic and travel information services	Integration of alternative energy sources and utility functions



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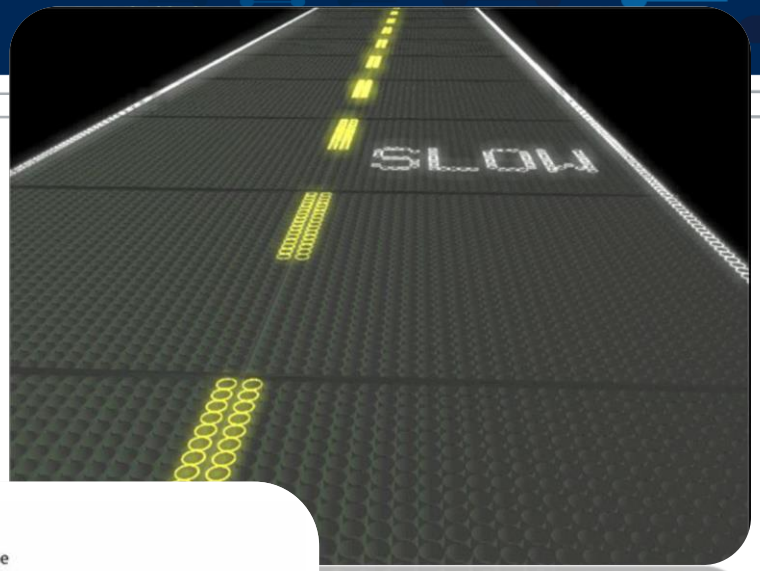
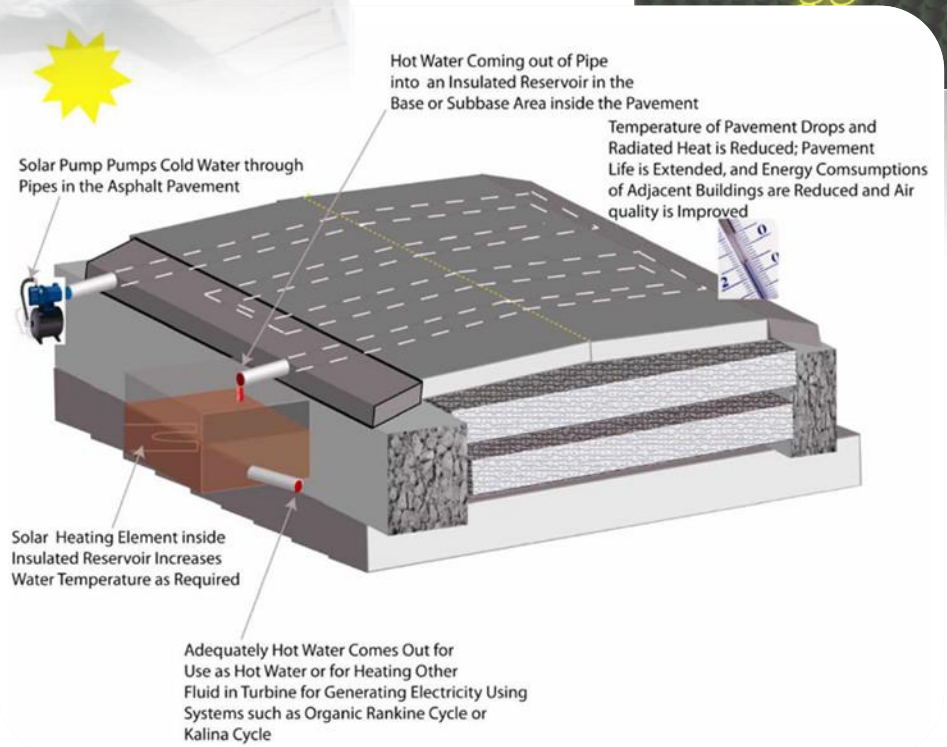
Innovation Themes and Topics (2)

	Adaptable Road Element	
Innovation theme	**Innovation in design**	**Innovation in delivery**
Innovation topics	**Modular design**	**Prefabrication methods**
	Low energy consumption pavements	**Low carbon materials and components**
	Climate resilient infrastructure	**New materials in pavements, bridges, tunnels and structures**
	Safe roads: self-explaining and forgiving infrastructure	Asset management toolbox and performance standards
	Built-in and wireless sensors	Automated inspection and survey methods
	Long-life pavements	Low cost and rapid maintenance methods

Adaptable Road Technologies..

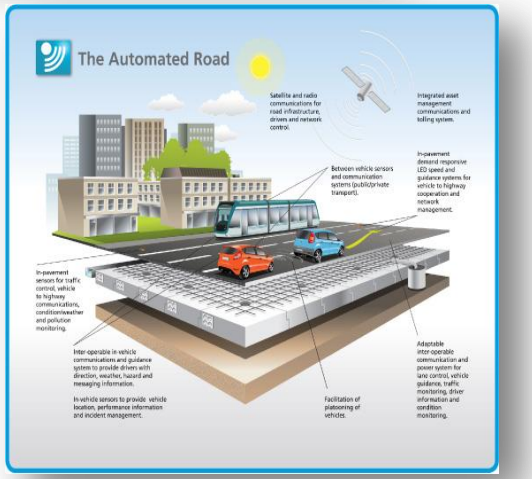




M.J. Lamb et, al, THE FOREVER OPEN ROAD – DEFINING THE NEXT GENERATION ROAD

Smart Road Technologies

- **End Objective:**
  - Improved design, construction and maintenance processes
  - Next-generation road construction products
  - *The goal is to potentially reduce road construction costs by 10 to 20 %, as well as improvements in life-cycle performance of roads, energy efficiency and safety.*
- **Objectives for 2018/19:**
  - Road Maps for *Smart Roads* and *Industrialisation of Construction Processes*
  - Longer life pavements (e.g. self-healing mechanisms, binder ageing, aggregate degradation, asphalt compaction simulation models, pavement design software)
  - Green technologies and products: (e.g. reduction in water usage in road construction, green paving blocks, sustainable reuse of plastic in roads)
  - Modification and stabilisation (e.g. nano-modified products)



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Smart Road Technologies (Cont)

- **Synergies and uptake potential:**
  - **Synergies** with SANRAL's *SMART Roads programme*, FEHRL's *Forever Open Roads programme* and UK DFID's *High-Volume Roads Applied Research programme*
  - Development and transfer of new design and construction methods and national guidelines in co-operation with **SA public and private sector**
  - Development of regional guidelines in cooperation with **African road agencies/authorities** (e.g. ASANRA, TANROADS, Mozambique, etc.)
  - **Commercialisation** and implementation of new products through licensing agreements with the private sector
  - Piloting of new products through **demonstration projects** with local, provincial and national road authorities and state-owned companies

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Smart Road – Rollpave: *Dutch 'Road to the Future'*

M.J. Lamb et, al, THE FOREVER OPEN ROAD – DEFINING THE NEXT GENERATION ROAD

Future of Highways

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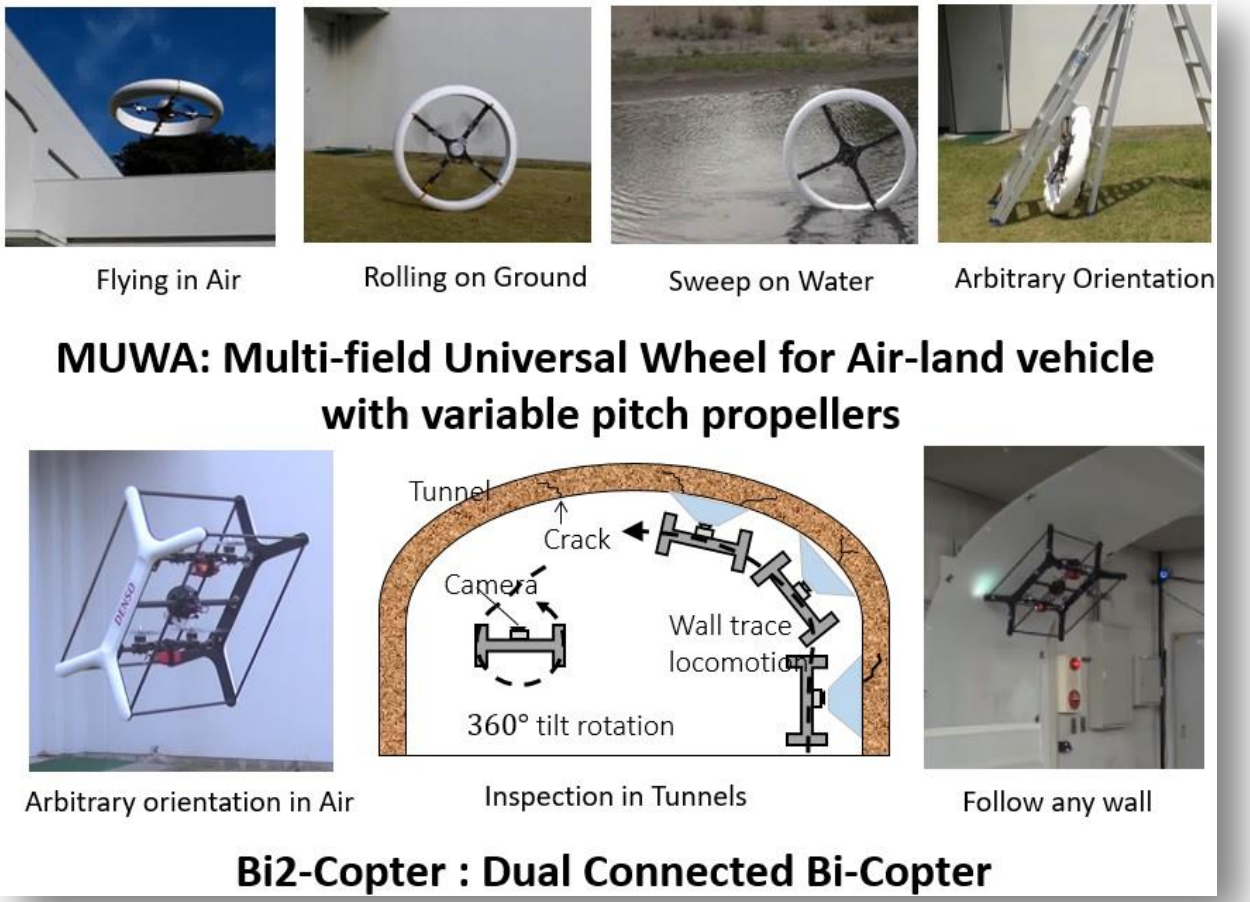
DRONES…"the sky *isn't* the limit…"



http://www.jsk.t.u-tokyo.ac.jp/research/multirotor.html

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Smart Road Studs..

Smart road studs guide drivers to safety

Since their invention in the 1930s, reflective road studs have helped drivers stay safe at night. EU-funded research has now demonstrated that upgrading such devices with smart energy-saving technology has the potential to save lives.

© envfx - fotolia.com

European Commission

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Smart Road Technologies

- Paint that changes colour with temperature
- Self healing polymer
- Self healing bugs in concrete
- Solar roads..

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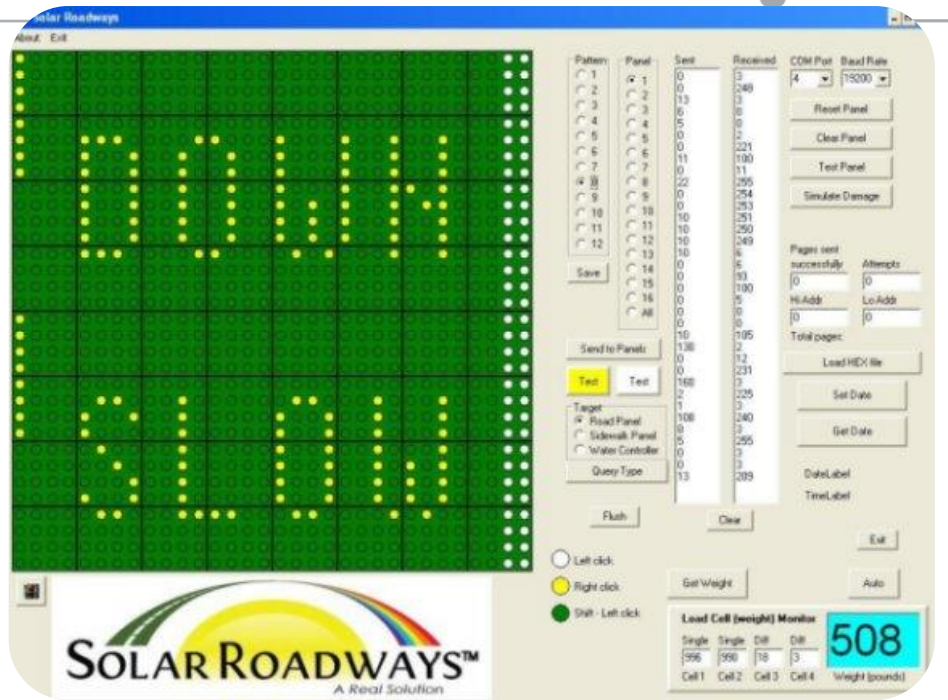
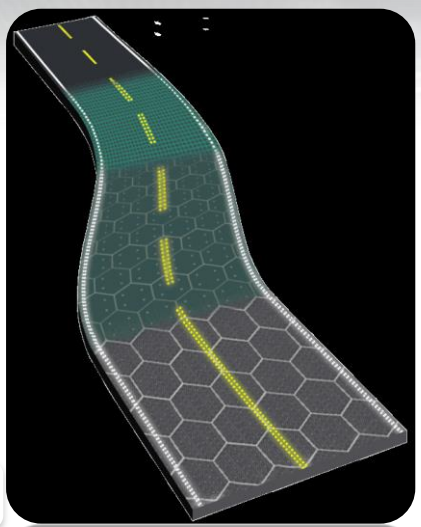
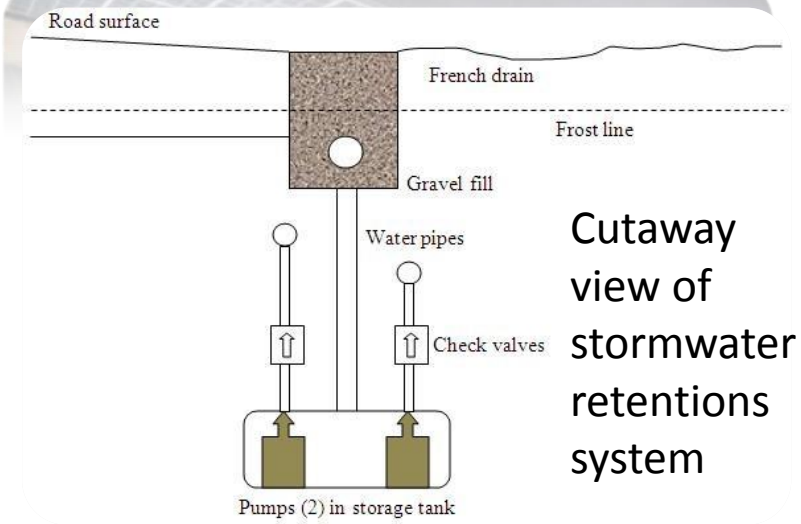
Smart Road Technologies…. SOLAR ROADS..

http://www.vidafine.com/blog/2009/11/solar-roads/







Cutaway view of stormwater retentions system

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Some Comparisons…of Surface Features….

http://www.solarroadways.com/

SURFACE FEATURES	SOLAR ROADWAYS	CONCRETE	ASPHALT
Flat place to walk and drive	●	●	●
Provides parking	●	●	●
Provides traction	●	●	●
Doesn't soften at high temperatures	●	●	
Generates energy	●		
Intelligent	●		
LED lights for lines and signage	●		
Remains snow/ice free	●		
Impervious to potholes	●		
Can protect animals	●		
Modular for faster maintenance	●		
Requires no paint	●		
Aesthetic benefits	●		
Has ROI	●		
Facilitates energy independence	●		
Can charge EVs with clean energy	●		
Water can be stored, treated or moved	●		
Provides a "home" for cables, wires	●		
Can provide emergency warning system	●		
Expandable Technology Package	●		

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Cost of Sensors vs Infrastructure Costs....

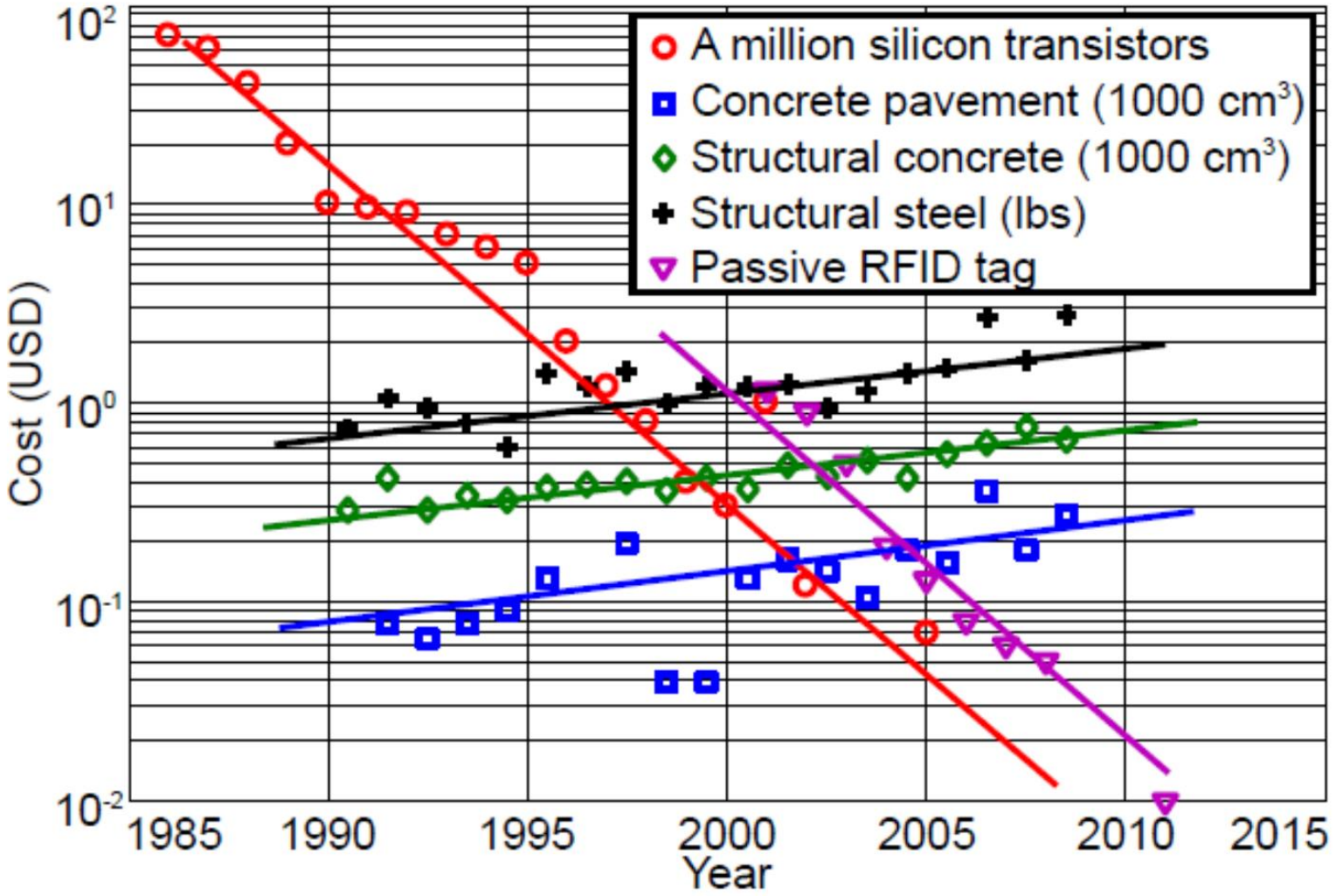
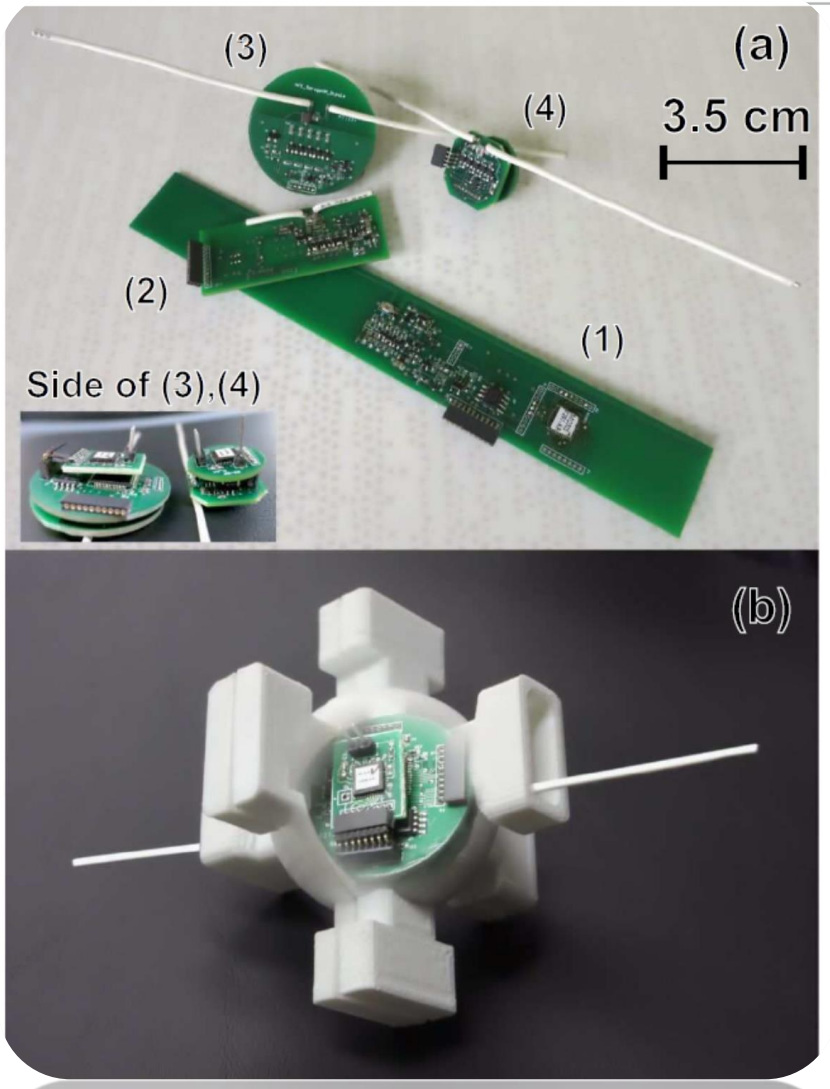


Fig. 1. Economic trends of silicon ICs and typical construction material.

