COST Action TU1208

Civil Engineering Applications of Ground Penetrating Radar

This presentation is part of the TU1208 Education Pack

Pavement management

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Summary of the lecture (1/2)

Introduction

- What is a road network worth?
- The importance of maintenance
- Preventative or curative maintenance?
- Lifecycle of a road network
- Asset/Pavement Management Systems (APS/PMS)

The work of a road manager and the needs of stakeholders

Management systems for some assets other than pavements

- Bridge management
- Management of water and sewer systems, pipeline and cable networks
- Asset management of equipment

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Summary of the lecture (2/2)

Pavement Management Systems

- Typical ingredients: checklist
- Evaluation of the current condition of the road network
- Indicators, thresholds for interventions and maintenance matrices
- Short-term planning without prediction models
- Multi-annual planning and budget
- Financial analysis → communication → decisions

Futuristic data collection

- Destress of the road surface
- CANbus, Smartphones

GPR for road network analysis

Biography and contact details of the Author

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Introduction

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What is a road network worth?

- Hypotheses:
  - 350 km of roads in a communal network
  - Average width of a road: 6 m
  - The construction of 1 m^2 of road costs 100 €

- Then the “equivalent new value” of the network is:
  (350.000 m x 6 m) x 100 €/m^2 = 210.000.000 €

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The importance of maintenance

- Road infrastructure is built for a long but finite period of time:
  - Roads are designed to last for 20 to 40 years (= “design life”)
  - Bridges are designed to last for 100 years (hence: a limited time)
- Maintenance is an investment (not a cost) made in order to maximize the return on the initial investment of construction.
- PIARC 2014R02EN “The Importance of Maintenance”:
  - A key principle of road maintenance is that spending money now saves future costs.
  - Without proper maintenance the high value of any road network can be quickly eroded (..).
  - Evidence shows that adoption of sound asset management principles as the basis for technical and management decisions will improve road network performance.

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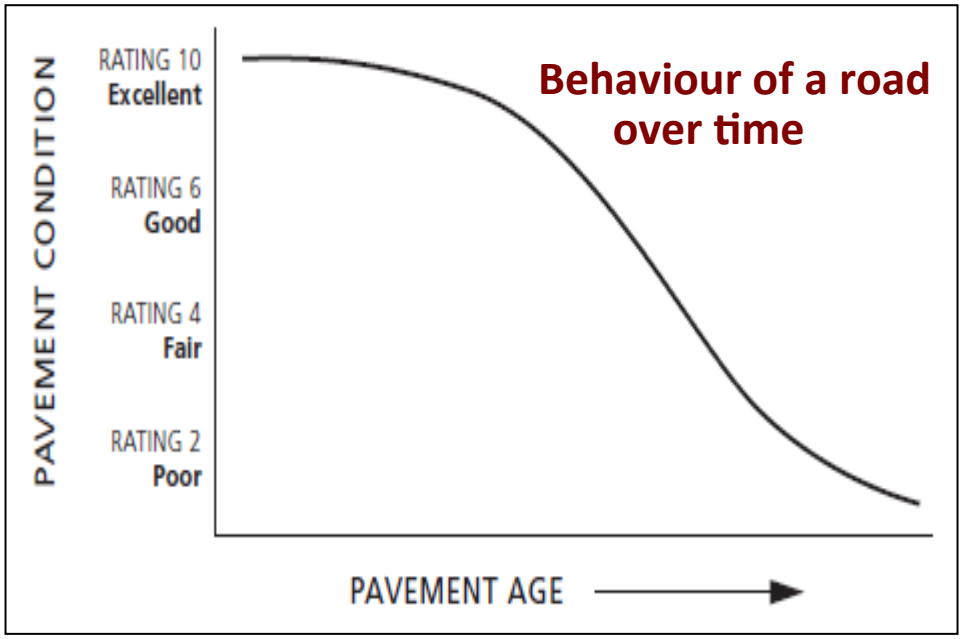
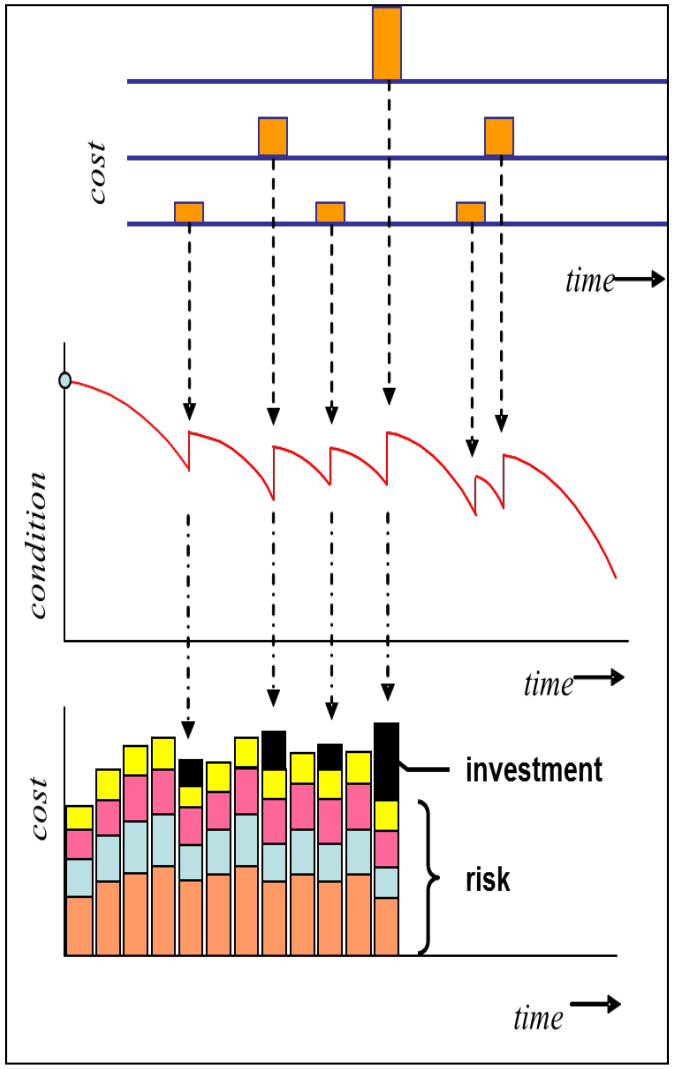
The importance of maintenance

- Without maintenance, the condition (and safety) of the road decreases.
- Maintenance improves the condition.





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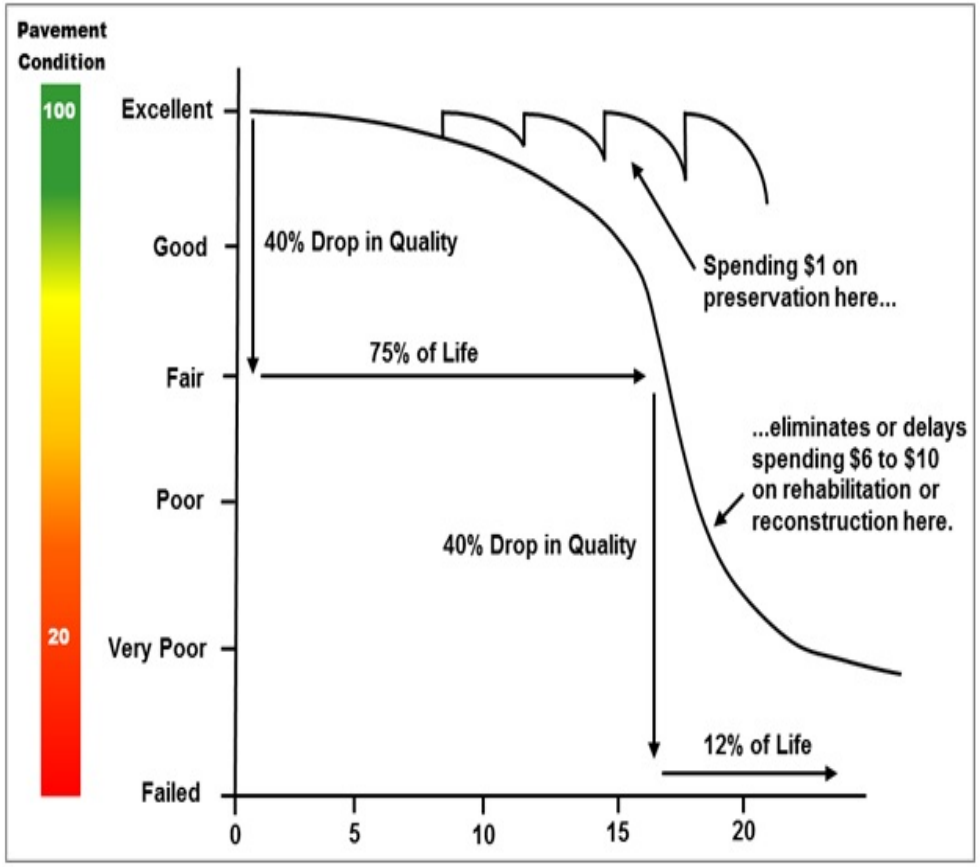
Preventative or curative maintenance

- Investing in preventative maintenance (in time) allows to avoid or delay reinforcement or reconstruction works…



© http://www.thruway.ny.gov/oursystem/capitalprogram/current-infra-info.html

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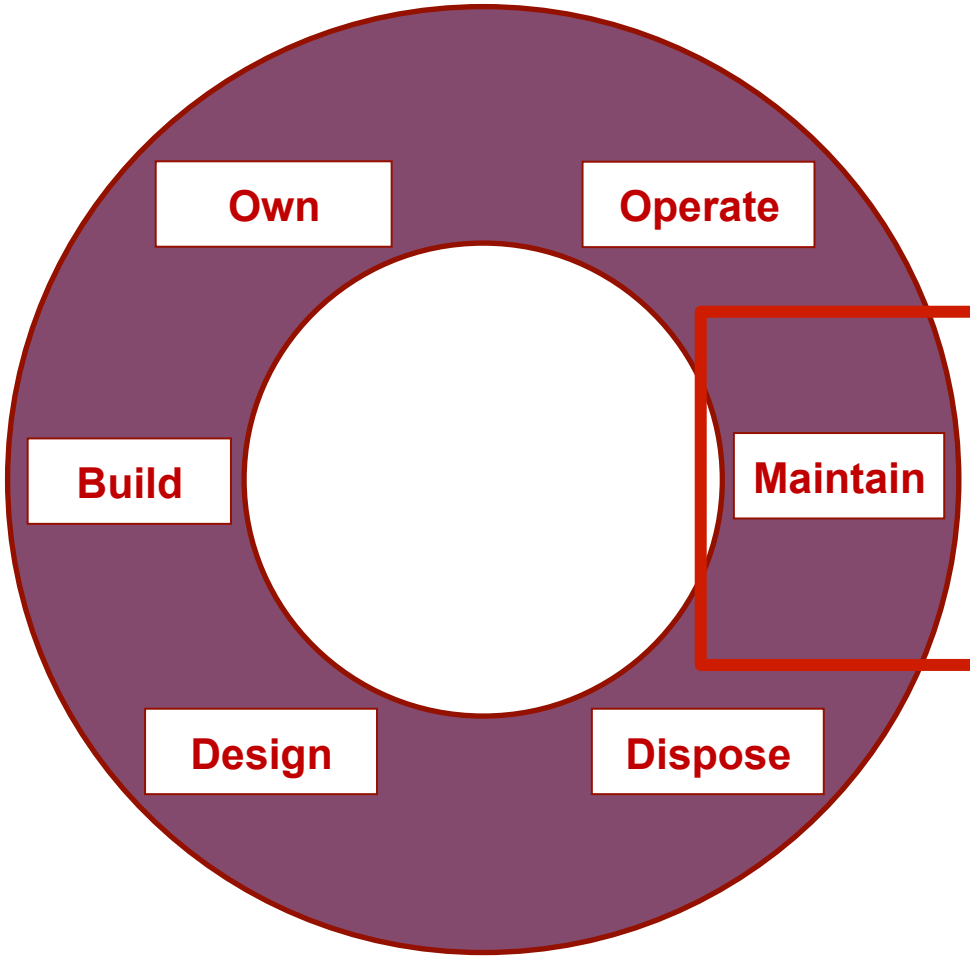
Lifecycle of a network (roads & equipment)

- For every asset of the network:



LEGAL TRANSFER AND VERIFICATION

CONSTRUCTION

ROAD STRUCTURE TRAFFIC

DAILY ROUND OF THE STEWARD: URGENT INTERVENTIONS

MAINTENANCE CYCLE: MULTI-ANNUAL PLANNING, PAVEMENT MANAGEMENT SYSTEM

END-OF-LIFE

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Asset & Pavement Management Systems: a cycle

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*** other asset: sewers, greens, bridges, tunnels, roadsides, embankments, signs, electro-mechanic equipment, …**

Motivations for "Pavement & Asset Management"

Citation…

"Where it (AMS) has been adopted for highways,

savings of at least 5% on budget have been reported."

