

Kennisprogramma Knowledge-based Pavement Engineering

Dinsdag 31 oktober 2023 is er weer een KPE-activiteit. Dit keer niet van een individueel project, maar van het geheel. Naast een blik op de tussen resultaten geven we een sneak-preview van het einde van het programma.

#####

Knowledge programme Knowledge-based Pavement Engineering

Tuesday October 31st 2023 there will be another KPE-event. This time not from one of the individual projects, but of the whole. Besides intermediate results, we will give a sneak preview of the end of the programme.



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CO₂



Programma

13:00 – 13:15: Welcome and introduction

13:15 – 14:20: Advancing Asphalt Durability Assessment

14:20 – 14:50: Break

14:50 – 15:10: Assessing reliability of base layers 'Heal for Service

15:10 - 15:30: Towards sustainable road infrastructure: investigating and improving Rolling Resistance Prediction

15:30 – 15:50: Lifetime Prediction

15:55 – 16:15: Discussion, wrap up and closure

16:15 – 17:15: Drinks



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Seminar: 'Bouwen op Kennis'

*Met KPE naar een
klimaatneutrale weg*

31 oktober 2023

**Knowledge-based
Pavement
Engineering
2020-2024**

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31 oktober 2023

➤ Naar klimaatneutrale en circulaire
rijksinfrastructuurprojecten (duurzame-infra.nl)

**Knowledge-based
Pavement
Engineering
2020-2024**

Knowledge-based Pavement Engineering 2020-2024

Met KPE naar een klimaatneutrale weg

31 oktober 2023

Cecile Giezen



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Duration

4 years
2020-2024

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2020-2024

Overall Aim

Improving the frame work
RWS has to set
requirements for the
quality and performance
of the Dutch Highway
Network in all phases of
the pavement life cycle,
addressing both the
classical and new
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requirements

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Structure

6
Projects

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Structure

6
Projects

Dissemination

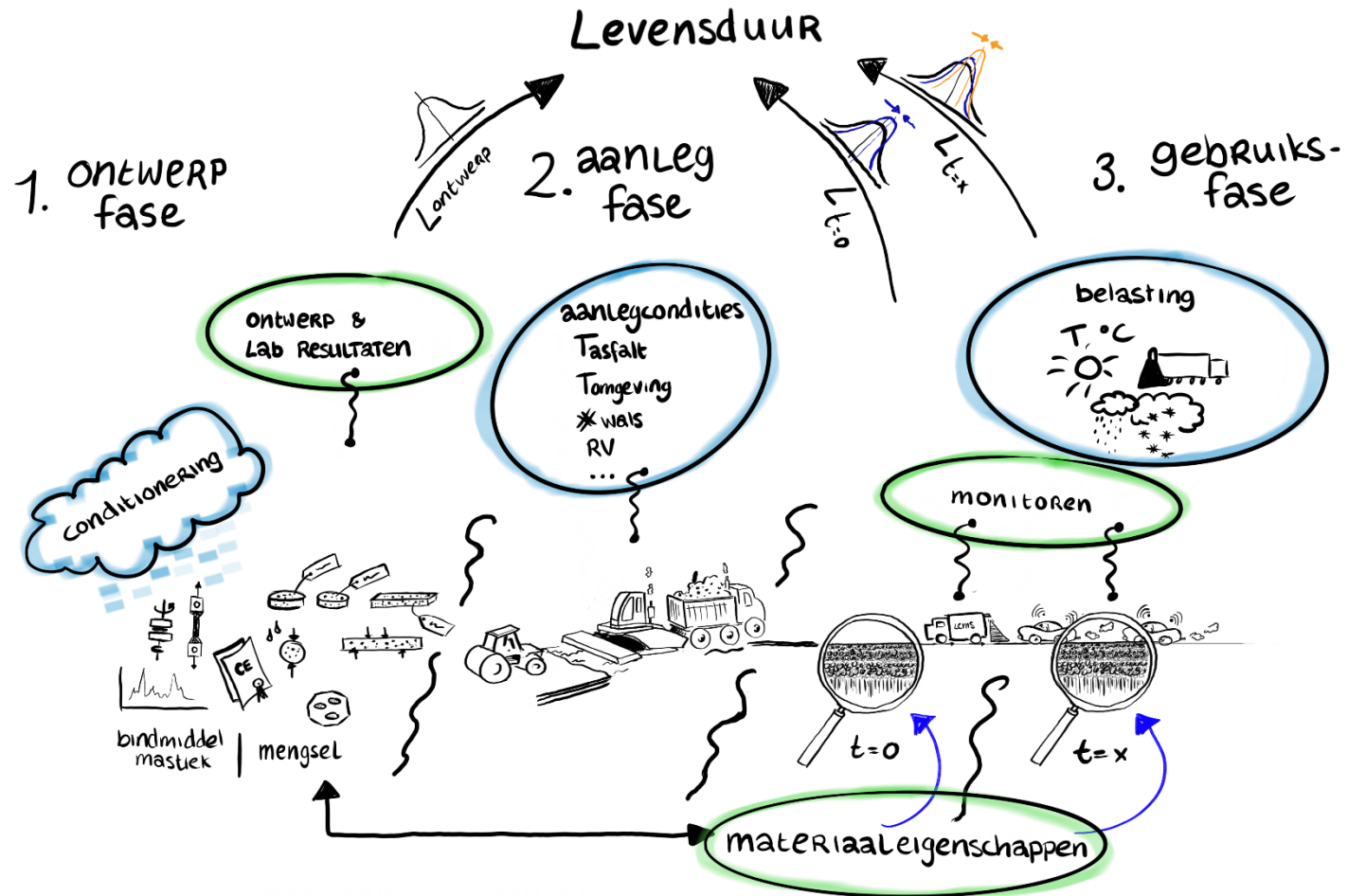
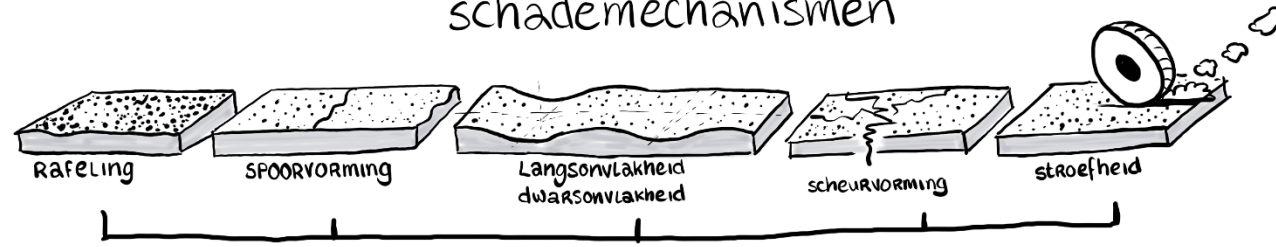
- **KPE day 2021**
 - **Website**
- **Several workshops**
 - **And today**

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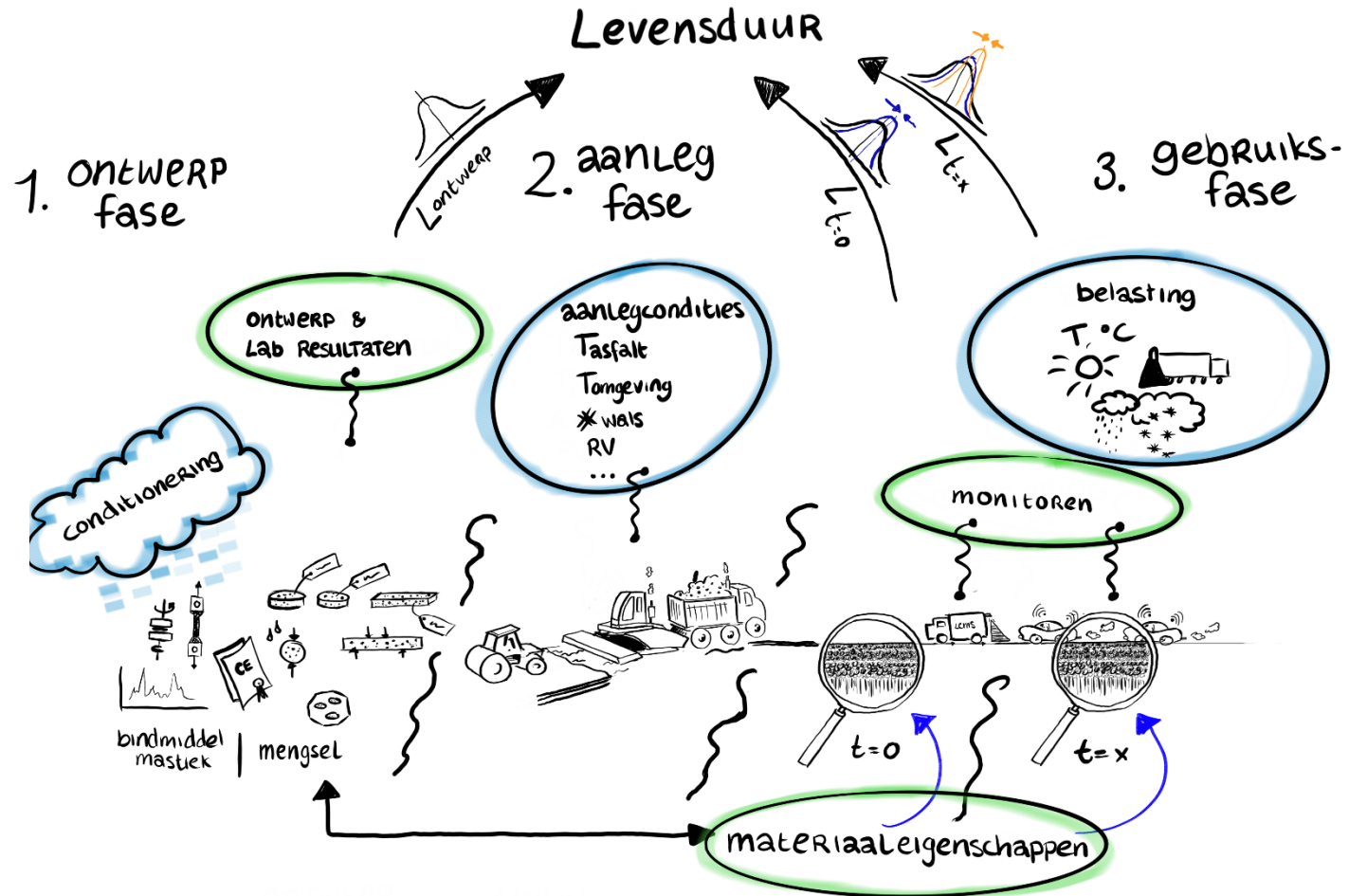
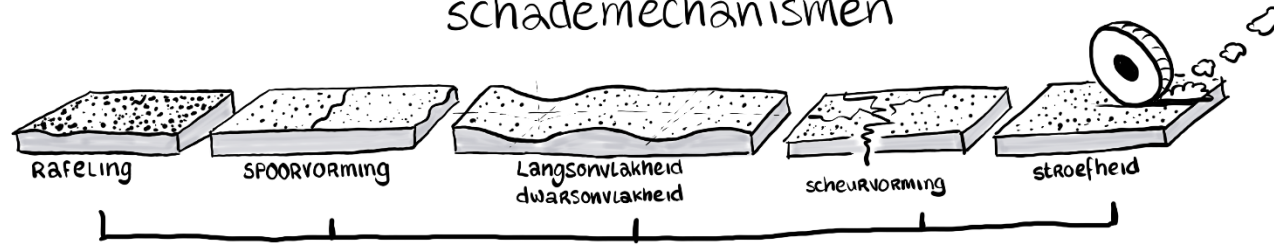