Infrastructural Health Monitoring Using Self-powered "Internet-of-Things" (IoT)
Kenji Aono *et al.*, 2016

Sensor Technology…



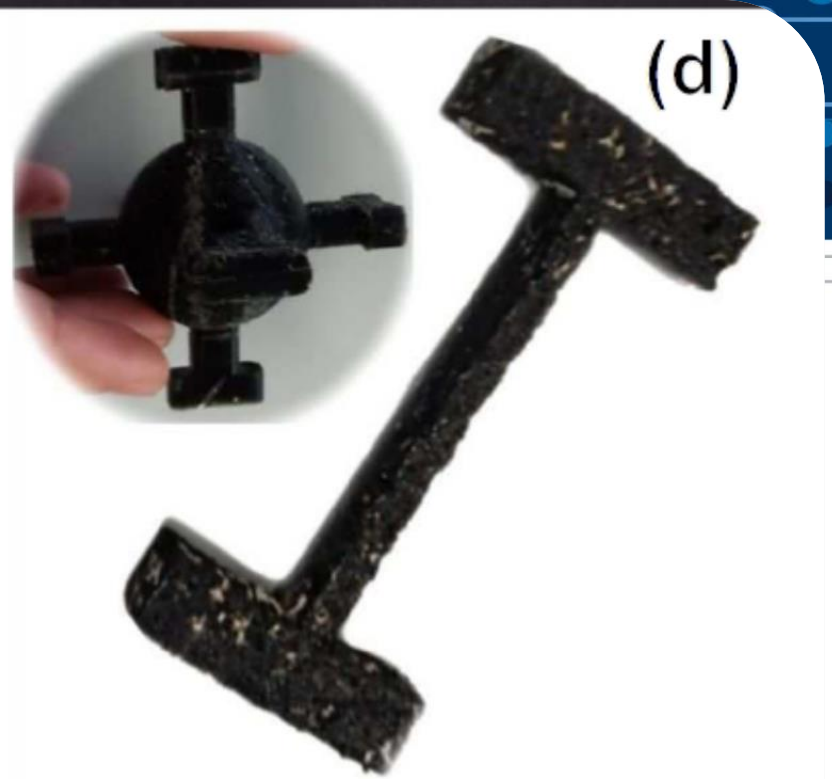


Fig. 4. Showcasing sensors with supporting circuitry, in (a) we show four different generations of sensor boards getting smaller as time progresses. A virtual cutaway in (b) illustrates how the third generation board is packaged for in-field use. (c) shows a UHF implementation in the H-shaped configuration. (d) The sensors from (b) and (c) after they have been coated and compacted for installation in asphalt.

Applications…limitless…

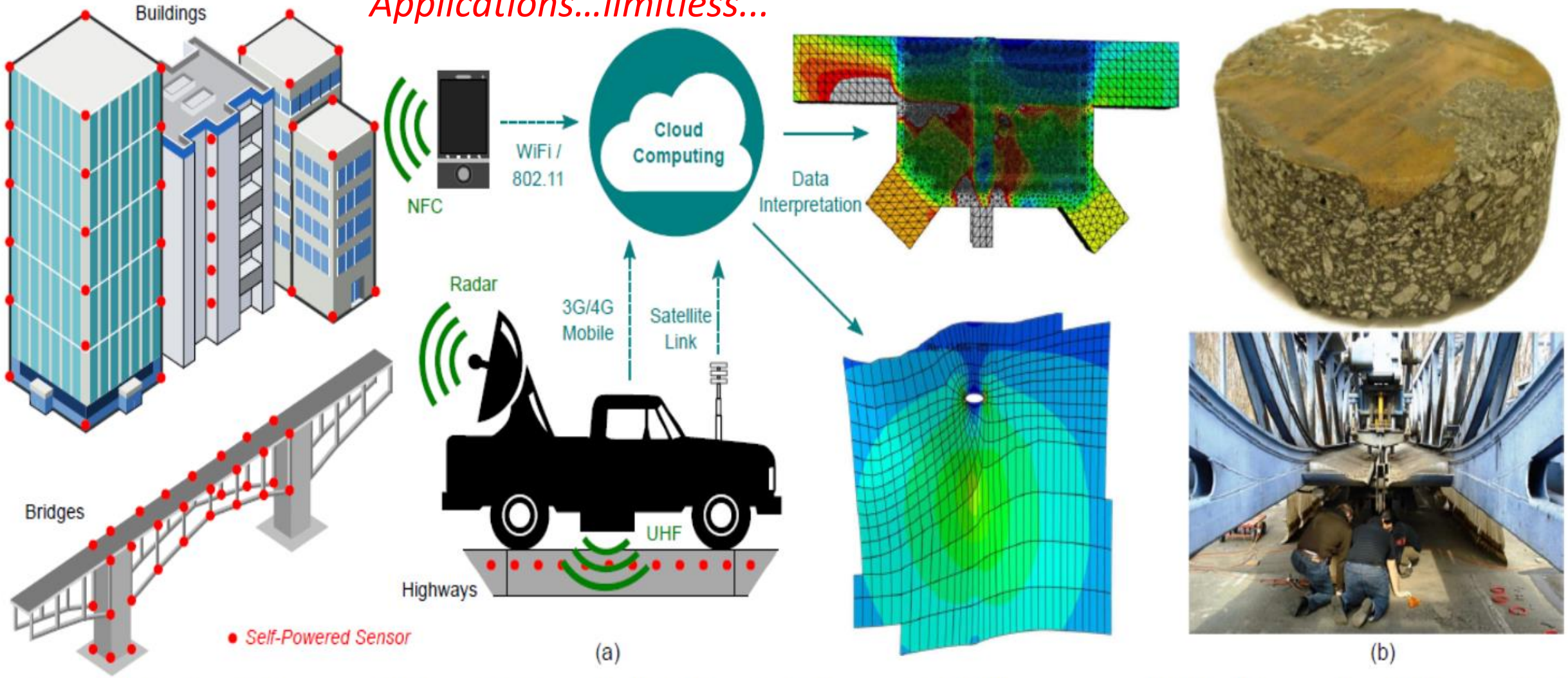


Fig. 2. (a) Illustration of the proposed Internet-of-Things (IoT) platform for infrastructural health monitoring (IHM). It has a physical layer (red dots), a sensing layer (shown as green waves), a network layer (teal dashed arrows), and an application layer (teal solid arrows). The physical layer is an actual sensor, a sensing layer can be any commercial off-the-shelf reader, a network layer can use any method for connecting to the "cloud," where the application layer resides, to analyze data. (b) shows a sensor packaged into a concrete installation (above) as well as being affixed to steel beam structures (below).

Instrumented Roads…self powered sensors..

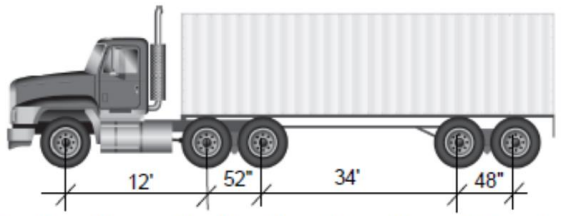
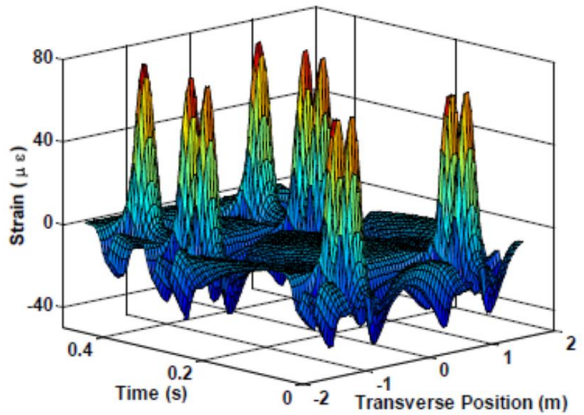
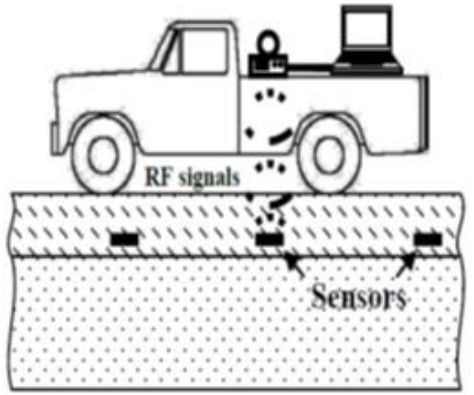


Figure 208. Illustration. Example of a class 9 truck used for strain response data generation.



1 ft = 0.305 m

Figure 209. Graph. Example of longitudinal strain profile evaluated at the bottom of the HMA layer for a moving load induced by a class 9 truck.



Pavement structure

Figure 1. Illustration. Array of self-powered sensors capable of monitoring cumulative strain history of the host pavement structure.

Strain Sensors signals...Multi-Axle Vehicle

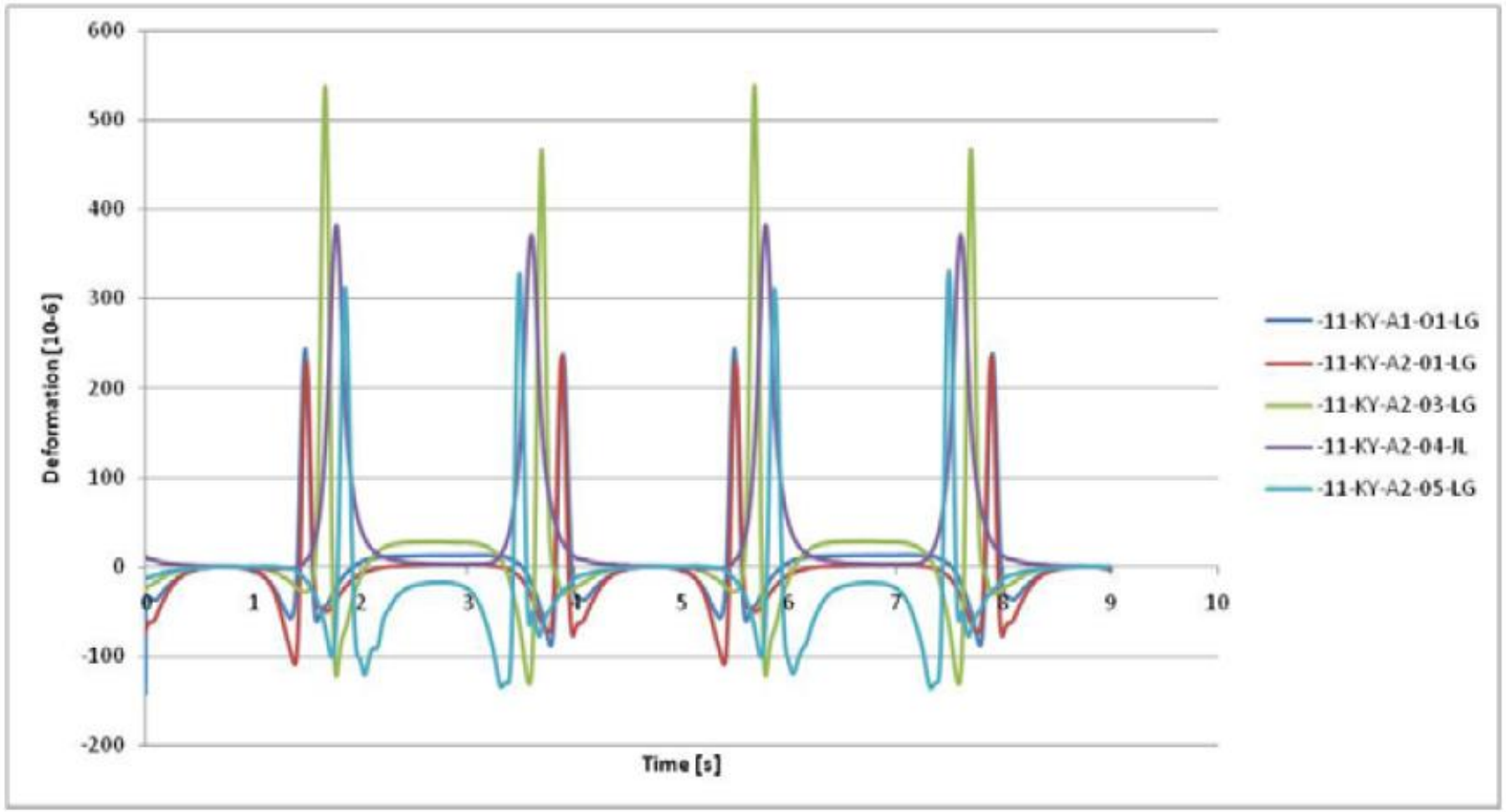
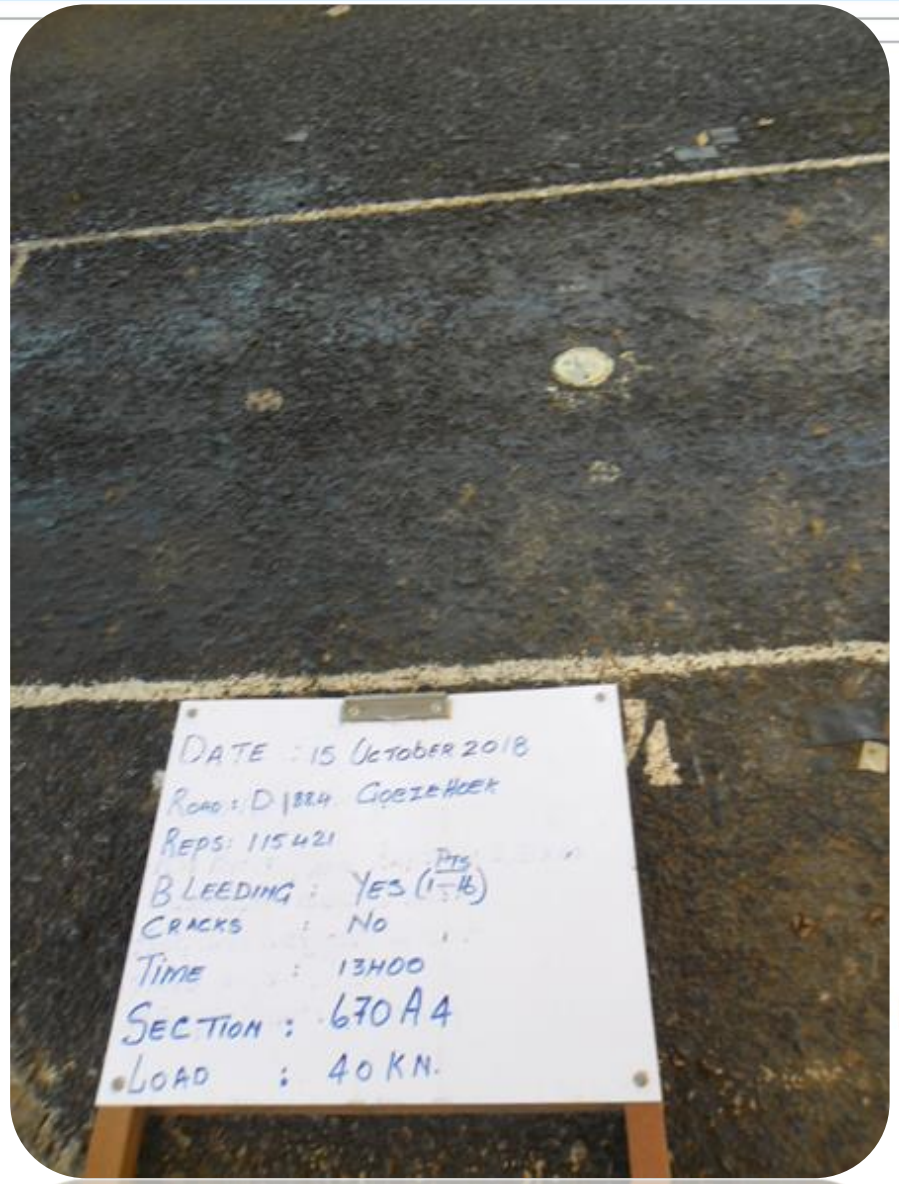


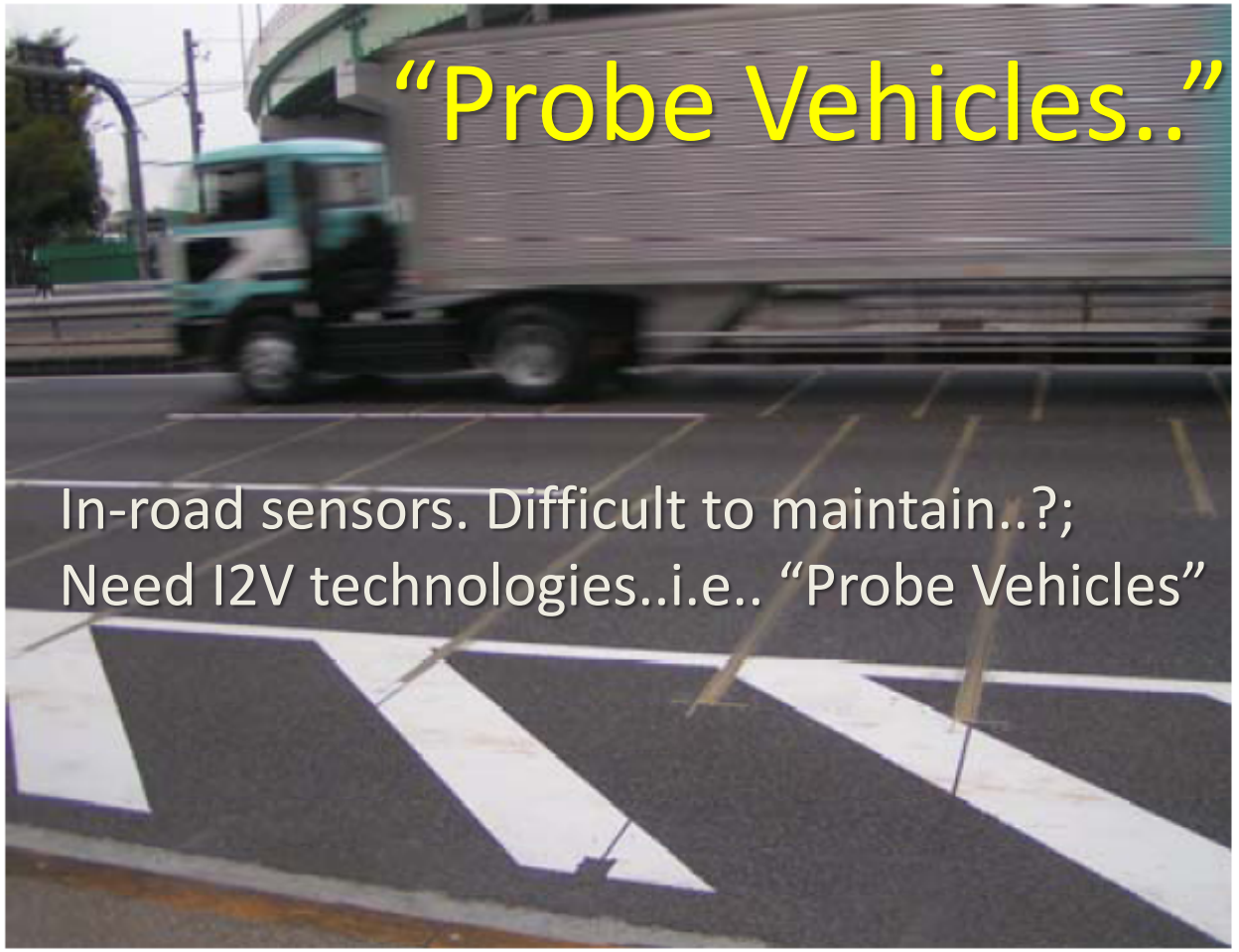
Figure 4. Strain gauges measurements (15 °C, 8 tons).

Multi-Depth Deflectometer (MDD) ..!



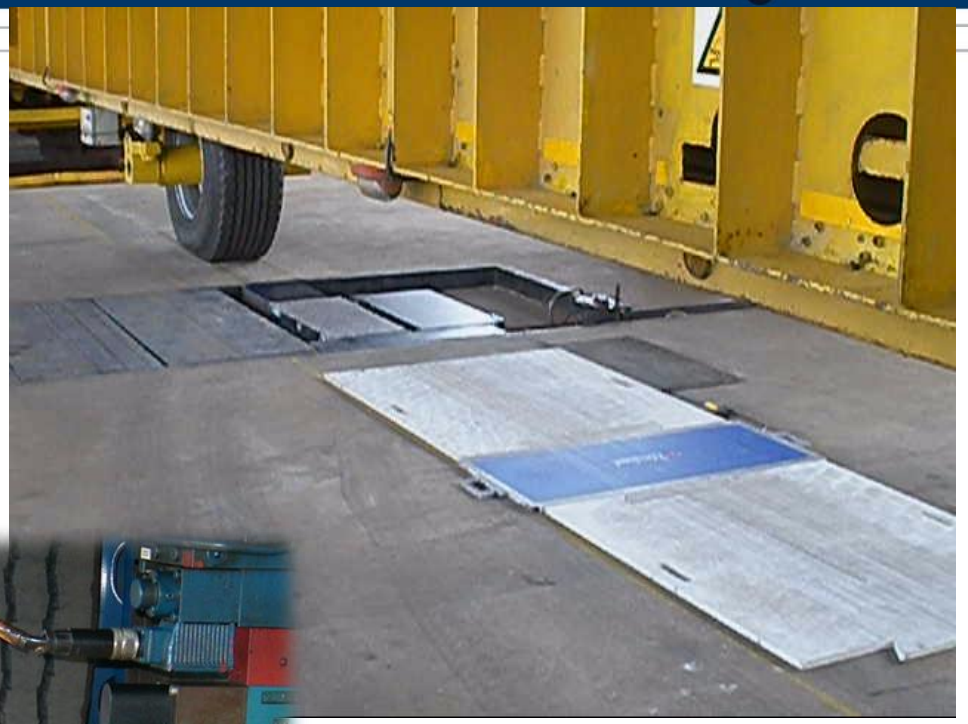
Moisture/Suction – Difficult to measure in-situ..

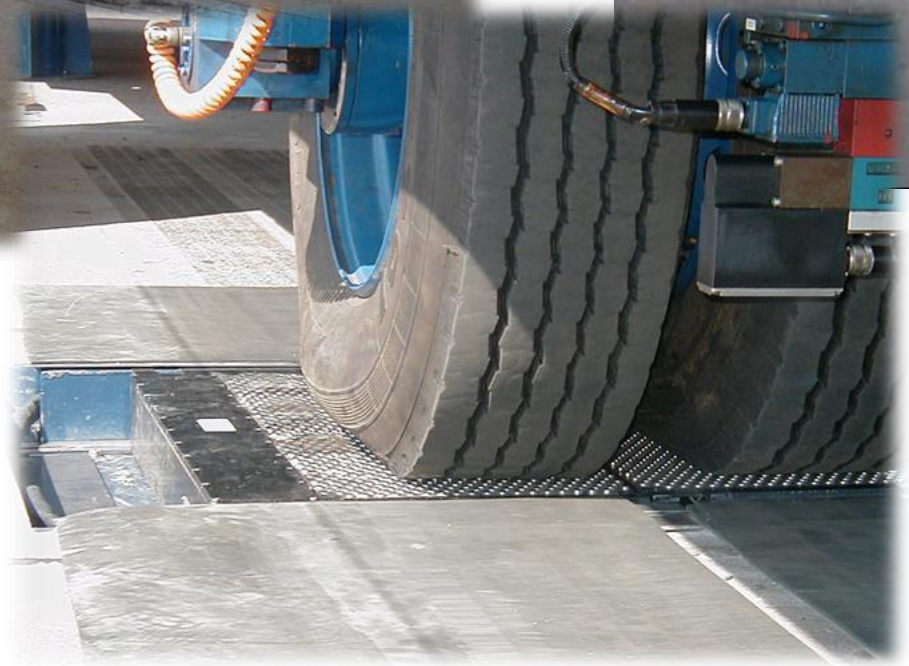
Figure 218. Photo. Testing setup for the moisture cell.