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The work of a road manager and the needs of stakeholders

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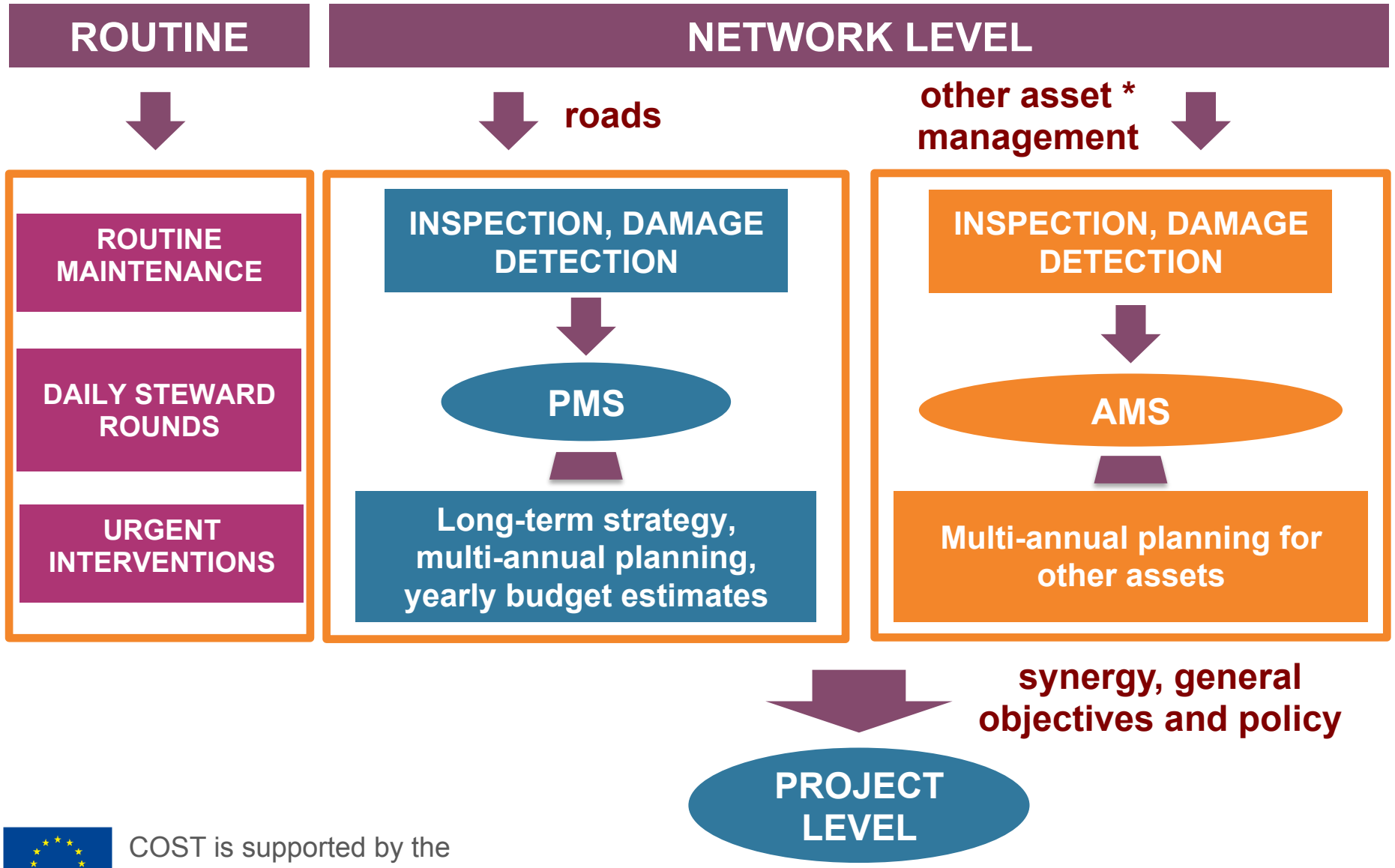
Road management



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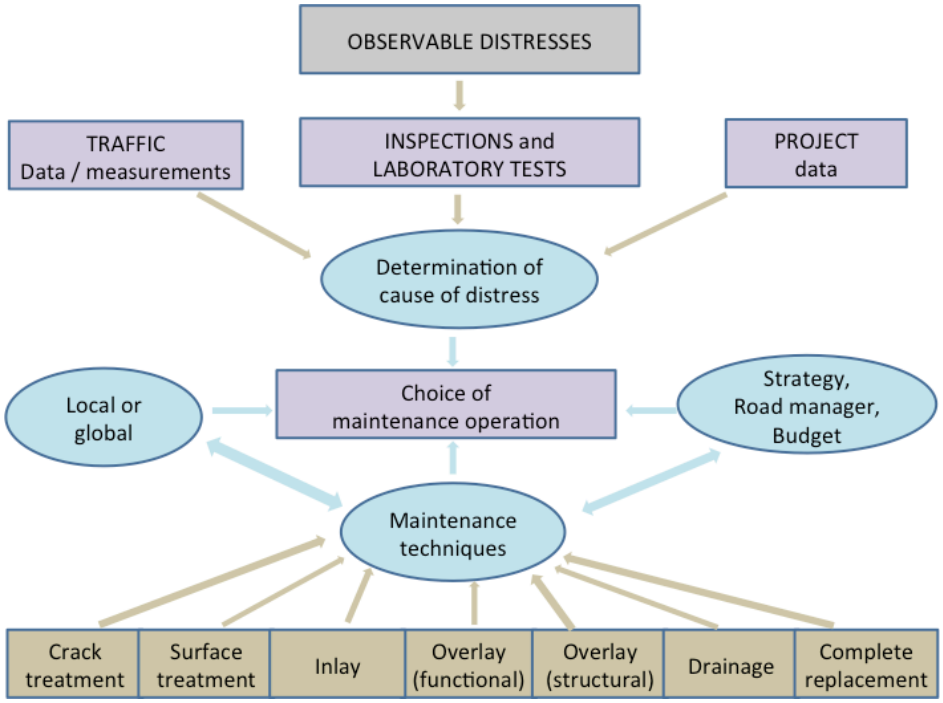
Road management

PROJECT LEVEL

LIST OF PROJECTS FOR NEXT YEAR

CONTRACT SPECIFICATIONS, EXECUTION

complex project preparation



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Stakeholders and their “needs”

- Definition of ‘Stakeholders’: “Person or group affected by or responsible for the organisational performance, success or impact of activities”.
  - Examples, relevant to roads: road users, neighbours, supporting organisations (such as emergency services), decision makers, funders, owners, suppliers, operators.

- Literature on the stakeholder category ‘Road Users’:
  - According to the literature, the category includes motorists, heavy goods vehicle drivers, motorcyclists, cyclists, passengers and pedestrians;
  - The key aspects of stakeholder concern are the ride quality (comfort) and the road safety.

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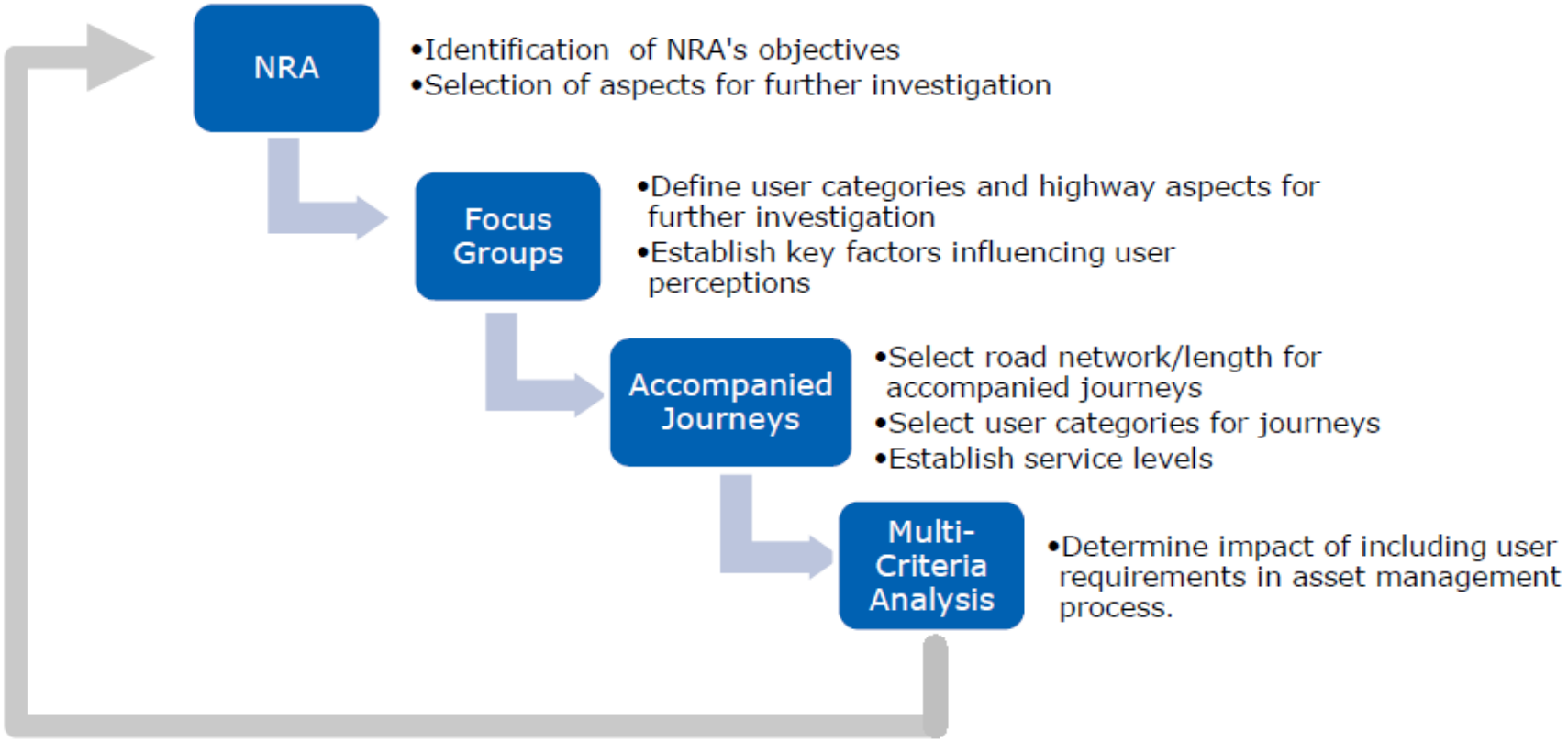
ERANET ROAD project (+/- 2012)
EXPECT: methodology

Identification procedure for determining ‘stakeholders needs’:



Repeat the cycle (as appropriate)

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EXPECT: integrate 'stakeholders needs' into asset management

Use of multi-criteria analysis (because of contradictory needs between stakeholders)
E.g.: weights from stakeholders' expectations for Multi-Criteria Analysis:

User Criteria	Car drivers	HGV drivers	Motorcyclists	Van drivers	Bus drivers	Mobility Impaired	Pedestrians	Cyclists	Horse Riders	Weight
Rutting	2	1	3	2	1	3	0	2	0	0.336
Unevenness	3	0	3	1	1	3	0	3	0	0.343
Texture	1	0	3	1	1	2	0	3	0	0.253
Cracking	0	0	2	0	0	0	0	3	0	0.117
Skid Resistance	2	2	3	2	1	3	2	3	2	0.454
Potholes	3	0	3	2	2	2	2	3	1	0.407
Damaged road edges	3	0	3	1	0	2	0	3	0	0.306
Slippery road markings	0	0	3	0	0	1	2	3	0	0.198
Slippery repairs	0	0	3	0	0	2	2	3	0	0.219
Spray	3	0	1	0	0	0	2	2	0	0.210
Gravel on surface	1	0	3	1	0	2	3	3	1	0.306
Litter	3	0	1	0	0	0	2	2	1	0.222
Leaves on carriageway	0	2	2	0	0	0	2	2	0	0.191
Faded signs	2	0	3	2	0	3	0	0	0	0.241
Reflectivity of Road Markings	3	2	2	2	0	0	0	0	0	0.250
Noise	2	0	0	0	0	0	0	0	0	0.068
Bridge cosmetic condition	0	0	0	0	0	0	0	0	0	0.000

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Management systems for some assets other than pavements

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Bridge Management System

- Often the visual inspection results in an “expert opinion”.
- The expert classifies the bridge, and:
  - Highlights the need of urgent repairs
  - Recommends further investigations
  - Recommends a follow up in 6 months, 1 year or 6 years

BMS purposes

© http://www.bridgemanagement.com/bmobjects.php :

- To provide a clear roadmap for the maintenance and rehabilitation of the bridge inventory.
- To provide one or more strategies for bridge maintenance, according to budget constraints.
- To assess the minimum budget requirements for a targeted level of service.
- Above all, BMS must provide instructions for the safety and utility of the entire network.

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Management of water and sewer systems, pipelines and cable networks

The inventory of water and sewer systems is often incomplete…

A proper inventory should contain:

- Location of water and sewer systems
- Materials
- Condition and remaining life
- Level of service

For gas and cable networks, the main difficulties are:

- Often these are managed by various entities (companies)
- Coordination of maintenance interventions requires “synergy”
- Sharing of information about the location (position and depth) is necessary

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Asset Management for Equipment: CEDR project PREMiUM

Asset types:

- Road signs
- Road markings
- Vehicle restraint systems (VRS)
- Noise barriers

Some findings:

- Often the assets “cannot” be inspected at “traffic speed,” yet.
- Noise barriers: several road administrations carry out an “expert survey” by visual inspection (analogous to bridge management).
- Often maintenance is “local” of “general” replacement…

Current work in progree:

- Development indicators for potentially measurable characteristics.
- Show that AMS is possible (thresholds, maintenance planning).

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Final results of this project: end of 2017

Pavement Management Systems

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Typical PMS ingredients: checklist

- Inventory of the network.
- Evaluation of the current condition of the network elements.
- Indicators:
  - Technical and functional indicators
  - Performance-indicators
- Thresholds for interventions, maintenance matrices
- Prediction of evolution of the condition level
- Multi-annual planning (maintenance interventions and priorities)
- Financial analysis (limited budget and effects on the quality levels),
- Communication, presentation of the analysis, decisions
- [Execution of works on project level]
- Checking the results (and adjusting the procedures)
- Repeat!