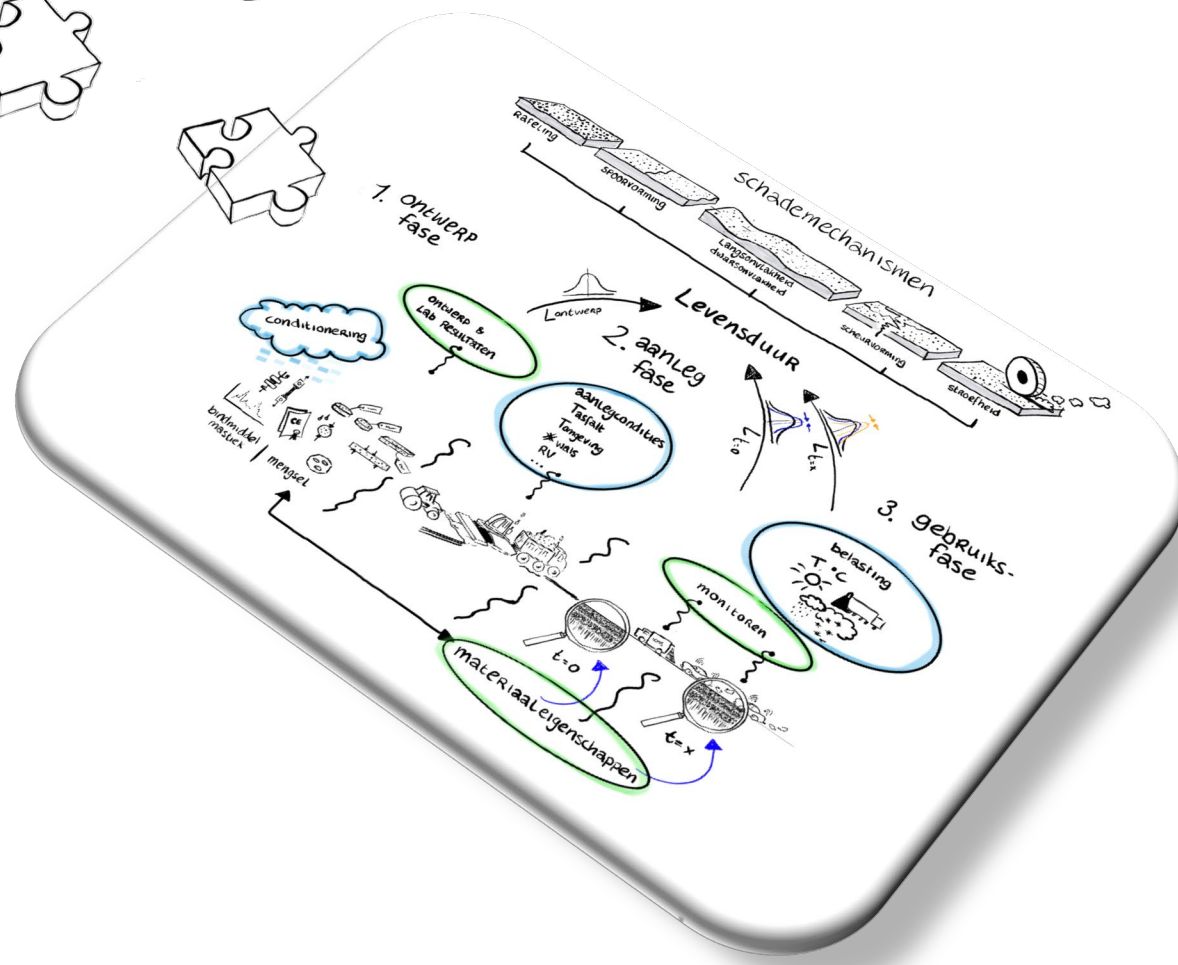
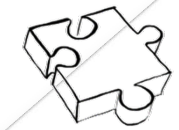
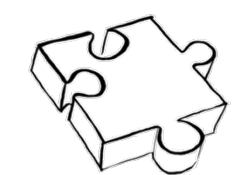
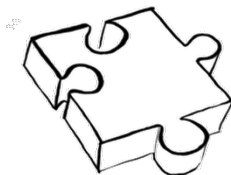
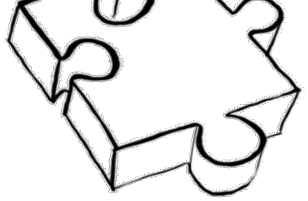
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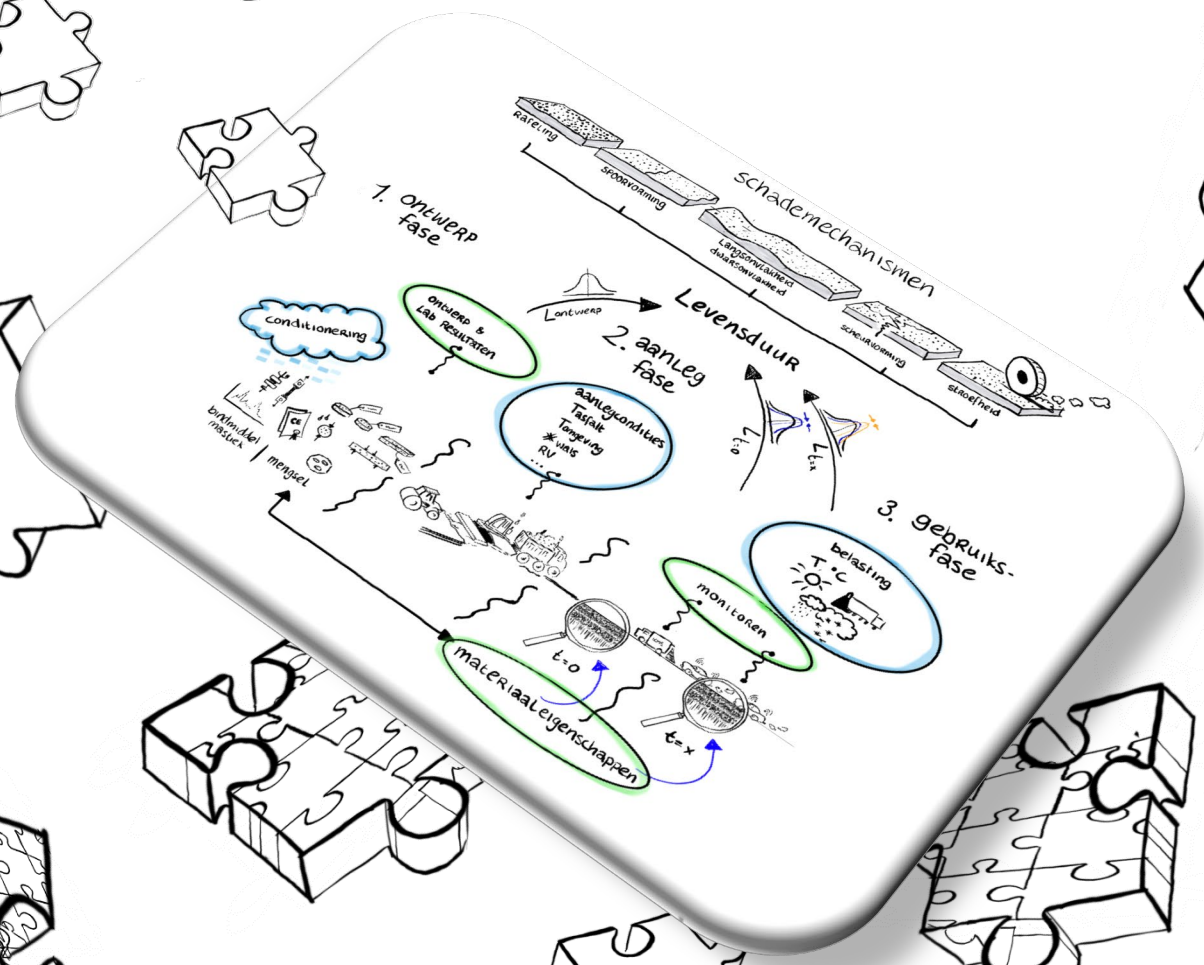
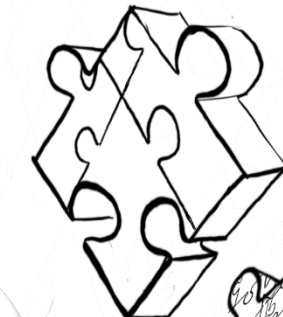
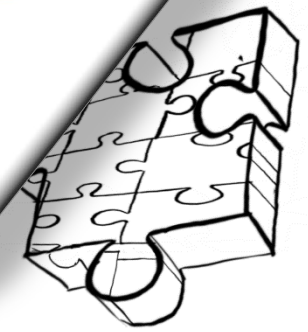
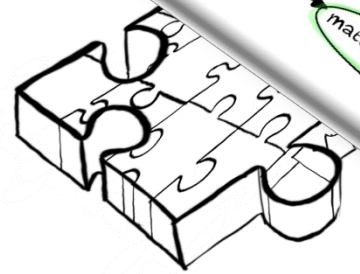
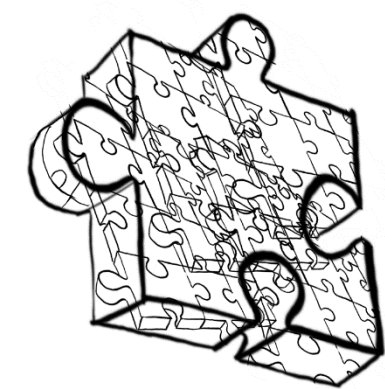
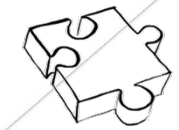
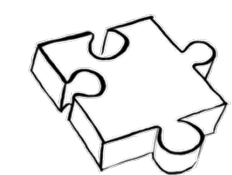
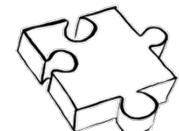
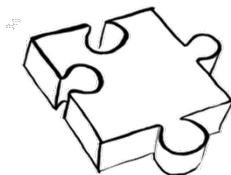
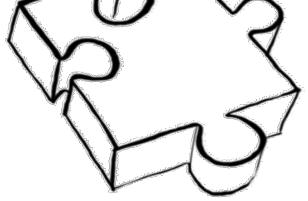
schademechanismen

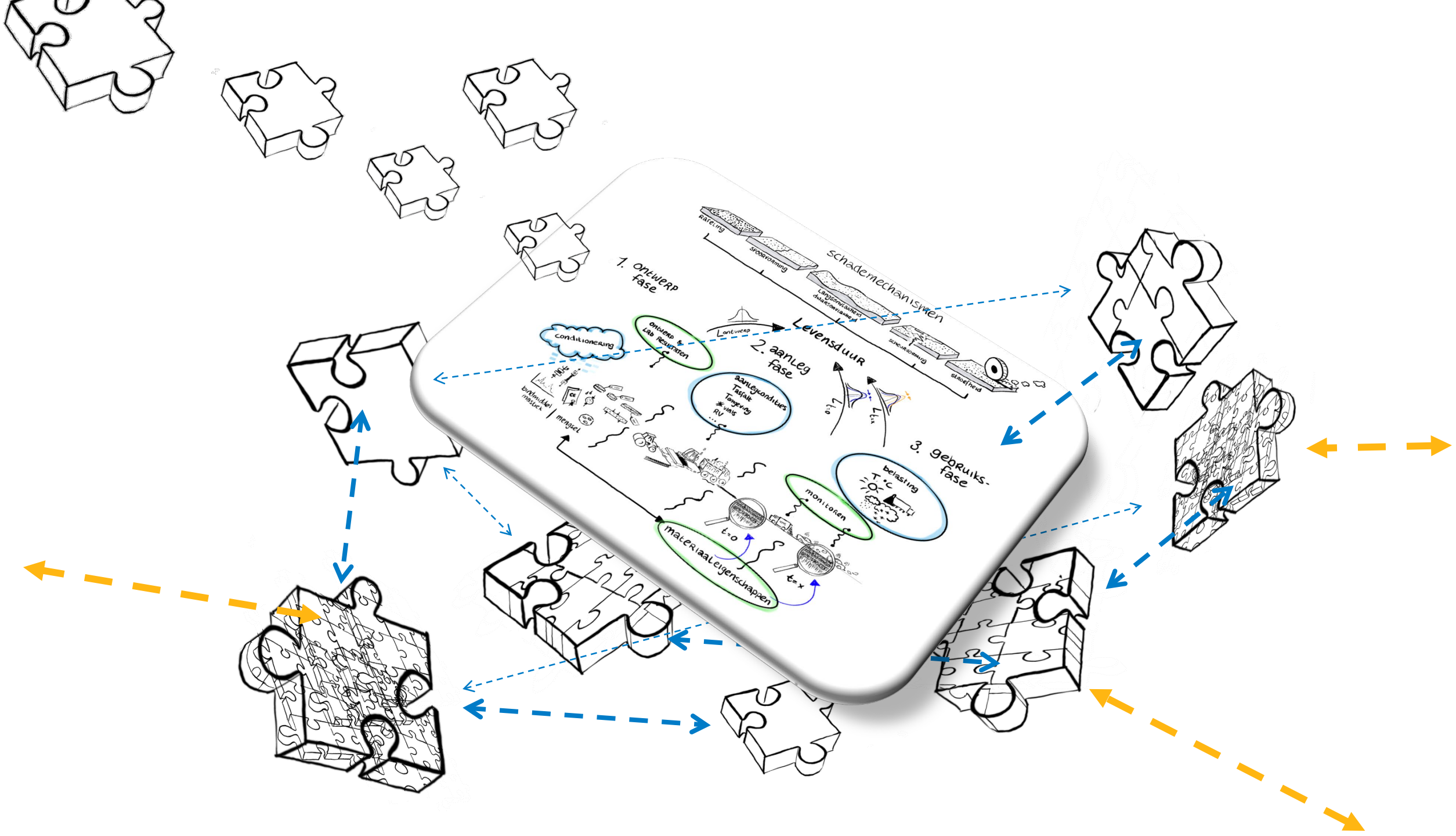


schademechanismen









Advancing Asphalt Durability Assessment



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Seminar: 'Bouwen op Kennis'

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31 oktober 2023

CEAB

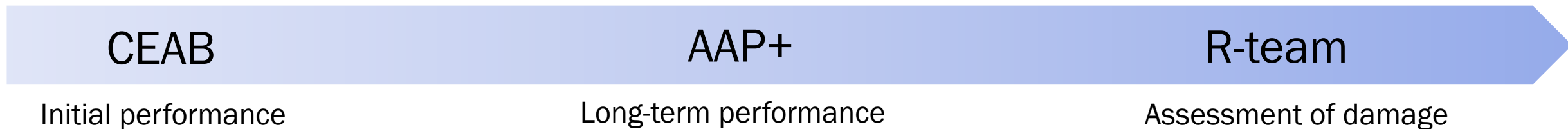
AAP+

R-Team

**Knowledge-based
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2020-2024**

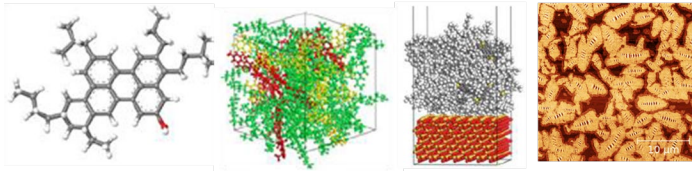
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Performance assessment during the lifetime of asphalt

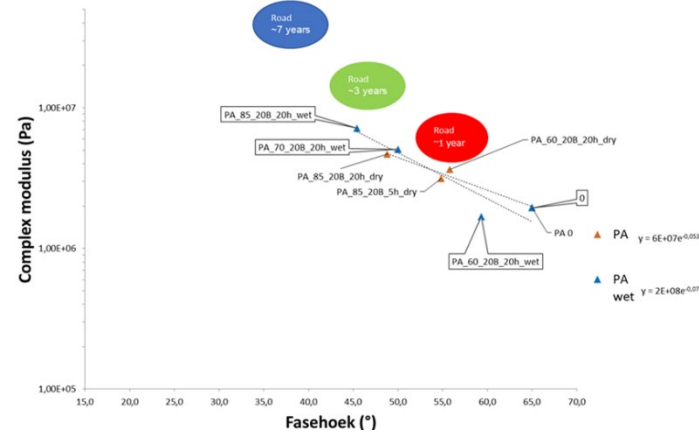


Goals

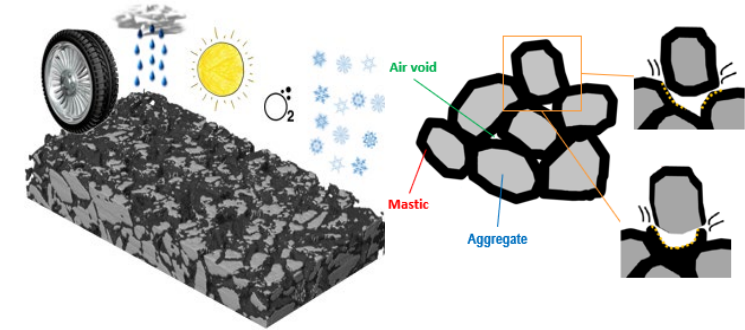
CEAB



AAP+



R-team



- Influence of **source, production** process on bitumen properties and potential for rejuvenation
- Evaluation methodology and binder **performance indicators** that validate **suitability, ageing susceptibility, and recyclability** of asphalt binder