Traffic disturbance, caused by the implementation of in-situ sensors and their maintenance costs temper enthusiasm to install more than strictly necessary. In this respect, in-vehicle sensors are preferable. The current low “density” in-situ sensors (Weight In Motions systems, strain gauges, traffic and speed counting loops, etc) in combination with specialist survey vehicles generate data for modelling structural deterioration of roads and bridges and modelling traffic flows. This is then used for asset management models at network level. To improve the management of maintenance at road section level and to bring impending problems to the attention of road operators before significant deterioration occurs, sensors must be developed. Fitted to standard vehicles (“probe vehicles”) these sensors can provide up-to date information about the road condition and surface characteristics of the pavements. Probe vehicle and in-situ measurements will together provide the data needed to achieve “system optimum” and enable road authorities/operators to maintain the networks to the high levels of comfort and safety expected by the road users.

Stress_In_Motion (SIM) Technology: Tyre/road interface testing





Stress_In_Motion (SIM) – large database at CSIR

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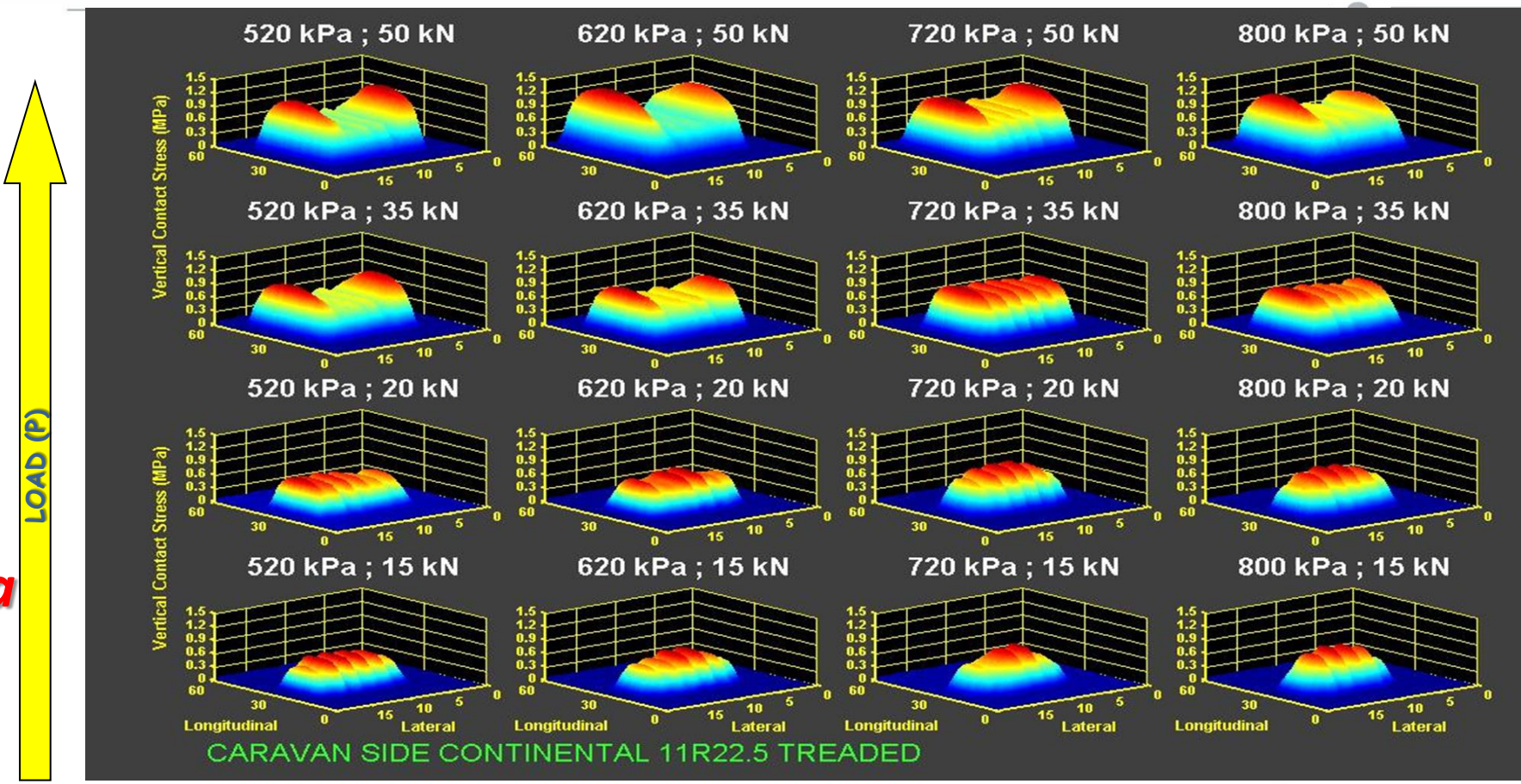
Dual SIM System..

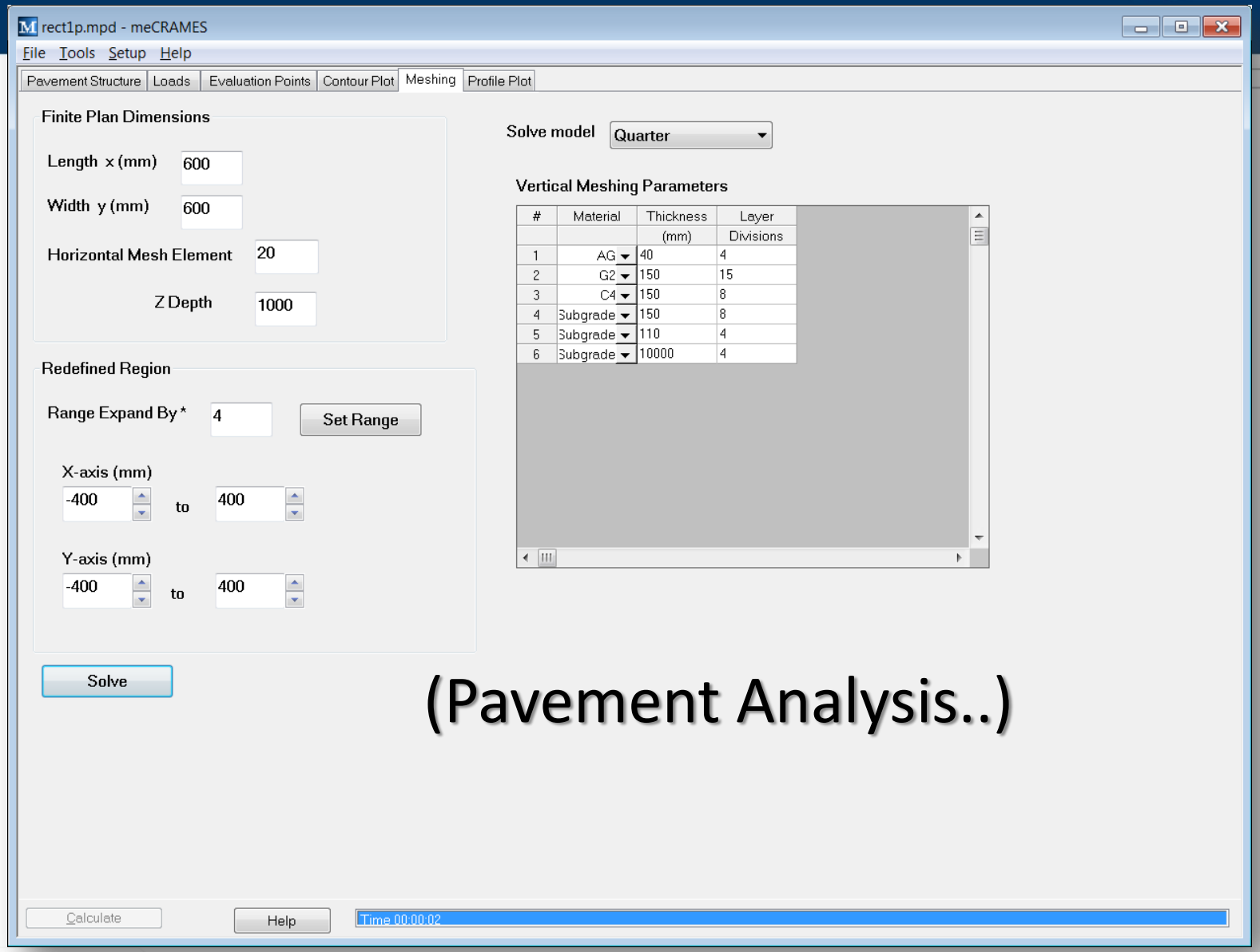
Tyre "finger prints": Vertical contact stress distribution

Dual SIM Mk V-B Units: Side View

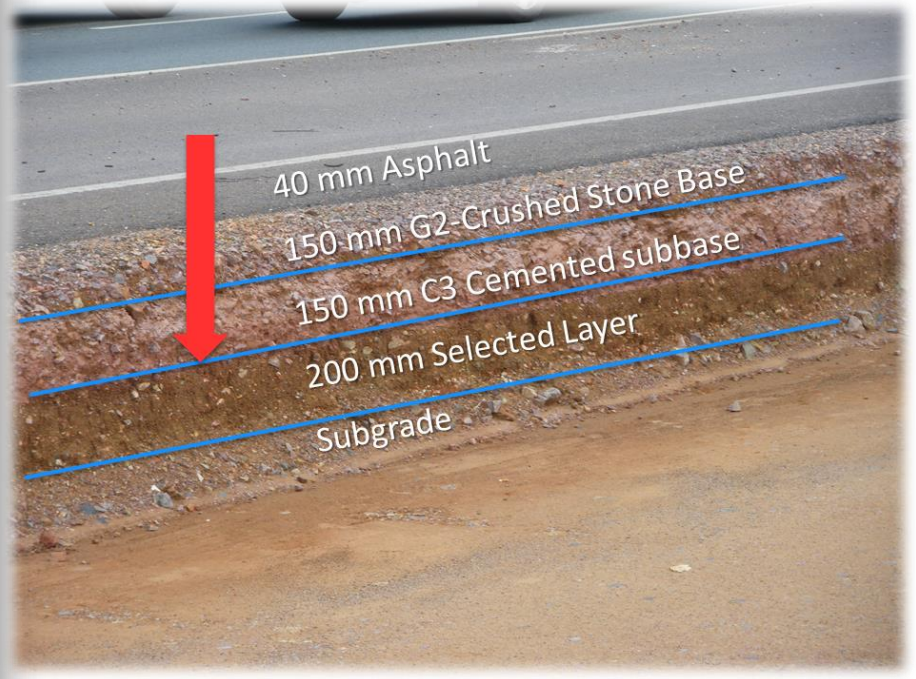
Vertical Tyre contact data integrated with SANRAL SARDS design system..



Multi-Layered Linear Elastic (MLLE) Structural Analyses....



(Pavement Analysis..)



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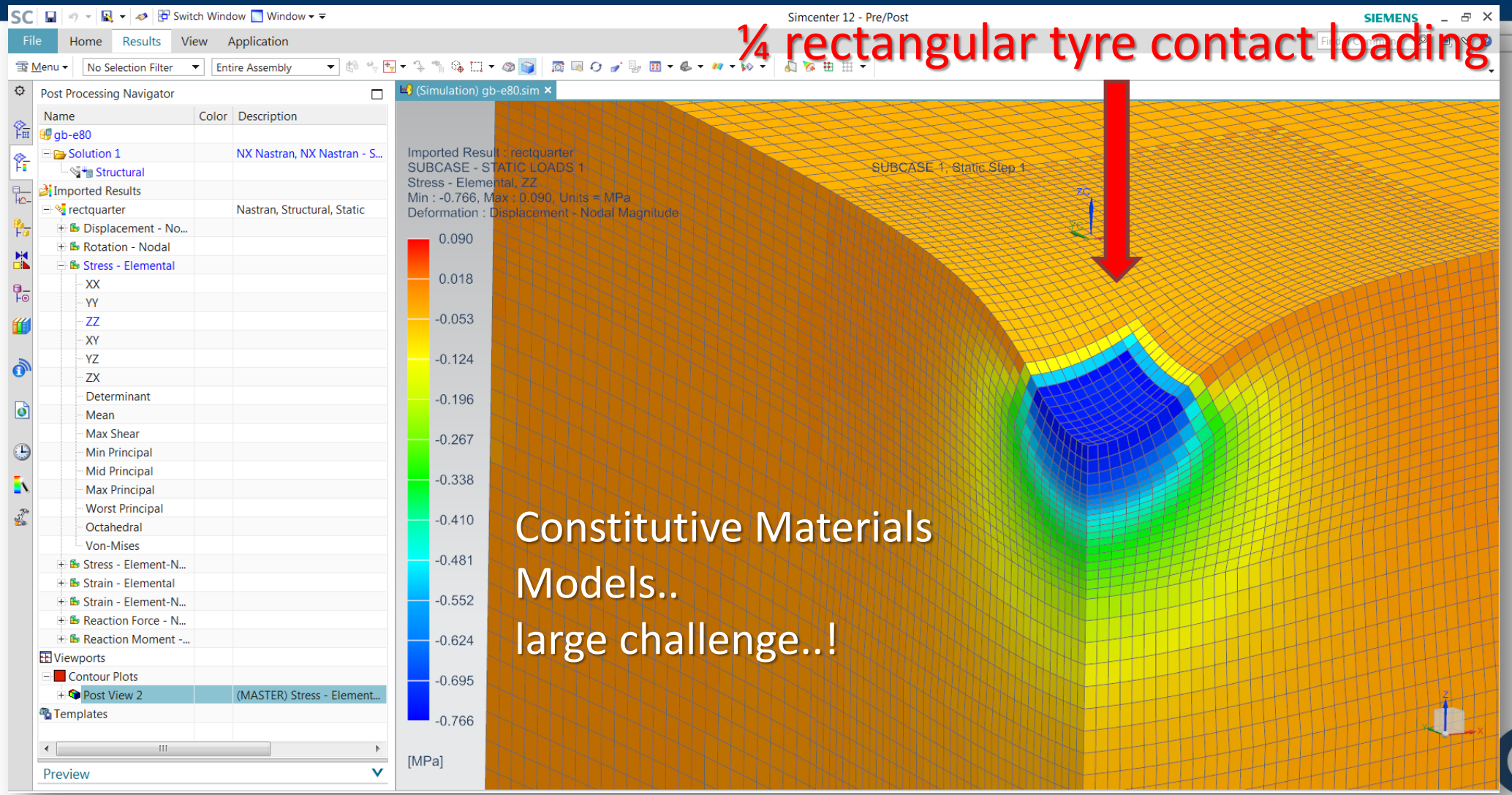
Pavement Structural Analyses....Benchmarking with FEM



Finite Element Methods (FEM) – Allows for non-linear and/or visco-elasto-plastic analyses..

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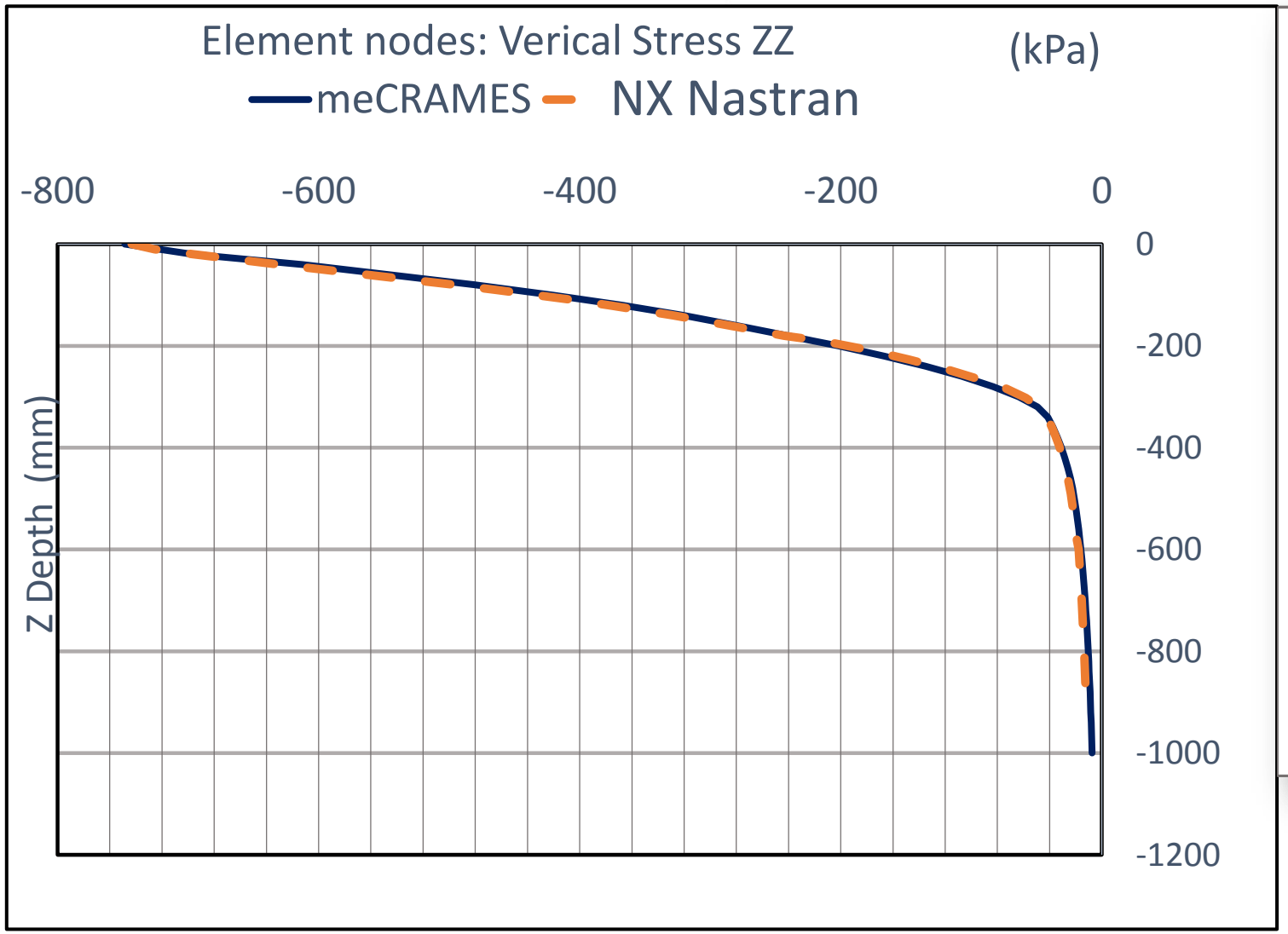
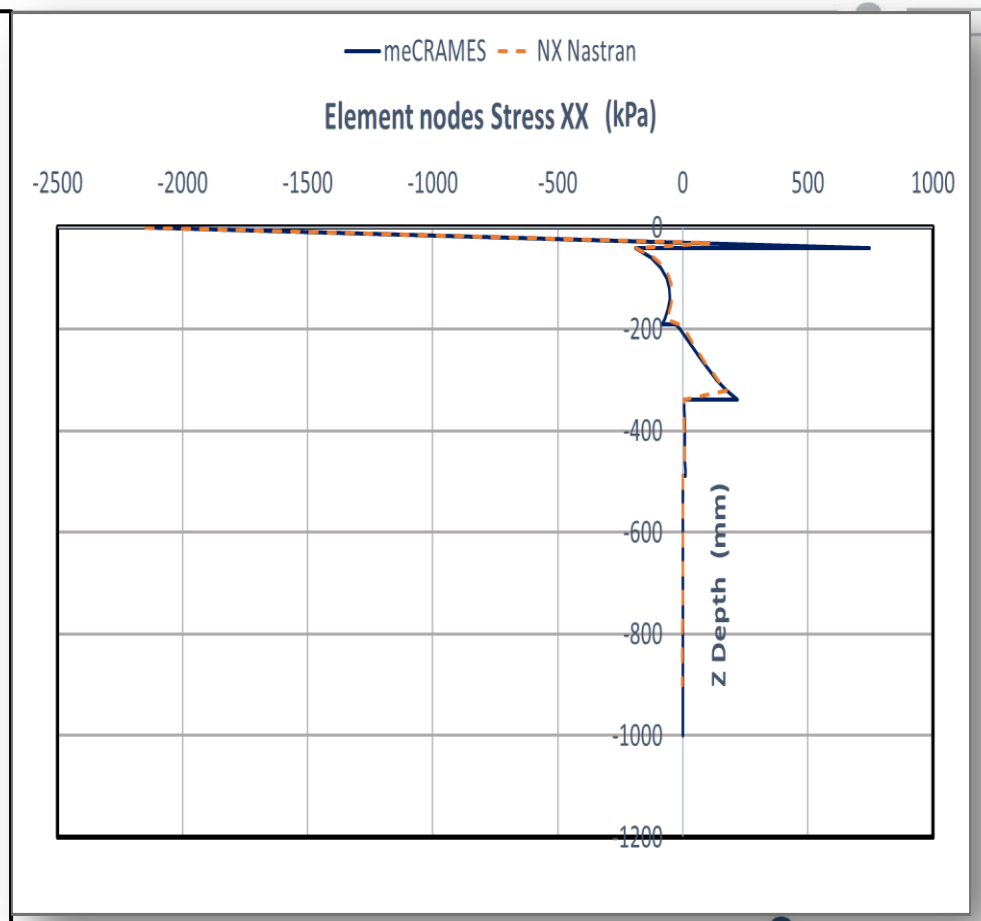
Benchmarking: Example: ZZ Stress and XX Stress at Z @ (0,0): NASTRAN and meCRAMES





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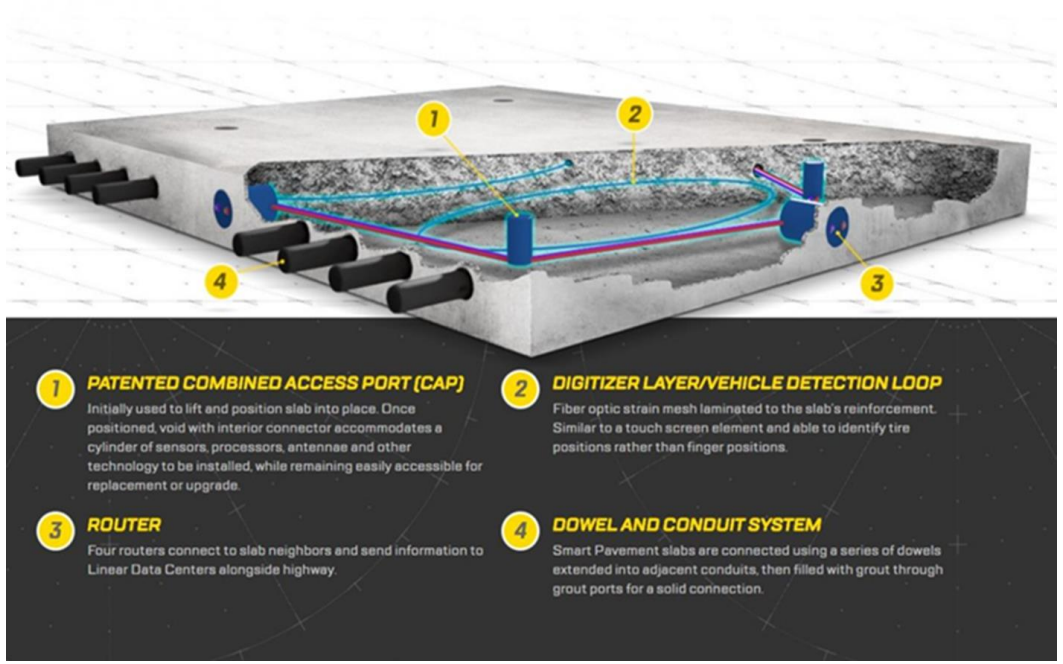
Air Purifying ($C0_2$ & NO_x) Pavements:…

Engine maintenance:
-driver education,
etc..