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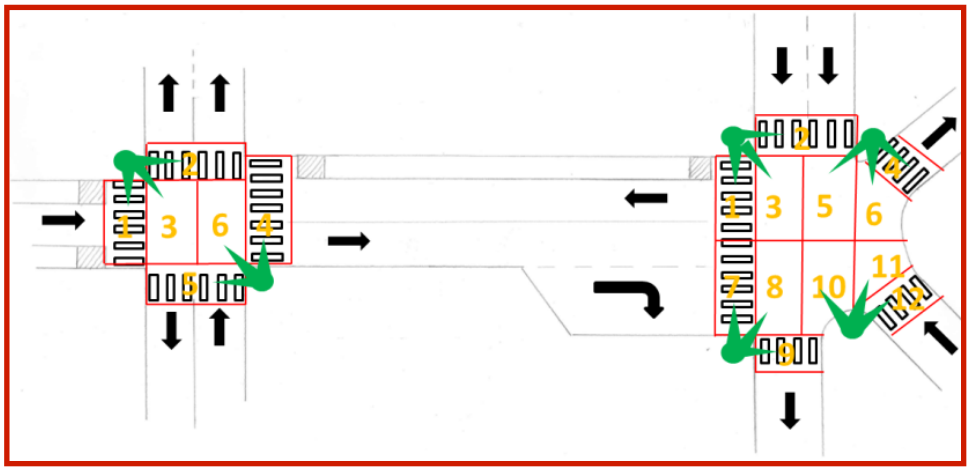
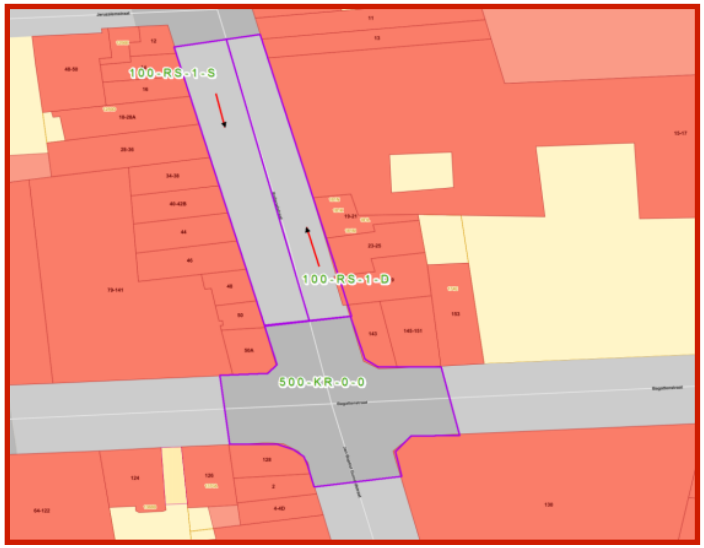
Inventory: 1x creation of asset database

- Subdivide roads in segments that will be inspected and managed individually.
- Subdivision is up to the road manager…



Existing maps: GRB (Flanders), URBIS (Brussels), PICC (Wallonia):



Other handy tools: software (ArcGIS, QGIS,…), web applications, …

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Condition measurements of the road network

- "Objective", repeatable and reproducible measurements have to be carried out on the whole network (high quality data).

Regional/National roads: multifunctional vehicles
e.g. Flanders: ARAN & SCRIM

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Condition meas. of the road network

e.g. Wallonia: VAMOS & SCRIM

Other devices:

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Communal roads: visual inspection is sufficient

The Netherlands, France, USA

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Communal roads: visual inspection is sufficient

BRRC, Belgium
MN89/15 & training

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Indicators

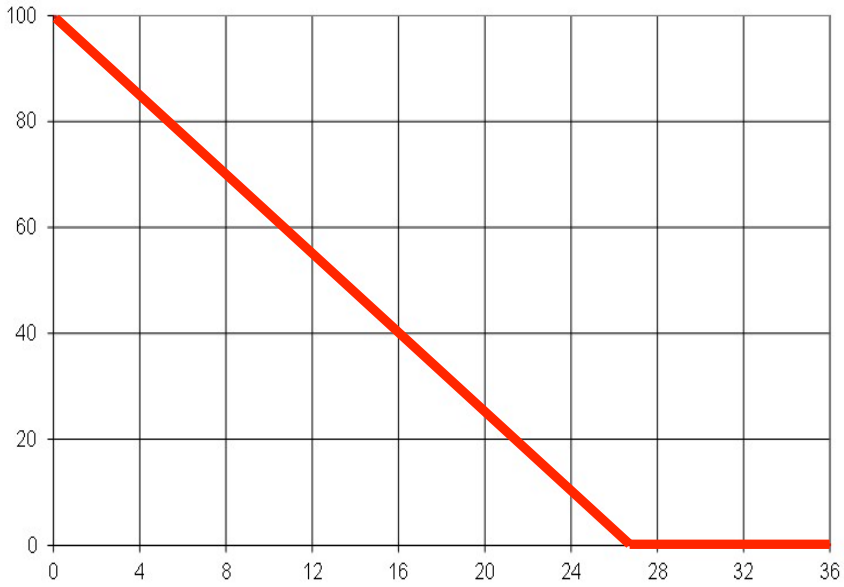
Technical indicator: e.g. “skid resistance of the road surface” (this technical property is not the only parameter in traffic safety)

Functional indicator: e.g. “number of casualties in traffic accidents” (does not say which technical modification could lead to a functional improvement)

From a technical parameter to a technical indicator:
e.g. transfer function from “rut depth” to a score without unit:

I_{SD}

Indicator = score between 100 (perfect) and 0



Rut depth in mm

Combined indicator:

$GI = \min(I_{DWC}, I_{SD}, I_{VC}, I_{VI} - p \,.\, (100\text{-}I_{3,average})$

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Combined indicators, thresholds and maintenance levels

Communal road network (BRRC approach):

- $I_v = \max(0{,}90 - \Sigma_{sb}\, w_{sb} \,.\, P_{sb} \,;\, 0)$
- $I_s = 1{,}2 \,.\, I_v - 0{,}18$
- $I_G = (I_v + I_s)/2$

	Value of indicator I_G	Type of maintenance	Remarks
	$0.9 \geq I_G > 0.8$	**Routine**	**No need for repairs.**
	$0.8 \geq I_G > 0.5$	**Local repairs**	**Isolated repairs at locations where defects were registered during inspection.**
	$0.5 \geq I_G > 0.3$	**Generalised repairs**	**Maintenance of the upper layer(s) of the road structure over the full length of the road segment.**
	$0.3 \geq I_G$	**Reinforcements**	**Structural improvements of the road structure over the full length of the road segment.**

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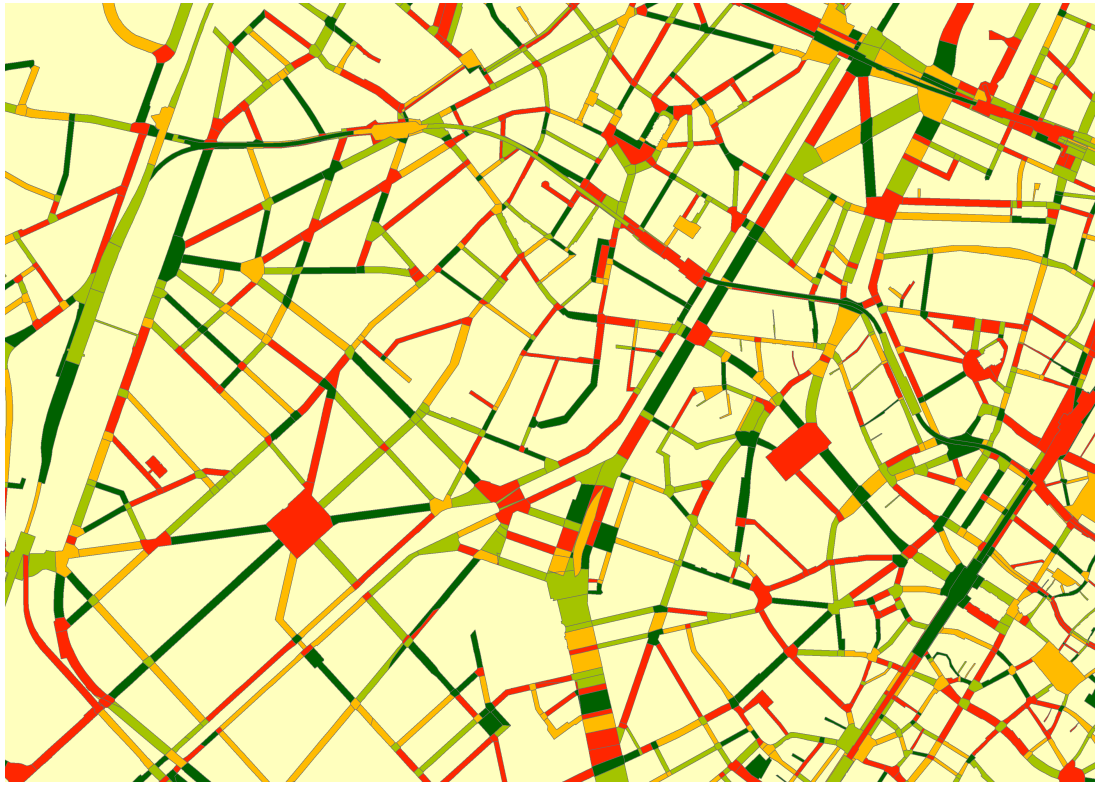
Short term planning without prediction models



- Based on thresholds, all road segments are classified

	Value of indicator I_G	Type of maintenance	Remarks
	$0.9 \geq I_G > 0.8$	Routine	No need for repairs.
	$0.8 \geq I_G > 0.5$	Local repairs	Isolated repairs at locations where defects were registered during inspection.
	$0.5 \geq I_G > 0.3$	Generalised repairs	Maintenance of the upper layer(s) of the road structure over the full length of the road segment.
	$0.3 \geq I_G$	Reinforcements	Structural improvements of the road structure over the full length of the road segment.

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Short term planning without prediction models

- Short term maintenance is needed near thresholds

➢ Objective: prevent the road segments to fall into a lower category by applying preventative maintenance

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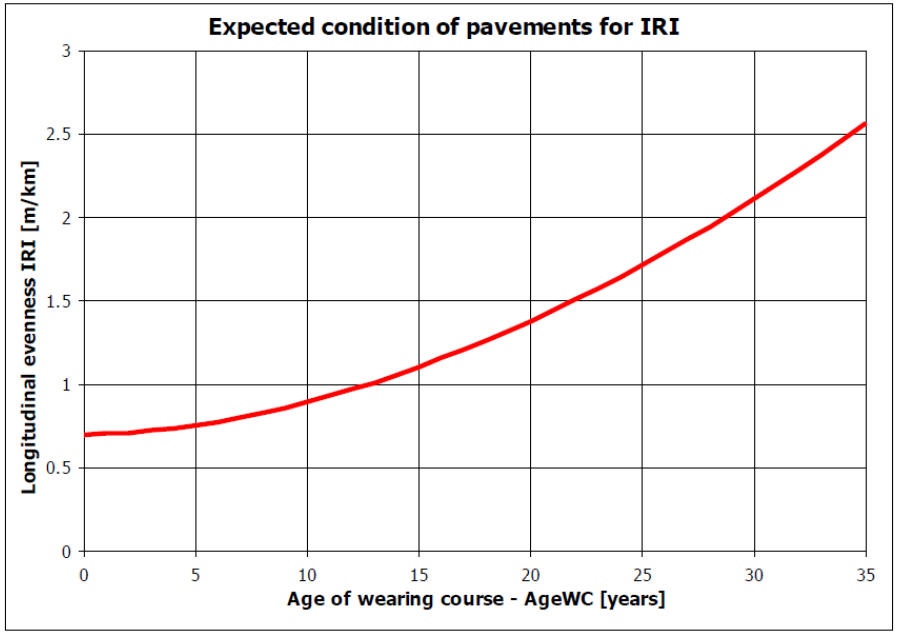
Evolution models for indicators

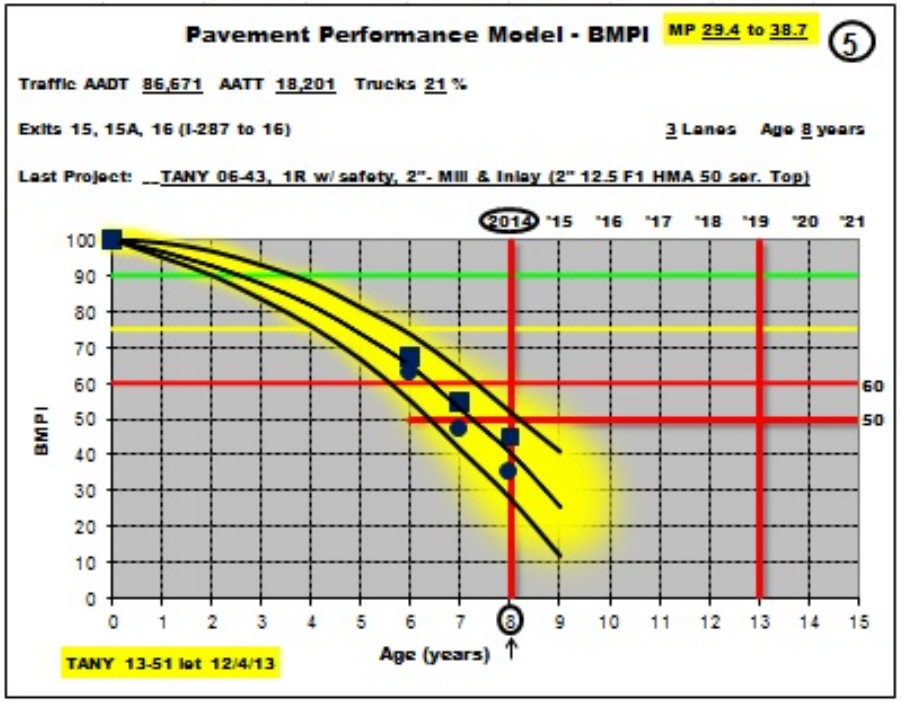
- Predictions of how the indicator values will evolve over time

$$IRI = 0{,}0031 \cdot AgeWC^{1{,}8} + 0{,}7$$



Evolution model over time (35 years) for the longitudinal evenness, expressed in IRI, on motorways in Slovenia,

in © ASCAM Inventory Pavement Management practices (Deliverable N° 2)



Prediction with an uncertainty margin, as in use in New York State (USA).