- Protocols to assess **long-term ageing** that correlate with field ageing
- **Validation** of AAP and understanding **degradation** process (oxidation + moisture)

- Assessment method to **distinguish** good from poor asphalt mixtures/mastic w.r.t. ravelling.
- Establish a **database** with **defined limits** for predicting ravelling performance (long term)

Characterization and Evaluation of Asphalt Binder Properties (CEAB)



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Dr. S. Nahar

Dr. X. Liu

Dr. P. LIN

Ir. S. Ren

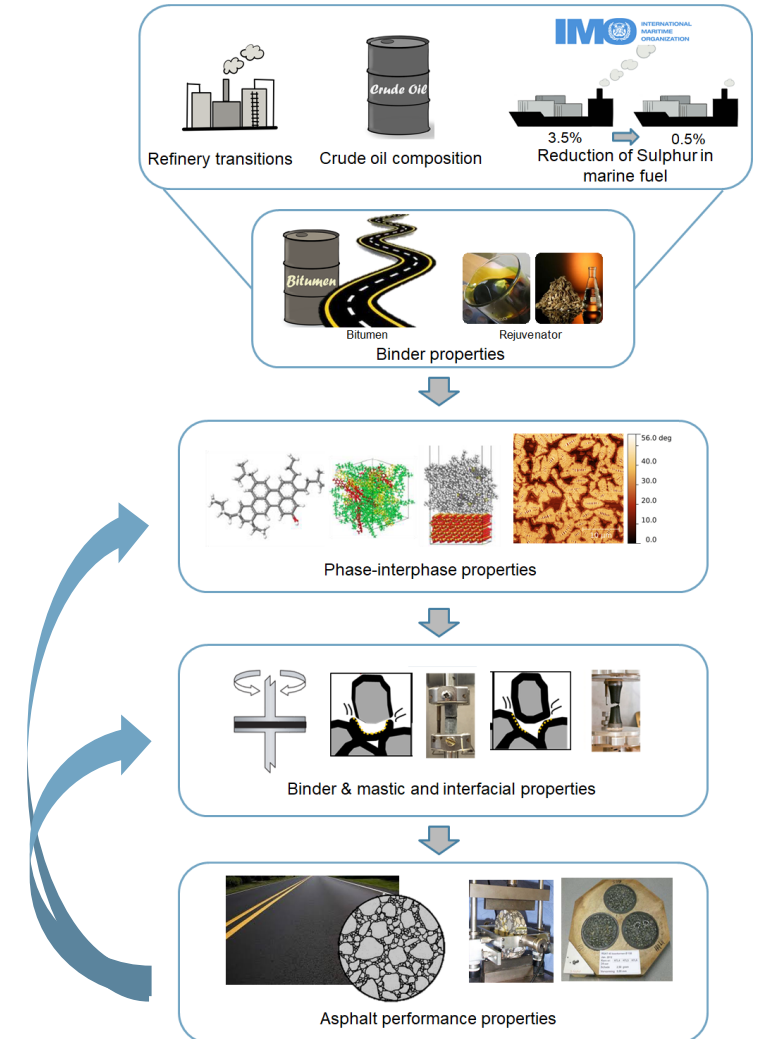
Ir. E. Assaf

Ir. L. Mortier

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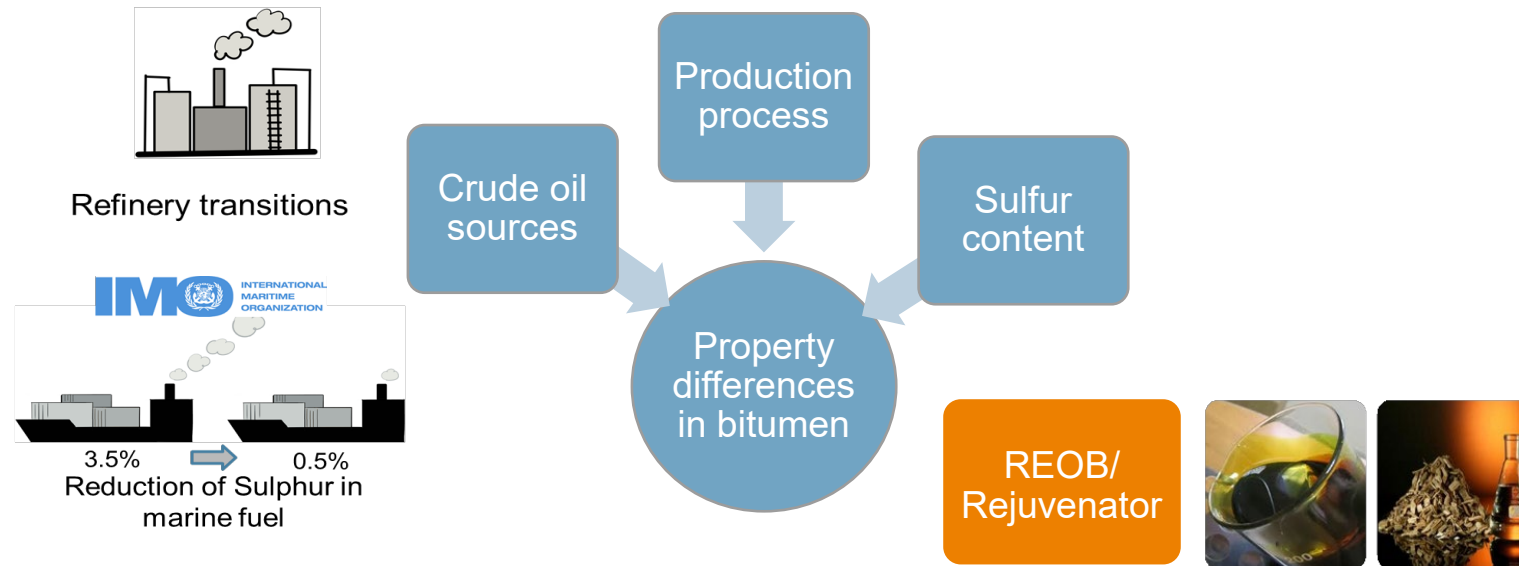
OBJECTIVE OF CEAB

- Mapping the impact of **source variability**, **refining methodologies** and **additives (i.e. rejuvenators, extenders)** on the compositional and performance attributes of bitumen.
- To develop a comprehensive evaluation methodology to establish **correlations** between rheological and chemical properties and to define binder **performance indicators** that confirm **suitability**, **durability**, and **recyclability** of binder for asphalt application



Schematic of Multi-scale Analysis

Task 1 Mapping changes in bitumen/rejuvenator properties

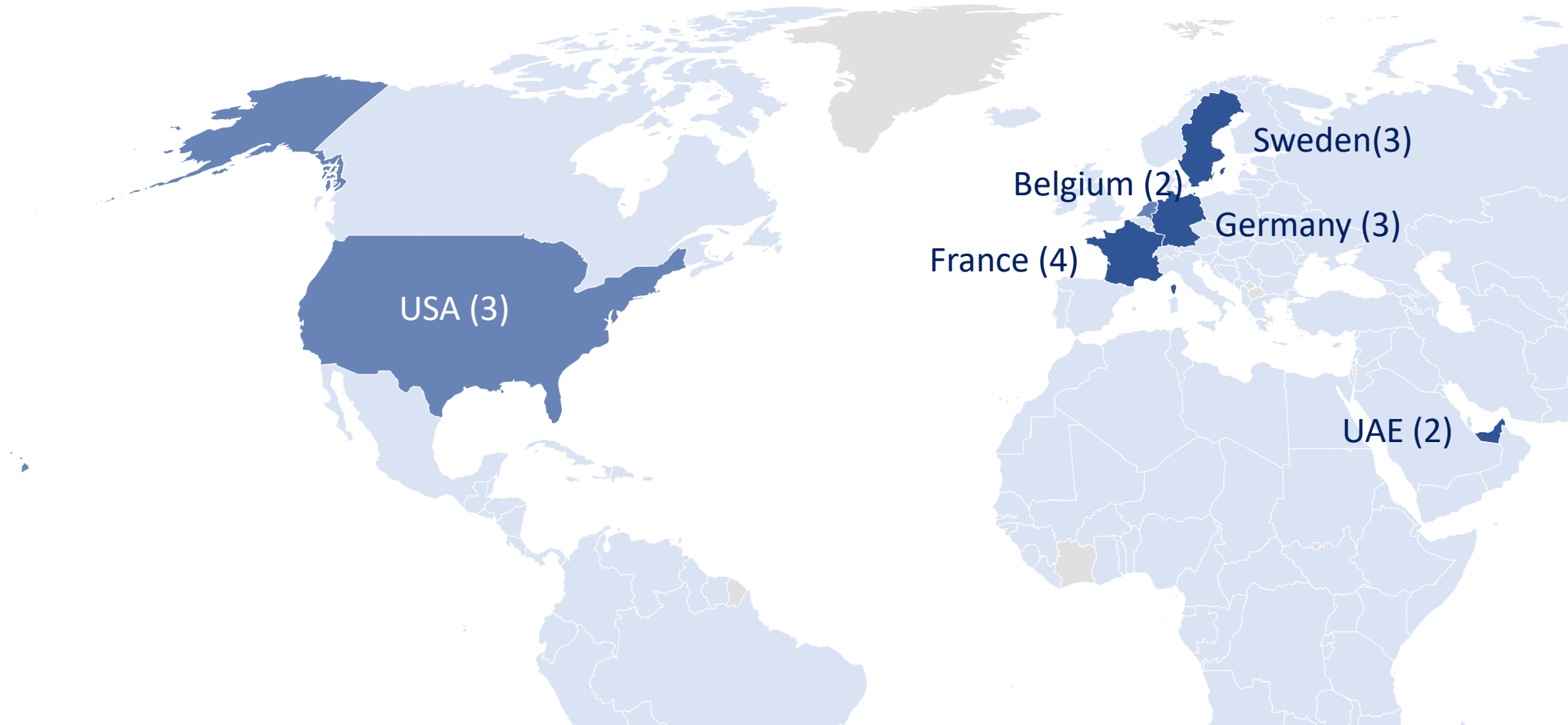


- **Influence of sulfur in bitumen properties:** Sulfur in bitumen increases polarity, promotes the agglomeration of asphaltenes affecting viscosity, yet its direct impact is complex as it is dependent on the asphaltene and trace metal content of the binder.
- The **rejuvenation mechanism** is depended on the bitumen properties and different chemical nature of rejuvenator additives.

<https://www.duurzame-infra.nl/kennis-informatie/knowledge-based-pavement-engineering/ceab>

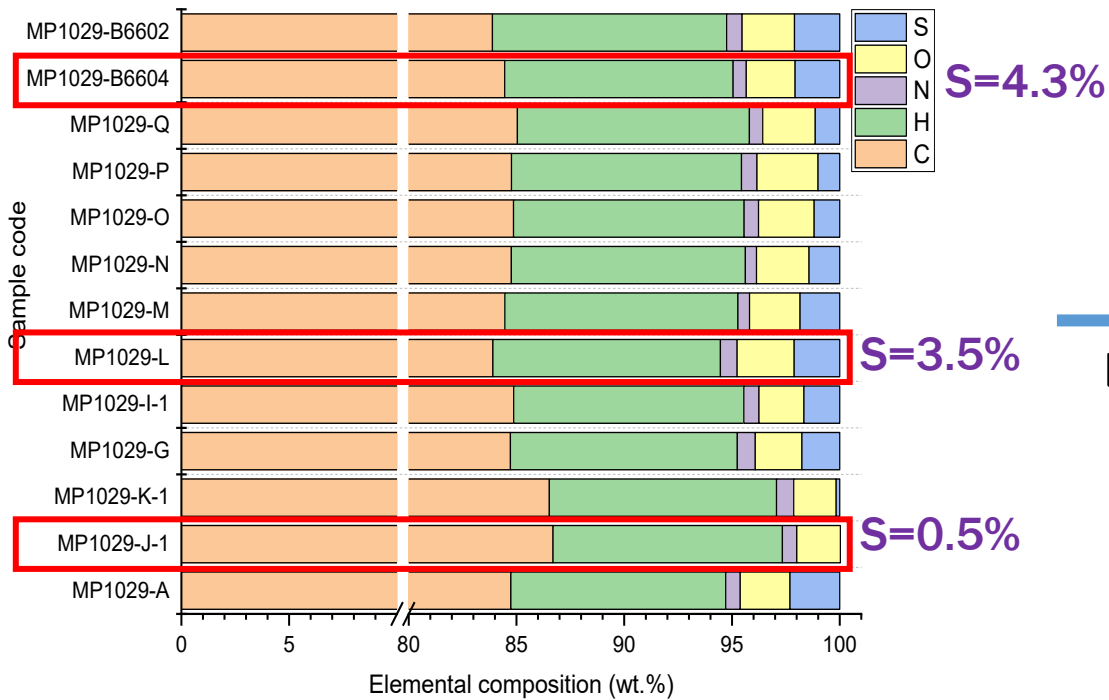
Task 2 Assessment of bitumen & rejuvenator properties

17 types of base bitumen sourced from Europe, Asia, and North America.