Road transport is the primary source of transport-related CO_2 emissions in South Africa, with road transport having been estimated as contributing to 91,2% of total transport GHG emissions in 2010 (DEA, 2014).

Environment: CO_2 & NO_x absorbing road surfaces..

"For *diesel and petrol vehicles to provide* friendly road pavements surfaces that absorbs CO_2 & NO_x pollution…



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International Workshop: RILEM CO_2 Storage in Concrete

Decreasing natural resources of sand and gravel and increasing problems with waste management support the recycling of the accumulating waste materials. If the vision of a sustainable material flow is to be realized, the amount of recycled waste has to be increased.

The building industry in particular is a major consumer of materials and at the same time a major producer of waste and CO_2 emissions by production of Portland cement which represents 5 to 8% of CO_2 emissions worldwide.

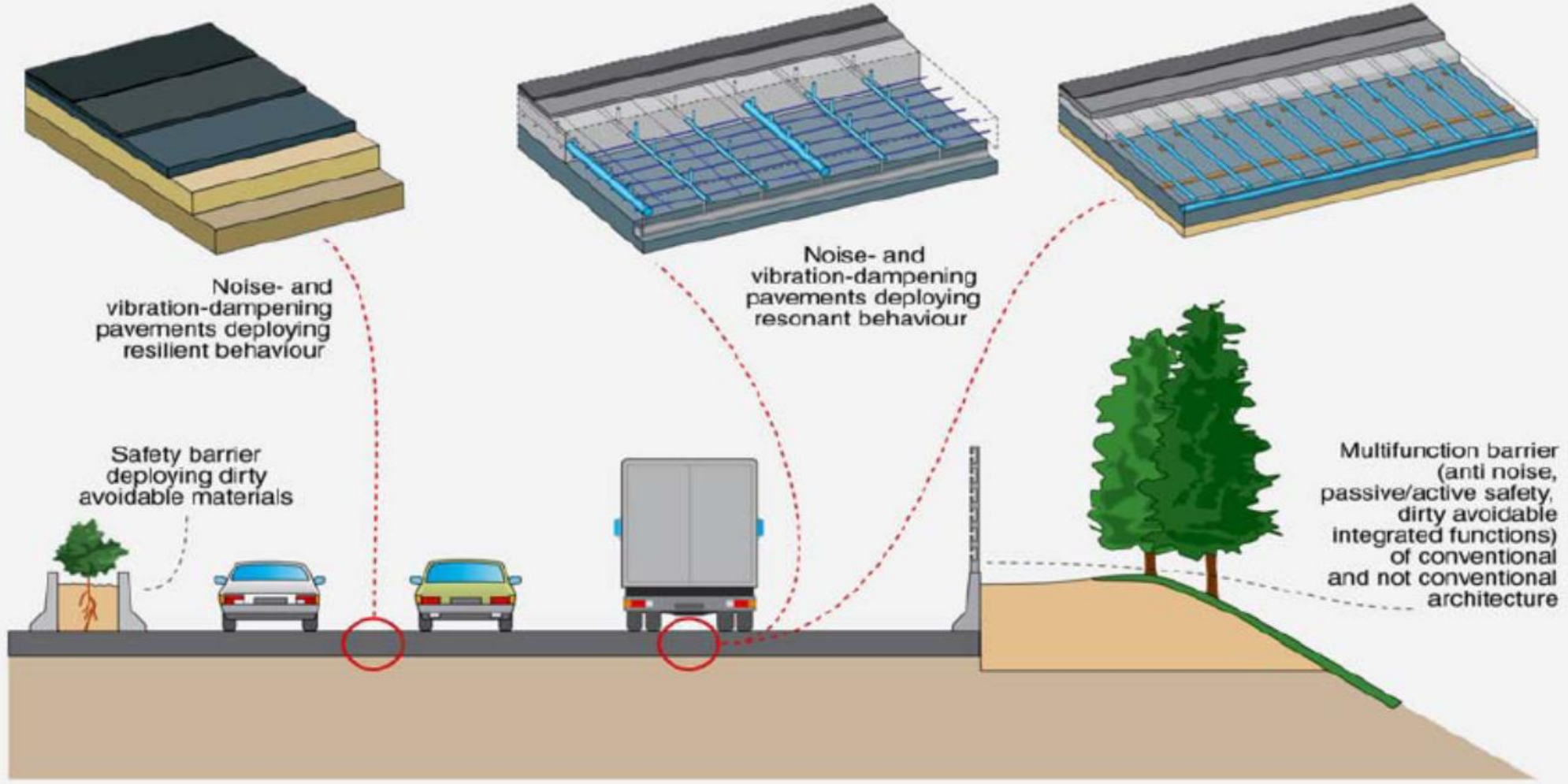
« CO_2 storage in concrete » focuses on the ability of concrete to store CO_2 during its life cycle.

24-26 June 2019, Marne la vallée, France

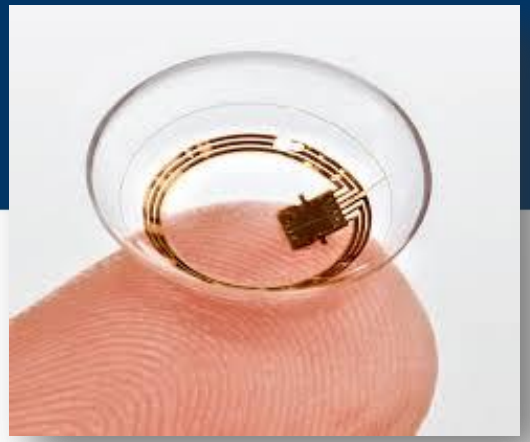
co2sto2019.ifsttar.fr

The challenge:

Rethinking structural road design…with variety of materials, systems, sensors…

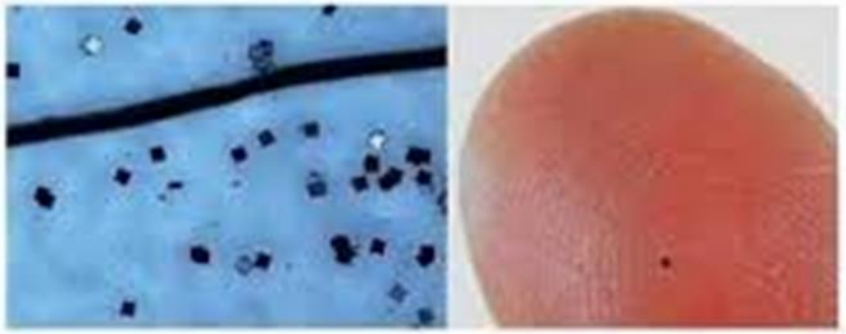


Smart Dust…



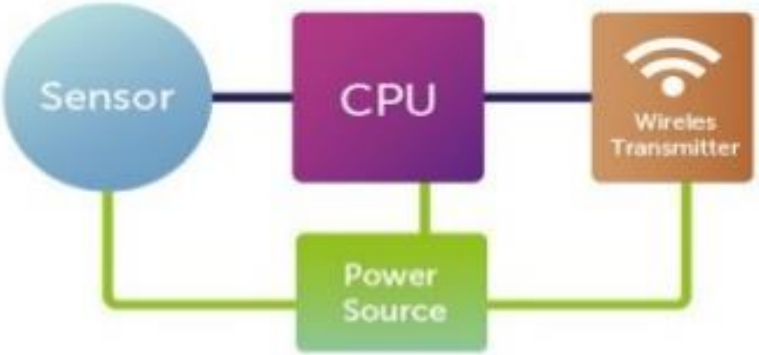
"..Motes.."

GPS Dust Particle:
0.15 mm x 0.15 mm…



"These are made by Hitachi. They measure only.15X.15 mm each and have GPS capabilities! Sometimes called 'smartdust' as they can be sprayed on us and absorbed or taken in foods,drinks and even injected."

How it works?



- Smart Dust is a network of 'motes', identical or similar tiny computers consisting of four miniaturized components:
  - Ambient sensor
  - Wireless Transmitter
  - CPU
  - Power Source

Smart Dust…"Motes" and "MEMS"...

Smart Dust is made of "**motes**" which are tiny sensors that can perform a variety of functions. They are made of "micro-electro-mechanical systems" known as **MEMS**. Nov 14, 2013

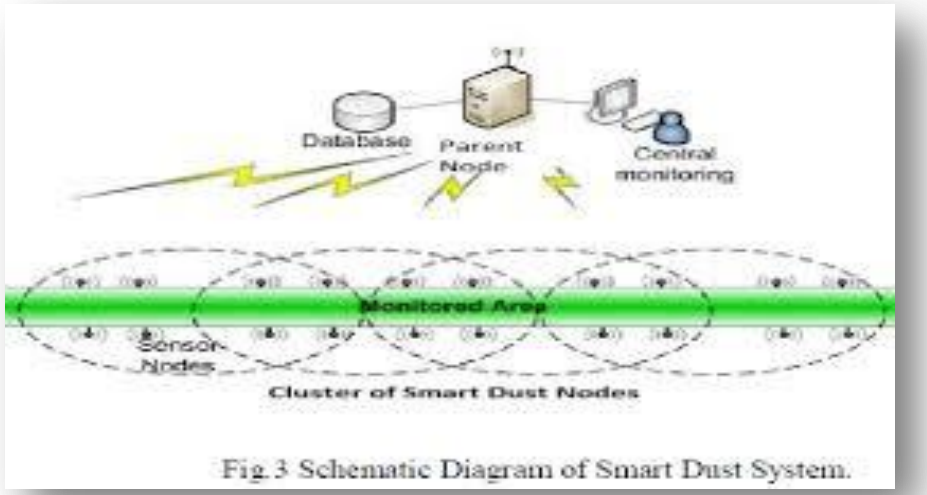
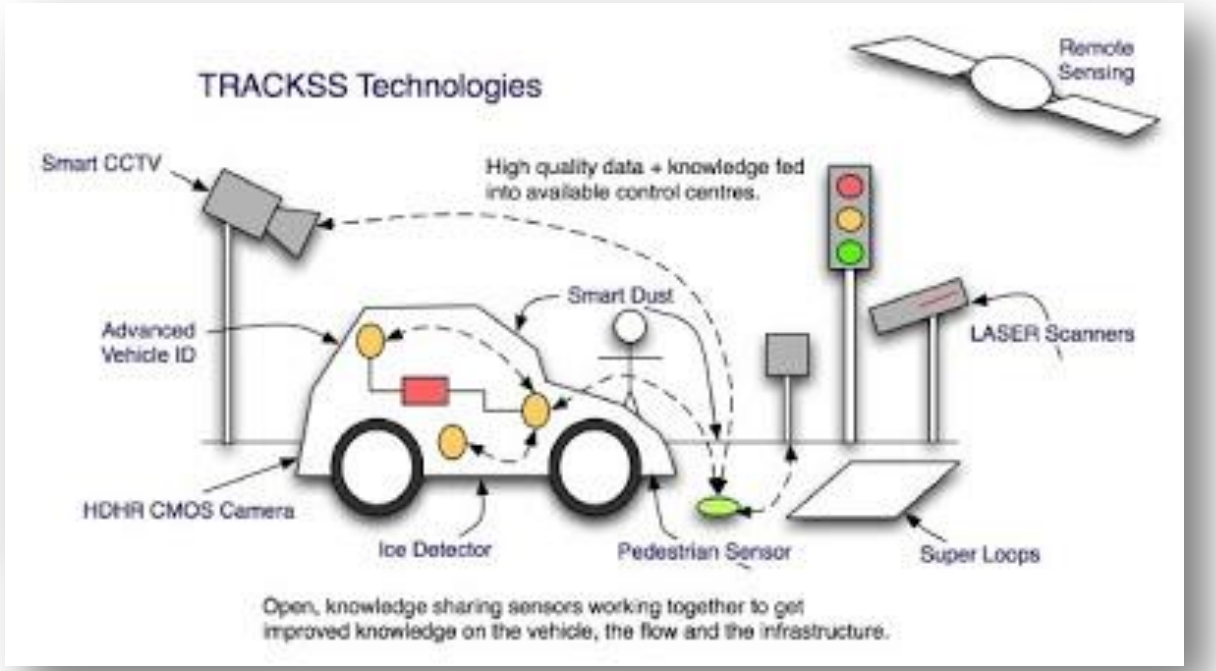
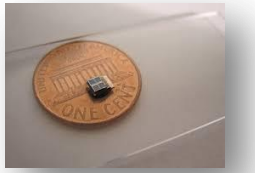


Fig.3 Schematic Diagram of Smart Dust System.





https://www.google.com/search?q=%22Smart+Dust%22&tbm=isch&tbs=rimg:Ca1h3YPSX1XtIjjIjf85iwbm8P0fyMaTUXnQ3ziajNTdmbAwq79aGPkNOQEh3Vlg99h8nO3YKJdsvmw7dGEJDQ94ioSCciN_1zmLBubwEdwg7VHbB2nBKhIJ_1R_1IxpNRedARPCBV9aWqdE4qEgnfOJqM1N2ZsBGxtAiBuh6bmyoSCTCrv35oYQ0Edrzk98OJeTLKhIJ5ASHdWWD32ERYnvZ1qsNtrEqEgnyc7dgol2y-REL2yP-AH0veCoSCbDt0YQkND3iEfGE57NrMsKH&tbo=u&sa=X&ved=2ahUKEwjut5fy09DcAhVQOBoKHcRBDk4Q9C96BAgBEBs&biw=672&bih=386&dpr=2.5#imgrc=aVZiH2IbzRqlSM:&spf=1533291486891

Intelligent Compaction (IC)..& Reporting..

Ammann/Case

Caterpillar

Dynapac

Bomag America

Sakai America

Figure 7. Single smooth drum IC rollers.

From: Final Report Publication No. FHWA-IF-12-002 - July 2011

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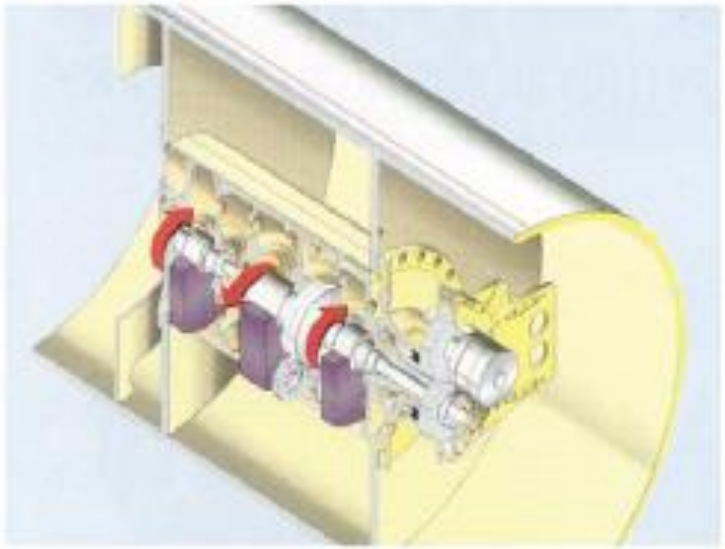
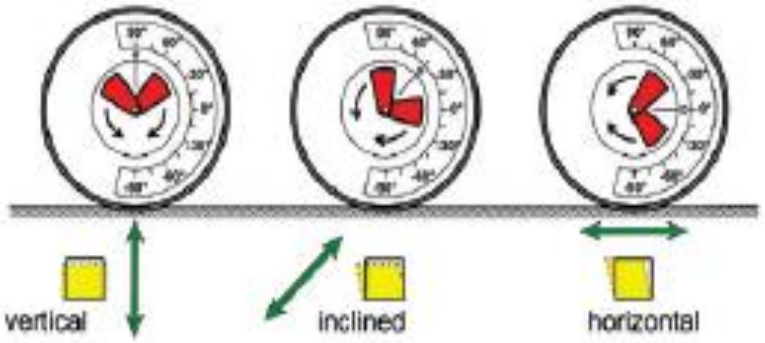
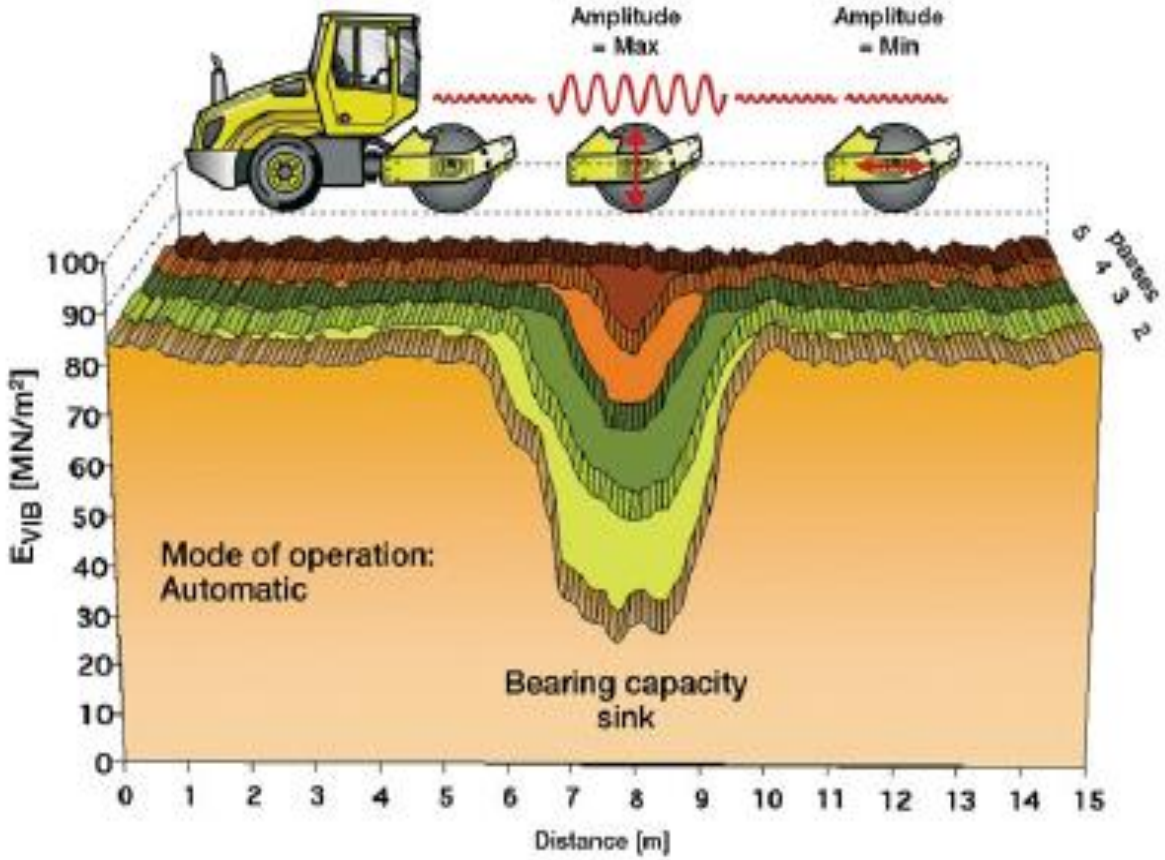
Intelligent Compaction (IC)..do we know what is really measured ?







Intelligent Compaction (IC).. Influence Depths..

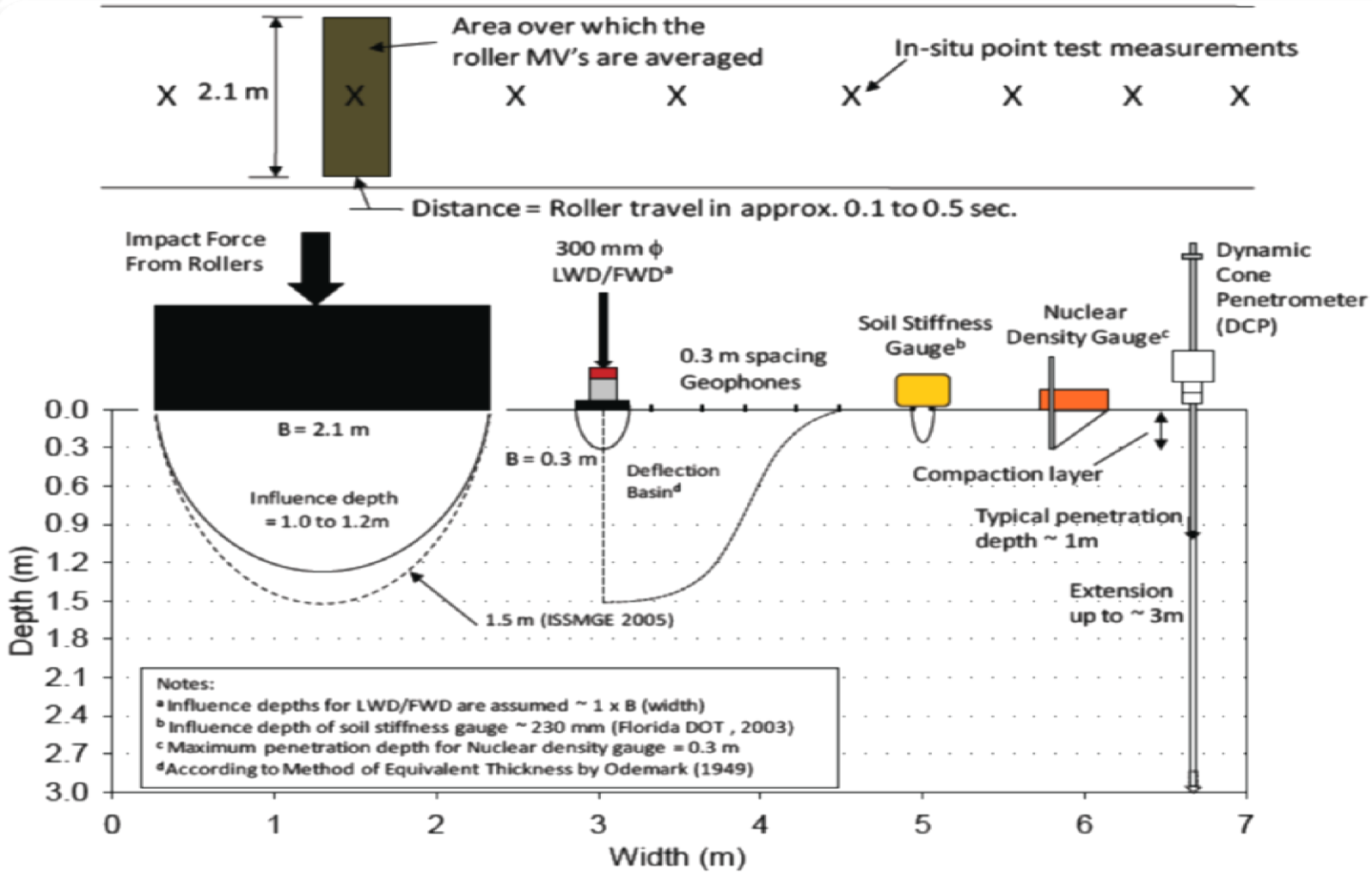


Figure 29. Illustration of differences in measurement influence depths for different measurements (modified from White 2008).