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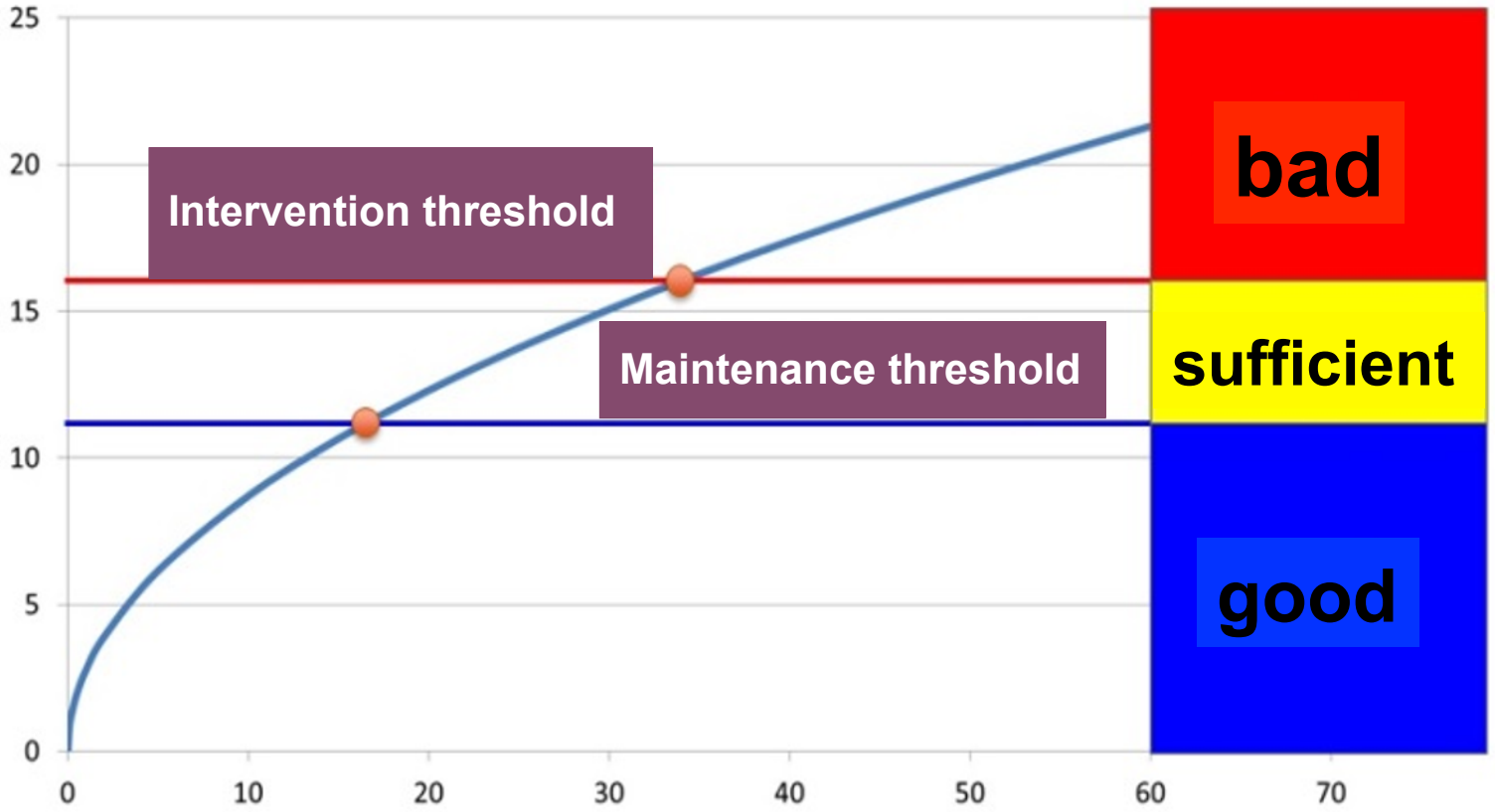
Maintenance thresholds and decision matrices

- Example: motorways in Flanders (Belgium)



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Maintenance thresholds and decision matrices

- Example: motorways in Flanders (Belgium)

Evenness \ Rutting	bad	sufficient	good
bad	AAI20 / ABI20	AAI20 / ABI20	AAI20 / ABI20
sufficient	AAI12	AAI04	VV00
good	AAI12	AAI04	VV00

Decision matrices for maintenance interventions

Types of maintenance

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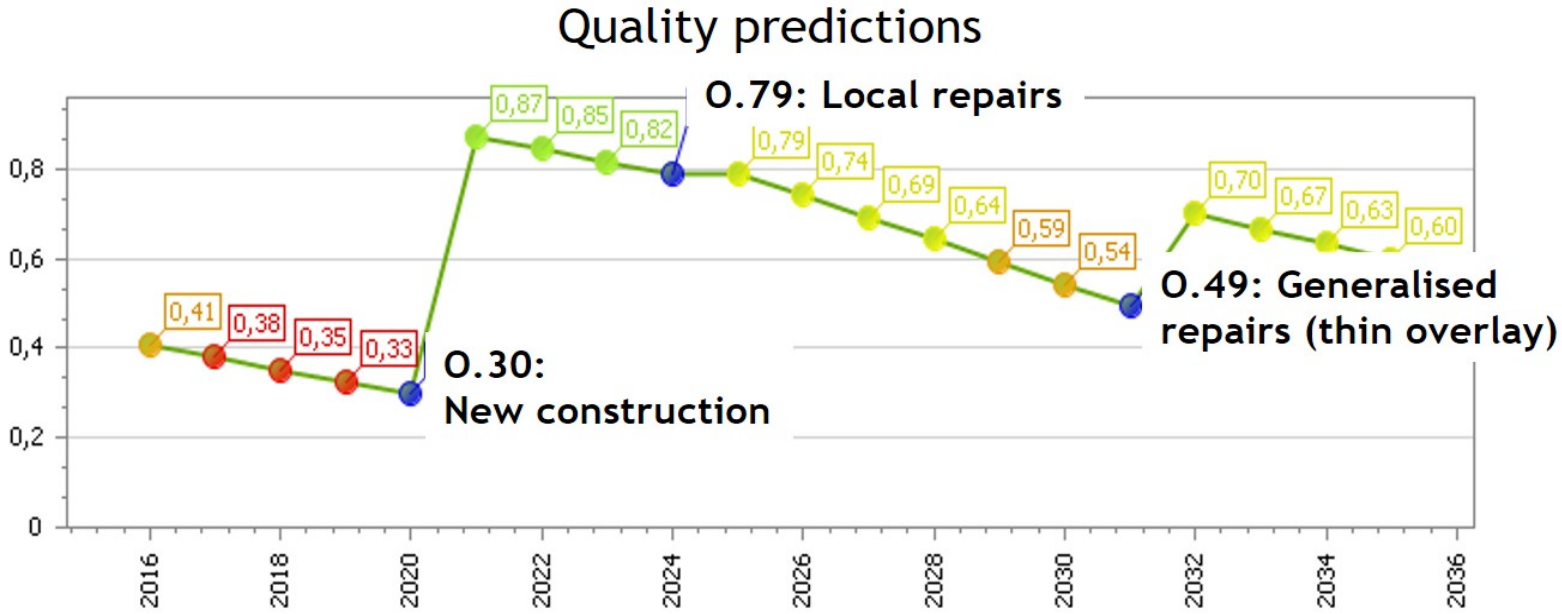
Influence of maintenance operations on the condition of a road

- Inspection = current condition.
- Evolution model = prediction of the deterioration of the condition, without maintenance.
- Threshold reached in year +N: do maintenance.
- Prediction of benefits if maintenance is done now.



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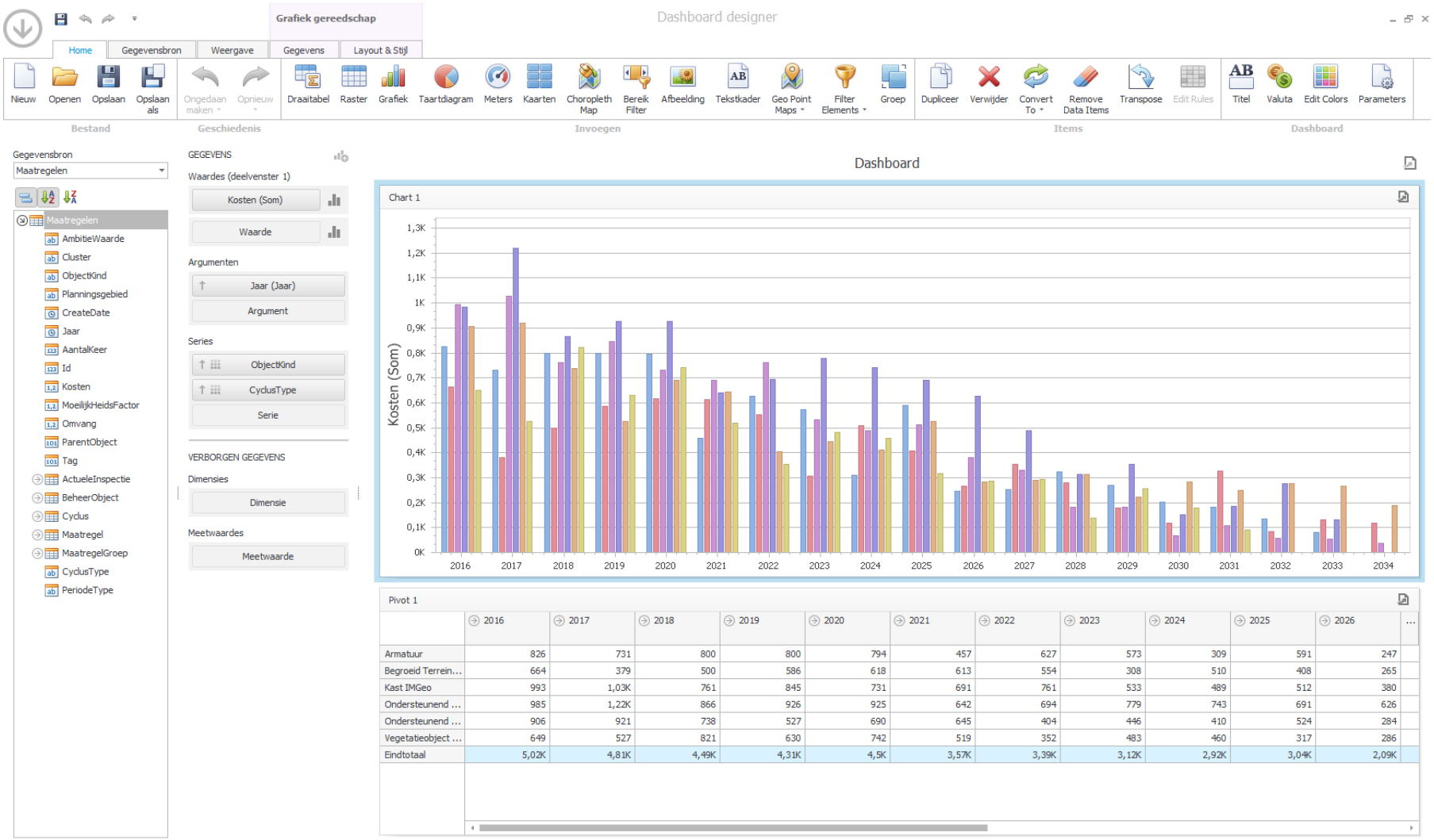
Multi-annual planning and budget



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Armatuur	826	731	800	800	794	457	627	573	309	591	247
Begroeid Terrein...	664	379	500	586	618	613	554	308	510	408	265
Kast IMGeo	993	1,03K	761	845	731	691	761	533	489	512	380
Ondersteunend ...	985	1,22K	866	926	925	642	694	779	743	691	626
Ondersteunend ...	906	921	738	527	690	645	404	446	410	524	284
Vegetatieobject ...	649	527	821	630	742	519	352	483	460	317	286
Eindtotaal	5,02K	4,81K	4,49K	4,31K	4,5K	3,57K	3,39K	3,12K	2,92K	3,04K	2,09K