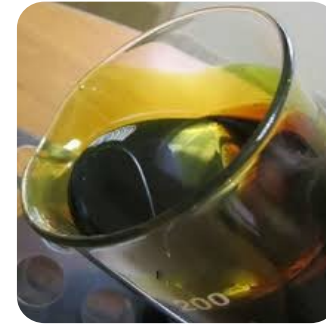
Task 2 Assessment of bitumen & rejuvenator properties

3 selected types of base bitumen and **4** types of typical rejuvenators



Short-term
20h PAV
40h PAV
80h PAV

Lab aging



Aromatic Extracts



Paraffinic Oil



Bio-based Oil

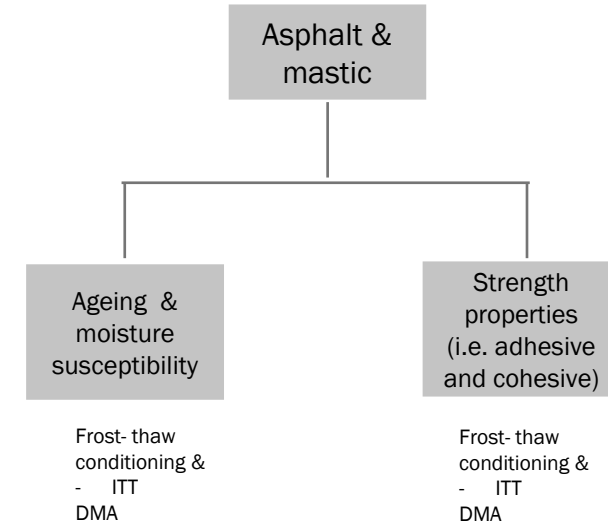
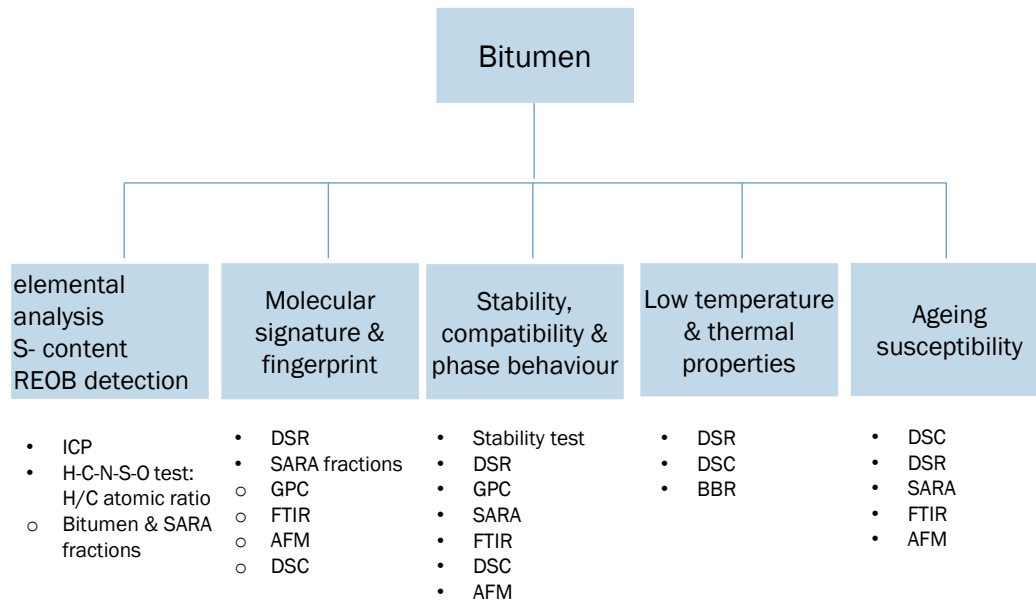


Naphthenic Oil

3 selected base bitumen

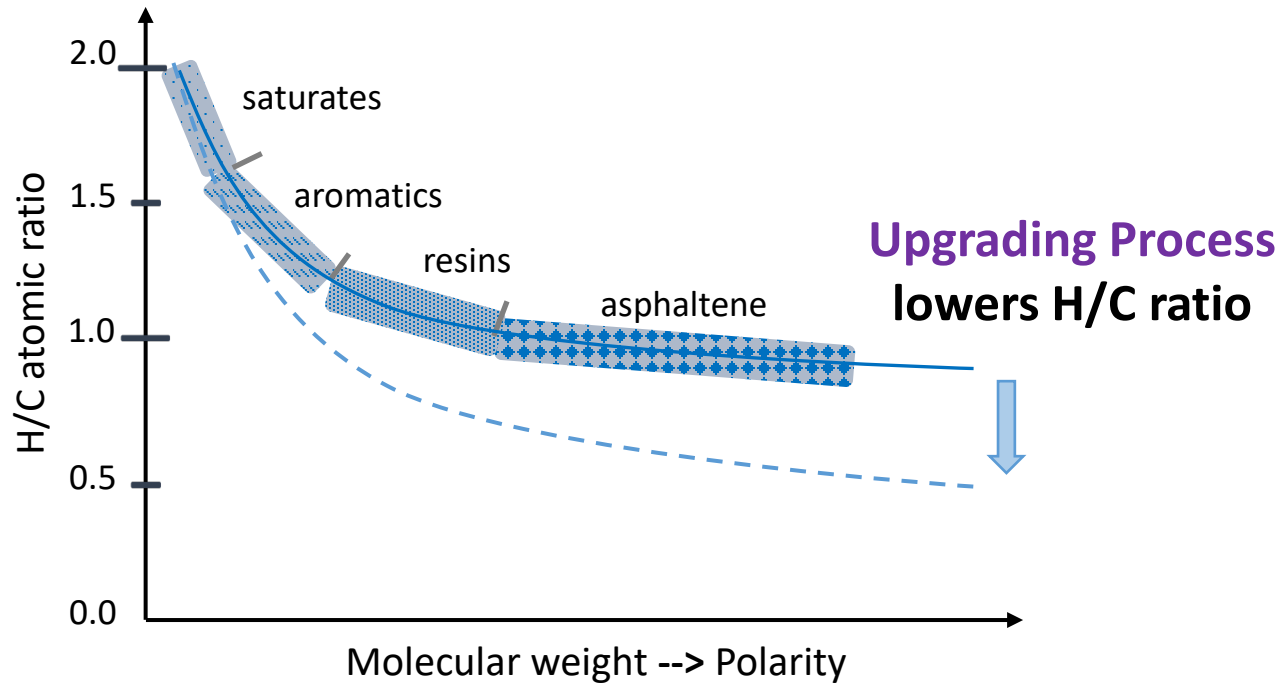
4 Typical Rejuvenators

Task 2 Assessment of bitumen & rejuvenator properties



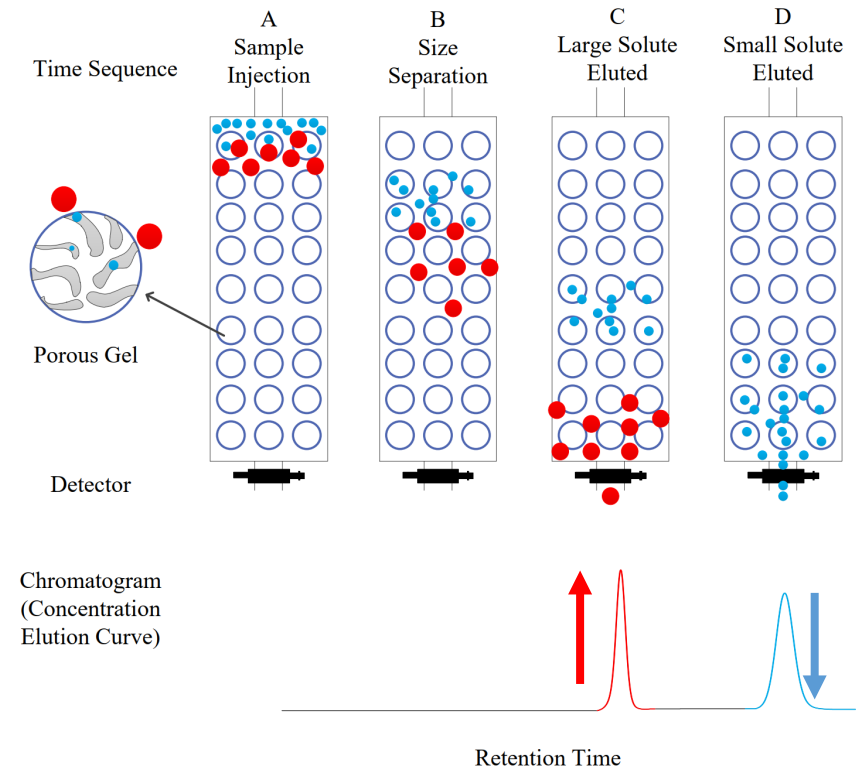
Task 2 Assessment of bitumen & rejuvenator properties

Influence of Refinery Process on the bitumen chemical composition



Relation Between H/C and Molecular Weight

Upgrading Process --> decrease of H/C

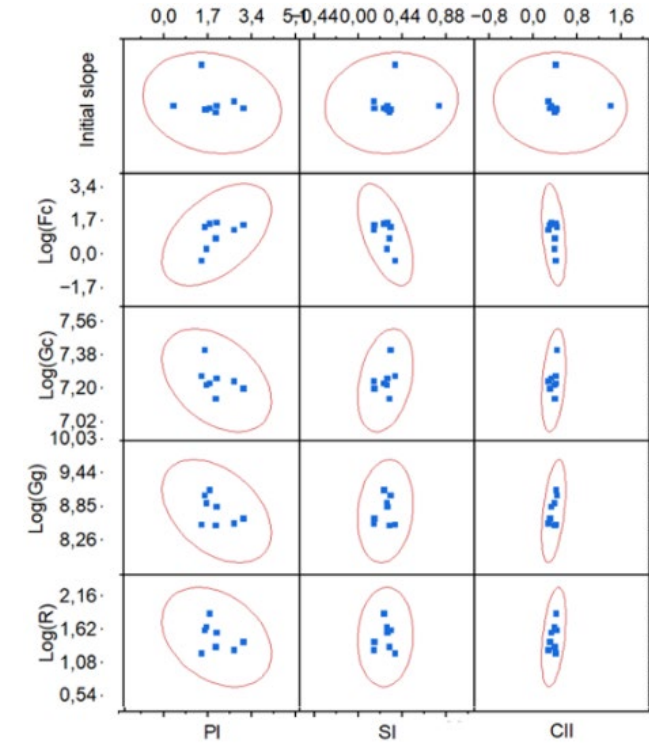
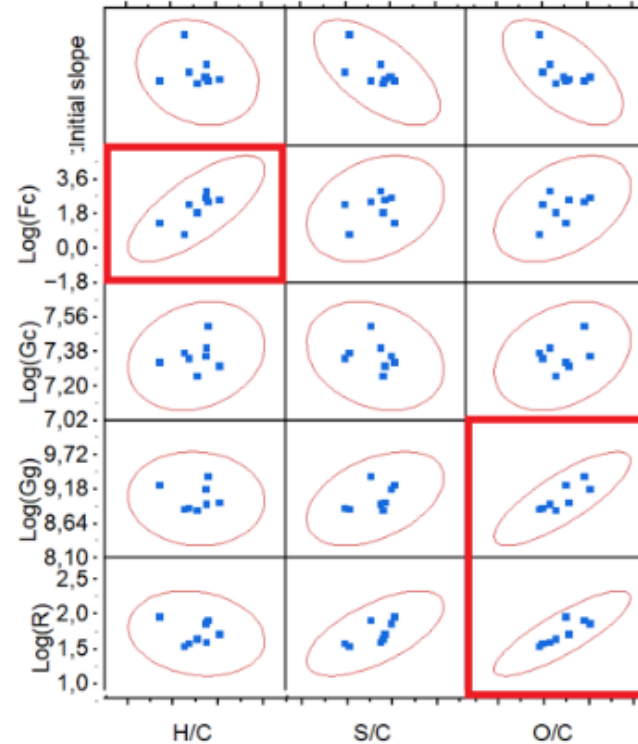
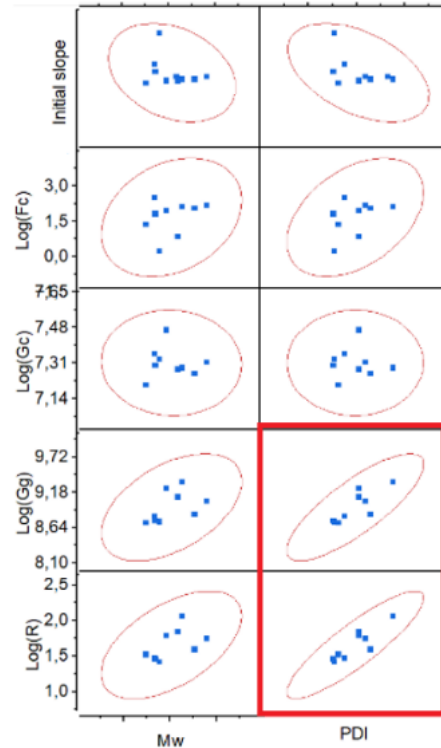


Schematic of GPC analysis

$$\text{Polydispersity index (PDI)} = \frac{M_w}{M_n} \uparrow$$

Task 2 Assessment of bitumen & rejuvenator properties

Influence of Chemical Properties on Rheological Properties at virgin state

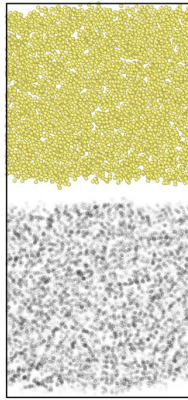


- **O/C and PDI** --> Good and Positive correlation with G_g (Glass complex modulus) and R value
- **Upgrading Process** --> Base bitumen become stiffer at low and medium temperature

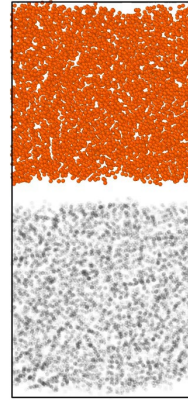
Task 2 Assessment of bitumen/rejuvenator properties

MD simulation: Influence of bitumen on Rejuvenator Efficiency

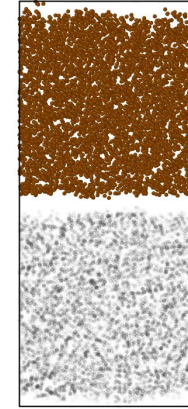
Bitumen-F
(Sulfur 4.3%)