From: Final Report Publication No. FHWA-IF-12-002 - July 2011

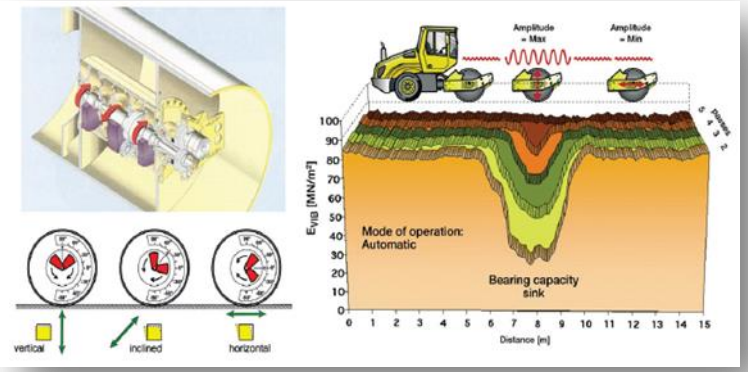
Pavement Service Life by Bad Asphalt Construction Practice

Construction Quality vs Pavement Service Life..(LCCA)..

Ref: •Granlund - REDUCED PAVEMENT SERVICE LIFE- CAUSES AND COSTS.pd

Intelligent Compaction (IC) – Some Informative References

- http://www.intelligentcompaction.com/
  - …" The **40th Years of Continuous Compaction Control (CCC) (or called Intelligent Compaction** – IC in the US)" Symposium will be held in Vienna, Austria, on November 29, 2018…
  - http://www.intelligentcompaction.com/learn/intelligent-compaction-fundamentals/
    - https://youtu.be/jmrI_bpcRVY



- http://www.iictg.org/ - *International Intelligent Construction Technologies Group*
- *« Every meter counts »*

Electrical Vehicles: EVs- Huge challenges & Opportunities..:

Search for Tesla, Nissan Leaf, etc.

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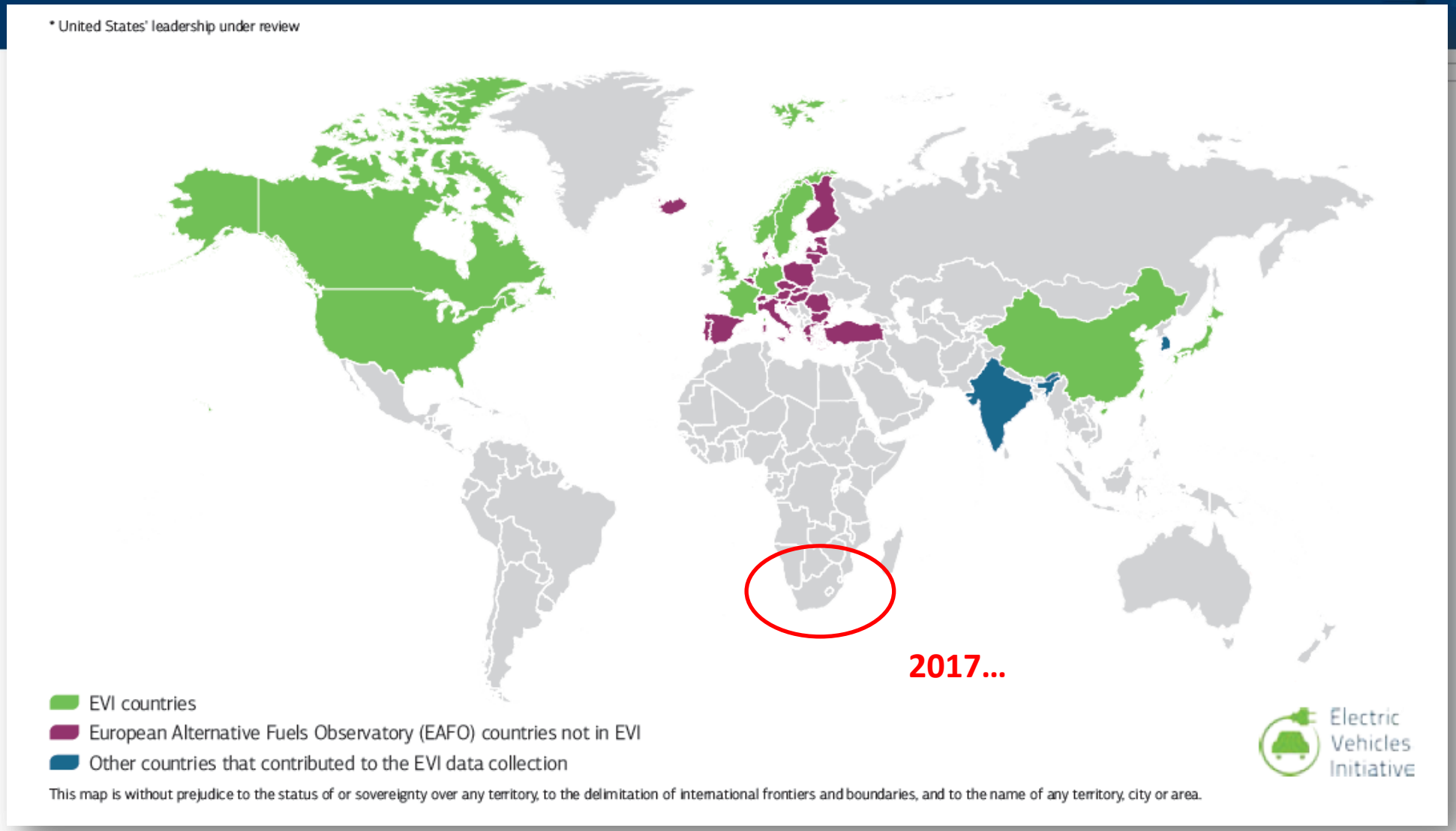
Electrical Vehicles (EVs)_Global Outlook_2017:



http://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

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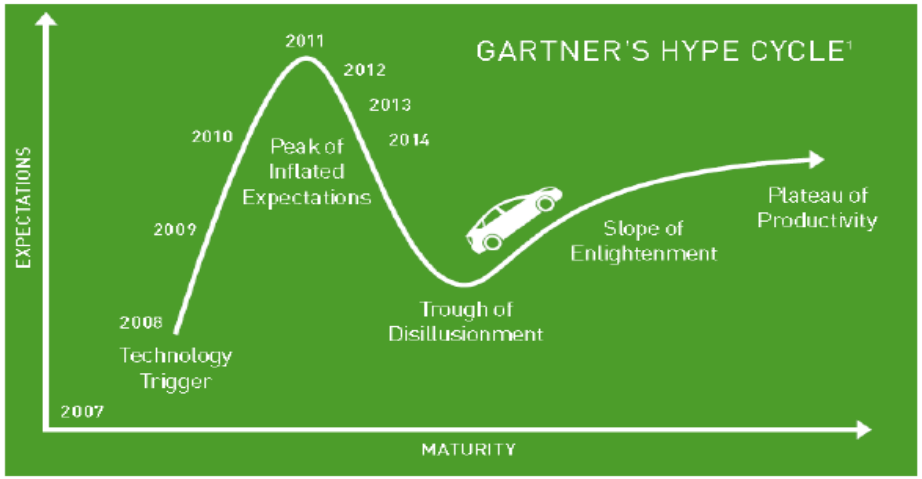
Electrical Vehicles: EVs: Gartner's Hype Cycle_ **Slope of Enlightenment**

e-Mobility – Past, Present and Future

2014 AND BEYOND:

- Transition from the early niche market to mainstream consumers
- Many new technologies can be pulled into the market
- 'Big Ideas' will play a pivotal role in shaping the future of electric mobility



Source: Gartner Hype Cycle; Urban Foresight Limited

UYILO E-MOBILITY PROGRAMME
enabling electro-mobility innovation

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Electric Vehicles (EVs) …the **Policy Challenge**:

..“***Funding*** *infrastructure, creating* ***industry standards****, legislating to* ***reward and cheapen*** *less-polluting cars, and* ***educating the public*** *are all part of the challenge*,” she said…

Prof Matternicht, Australia: https://www.news.com.au/technology/innovation/motoring/australia-is-the-worstequipped-nation-for-electric-cars-and-we-lag-a-decade-behind-the-world/news-story/9c8cfbbf9275c5a067180eb0a4ce5e0f

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E-Mobility Wireless Infrastructure – **Static non-contact Inductive charging:**

https://tse3.mm.bing.net/th?id=OIP.S4ciO-UOuhL231QutURsZwHaEK&pid=Api

E-Mobility Infrastructure – Opportunities….

e-Mobility Infrastructure

UK's Electric Vehicle highway charging lanes

Source: Highways England

Dynamic Wireless Power Transfer (DWPT) systems on the Strategic Road Network (SRN)

Battery Swap Stations

Source: Phoenix Contact

Port city of Qingdao, China, battery units of over 40 buses are replaced two or three times each day

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enabling electro-mobility innovation

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E-Mobility Wireless Infrastructure –
Dynamic non-contact inductive charging:

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E-Mobility Wireless Infrastructure - Inductive Charging lanes:

https://www.thetorquereport.com/news/renault-previews-future-never-plug-in-ev/

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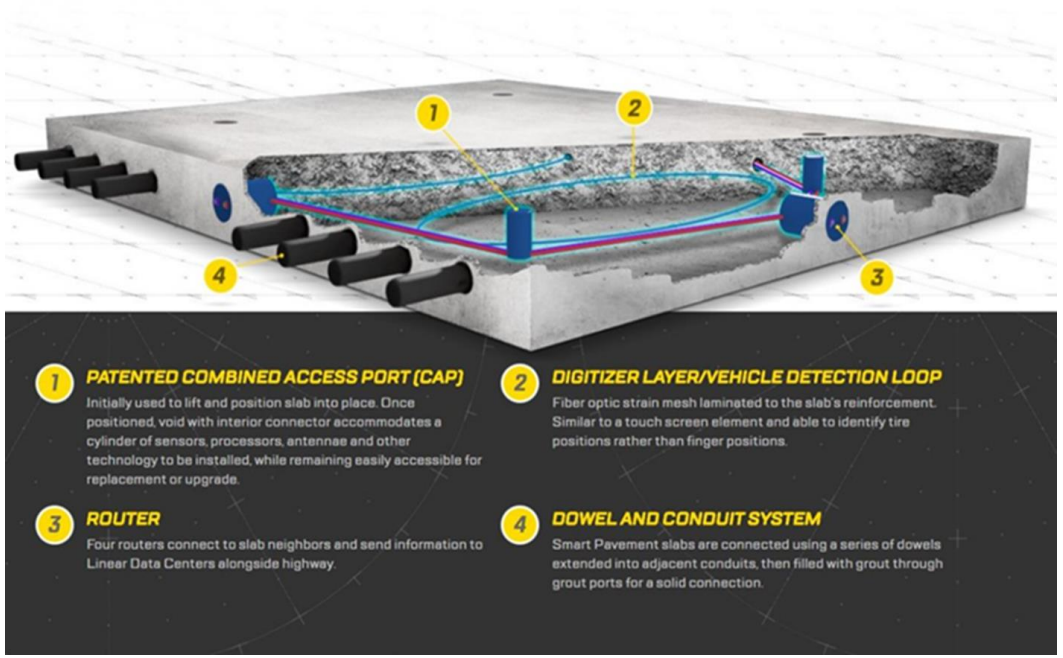
E-Mobility Wireless Infrastructure & and Comms..V2V; V2I; I2I..

Electric Vehicles (Evs) …the research challenge

"Creating EV friendly road pavements that charges EVs on the fly..", *e.g. magnetic loops (wireless induction charging) within the road surface, and/or charged by Solar…*



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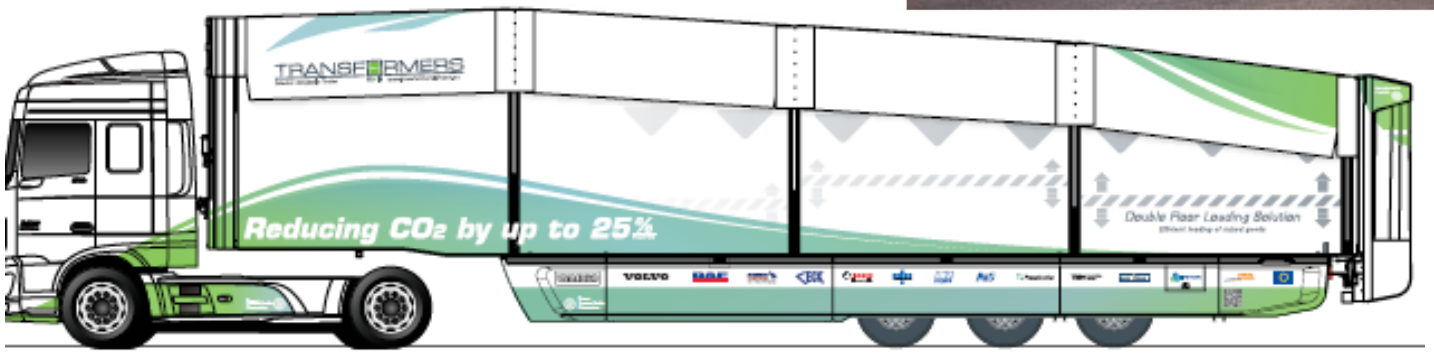
Innovative Concepts - Heavy Vehicle Transport Technology (HVTT15) – Smart Trucks..

TRUCK-SEMITRAILER COMBINATIONS



Ref: •Wilkins - INNOVATION CONCEPTS FOR TRUCK-SEMITRAILER COMBINATIONS TRANSFORMERS PROJECT.pdf

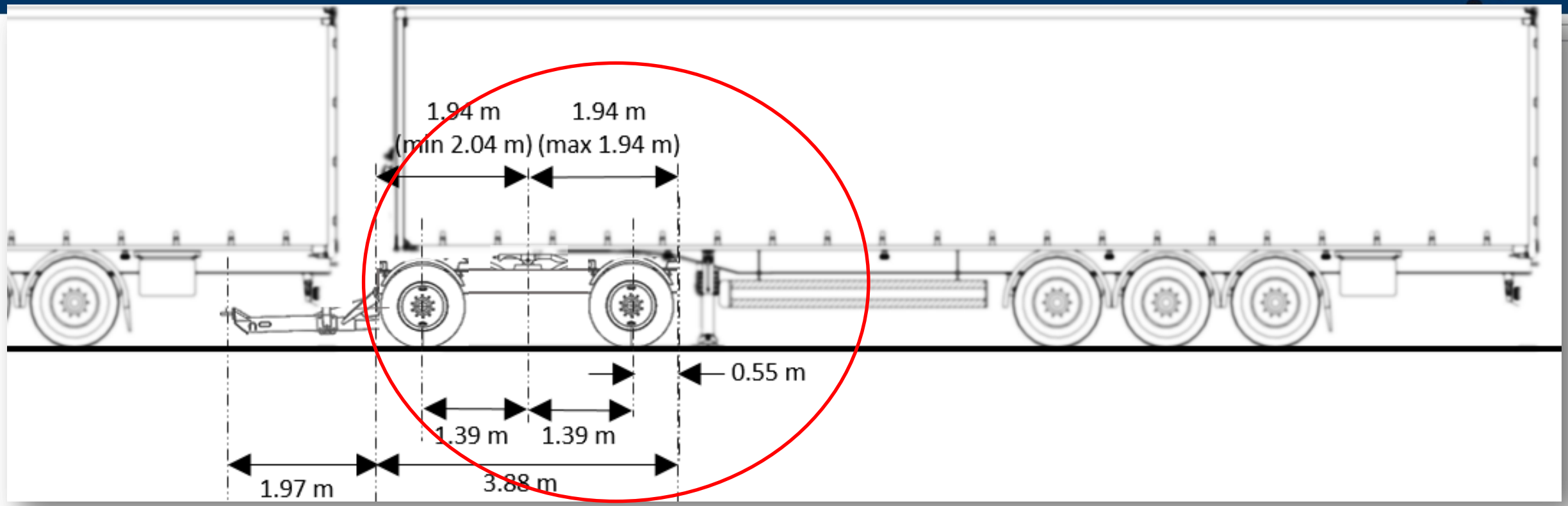
Volvo: Project VERA: Autonomous Vehicle..

THIS IS VERA – A VEHICLE LIKE NO OTHER SEEN FROM Volvo BEFORE

Vera is an **autonomous, electric vehicle** that can operate with significantly less exhaust emissions and low noise levels. It is controlled and monitored via a control centre, and has the potential to make transportation safer, cleaner and more efficient.

https://www.volvotrucks.com/en-en/about-us/automation/vera.html

Innovative Steering 4x4 dolly: A-double HCV - HVTT15



Long trucks…Innovative Steering dolly..

Ref: Besselink - STEERED AND POWERED DOLLY FOR AN A-DOUBLE HIGH CAPACITY VEHICLE.pdf

Infrastructure - Heavy Vehicle Transport Technology (HVTT15, Oct 2018)

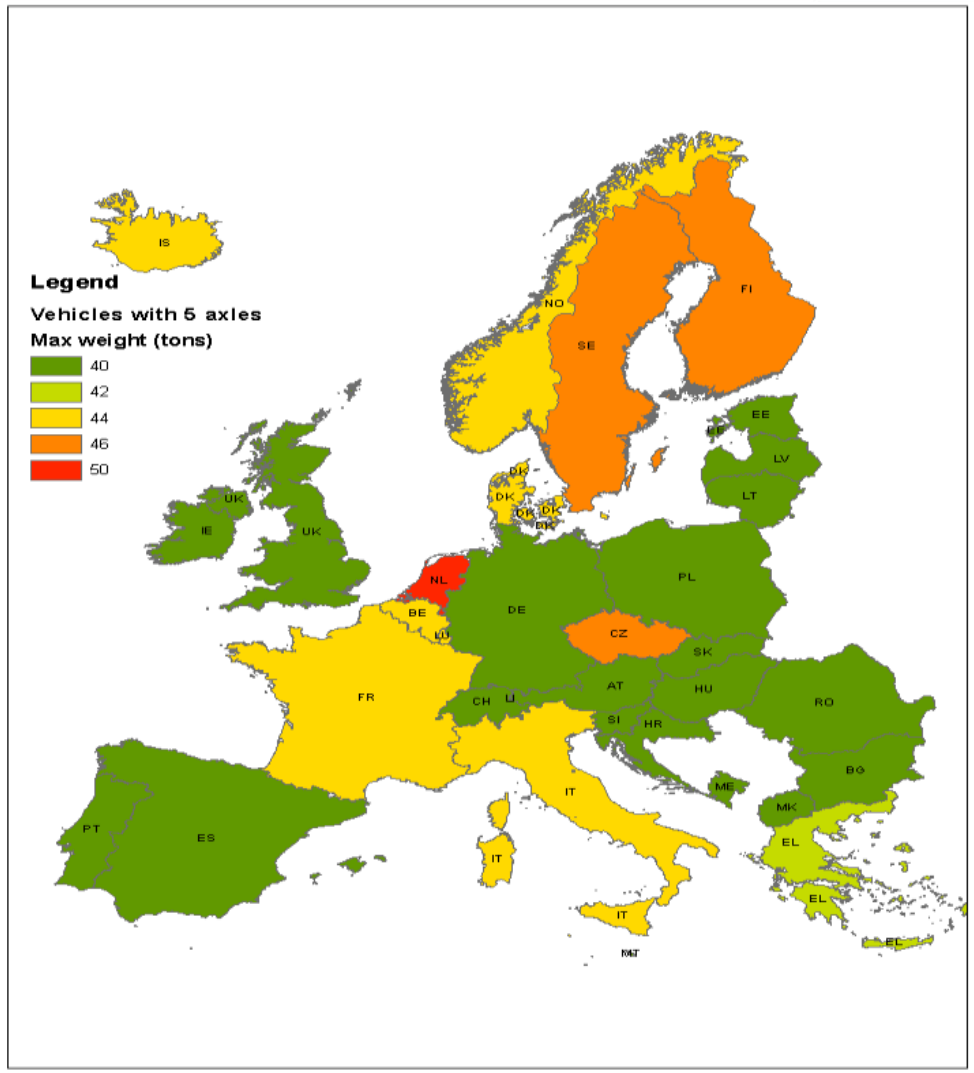
Infrastructure in the narrow sense contributes to CO_2 reduction through the road pavement and its Rolling Resistance Coefficient (RRC),

EU Project MIRIAM project - 10% improvement in RRC can be achieved (in addition to the improvements in tyre rolling resistance).

Normal road-maintenance cycle (resurfacing roads for the sole purpose of emissions reduction does not happen), could lead to around 3% decrease in fuel consumption by 2030. Although it is possible that further specialised pavement surfaces (or other modifications) allow for greater reductions by 2050, little to no information is available on this matter.

Ref: Breemersch - COMMERCIAL VEHICLE OF THE FUTURE.pdf

Road freight transport – Cross border issues - HVTT15



High Capacity Vehicles (60 tons), which have become more popular over the past few years, are allowed in The Netherlands, but have only limited use when carrying out **cross-border operations**. – Lesson for Africa ?

Ref:Chen - IMPACT OF DISRUPTIVE INNOVATIONS ON ROAD TRANSPORT STRATEGY.pdf

Road Freight Truck Platooning (TP)..HVTT15

Truck Platooning (TP).., Loading - on pavements, channelized or linear wheel path tyre loading..?

Ref: Cornelissen - Characteristics of Road Freight Transport policy in The Netherlands, Joris Cornelissen, Rijkswaterstaat, May 2018.pdf

Road Freight Transport – On Highway Platooning - HVTT15

Trucks

ON-HIGHWAY PLATOONING SHOWCASE

- First public on-highway platooning showcase between a truck OEM and transporter in the U.S
- Volvo Trucks in platooning research collaboration with FedEx and North Carolina Turnpike Authority
- Volvo's Cooperative Adaptive Cruise Control (CACC) using wireless vehicle-to-vehicle (V2V) communication technology

Van Vliet, et al (2018). Europe:

"There are many expectations of TP. In the short stakeholders mainly look for benefits on fuel consumption, enhanced road safety and improved traffic flows."