© screenshot GISIB/ViaBEL

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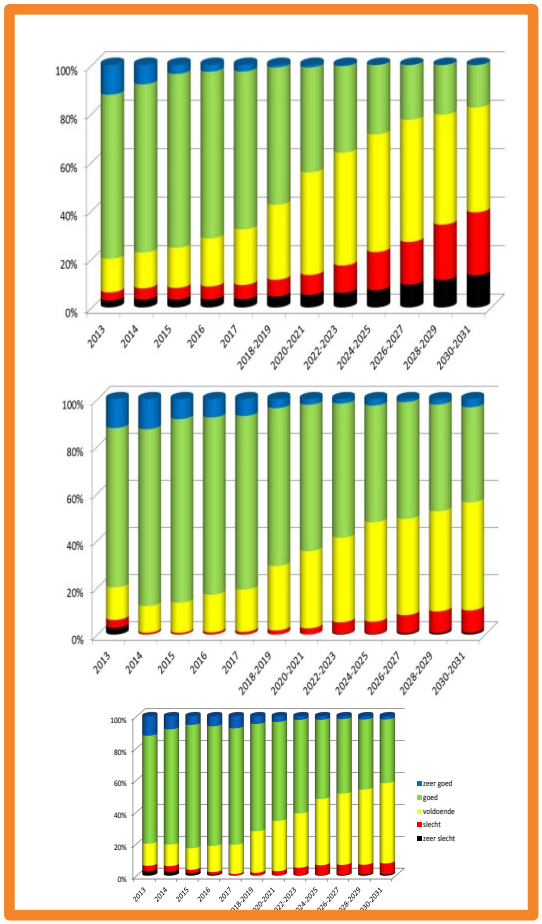
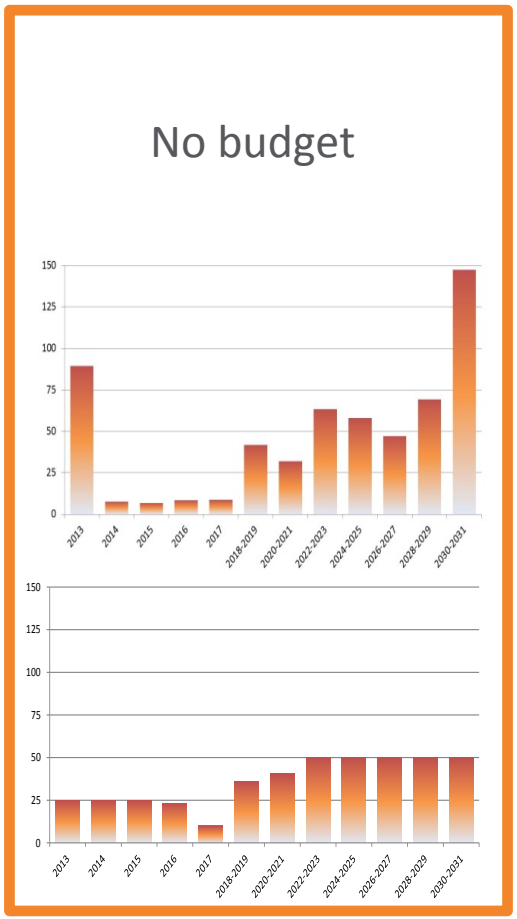
Analysis: limited budget long-term effects

Condition of the network (global indicator)



Budget (over ± 20 years)



Technical optimum, unlimited budget

Limited budget

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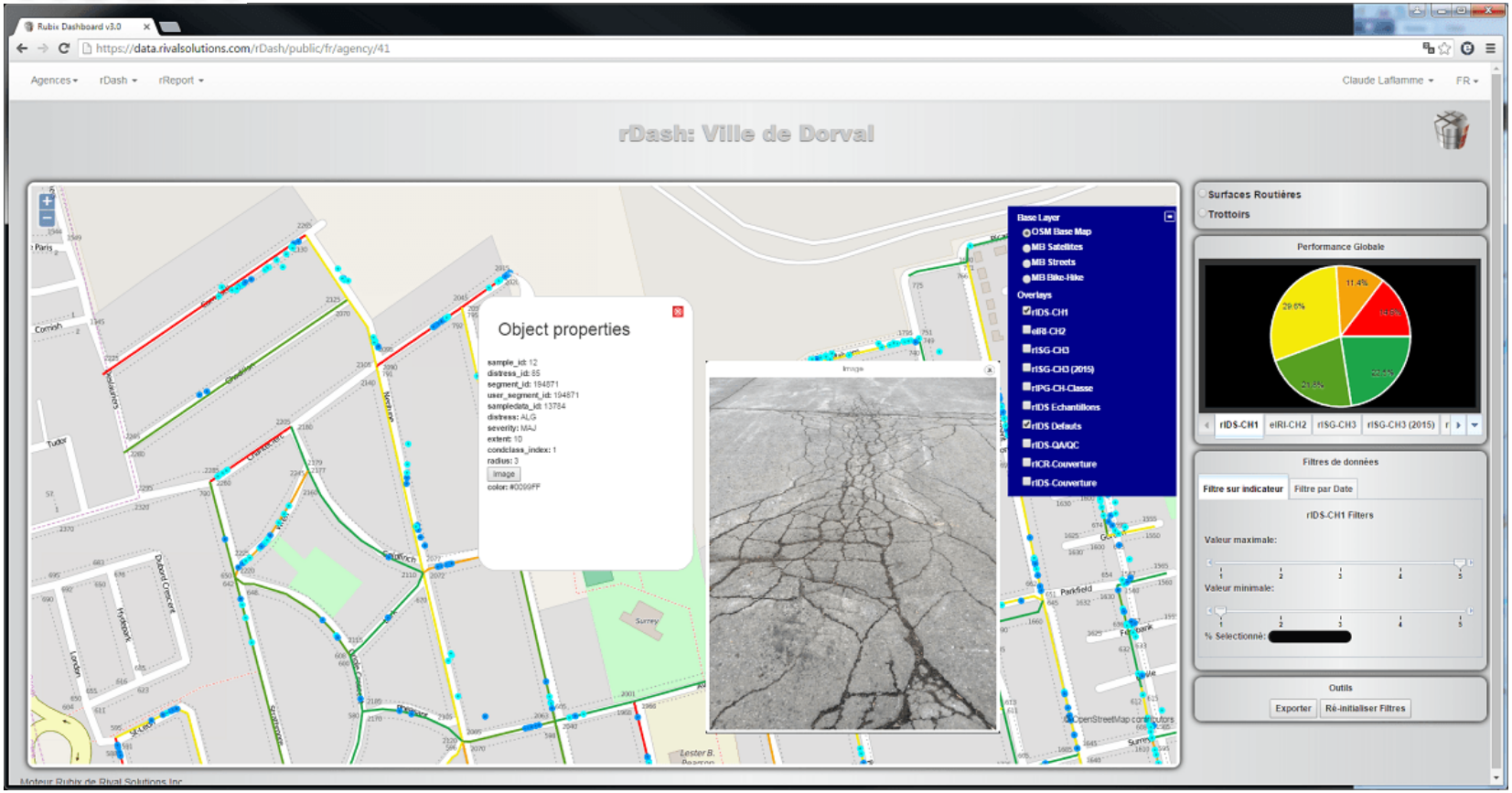
Communication/presentation: dashboards

- Inventory (database), on a map (GIS), inspection results, analyses (technical and financial), various ways of presentation (tabels, graphs, maps,…).

RUBIX

Some examples of "dashboards":



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Communication/presentation: dashboards

- Inventory (database), on a map (GIS), inspection results, analyses (technical and financial), various ways of presentation (tabels, graphs, maps,…).

Some examples of "dashboards":

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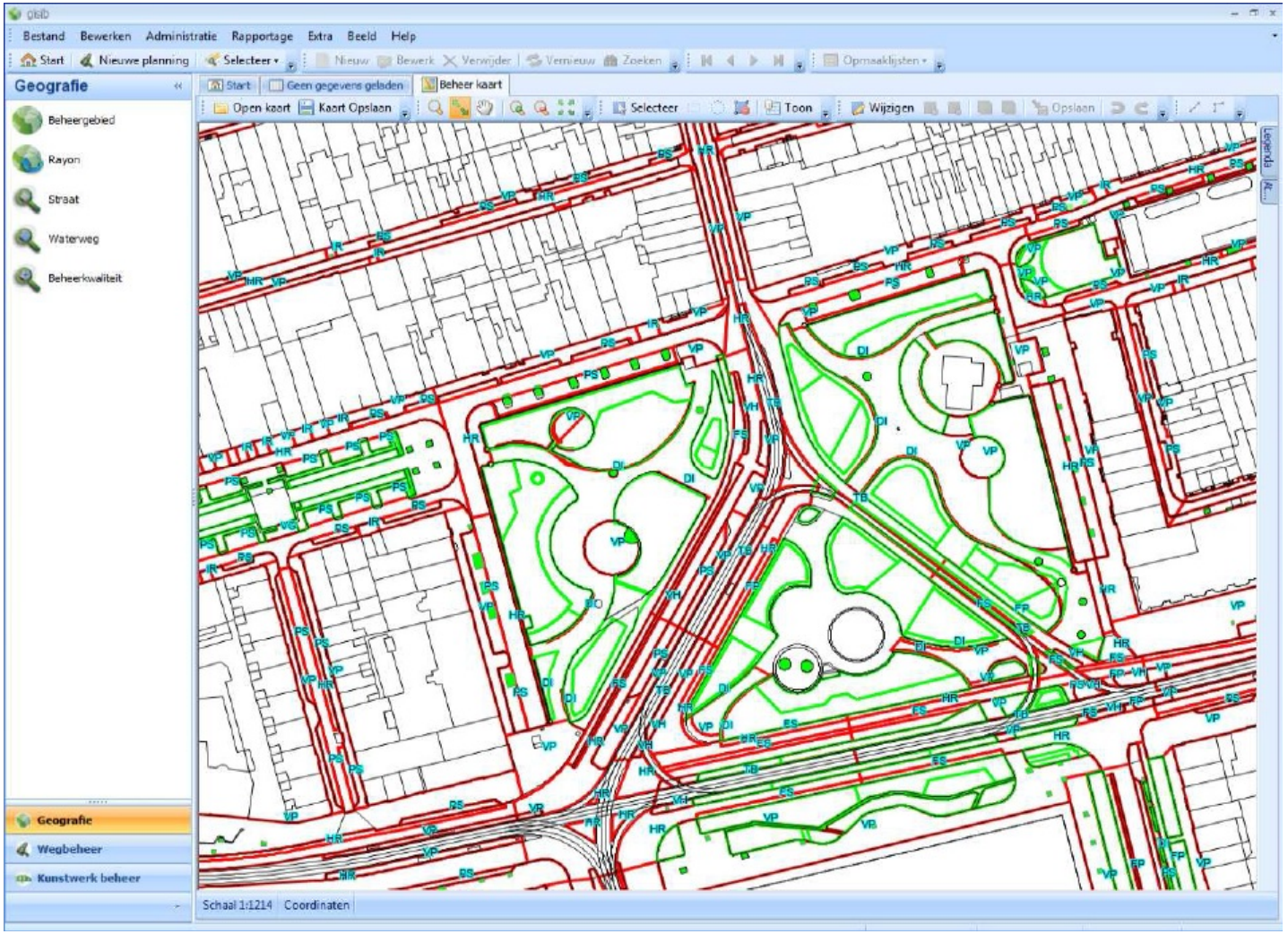
Asset management for other assets

- Some examples of “green” management in town...



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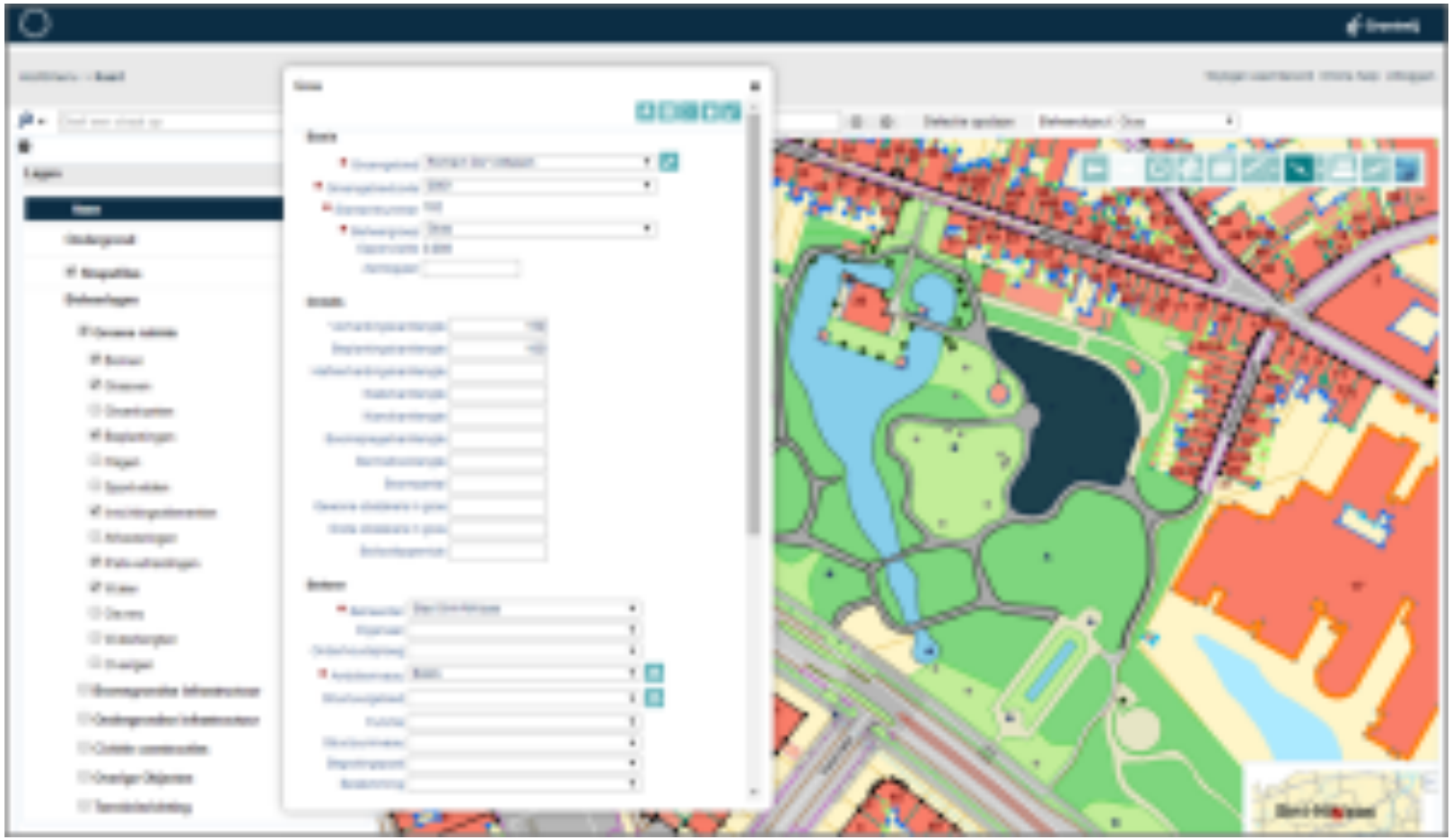
Asset management for other assets

- Some examples of “green” management in town...