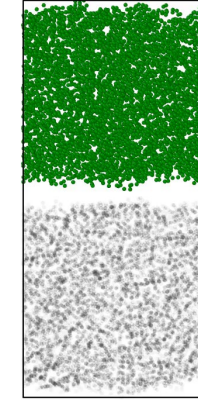
Vegetable Oil



Engine Oil

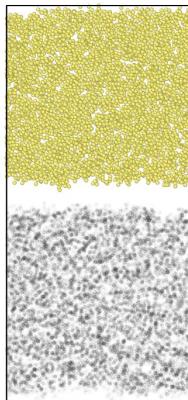


Aromatic Oil

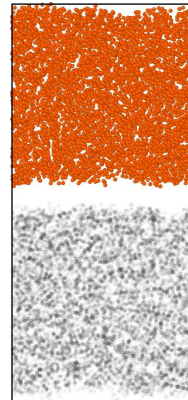


Naphthenic Oil

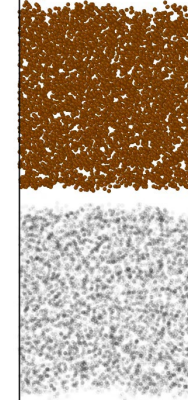
Bitumen-N
(Sulfur 0.7%)



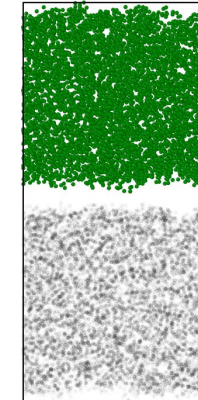
Vegetable Oil



Engine Oil



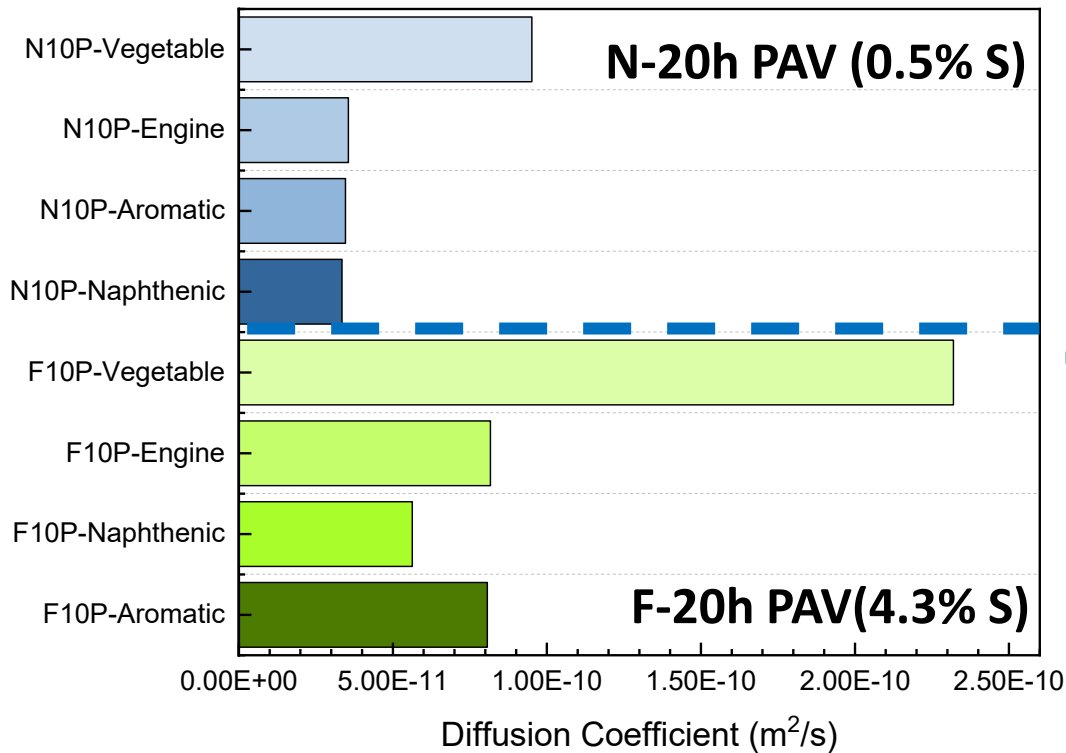
Aromatic Oil



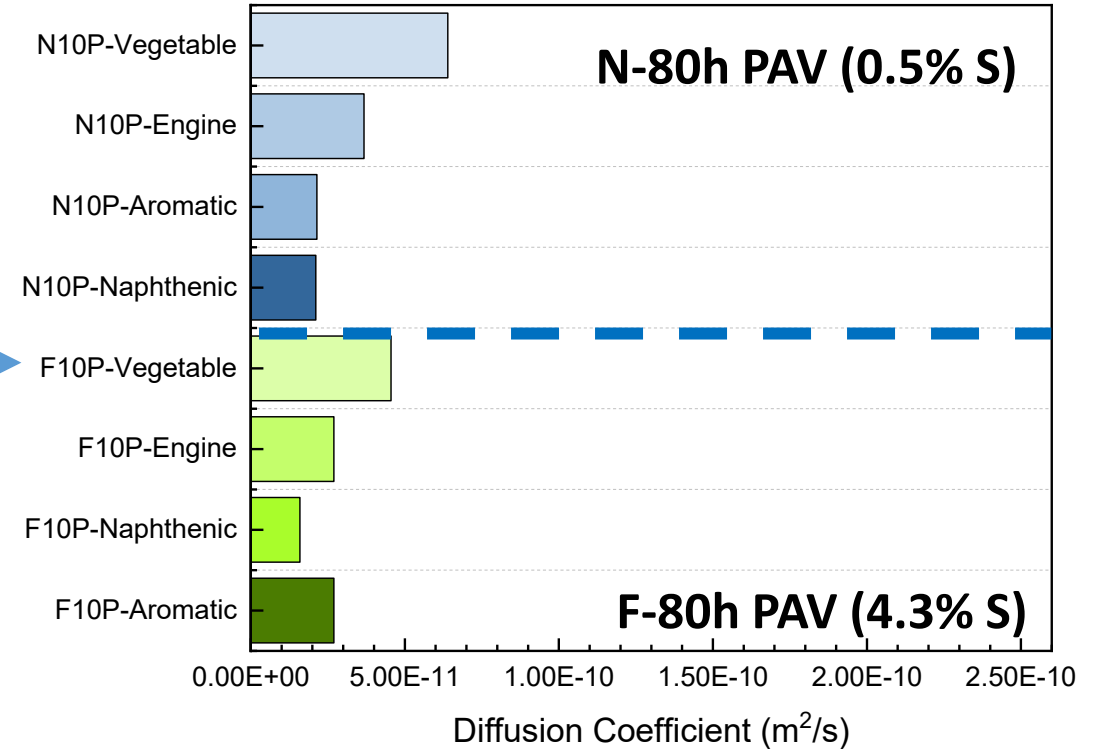
Naphthenic Oil

Task 2 Assessment of bitumen/rejuvenator properties

MD simulation: Influence of bitumen on Rejuvenator Efficiency



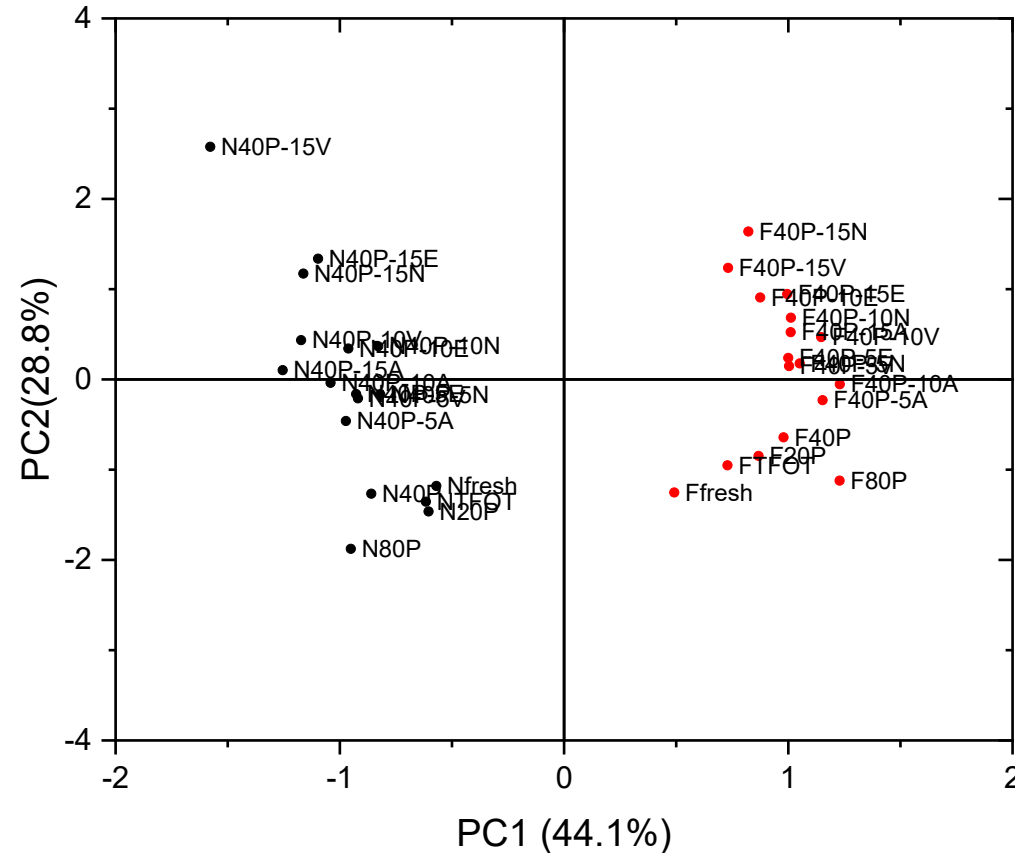
Lab Aging



Sulphur content influences the **rejuvenation efficiency** at different aging degrees.

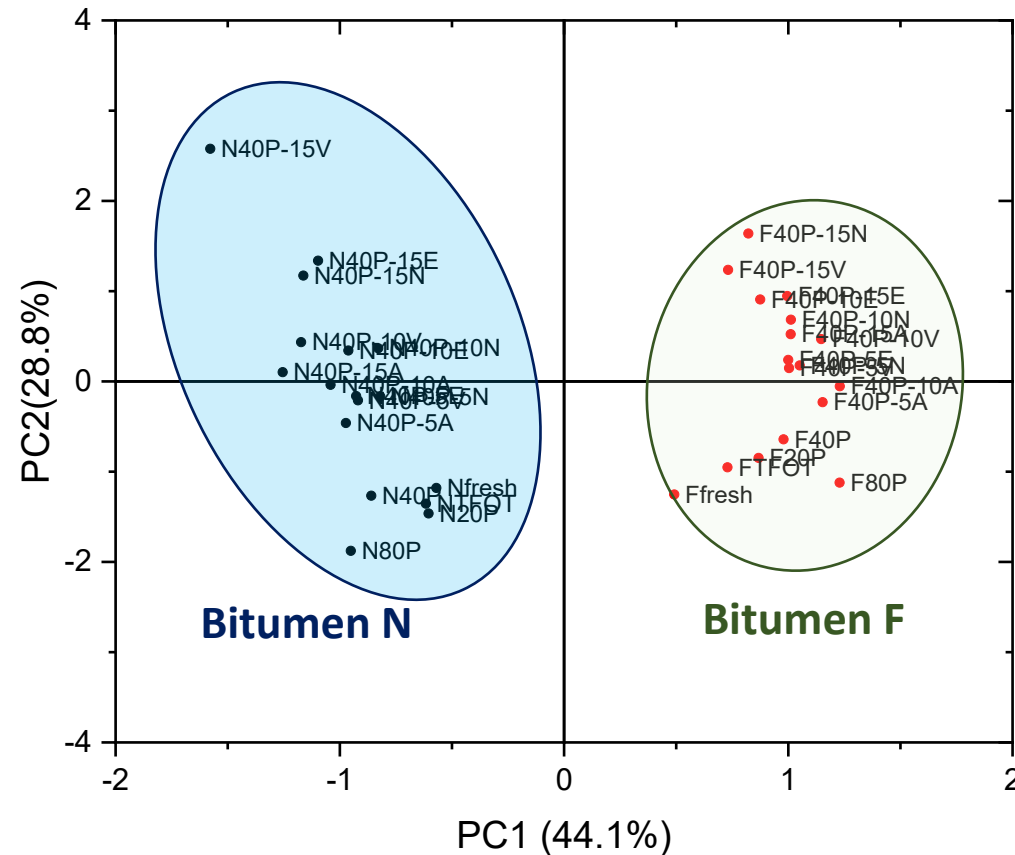
Task 2 Assessment of bitumen/rejuvenator properties

PCA: Distinguish the Influence of Bitumen Property and Rejuvenation Effect



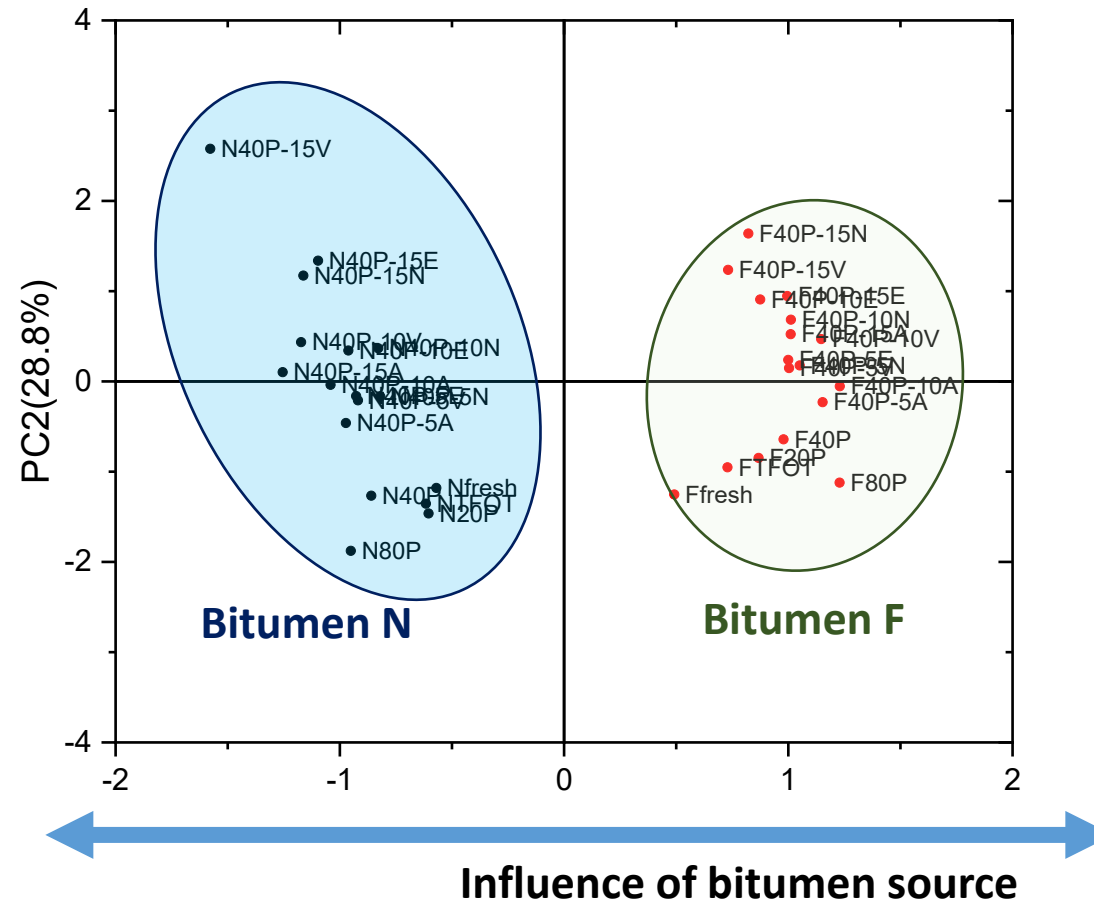
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PCA: Distinguish the Influence of Bitumen Property and Rejuvenation Effect