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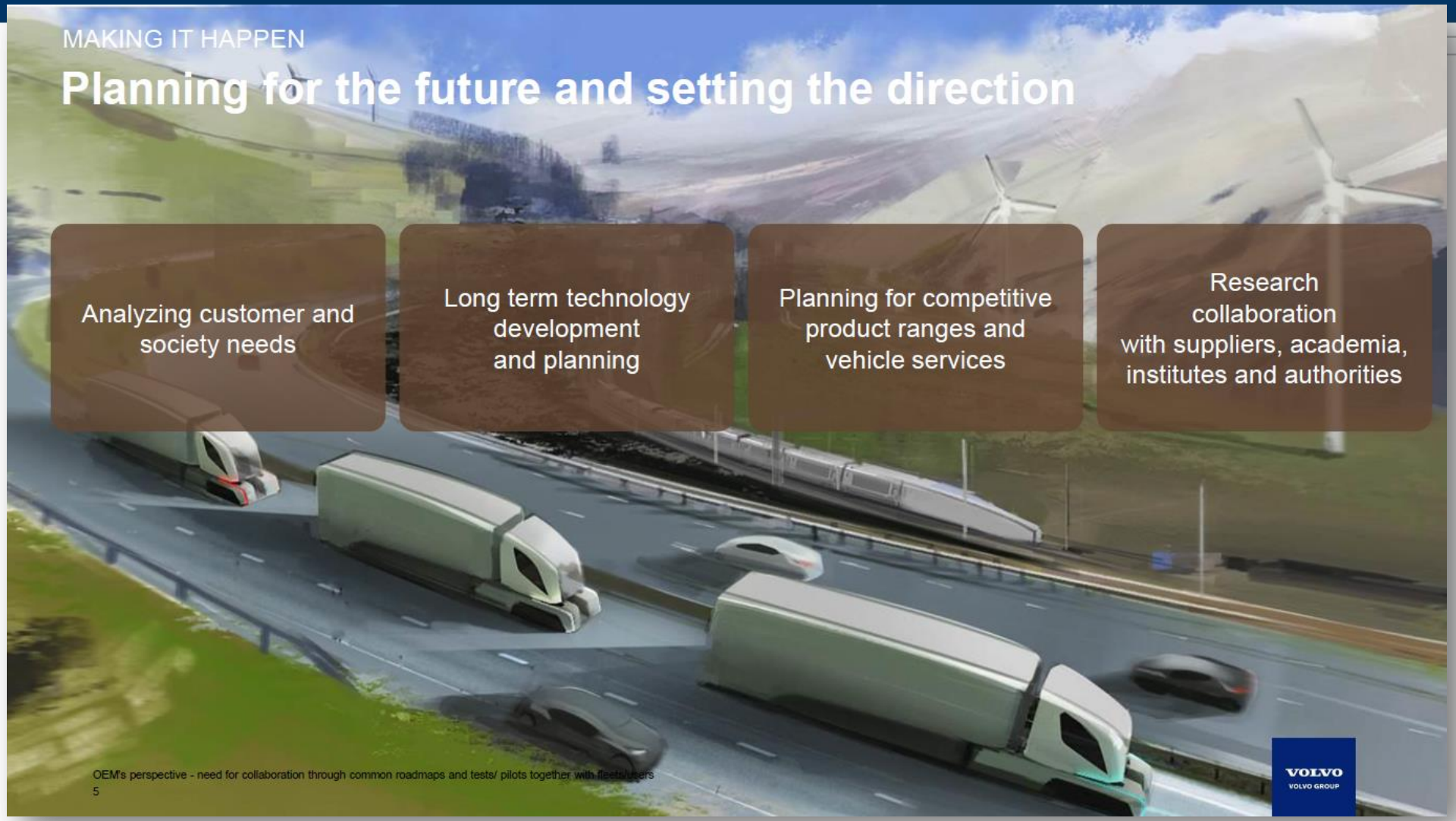
https://www.volvotrucks.com/en-en/about-us/automation/vera.html

Road Freight Transport – Planning For The Future - HVTT15



Part I - "Automated transport: truck platooning and beyond" *rosenqvist.pdf, HVTT15, 2018*

https://www.volvotrucks.com/en-en/about-us/automation/vera.html

Type Vehicle Combinations – High Capacity Vehicles (HCT) - HVTT15

Sweden: Truck
Tests on 25.25 m to 34 m Trucks

Lift of the last wheels on a B-double, but the load transfer ratio is not 100%

– Effect on loading ?

Ref: •Larsson - TYPE VEHICLE COMBINATIONS - HCT SWEDEN 25.25 TO 34 METERS.pdf

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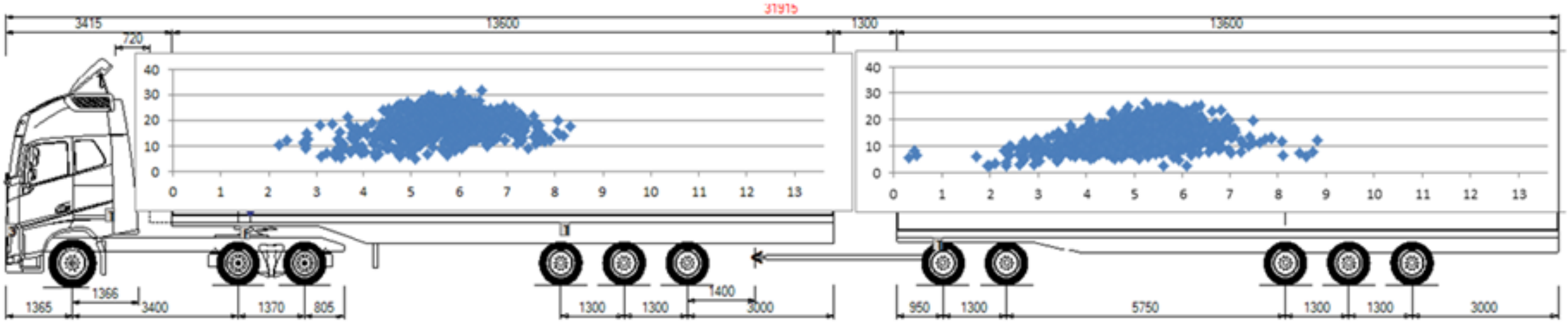
Duo Trailer An Innovative Transport Solution
Co-optimizing Multi Vehicle Combinations - HVTT15



Actual load and centre of gravity from 981 transport trucks in Sweden..

Ref: •Lindgren - SWEDISH ROADMAP FOR ELECTRIC ROAD SYSTEMS.pdf

New CSIR: Project Synapse

Project Synapse, a process to define the contribution of the CSIR to industrial development in support of South Africa's economic competitiveness..

Note: -- detail currently under construction --

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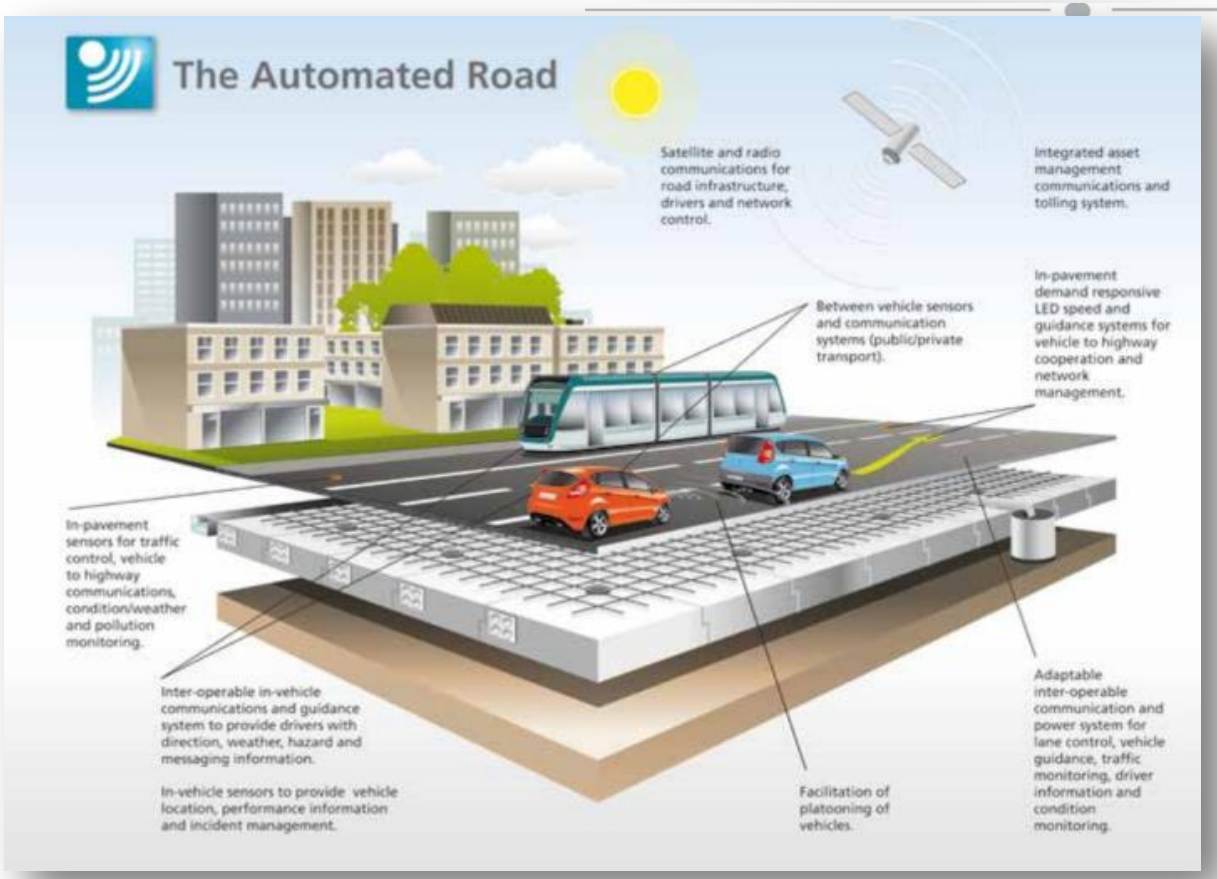
CSIR: Focus on **Industrialisation**

- Increased quality and durability
- Increased speed of construction
- Creation of new businesses
- Export opportunity
- New industrialist development
- Less corruption..
- Lower life cycle cost
- Smaller carbon footprint



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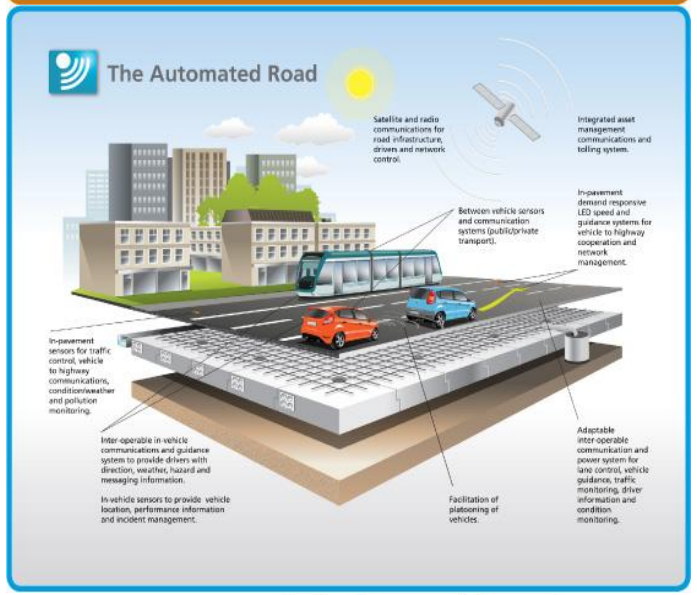
Smart Road Technologies

- **End Objective:**
  - Improved design, construction and maintenance processes
  - Next-generation road construction products
  - *The goal is to potentially reduce road construction costs by 10 to 20 %, as well as improvements in life-cycle performance of roads, energy efficiency and safety.*
- **Objectives for 2018/19:**
  - **Road Maps** for *Smart Roads* and *Industrialisation of Construction Processes*
  - Longer life pavements (e.g. **self-healing** mechanisms, binder **ageing**, aggregate **degradation**, asphalt **compaction simulation models**, **pavement design software**)
  - Green technologies and products: (e.g. **reduction in water usage in road construction**, green paving blocks, sustainable **reuse of plastic in roads**)
  - **Modification and stabilisation** (e.g. nano-modified bitumen emulsions)



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CSIR: Transport Infrastructure Engineering (TIE):

- **Advanced materials testing laboratories (AMTL)**
  - Bituminous binder laboratory
  - Asphalt materials laboratory
  - Cementitious and granular materials laboratory
  - Dynamic testing laboratory
- **Heavy Vehicle Simulator (HVS)** technology platform
  - Several technology (SIM) and software platforms (supporting advanced traffic/road research)
  - Mechanical workshops (supporting product development)

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Technical Focus Area: Sustainable Access Roads

- **End Objective:**
  - Development and implementation of methods and techniques for the delivery of **sustainable community access road infrastructure** in South Africa (and Africa)
  - Development and implementation of **novel and cost-effective design & construction solutions**
  - Capacity building (also building research capacity)
- **Uptake potential and channel:**
  - Uptake potential is significant in southern Africa, as well as in Africa and South-Asia through the UKAid-funded Research for Community Access Partnership (ReCAP) programme and in-country support (Africa & Asia)
  - Uptake through standards and guidelines, skills development and the development of local capacity, novel design and construction techniques, and decision support tools and guidelines.

Improved Low-Volume Road (LVR) maintenance and upgrading technologies..

Objective

- Evaluate scientific/engineering justification **of equipment used for measurement of in-situ properties of materials**
- Development/validation of novel soil treatment technologies

Overall Purpose

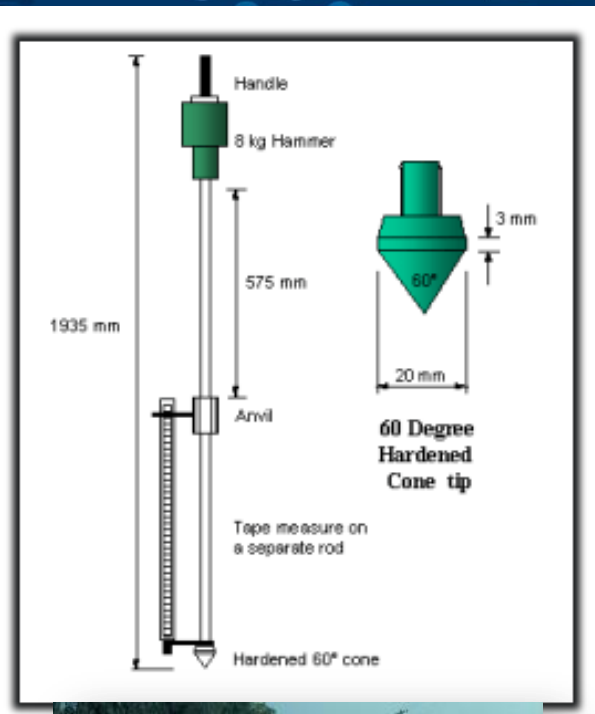
- Promotion of the **use of local/marginal materials**, including waste products, and treatment of materials with stabilisers to improve bearing capacity and durability, as well as assessment methods

Method to achieve outputs

- Verify/validate accuracy and **reliability of in-situ measurements under controlled** conditions
- Development **of bio-enzymatic stabilisers** in association with TUT ?

Expected Outputs

- Extending knowledge base of “Sustainable Access Roads”
- Report on effects and performance of bio-stabiliser on soil microstructure
- **Elucidation/Clarification of bio-stabiliser-soil interaction mechanisms**
- Capacity building and potential commercialisation opportunity



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Development of MORE sustainable asphalt mixes

Objective

- Development of **cold-mix asphalt products** for use as alternative surfacings on low-volume roads
- Establishment of (draft) design methods and specifications

Overall Purpose

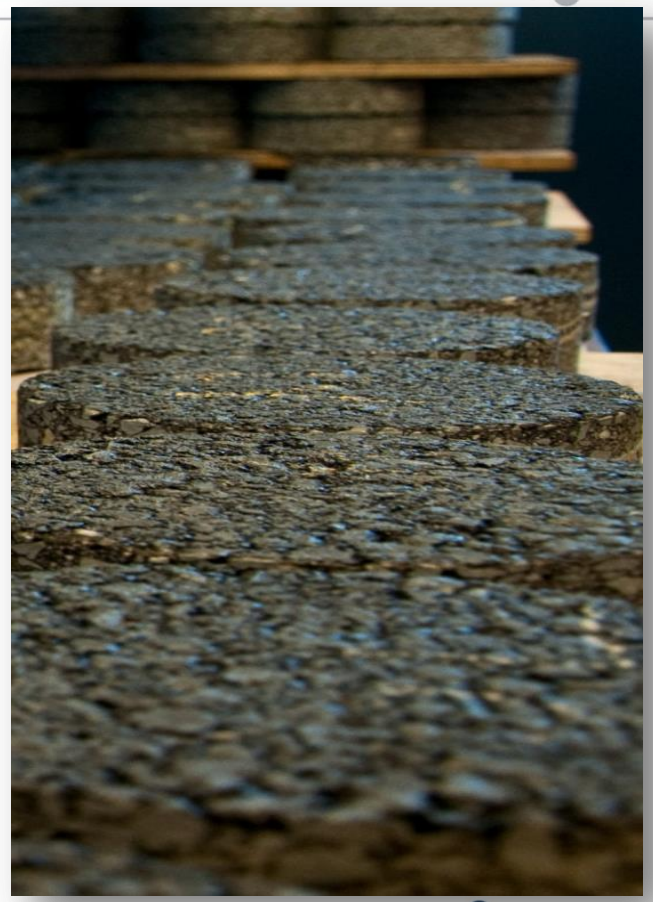
- Continued drive to characterise out-of-norm asphalt products that have potential for implementation on high and low-volume roads in South Africa (e.g**. HiMA, Coal-Ash asphalt, Glass asphalt: MEng-Ms Theresa George, CSIR**)

Method to achieve outputs

- Extensive state-of-the-art study & inventory of cold asphalts
- Consultation meetings with potential stakeholders
- Evaluation (laboratory) and interim guidelines

Expected Outputs

- Novel (interim) products
- Interim design/construction guidelines
- Human capital development **(MEng)**
- Articles and peer-reviewed conference papers



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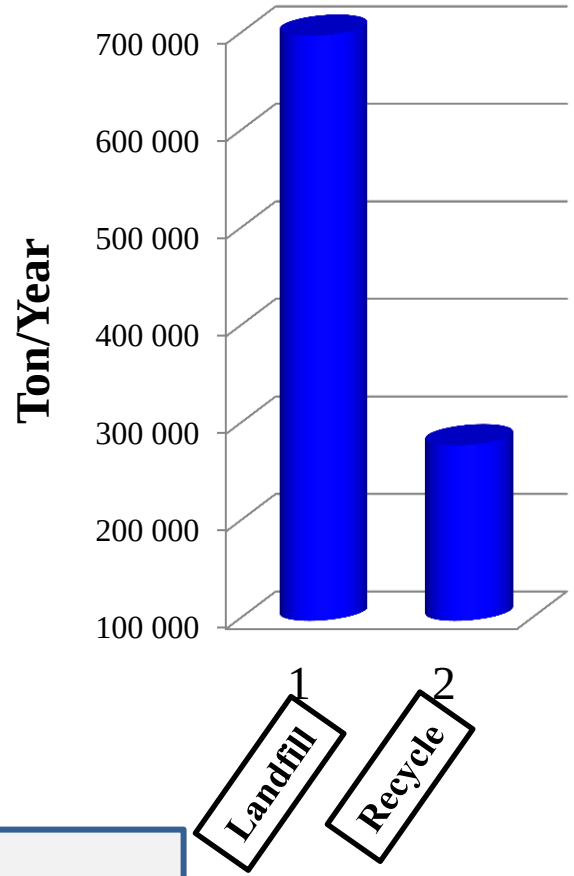
Crushed Glass....Importance with respect to national legislature

- National Environmental Management: Waste Act (Act 59 of 2008)
  - "Waste minimisation, reuse, recycling and recovery of waste"

- Considerable quantities of recycled crush glass fines (less than 5 mm), accumulate as stockpiles at glass packaging manufacturing plants in Gauteng and the Western Cape



- 3,000 TONS/MONTH
- R3 MILLION PER ANNUM - DISPOSAL AND TRANSPORTATION TO LANDFILL SITES

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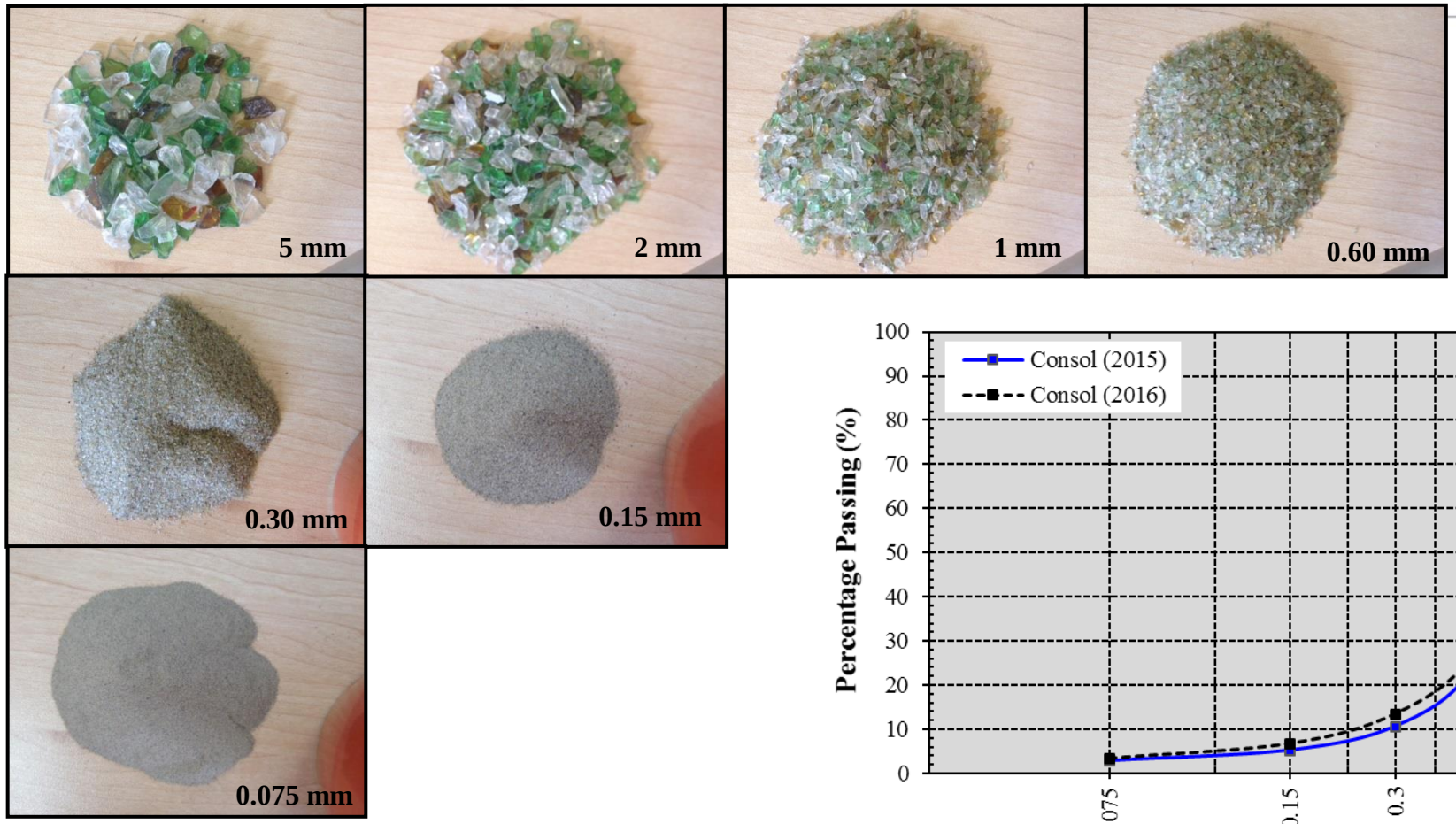
Crushed Glass....”Aggregate”.... Finely crushed particles (Max Particle Size = 5mm) – not coarse …