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Futuristic data collection???

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Destress of the road surface

- Can be seen from a technical point of view:
  - Longitudinal evenness: IRI, WLP, Belgian $EC_{2.5m}$, EC_{10m} , EC_{40m} ,
  - Rut depth in mm,
  - Skid resistance : side-force coefficient,
  - …

Technical indicators: Properties of the road

For acceptance of road works

For (technical) road management (PMS)

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Destress of the road surface

- Can be seen for the standpoint of the road user:
  - Are there any potholes?
  - Ride comfort?
  - Is the road surface slippery?
  - …

Functional indicators: Objectives, service to the users

For communication to road users

Additional input for road management and policy

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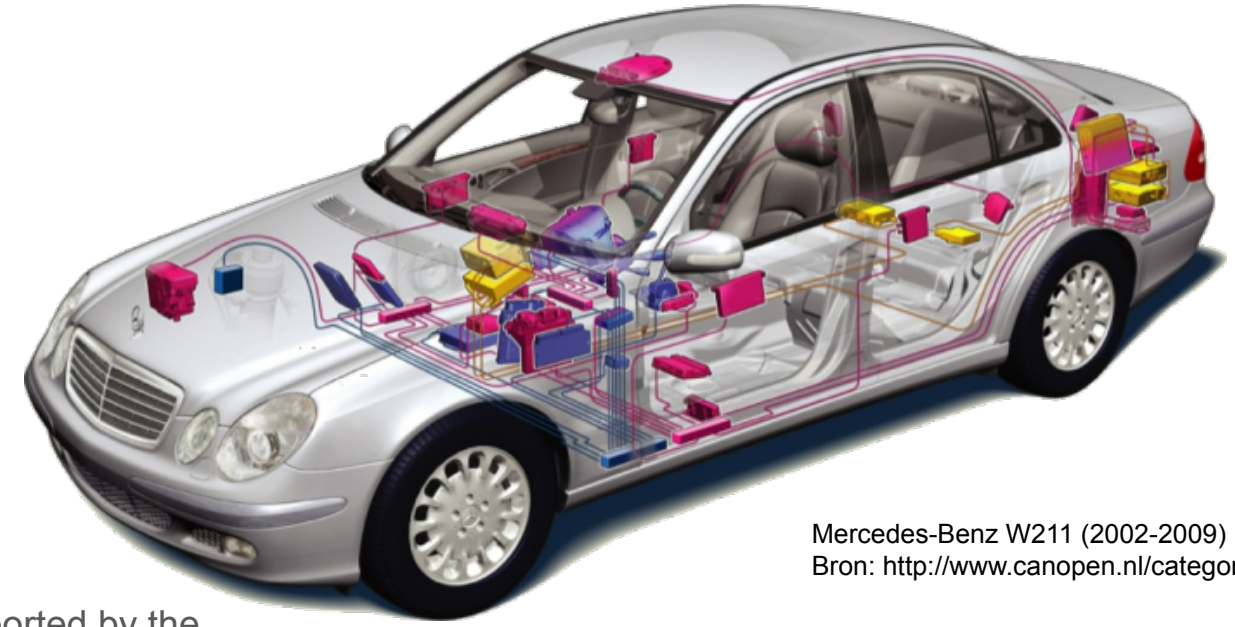
CANBus

- Controller Area Network (CAN) is a standard for serial databus communication in order to make communication between different electronic steering units in vehicles.
- Vehicles are full of sensors and “micro”-computers and they communicate with each other.
- The “OBD-plug” (on-board diagnostics) is used at the garage for data retrieval about “bad” functioning parts: hence, this is an access point to the CANBus.



Mercedes-Benz W211 (2002-2009)
Bron: http://www.canopen.nl/category/can-bus/

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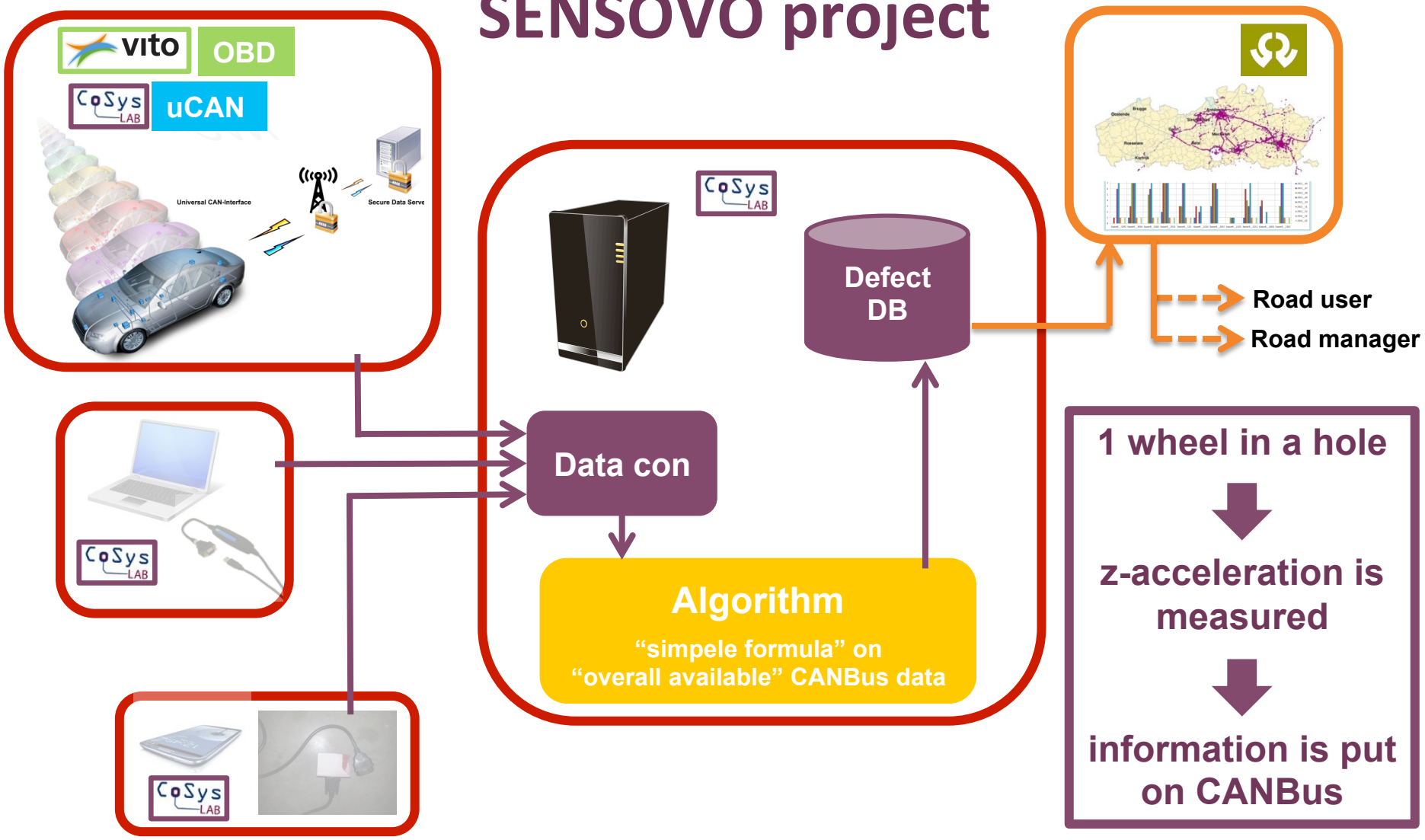
CANBus data (road surface defects)
SENSOVO project



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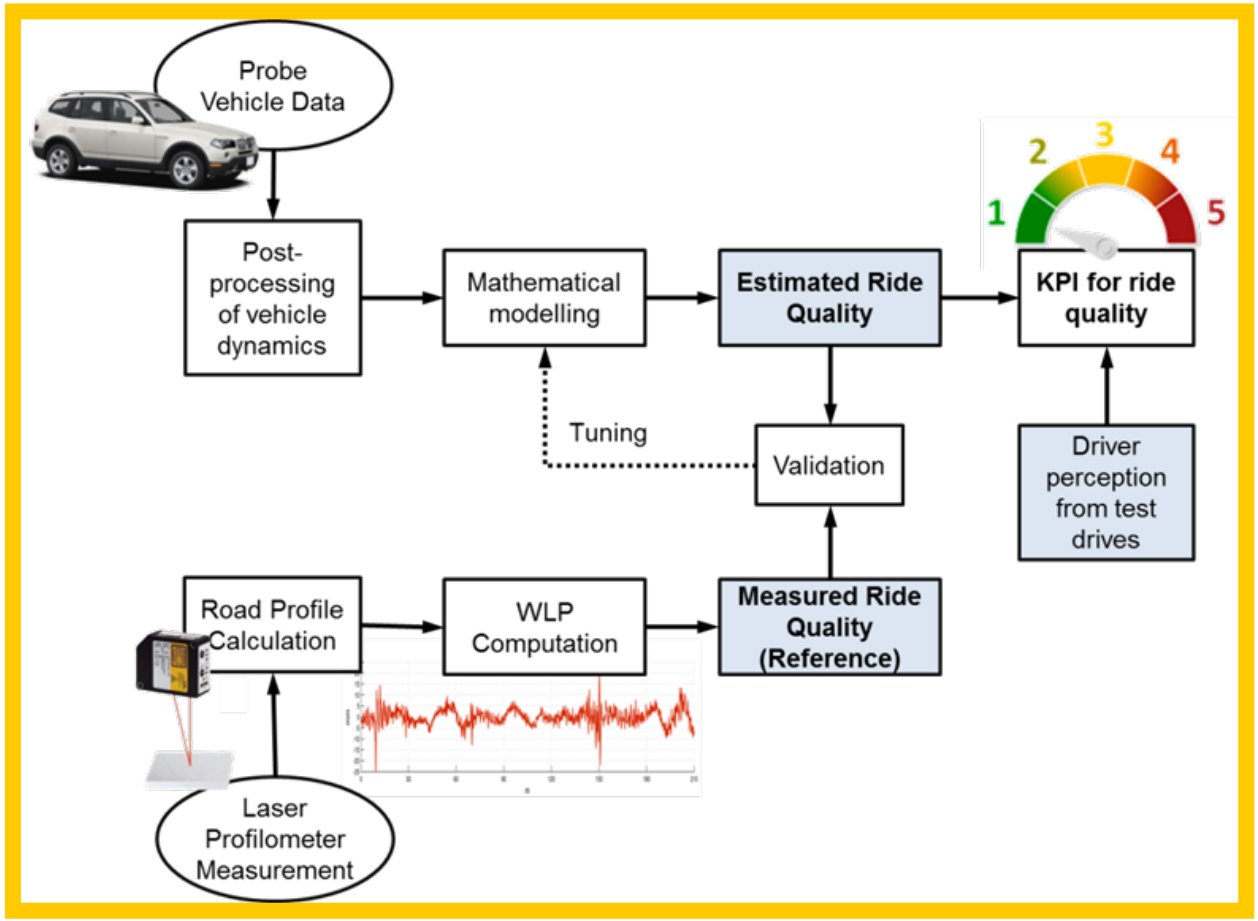
VIM project, executed by BRRC, UA, VITO (cf. http://www.vim.be/projecten/sensovo)

CANBus data (comfort) – TRIMM project

(European research project, Task 4.5 executed by BRRC, VTI, AIT, cf. Deliverable 4.4)

Several CANBus data are sent to a ANN in order to compute a comfort-indicator corresponding to a technical indicator (WLP).



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Ref. Nitsche Ph., Van Geem C., Stütz R., Mocanu I., and Sjögren L., Monitoring Ride Quality On Roads With Existing Sensors In Passenger Cars. In Proceedings of the 26th ARRB conference, Sydney, 19-22/10/2014.

CANBus data (slipperiness and ice on road, comfort, management) in Sweden, Finland and neighbour countries…

- BiFi (II): evaluation of bearing capacity of unpaved roads from (simulated) CANBus data (changes after frost-tawn cycle in Nordic countries)

  2011

  - GPS, 3G/GPRS and accelerometers, cars of Swedish postal service
  - lateral vibrations and speed of the vehicle, on board data treatment

- SRIS: evaluation of winter conditions from CANBus data

  2006-2008

  - Volvo V70s and Saab 9-5s CANBus data, taxis and company cars
  - EPS, ABS, temperature, use of windshield wipers

- MOBI-ROMA: quality of the road surface

  2011-2013

  - Volvo V70 CANBus data,
  - internal accelerometer, post-processing in MATLAB

- MOBI-ROMA does more:
  - software for maintenance management: indicators from CANBus data are stored, interpreted and presented.

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Ref. Pirkko Saarikivi, Magnus C. Andersson, Pär Ekström, Eric Zachrisson,Torbjörn Gustavsson, Stephanie Müller, MOBI-ROMA tool for mobile road monitoring, in Proc. of Transport Research Arena 2014, Paris.

Smartphones

With a smartphone you can make a telephone call…

- But the smartphone is also full of sensors allowing other applications:
  - a GPS-localization system, and
  - accelerometers
- And with those sensors it is possible to:
  - use existing “apps” (often without charge), or
  - program new “apps” by yourself.
- Some apps are already commercialized, other apps are under development and studied in research centres: here follows a small, unrepresentative selection.