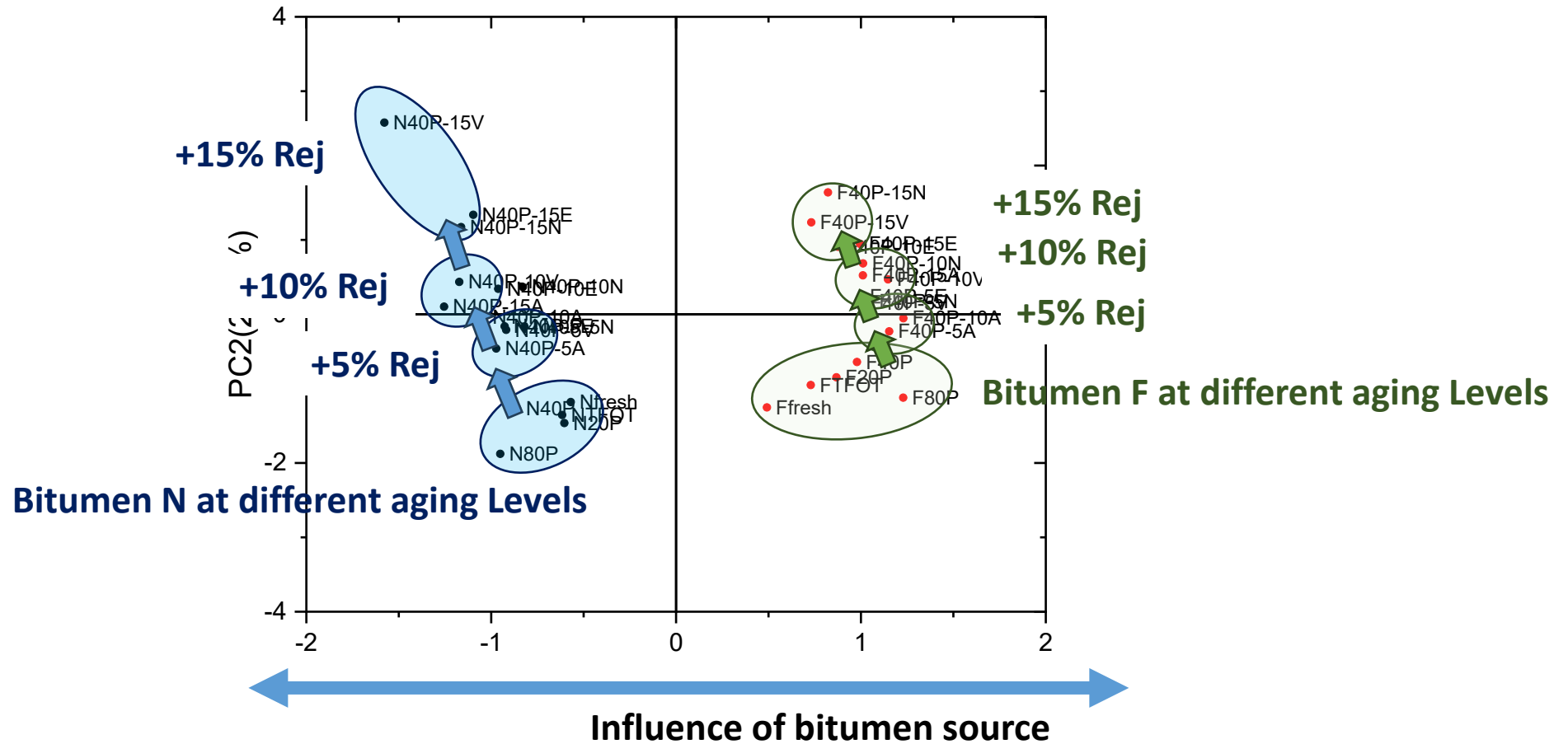
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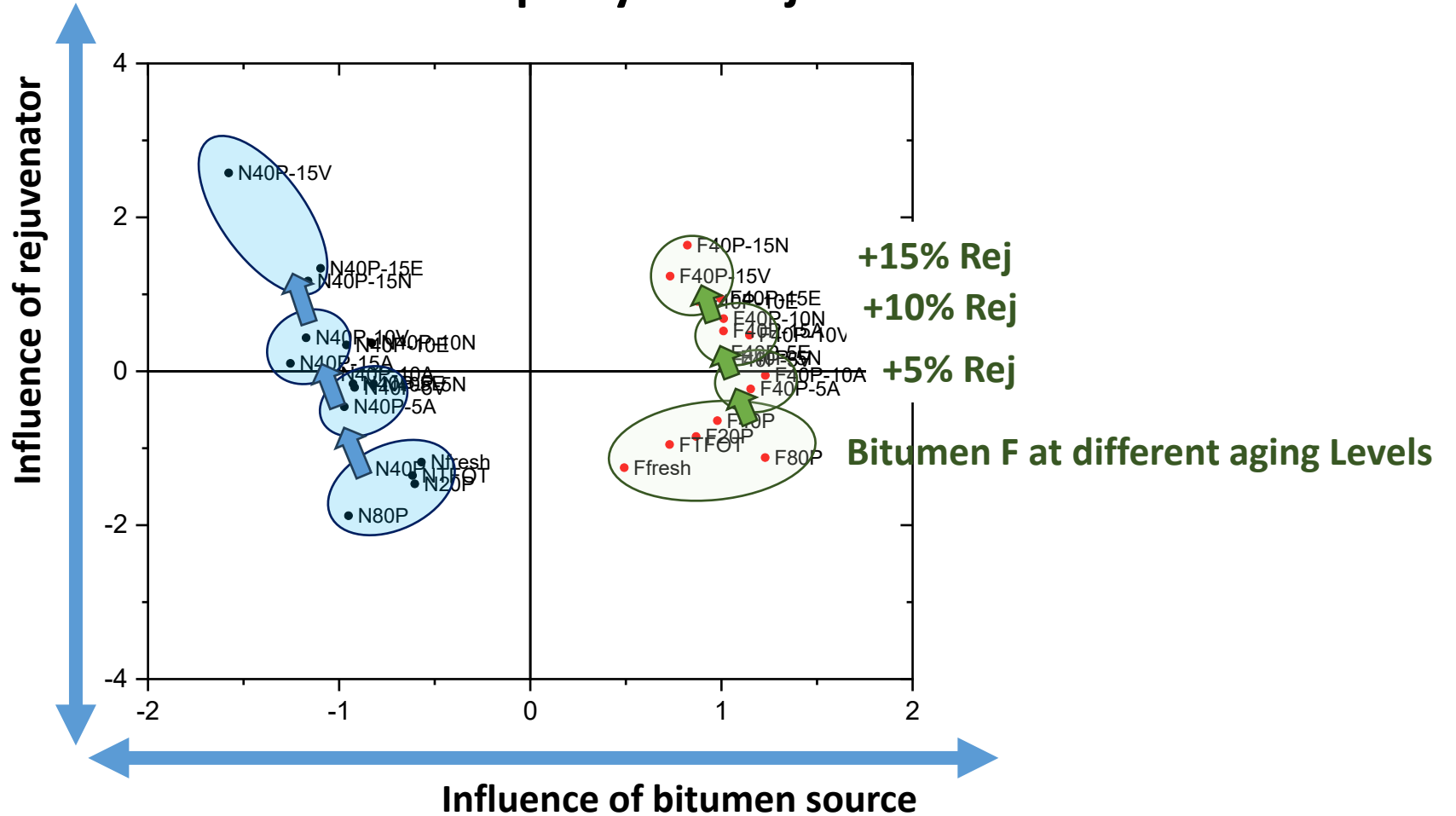
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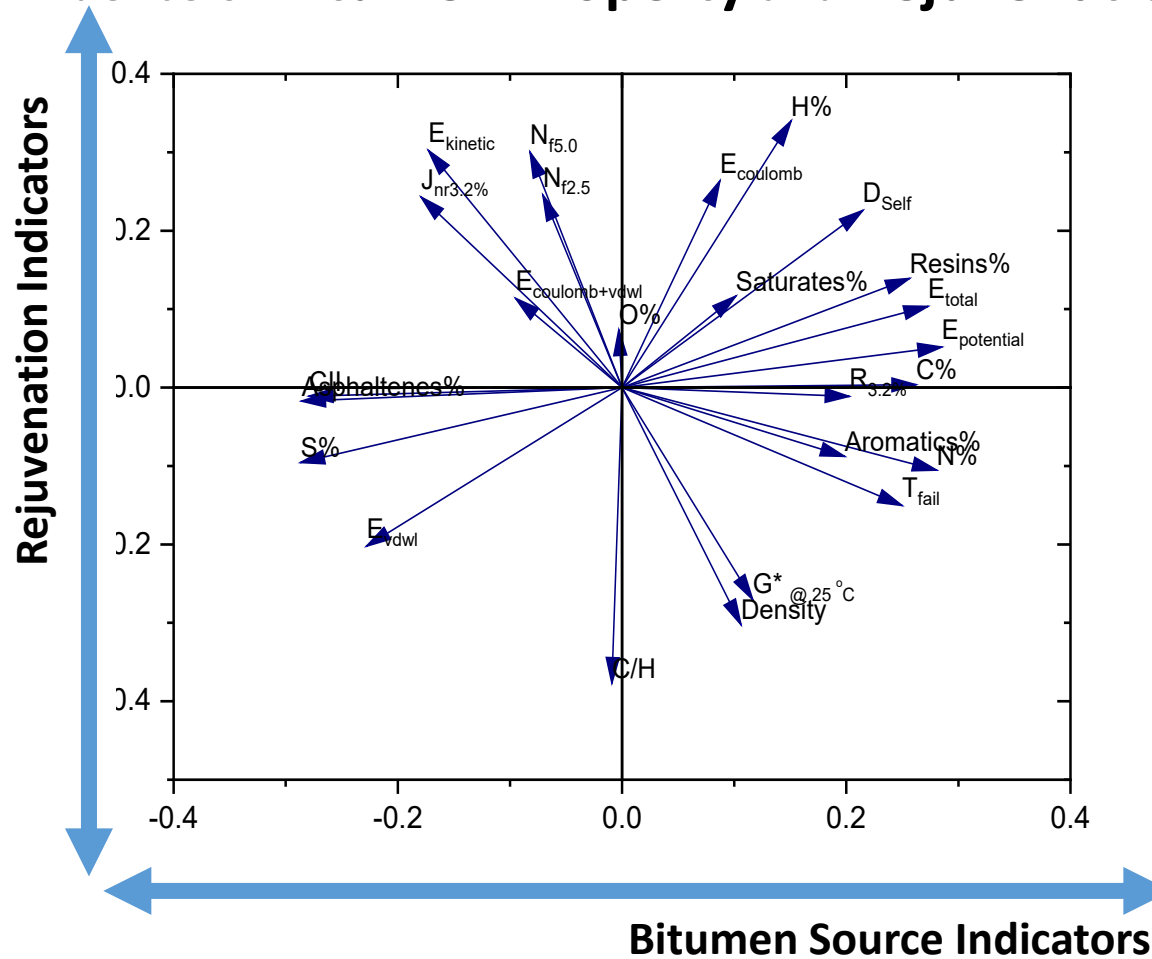
Task 2 Assessment of bitumen/rejuvenator properties