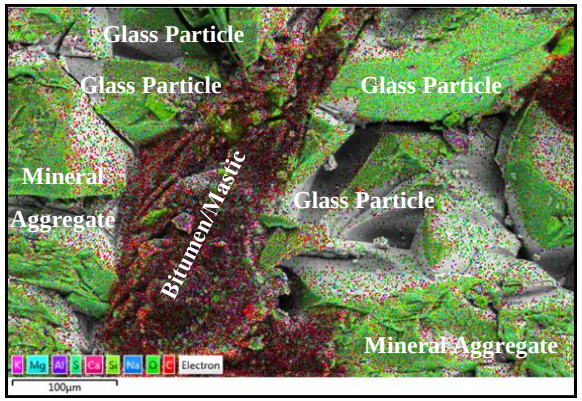
Glass-Asphalt... High angularity – assist in resisting permanent deformation [Cum Laude MEng - Me Theresa George (CSIR)]

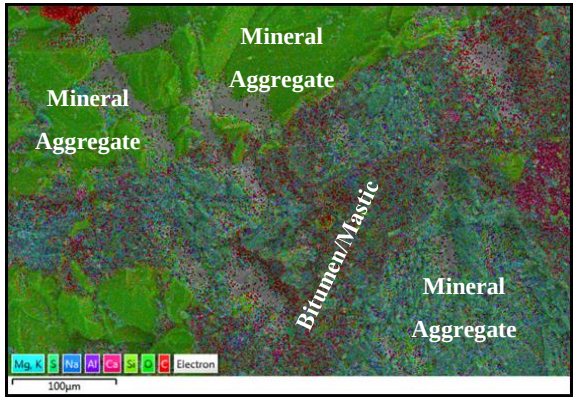
Microscopic Morphology of Crushed Glass

Aggregate	Uncompacted Void Content (%)
CD Andesite	44.6
CS Granite	45.0
Mine Sand	50.5
Recycled Crushed Glass	50.9

Fine Aggregate Angularity Testing: ASTM C1252

Scanning Electron Microscopy of Glass-Asphalt Mix





a) Glass-Asphalt Mix b) Conventional Asphalt Mix

(Anochie-Boateng & George, 2016)

Asphalt **compaction simulation models** for enhanced road performance (PhD – first year)

Objective

- Develop **3D computer simulation models for HMA aggregate** packing with mastic and void distribution in the mastic structure, and the actual influence of these on compaction process models

Overall Purpose

- Create better understanding of the relationship between HMA compaction and its volumetric and mechanical properties with the ability to identify potential compaction problems or identification of best compaction processes to be used

Method to achieve outputs

- **Analysis of methods for packing and HMA compaction methods**
- Study influence of aggregate grading, shape and packing, compaction energy and effect of temperature
- Modelling densification and void distribution, and evaluation of particle-to-particle interactions

Expected Outputs

- Interim report on PhD addressing: (a) analyses of methods to assess asphalt mix compatibility in the laboratory; (b) development of compaction simulation models; and (c) understanding distribution of air voids / density on compacted asphalt samples
- Journal article

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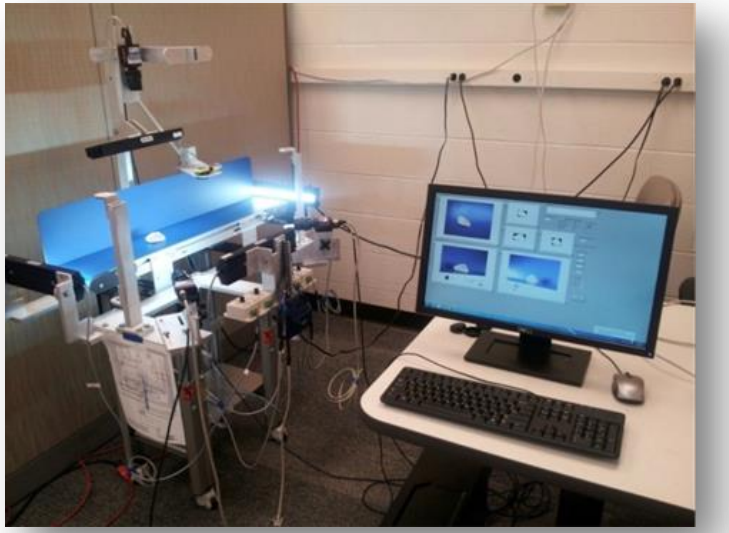
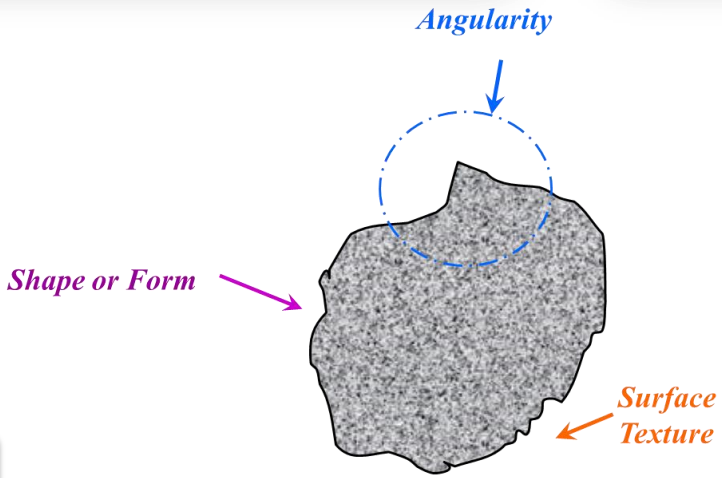
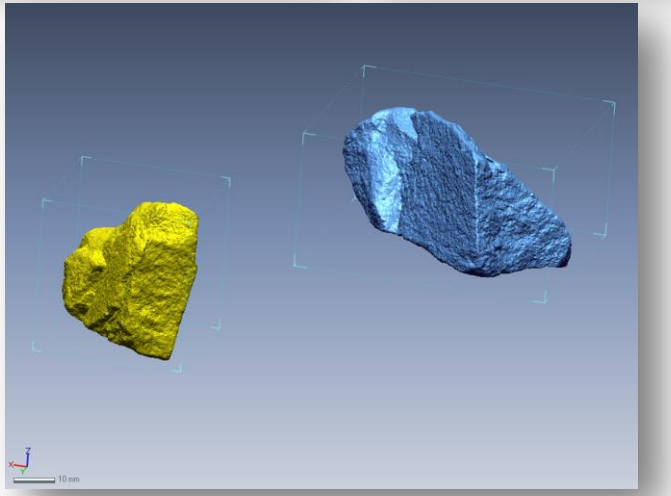
Characterisation of Aggregate Shape Properties..

3D Laser Scanner

Aggregate Imaging Analyser (AIA)

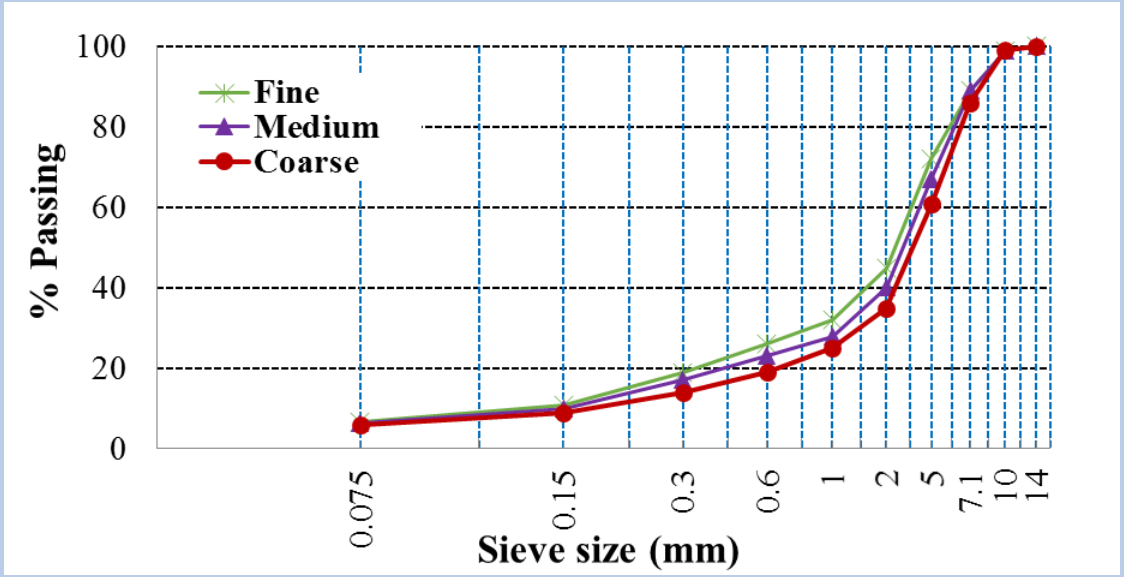


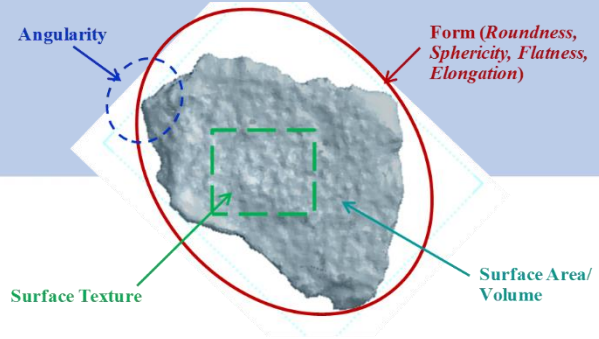


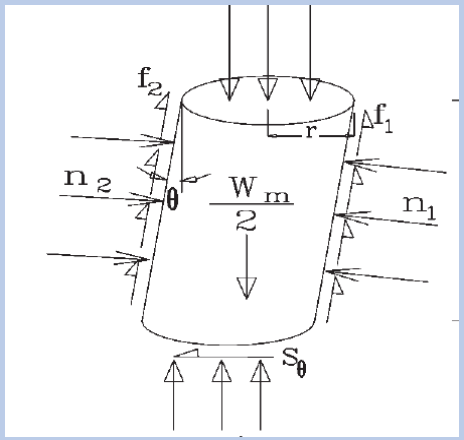


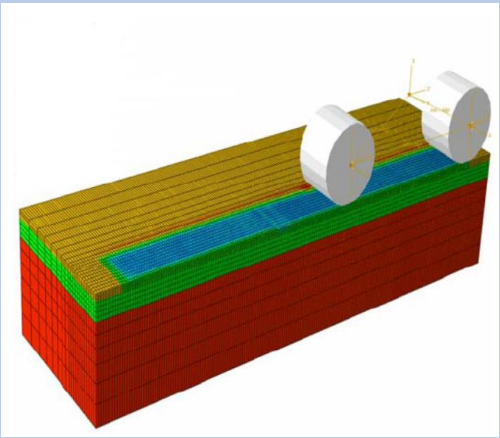
Asphalt: Aggregate Compaction Simulation…Gyratory..

- Effluence of gradation and packing characteristics









Uniaxial Shear Tester (UST) – new test method to determine shear properties of asphalt mixtures..?

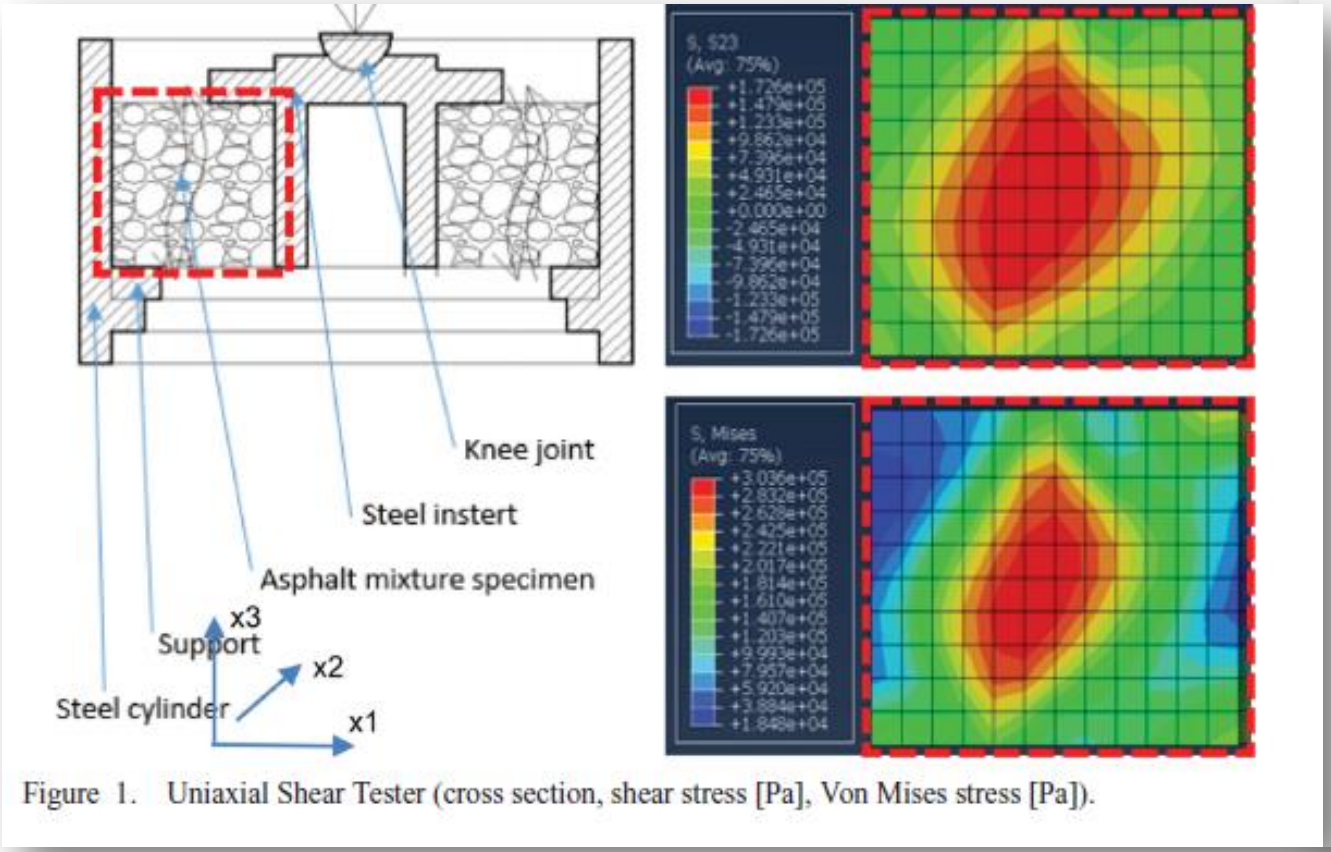
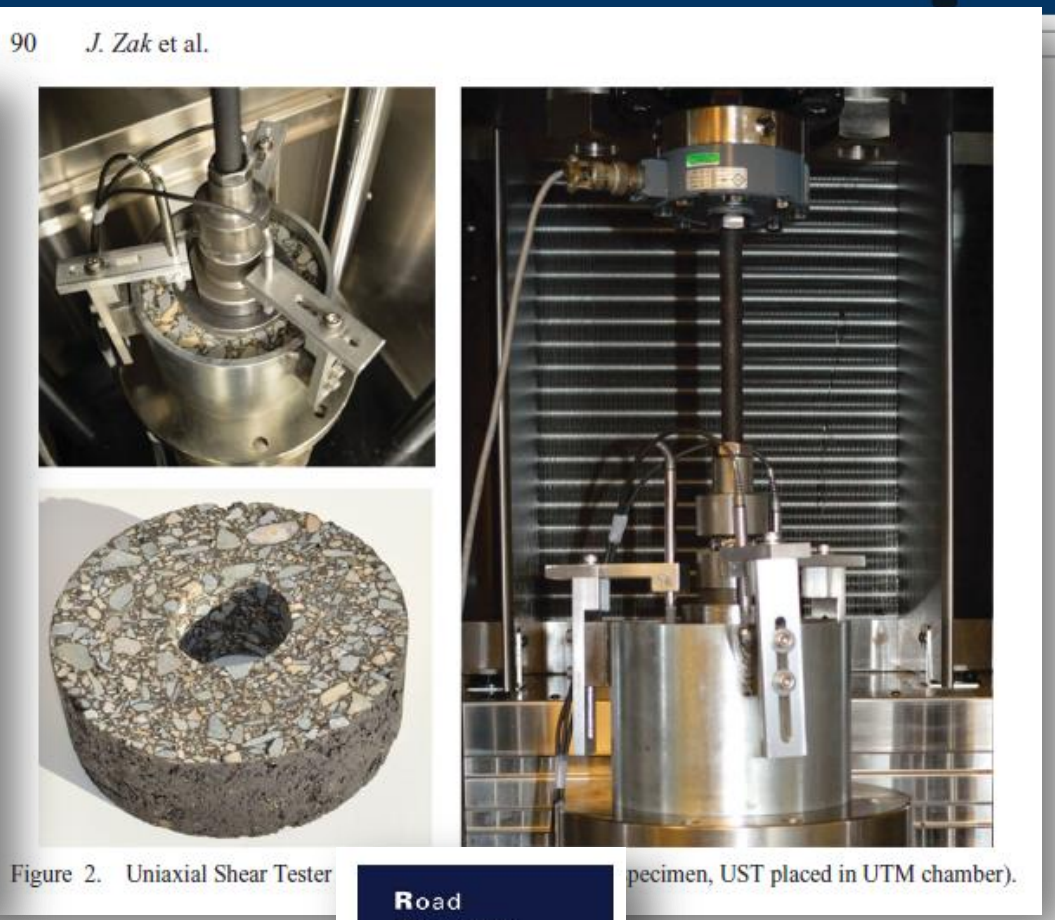


Figure 1. Uniaxial Shear Tester (cross section, shear stress [Pa], Von Mises stress [Pa]).



90 J. Zak et al.

Figure 2. Uniaxial Shear Tester pecimen, UST placed in UTM chamber).

Ref: Josef Zak, Carl L. Monismith, Erdem Coleri & John T. Harvey (2017) Uniaxial Shear Tester – new test method to determine shear properties of asphalt mixtures, RMPD, 18:sup1, 87-103, DOI: 10.1080/14680629.2016.1266747

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Ageing Models for Asphalt Materials

Future Smart Roads:
Can these asphalt models be replaced by sensors
?????

Prediction

Surface Crack initiation (Environmental)

~ Pothole formation

Maintenance Schedule to be Modelled
- with every asphalt surfacing construction

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Extended serviceability of asphalt pavements through **Self-Healing** (Phase 1)

Objective

- Conduct a detailed study on the healing capability of bituminous materials (binders, mastics and asphalt mixes) and identification of novel self-healing materials and technological methods

Overall Purpose

- Through a better understanding of **self-healing mechanisms** and the demonstration of viable solutions, to extend the maintenance-free life of bituminous products

Method to achieve outputs

- **State-of-the-art study**
- Identification of **technologies and novel materials** that have the potential to enhance self-healing
- Laboratory characterisation to assess healing capability

Expected Outputs

- State-of-the-art review
- Potential solutions to enhance self-healing
- Test protocols to assess healing properties of bituminous products
- Journal article and peer-reviewed conference paper **(PhD ?)**

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Development of Road Maps Smart Roads & Industrialisation of Construction Processes..

Objective

- Production of **Road Maps for Smart Roads** and Industrialisation of Construction Processes

Overall Purpose

- Development of a **10-year Strategic Plan** for activities to be undertaken by the CSIR in cooperation with industry, aligned with a shared vision for *Roads of the Future*

Method to achieve outputs

- Literature scans; industry consultations; synergies with similar programmes (SANRAL, FEHRL, FHWA, UK DFID)
- **Visioning:** identification of long-term goals and objectives
- Road Map development, followed by further consultation
- Finalisation and endorsement by industry

Expected Outputs

- **Comprehensive synthesis** of information related to the subject area
- **Road Maps (shared vision, technology development priorities, proving stages for new technologies, timelines and indicative budgets)**

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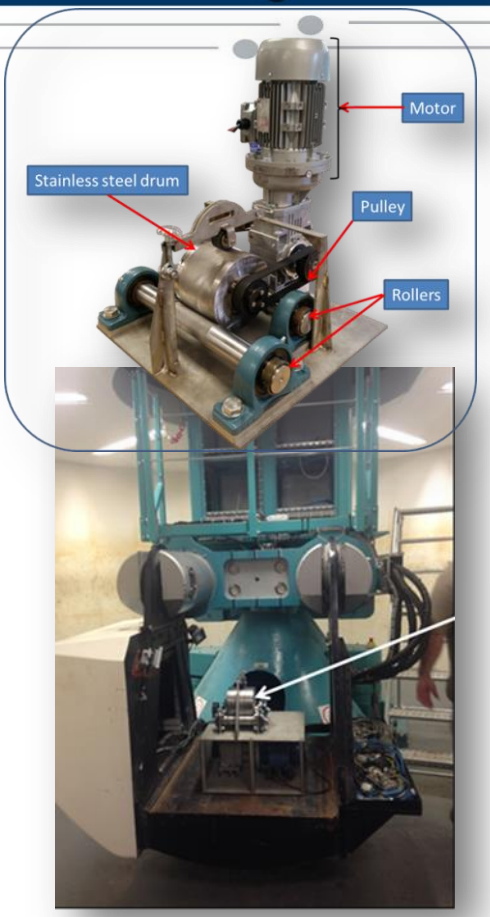
Further investigations into **aggregate degradation** processes: (UP Centrifuge)

Objective
- To conduct experimental investigation into characterisation of aggregates, including effect of stress level

Overall Purpose
- Evidence-based knowledge on aggregate performance taking into account parent rock, method of production, stress levels and shape characteristics so as to improve specifications and improve performance of pavement layers (road & rail)

Method to achieve outputs
- Source different types of materials (geology & crushing processes)
- Laser scanning (shape) and AATD testing
- Data analysis and reporting

Expected Outputs
- Comprehensive report on findings
- Preliminary recommendations on specifications for granular material performance testing
- Potential MSc (depending on UP student availability)
- Peer-reviewed conference paper



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Ref: Dr. Martin Mgangira, CSIR

Construction processes that are **less reliant on potable water** (Phase 1)

Objective

- **identify impacts of water quality** on road construction material performance
- identify means **(e.g. surfactants) that could be used to reduce water demand** while still achieving construction densities
- explore relationship between applied compaction energy and achieved densities within the context of water scarcity

Overall Purpose

- Promotion of construction methods that **are less dependent on water qualities/quantities but yet yield the desired performance**

Method to achieve outputs

- **State-of-the-art survey, inclusive of interactions with experts**
- Assessment of **impact of alternative water resources** on overall performance (e.g. grey/salt water)
- Exploration of **alternative compaction equipment requirements** to meet densities in absence of adequate compaction lubricants

Expected Outputs

- Progress report and position paper

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Sustainability indices for **smart/green paving blocks** (including LCA assessments and SABS approvals)

Objective

- Following previous development stages, to valuate the green blocks according to SABS standards for use in pavement construction as a permeable pavement system

Overall Purpose

- Mitigation of the effects of flooding, particularly on low-volume roads while fulfilling the structural requirements of the pavement. This product will also contribute to job creation.

Method to achieve outputs

- Optimisation of design and manufacturing processes
- Finalisation of block-making system
- SABS testing of paver
- Life Cycle Assessment (LCA)

Expected Outputs

- SABS approved product that can be demonstrated, industrialised and commercialised
- Formalisation of LCA indices

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“Green/Smart” composite paving block-Further R&D

Surface & Ride Properties

- High skid/Low noise
- Drainage (porous)
- Surface durability (long lasting or sacrificial / does not have to be only asphalt)
- **Reflectivity/Illumination (inbuilt)**
- Jointed or Seamless ?

Structural & Operational

- Light weight
- Structural Design life
- **Fast manufacture/Fast lay**
- **Fast repair (self repair, self destruct)**
- Economic
- Greener than ?