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Smartphones (comfort) – Canada

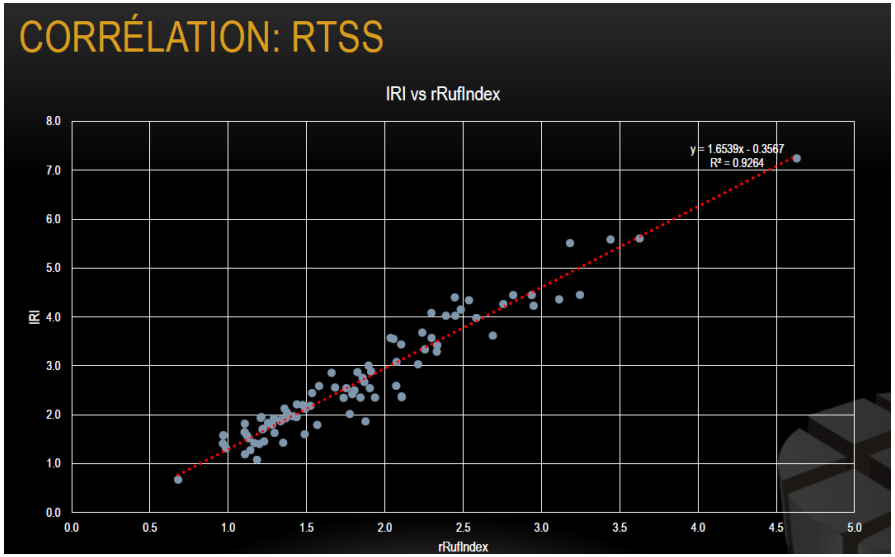
(cf. Rubix of firm Rival Solutions Inc.)

- iPhone 4.x and 5.x deliver a “comfort value” (rRuf).
- Meant for application to local roads (in Canada):
  - as a “inexpensive” measurement technique,
  - complements data from simple visual road surface inspections,
  - is used in PMS software of the firm.

rRuf from iPhone,
IRI from “class 1 profilometer”

rRuf would give a “reasonable” correlation with IRI comparable to “class 3”

some future directions are proposed for improving the correlation.



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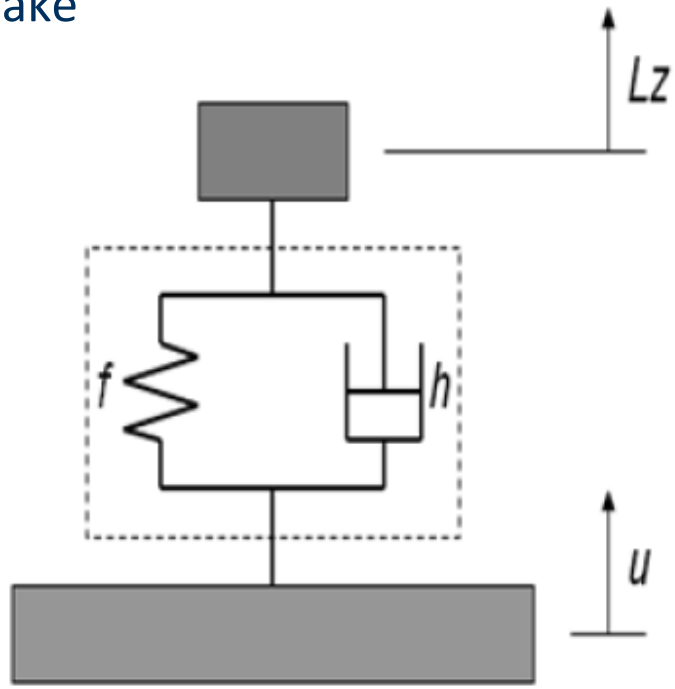
Source: Claude Laflamme (Rival Solutions), Democratizing the Measurement of IRI values (French),
INFRA 2014 Congress, 1-3 dec. 2014, Montreal, Canada.

Smartphones (cracks) – Japan
(cf. firma BumpRecorder Co. Ltd.)

- Smartphones were used before, for longitudinal evenness:
  - Vertical acceleration (Lz) from smartphone,
  - Simple model (1 spring under 1 body):
  - Fast Fourier Transformation (FFT) gives unevenness of the road (u)
- Was meant as a fast evaluation after earthquake
- Can be transformed in “IRI”



Source: Koichi Yagi, Extensional Smartphone Probe for Road Bump Detection, 17th ITS World Congress, Busan, 2010.

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Smartphones (cracks) – Japan
(cf. firma BumpRecorder Co. Ltd.)

- Proposal to detect cracks:
  - Compute from FFT the average fave of frequencies weighed by amplitude
  - Crack-index CI = f_{ave} x a_{ave} with a_{ave} the average amplitude
  - Sample rate has large influence on CI
  - Influence of brand of smartphone, brand of vehicle and speed during the measurements is expected
- Not yet a real proof that this really works.

Source: Koichi Yagi (BumpRecorder), Road Cracking Detection by Using Smartphone Acceleration, Pavement Evaluation 2014, 15-18 sept. 2014, Blacksburg, Virginia, USA.

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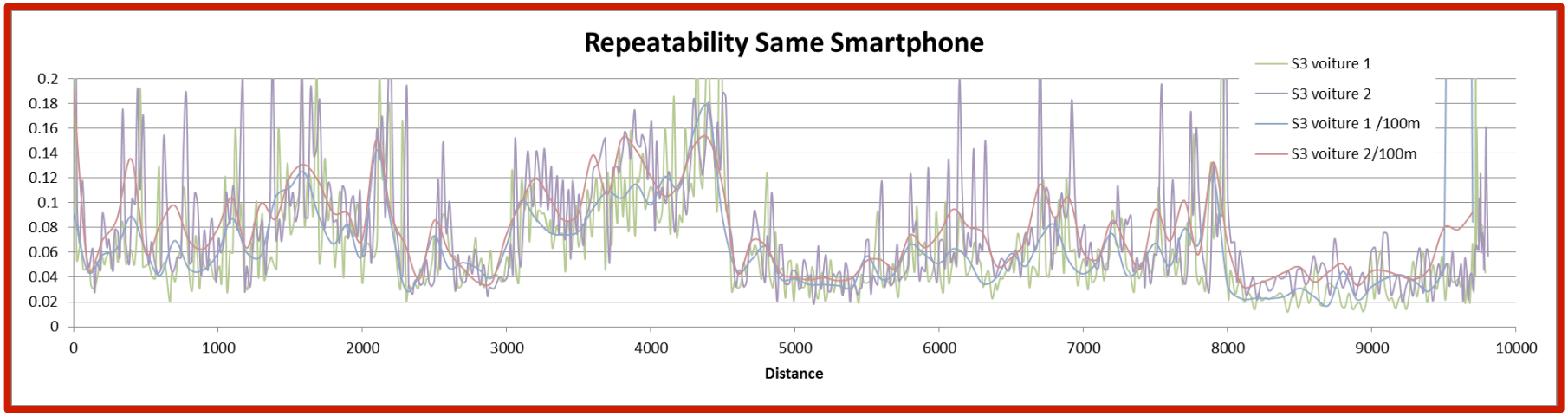
Smartphones (comfort) – TRIMM

(European research project, Task 4.5 executed by BRRC, VTI, AIT, cf. Deliverable 4.4)

- Tested: a “app” of VTI, 3D accelerations + GPS, Root-Mean-Square of vertical acceleration as comfort-index.

Confirmed influence of lots of things…



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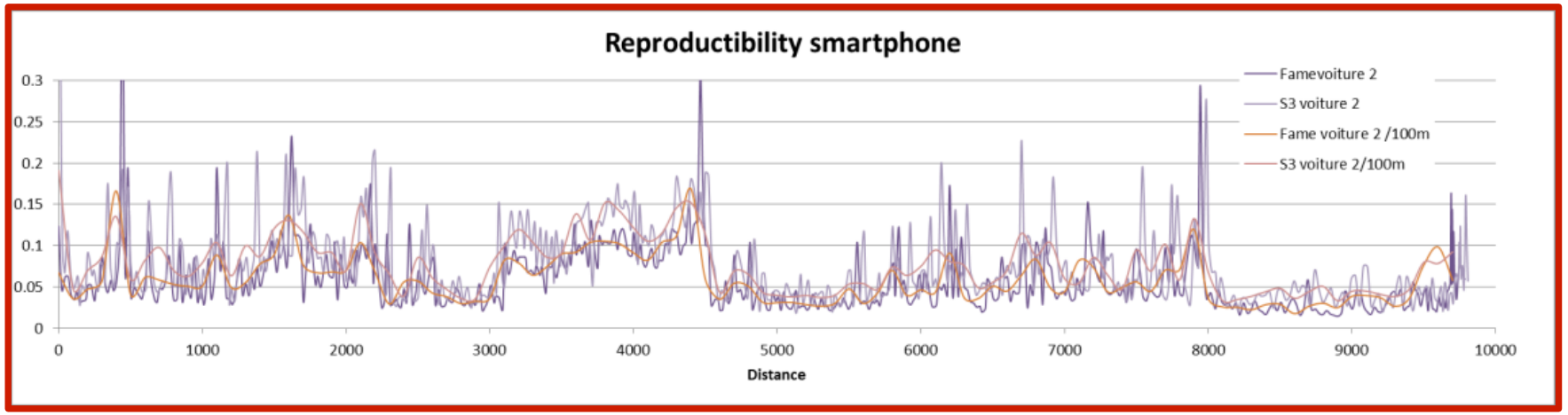
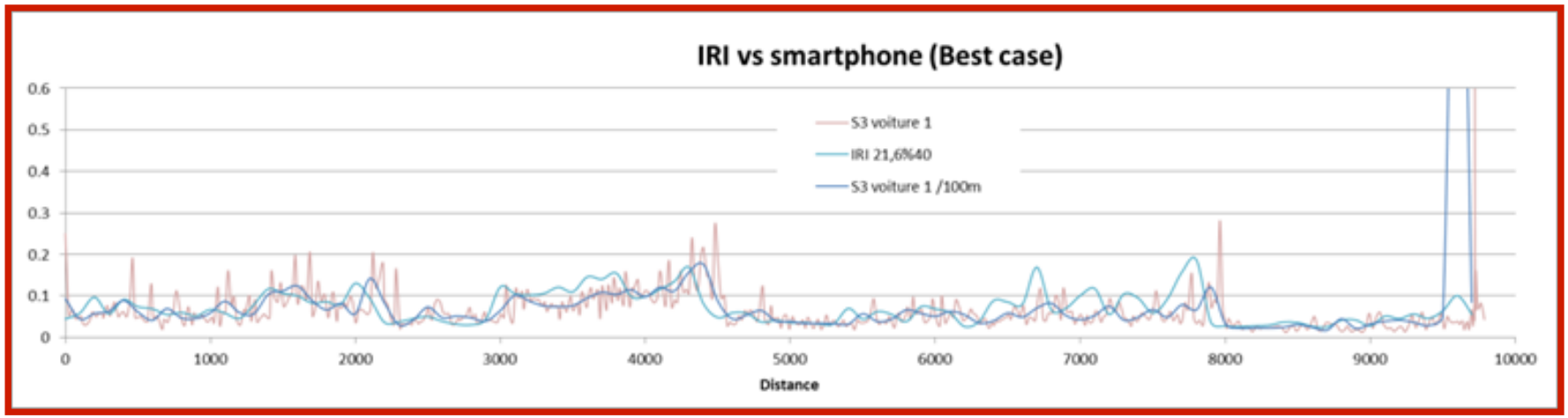
Smartphones (comfort) – TRIMM

(European research project, Task 4.5 executed by BRRC, VTI, AIT, cf. Deliverable 4.4)

Not certain that IRI is the best comfort index!



Sometimes we can get a good correlation…



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cf. TRIMM project Deliverable 4.4

GPR for road network analysis

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Analysis of structural performance of the “land network” of roads of the Brussels Airport Company

- Objectives
  - Brussels Airport Company wanted a quick global evaluation of the structural capacity of their roads on the “land” side of their territory.
  - Planning of budget for road maintenance in the forthcoming years + determination of priorities.
- Note
  - Road surfaces are in good condition since regular maintenance consists of surface dressing (i.e. very thin “overlays”): no distress will be seen by visual inspections).
  - Heavy traffic: need for analysis of bearing capacity and residual life.
- Approach
  - GPR: to determine homogeneous segments (= with the same road structure).
  - FWD: several points measured in each of those segments.
  - Computation of a few indicators

Ref. C. Van Geem, B. Berlémont (BRRC), P. Nigro (SPW), The use of deflection measurements in pavement management of the primary road network of Wallonia, Belgium, 9th International Conference on Managing Pavement Assets (ICMPA9), Alexandria, Virginia, USA, May 18-21, 2015.

  - Representation on a map + interpretation of the indicators.