PCA: Distinguish the Influence of Bitumen Property and Rejuvenation Effect



Task 2 Assessment of bitumen/rejuvenator properties

PCA: Distinguish the Influence of Bitumen Property and Rejuvenation Effect



Task 2 Assessment of bitumen/rejuvenator properties

Selection Critical Rheological and Chemical Indicators

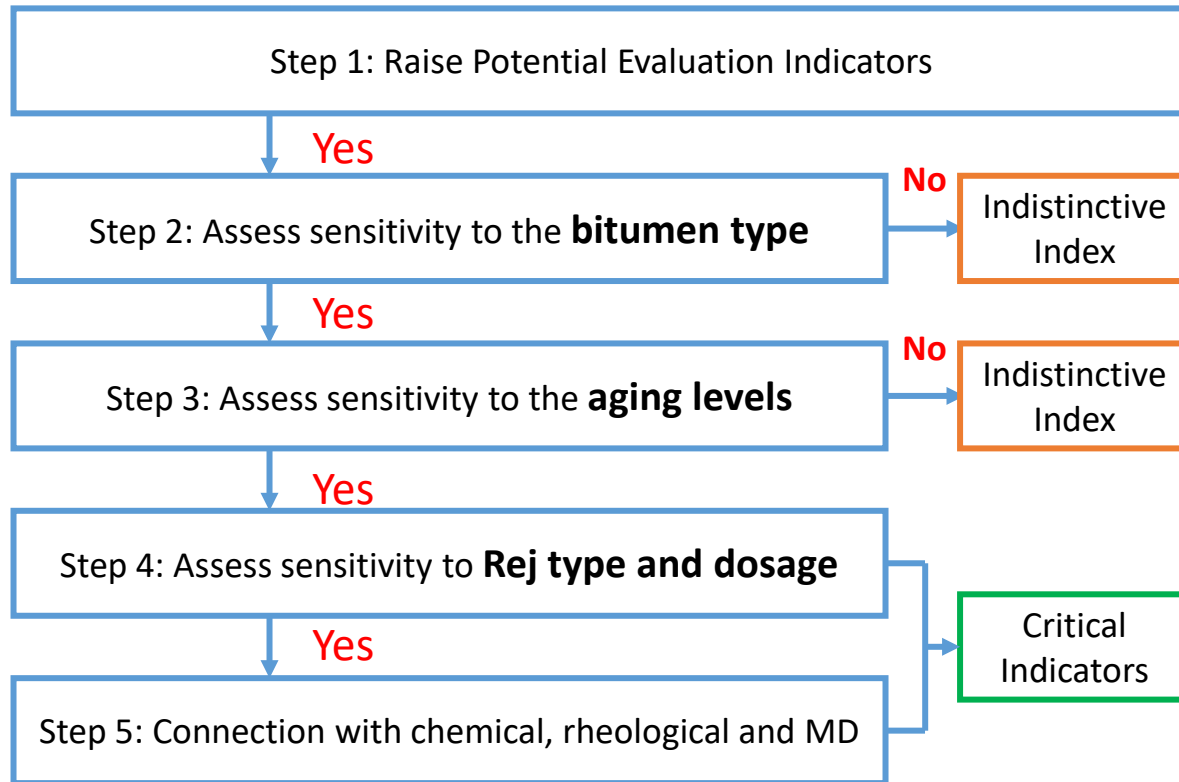


Fig. Procedure to Select Critical Rheological and Chemical Indicators



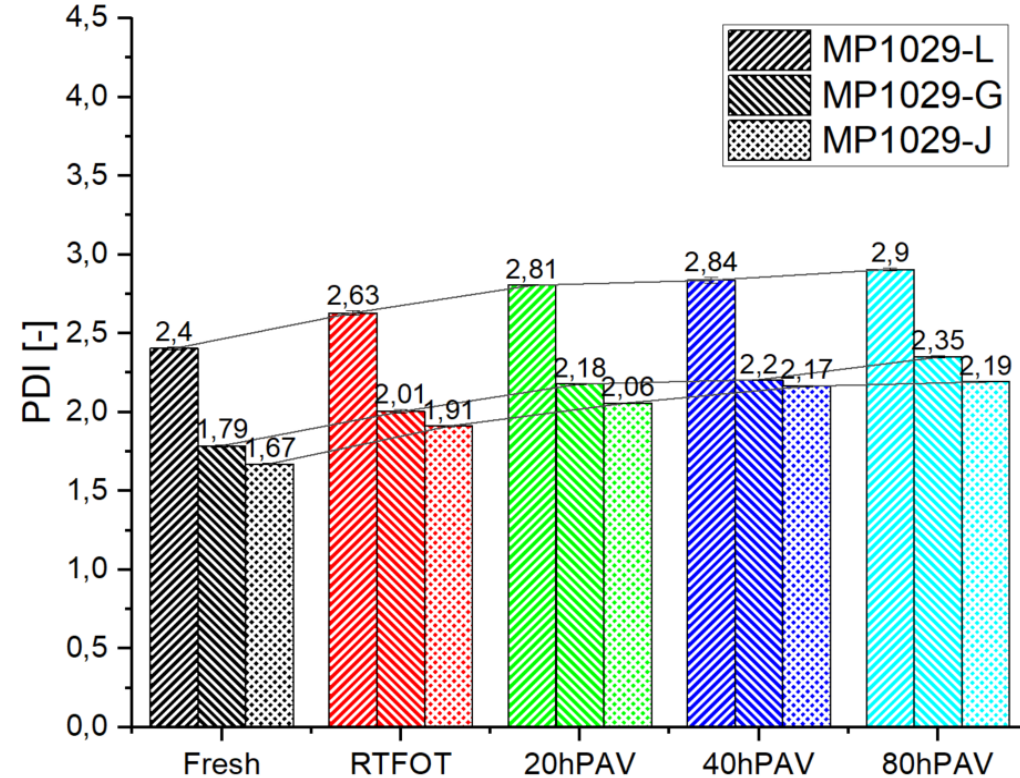
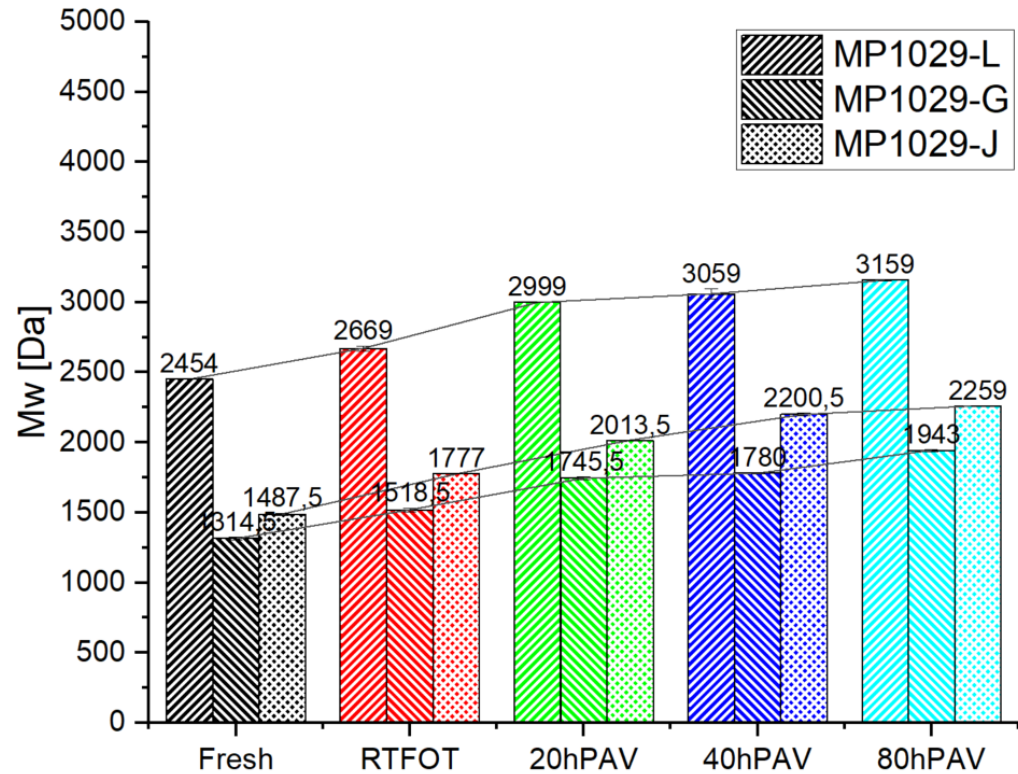
*Rheological parameters
(G^* , δ , G_c , f_c , A_{ML} , A_{MH} , A_{MT})
 **Rheological-based rejuvenation percentage
(G^*R , δR , G_cR , f_cR , A_{MLR} , A_{MHR} , A_{MTR})
 Rheological performance from DSR



*Chemical indices
(AI , AIL , $BAIL$, LCI , CI , SI)
 **Chemical-based rejuvenation percentage
(AIR , $AIRR$, $BAIRR$, $LCIR$, CIR , SIR)
 Chemical characteristics from FTIR

Task 3 Properties in relation to durability

Influence of bitumen type on molecular weight at different aging levels

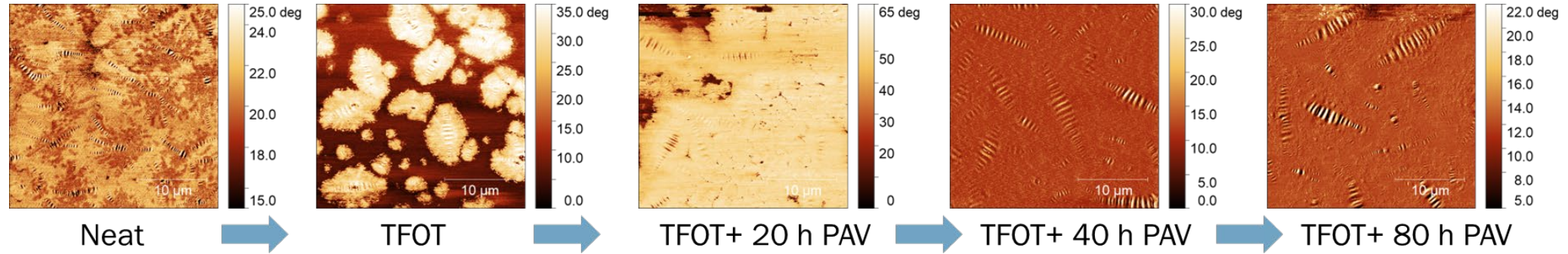


Bitumen with higher sulfur shows higher **molecular weight** and **PDI** after aging

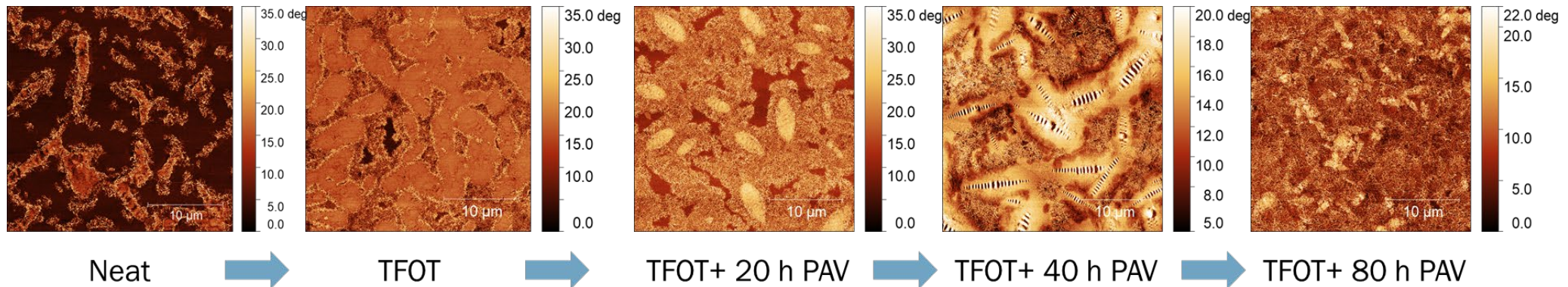
Task 3 Properties in relation to durability

Influence of bitumen type on AFM morphology at different aging levels

MP 1029-L



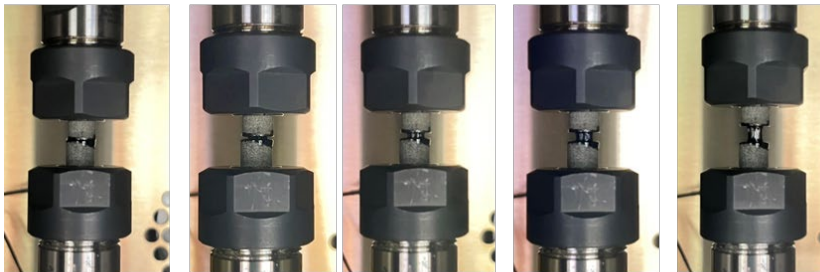
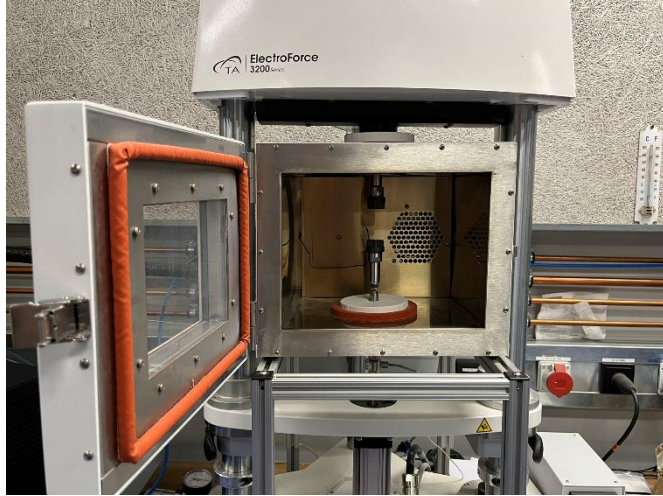
MP 1029-G



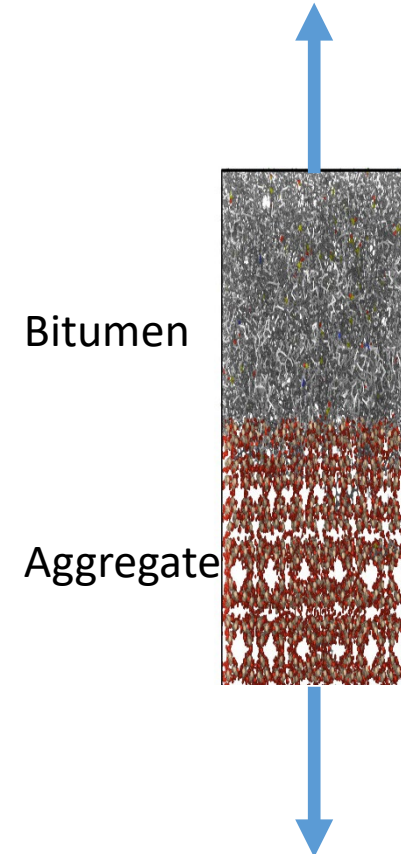
With different source and refining process , **aging effect on morphology** is obviously different.