High Tech.

- **Intelligent ?**
- **Self diagnostic**
- **Traffic analysis (traffic counter, SIM, etc.)**
- **Traffic signalling or warning signs**
- **Power generating (movement, solar, wind, etc.)**

“Green/Smart” composite paving block..

Concrete paving block incorporating:

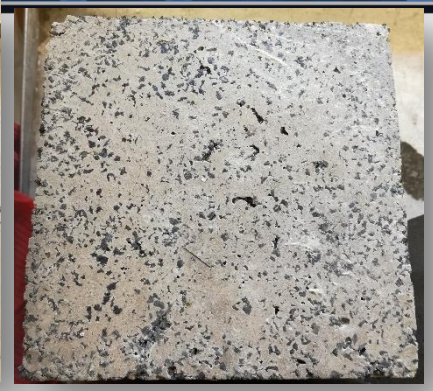
- coal ash
- waste rubber granules
- recycled plastic pellets
- Photo-Voltaic (PV)

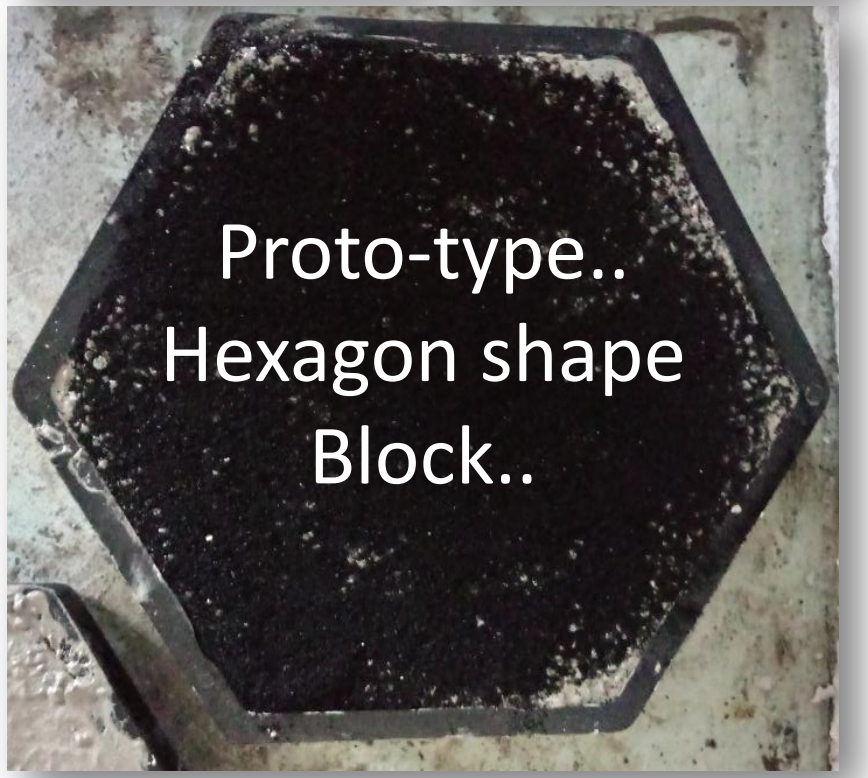
Laboratory tests:

- mix design investigation
- compressive and tensile strength testing
- skid resistance
- abrasion resistance
- water absorption

Sustainability Analysis:

- Life Cycle Assessment (LCA)
- **Permeable paving system**





Road construction materials - enhanced with **nano-modified emulsion products..**

Objective

- Evaluate properties and characteristics of road construction materials enhanced with NME and quantify the potential benefits for road construction industry: **HVS @ D1884: Meyerton, Gauteng**

Overall Purpose

- Forms part of a larger drive to characterise and catalogue non-conventional modifiers and stabilisers that have the potential to beneficiate marginal materials, and to assess their cost-effectiveness

Methodology to achieve outputs

- Literature review
- Laboratory testing programme (controls & NME materials)
- (HVS testing as part of a separate project for the GPDRT)
- Data processing, analysis and reporting

Expected Outputs

- Technical reports and peer-reviewed conference papers
- Groundwork towards an **MEng thesis, Mr Imraan Akhalwaya, CSIR**

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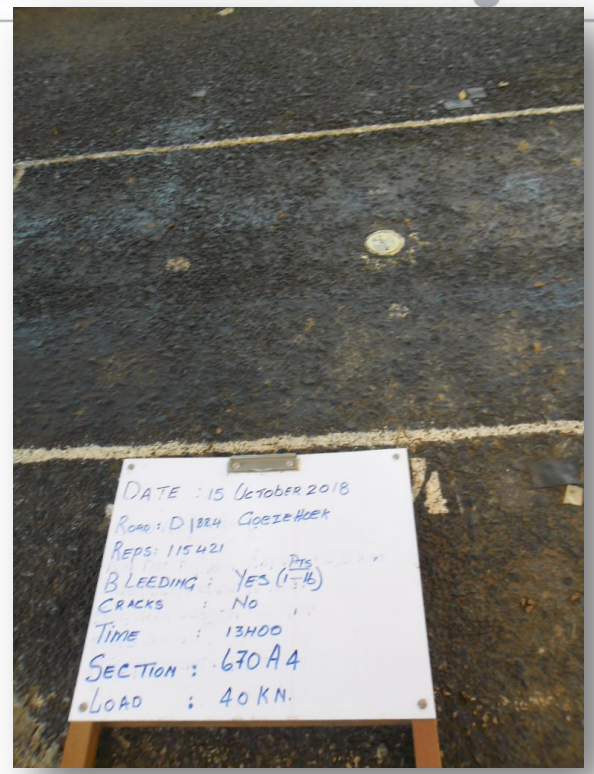
New HVS Testing_2018: Road construction materials enhanced with nano-modified products



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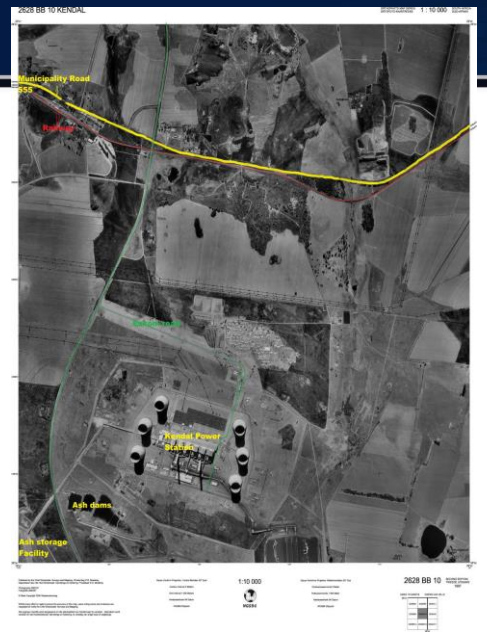
Coal Ash…



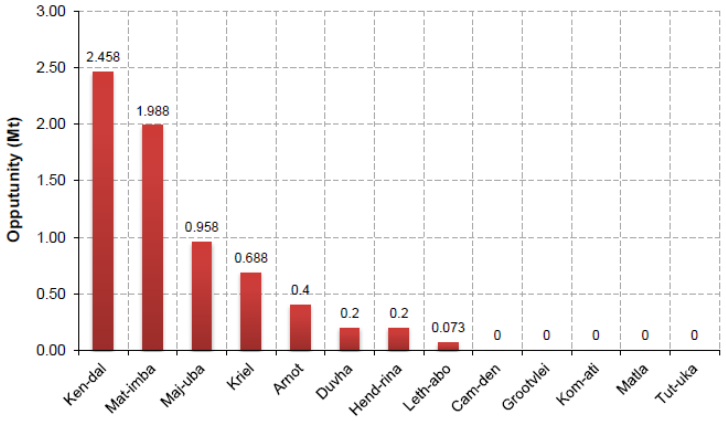
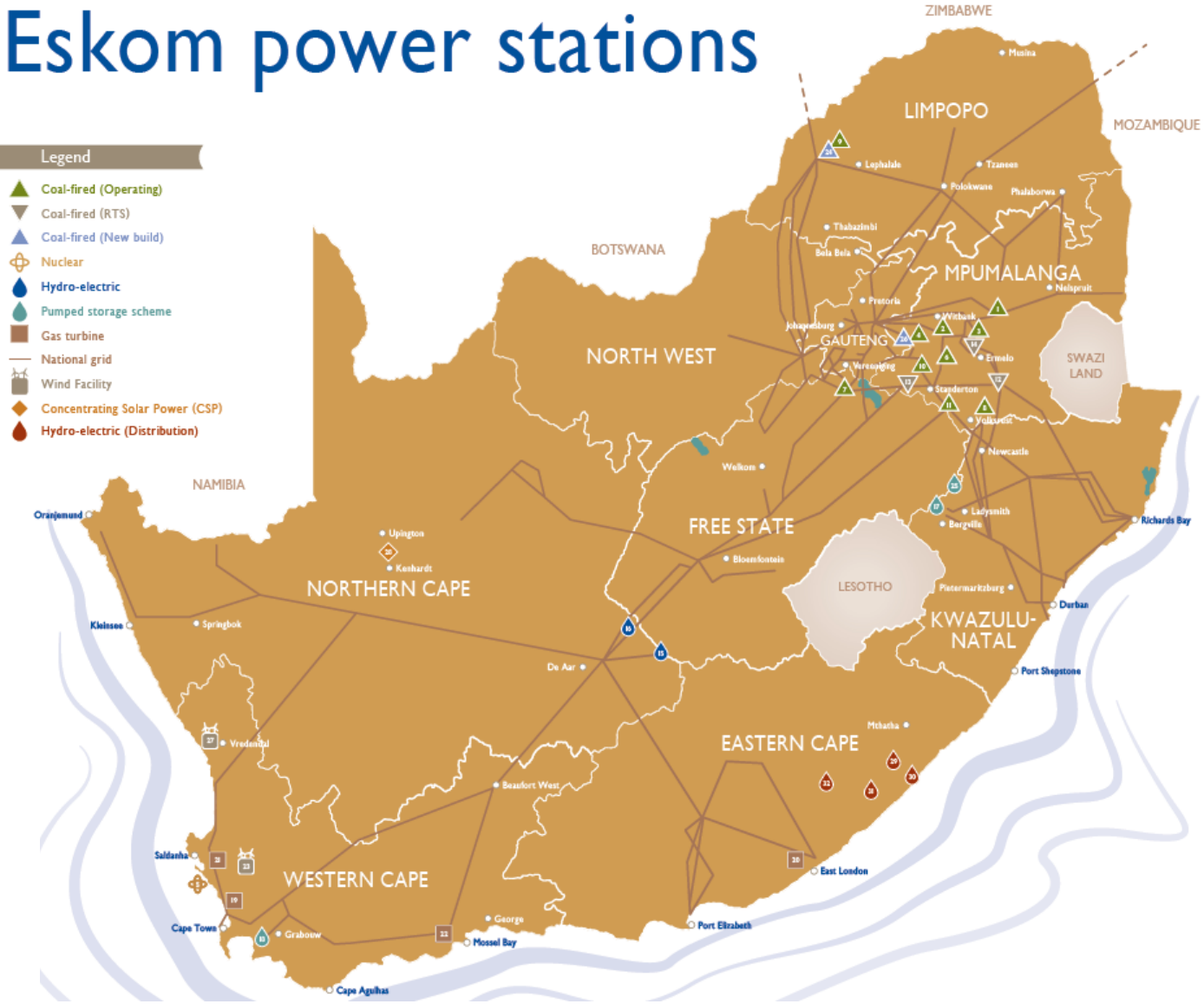


Figure 2 **Opportunity for sales at power stations**

Eskom power stations



Base load stations

1 Arnot	2 352 MW		7 Lethabo	3 708 MW
2 Duvha	3 600 MW		8 Majuba	4 110 MW
3 Hendrina	2 000 MW	Coal	9 Matimba	3 990 MW
4 Kendal	4 116 MW		10 Matla	3 600 MW
6 Kriel	3 000 MW		11 Tutuka	3 654 MW

Nuclear: 5 Koeberg 1 940 MW

Return-to-service stations

Coal: 12 Camden 1 510 MW; 13 Grootvlei 1 200 MW; 14 Komati 940 MW

The return-to-service (RTS) stations were mothballed in 1990 and are in the process of being recommissioned due to the growing demand for electricity. The return-to-service project for Camden power station ended on 31 March 2010 with the entire station fully commercial.

Peak demand stations

Hydro-electric	15 Gariep	360 MW
	16 Vanderkloof	240 MW
Pumped storage scheme	17 Drakensberg	1 000 MW
	18 Palmiet	400 MW
Gas turbine	19 Acacia	171 MW
	20 Port Rex	171 MW
	21 Ankerlig	1 338 MW
	22 Gourikwa	746 MW

The peaking stations can generate electricity within a few minutes of start-up, making them ideally suited to supply power during peak periods. They also assist in regulating the system voltage and frequency to ensure stability of the national transmission network.

Renewable energy

Wind Facility: 23 Klipheuwel Wind Facility 3 MW

New build

Coal	24 Medupi	4 788 MW
	26 Kusile	4 800 MW
Pumped storage scheme	25 Ingula	1 332 MW
Wind Facility	27 Sere Wind Facility	100 MW
Solar	28 Concentrating Solar Power (CSP)	100 MW

Distribution

Hydro-electric	29 First Falls	6 MW
	30 Second Falls	11 MW
	31 Colley Wobbles	42 MW
	32 Ncora	2 MW

These hydro-electric power stations fall within the Distribution Division in the Eastern Cape operating unit and are used to stabilise the distribution network in that area.

Eskom power stations distribution in South Africa (Eskom 2013)

Unpublished: Contract Report CSIR/BE/IE/ER/2018/0000/0

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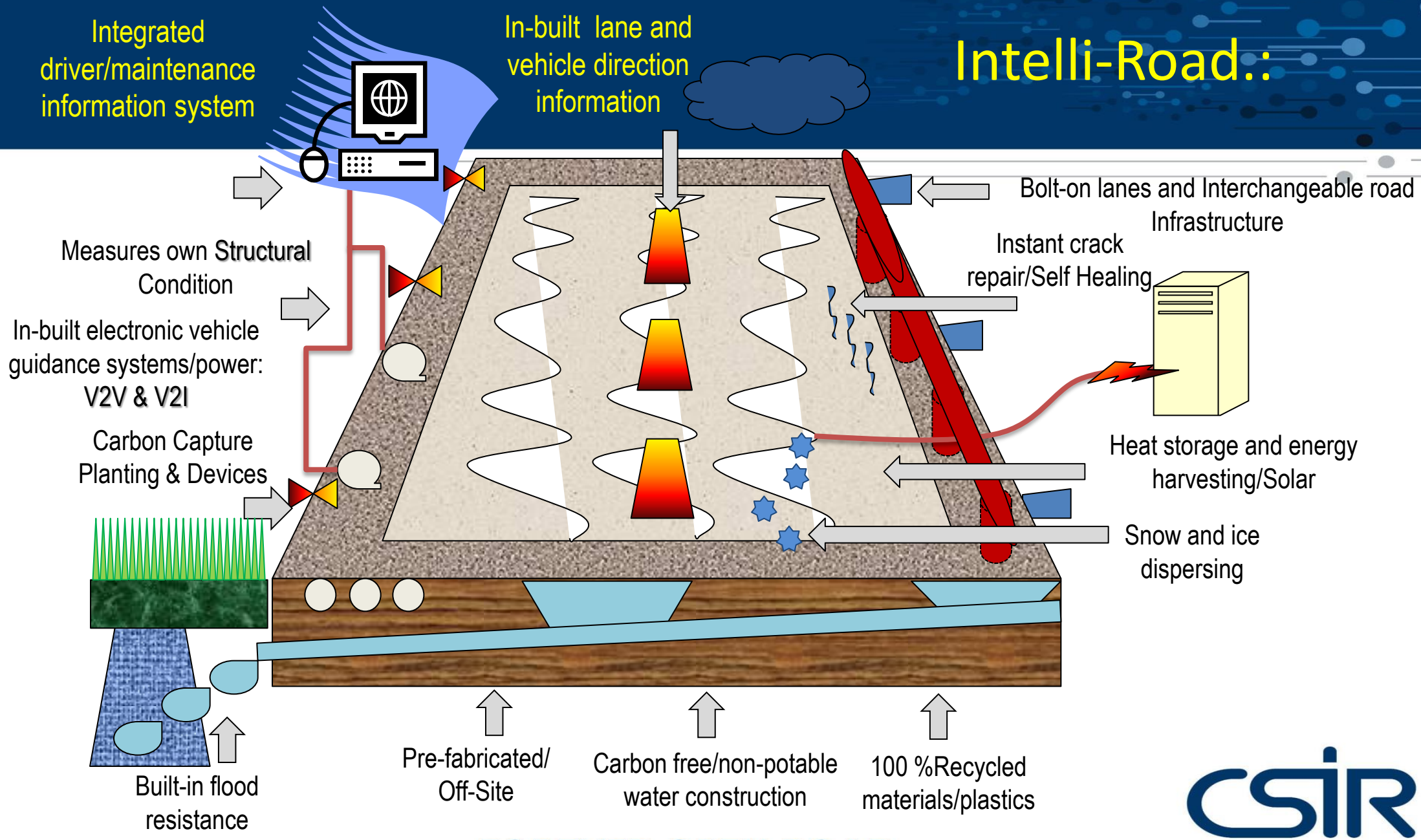
35th RPF:

Resolution 3

- That RPF should devote attention to Smart Roads Concept in view of advances being made in:
  - Autonomous Vehicles
  - Intelligent construction equipment and establishment of Mobility Centre for Africa
  - Use of Internet of Things (IoT).

Intelli-Road.:



FOREVER OPEN ROAD
Redefining Highway Transport for the 21st Century

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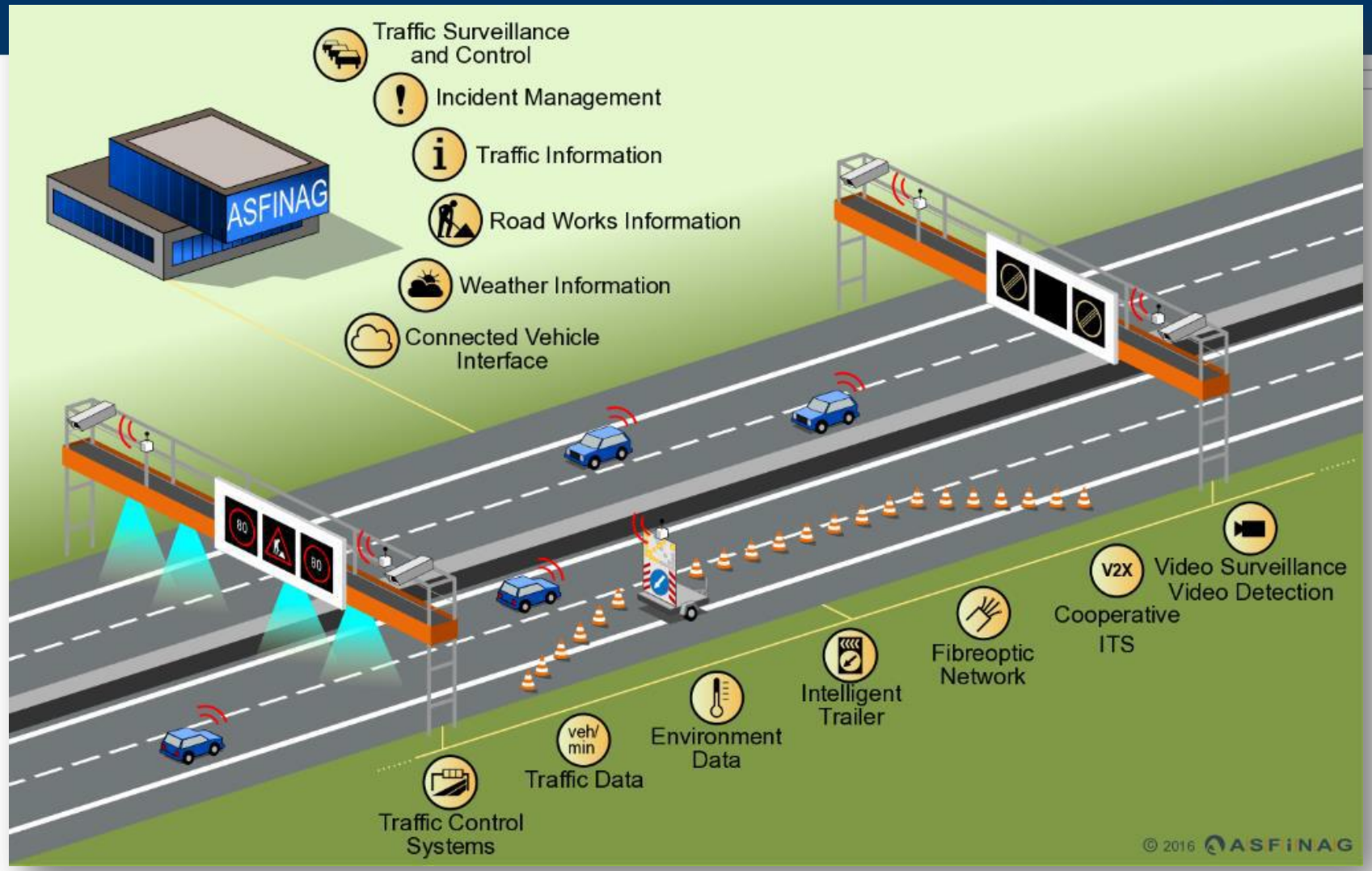
Modified From: Forever Open Road @ TRB.pdf

Innovation..:



Marko Jandrisits – ASECAP chair of the ITS committee

In Summary…

- Smart roads concept is much more than just sensors and feedback loops:
  - Solar roads, Inductive charging roads, innovative load bearing blocks, intelligent, self-healing, pay for themselves ?
- Advanced and alternative and/or intelligent materials/systems for roads:
  - R&D & Industrialization opportunities ?
- Off-site “smart” manufacturing and on-site “smart” assembly;
- Intelligent Compaction (IC): Equipment & Reporting:
  - a paradigm shift for the construction sector ?
- Incorporation of futuristic transport systems needs – time proof roads:
  - be ready for the 4th /5th Industrial Revolution ?
- Development of Road Maps for Smart(er) Roads
  - 10 year strategy for CSIR....?

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From recent: 14th SA South Africa Systems Engineering Conference, 2018

INCOSE - International Council on Systems Engineering

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So, What is a “Smart(er) Road” in Emerging Economies ?

We just need do our roads & Transportation works Smart(er)..

Smart essentials for success – 4IR:

We have a choice: a problem-centric leadership approach, which perpetuates declinism; or a vision-based leadership approach, which is an antidote to declinism.

Discovery CEO Adrian Gore, Nov 9, 2018

Smart essentials for success – 4IR:

- ..recognising the potential of our economy and investing in it. This is how change happens…

Discovery CEO Adrian Gore, Nov 9, 2018

Smart essentials for success – 4IR:

"Attitude drives fundamentals, not the other way around.."

Discovery CEO Adrian Gore, Nov 9, 2018

Smart essentials for success – 4IR:

- Buy-in, owns the challenge, innovate with with passion
- Responsibility & Accountability
- Authority and Firmness
- Attitude (..determines altitude..)
- Trust, Honesty, Ethics, Fairness and Integrity

--- LET'S END HERE ---

Towards Smart Road (SRI) Infrastructure..

Any Q or Comments?