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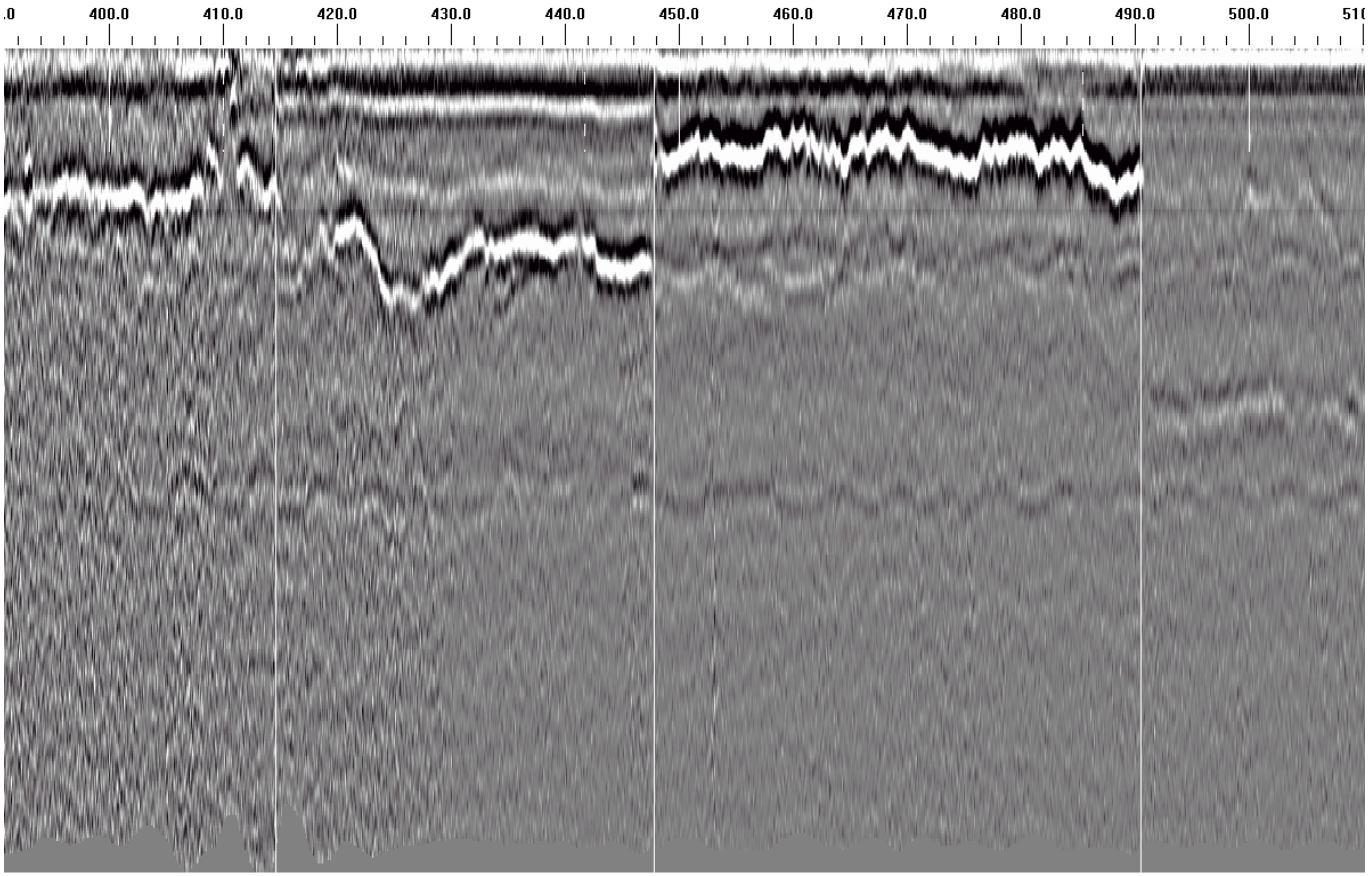
GPR at network level: Homogeneous segments and local “events”



4 different homogeneous segments

Most homogeneous segments have lengths between 35 m and 500 m, mean length = 127 m.

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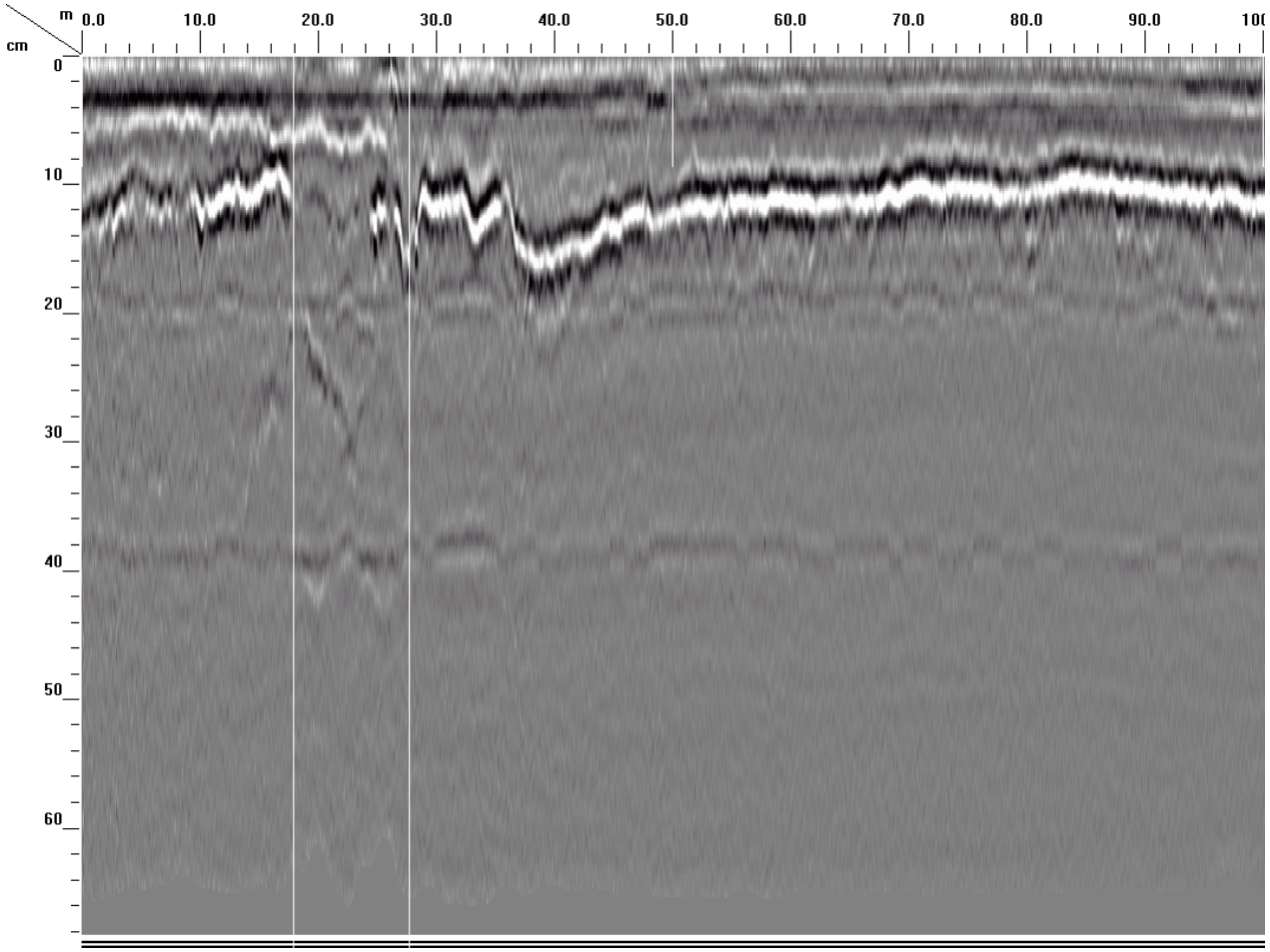
GPR at network level:
Homogeneous segments and local “events”



1 homogeneous segment and a 10m long local event

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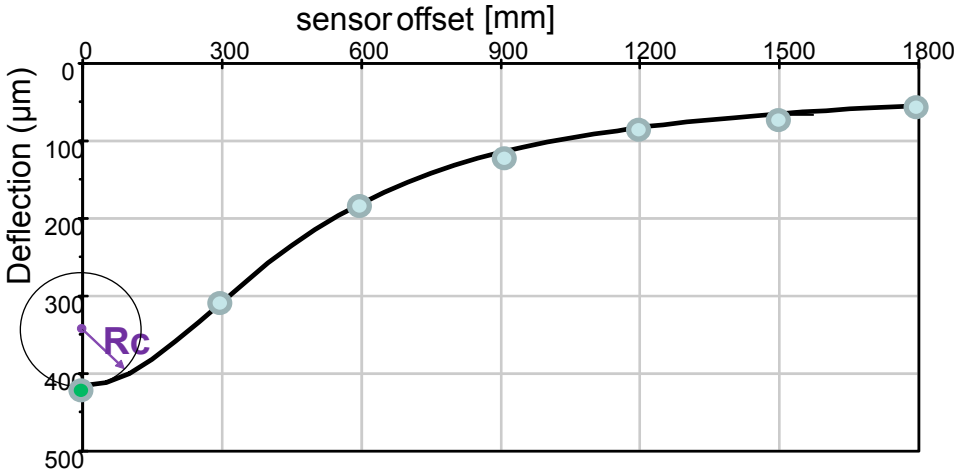
Useful indicator: “Tragfähigkeitszahl”

- FWD: $Tz = (Rc / D(0))^{0.5}$
  - Rc to be computed for FWD data
  - Tz low ~ bad bearing capacity



Ref. S. Jendia. Bewertung der Tragfähigkeit von bituminösen Straßenbefestigungen. Veröffentlichungen des Institutes für Straßen- und Eisenbahnwesen der Universität Karlsruhe (TH), Heft 45, 1995 (ISSN 0344-970-X, in German).

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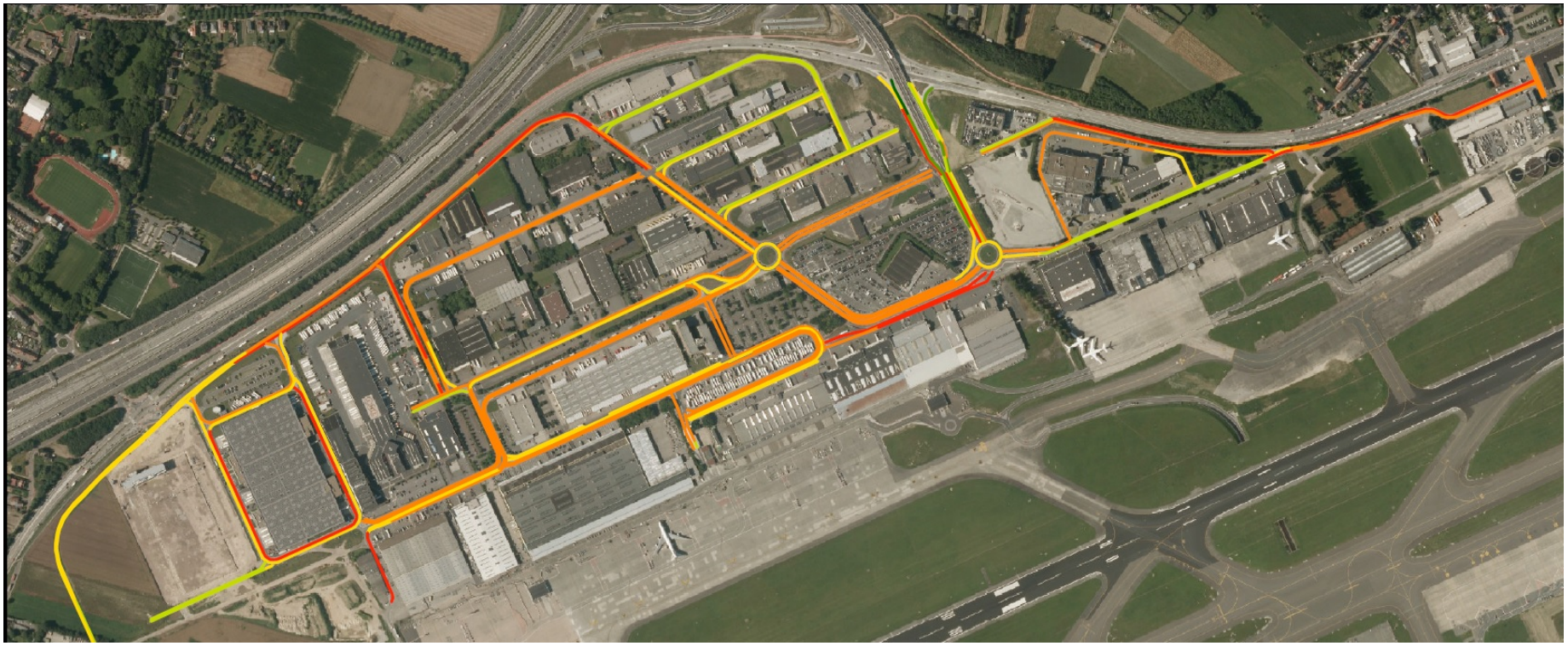
Roads, network level: map with current conditions

- inventory segmentation with GPR
- classification by indicator of bearing capacity with FWD



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Note: network level analysis

- In this case:
  - No need for further analysis than classification of road segments.
  - GPR was used for making an inventory of road segments
  - FWD was used for condition assessment

- GPR and FWD data are available and can be used at project level
  - GPR: determination of road layers and thicknesses
  - FWD: deflections and back-calculation

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Author

Dr. Carl Van Geem (c.vangeem@brrc.be) is a researcher in road management and monitoring techniques, since 2004 he is working in the Mobility, security and road management (MSM) division of the Belgian Road Research Centre (BRRC), in Brussels, Belgium. He is a Working Group Member of the COST Action TU1208.

In 1996, Carl Van Geem earned the doctoral degree in technical sciences from the Research Institute on Symbolic Computation (RISC-Linz), Johannes Kepler University, Linz, Austria.

The BRRC has several devices for the evaluation of road surface properties (roughness, skid resistence), for pavement management (visual inspection device “SAND”), and for measuring the bearing capacity of roads (FWD, curviameter, GPR). The main topic of Carl’s research is the interpretation of data obtained with these monitoring devices for an optimal management of road maintenance. Carl participated in several national and international research projects, including a “national pre-normative research project on the indicators of roughness”, the COST Action 354 “Performance Indicators for Road Pavements”, the PIARC technical committee D1 “Management of Road Infrastructure Assets”, and the FP7 project “Tomorrow's Road Infrastructure Monitoring and Management (TRIMM)”.

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Thank you

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