Task 3 Properties in relation to durability

Influence of bitumen type and rejuvenator on Adhesion durability (On Going)



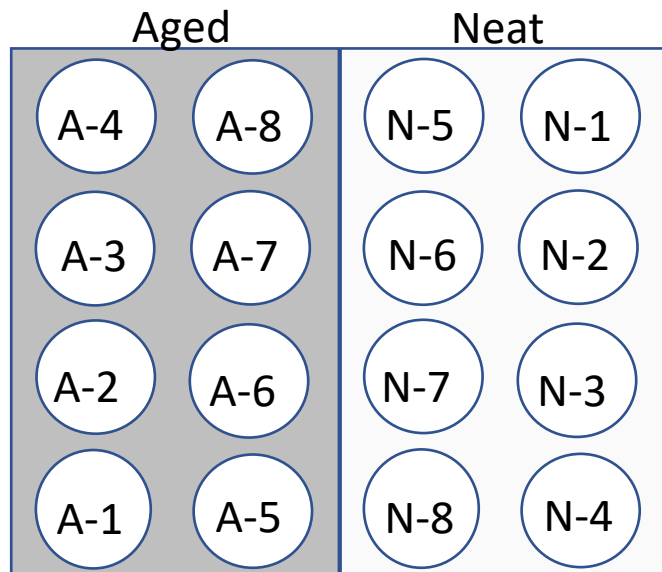
Dynamic Mechanism Analyzer



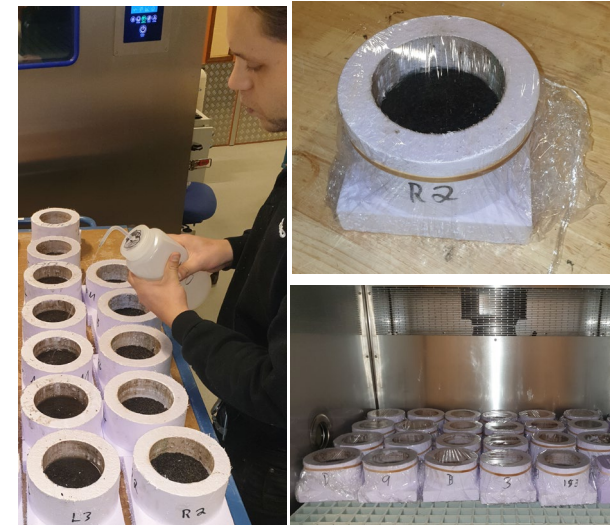
MD Simulation on Adhesion Property

Task 4 Impact and assessment of binder Properties in asphalt performance

- Evaluation in severe thermal cycles (**On Going**)
 - Aging susceptibility of asphalt mixture
 - Freeze/thaw cycle



Ageing in the oven for 3 weeks @85 °C



Freeze/thaw cycle

Future output for practical application

- **Binder performance indicators** that can *verify the suitability* of binders for asphalt construction and also *ensure quality, durability and recyclability*.
- Guideline and recommended *rheological and chemical parameters* to identify and assess the *performance* of different *rejuvenator types, and rejuvenator dosages* based on base bitumen type and aging degree
- *Framework for ‘characterization and evaluation of binder properties’* to give a better insight into current changes and *mapping the potential sources of change in relation to property or quality and consistency*



Ageing of Asphalt Pavements (AAP+)

AAP+ towards the next-generation ageing protocols



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and Water Management



Seminar: 'Bouwen op Kennis'

*Met KPE naar een
klimaatneutrale weg*

31 oktober 2023

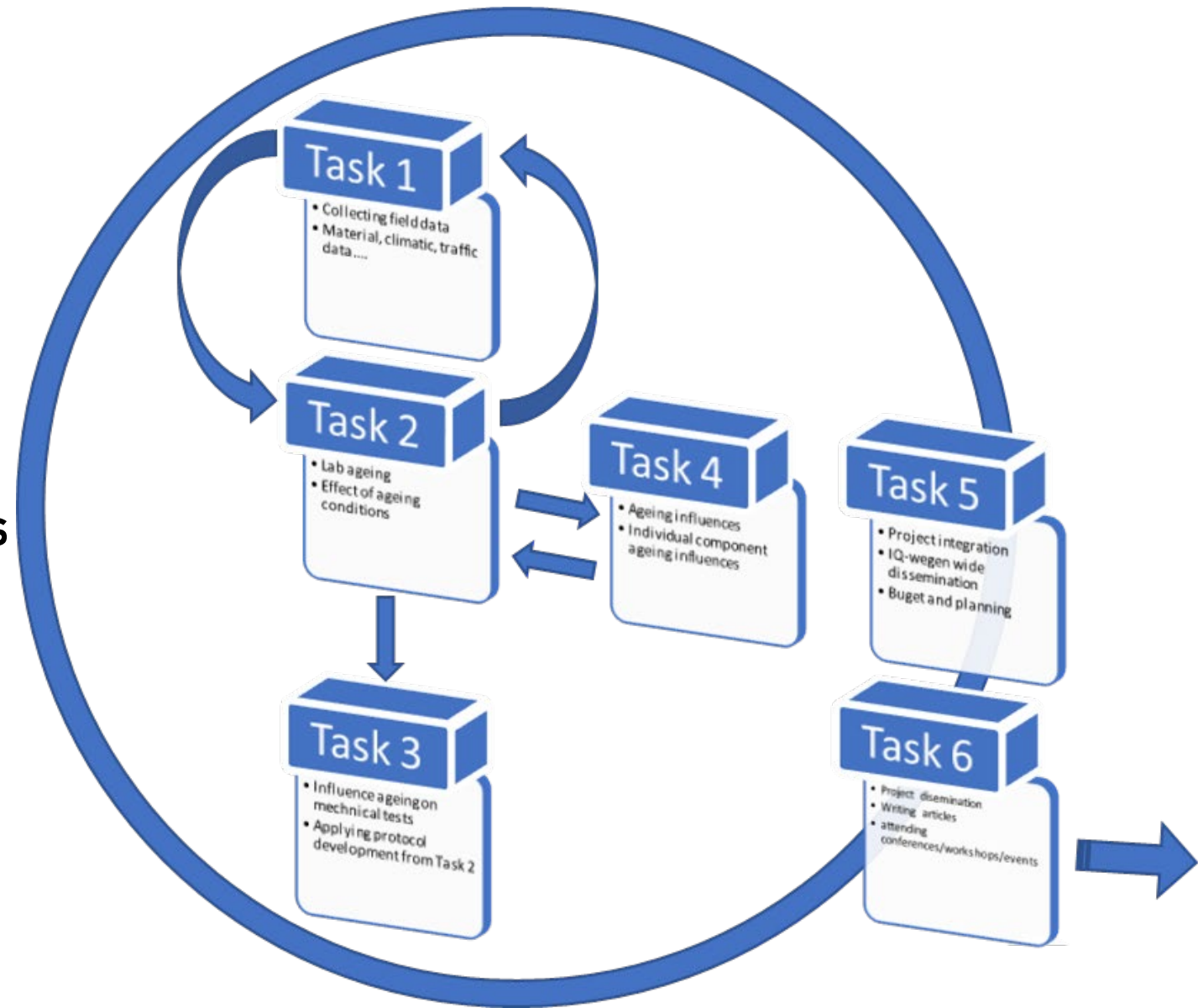
**Katerina Varveri
Diederik van Lent
Sadaf Khalighi**

**Knowledge-based
Pavement
Engineering
2020-2024**

TNO  **TU Delft**

Project overview

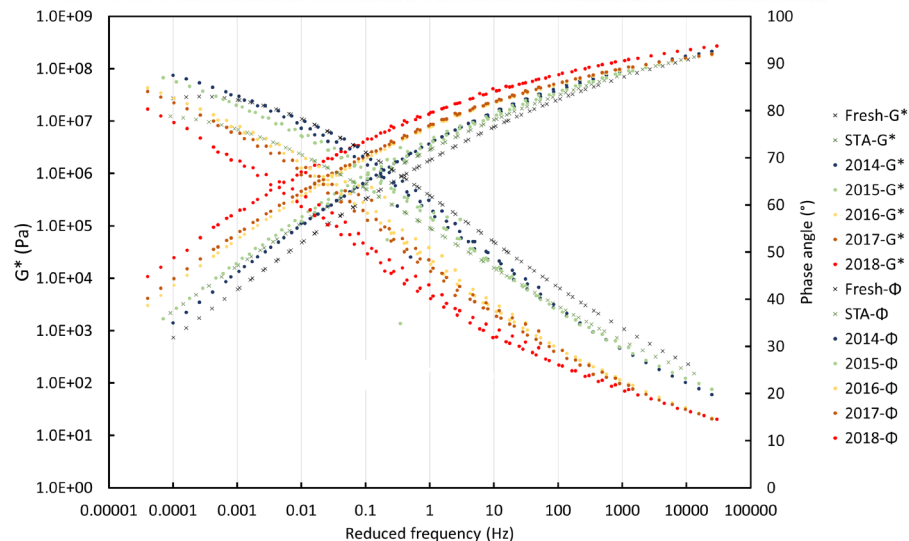
- Task 1: Field data
- Task 2: Development of lab ageing protocols
- Task 3: Ageing influence on mechanical properties
- Task 4: Influence of environmental/compositional aspects on ageing
- Task 5: Project integration
- Task 6: Publications



Task 1 Data collection

- **Objective:** collection of field ageing and climate data to set the boundary conditions and validate the laboratory ageing protocols

- **Activities and outputs:**



Field cores are characterized to serve as **reference for lab ageing protocol**



Extract info from
GMS data

Establish the boundaries for the lab ageing protocols (Task 2) by adding environmental factors that significantly influence the ageing process.

Task 2 Developing lab ageing procedures

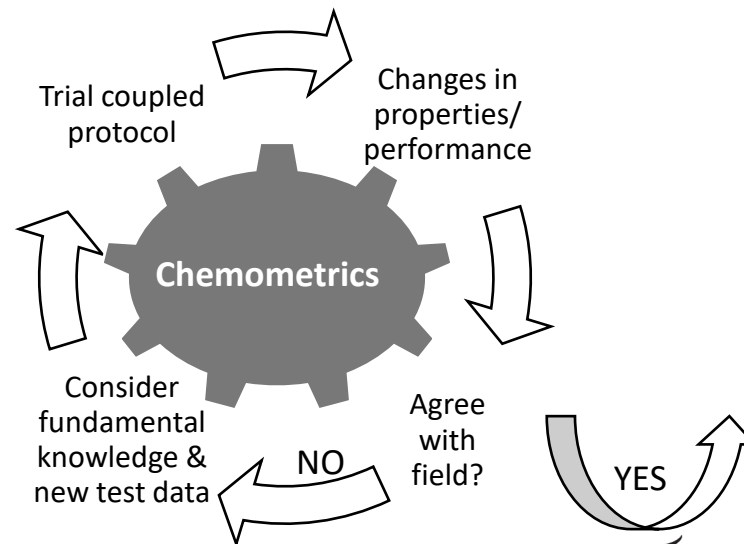
- **Objective:** Develop **artificial ageing procedures** that are more representative for road practice.

*What is a representative **binder/mixture ageing protocol** considering fundamental knowledge and field data (Task 1)?*

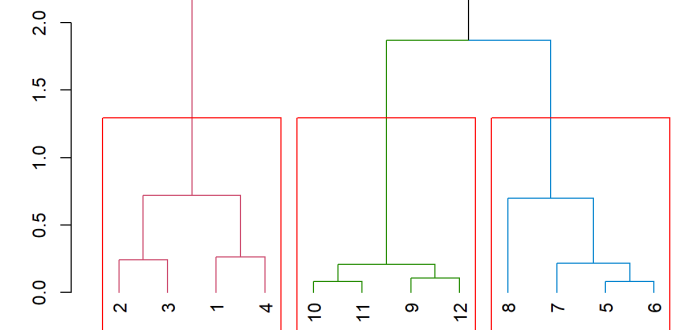
- Coupled conditioning: PAV at moist conditions, other reactive oxygen species (ROS), high pressures.
- Feedback loop so that mechanisms/processes at lab agree with those at field.



Bitumen/mixture scale



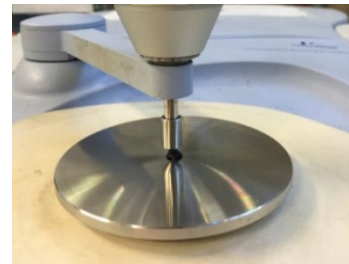
Chemometrics tool



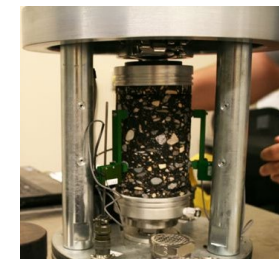
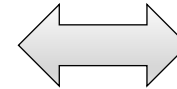
Task 2 Developing lab ageing procedures

- What is the **link between material performance** (bitumen/mastic level) with **mixture performance** of (porous) asphalt mixtures at initial conditions and after ageing?

Chemometrics; Multivariate statistics; Multiscale ageing modelling



Cross-scale relationships

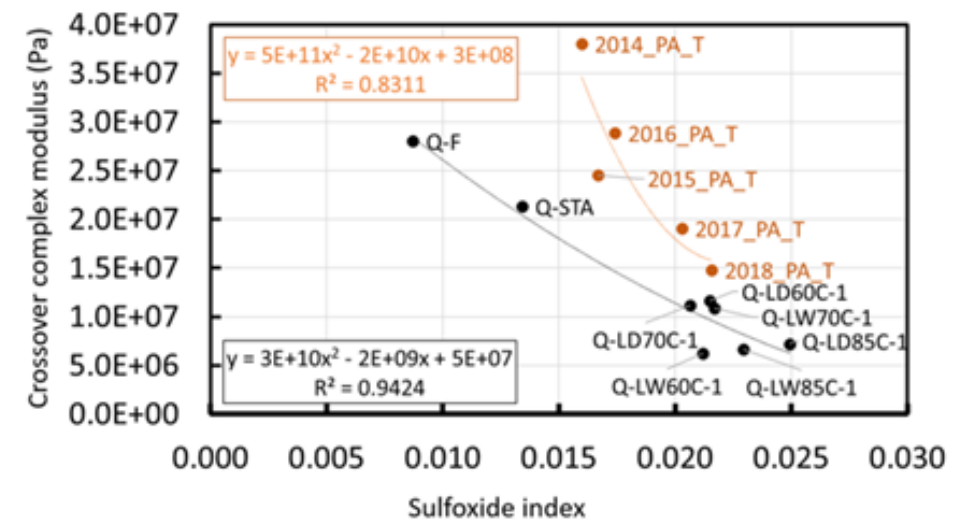


Chemistry & rheology

Strength & stiffness

- What are the **ageing sensitivity indices** to be used at the design/monitoring stage?

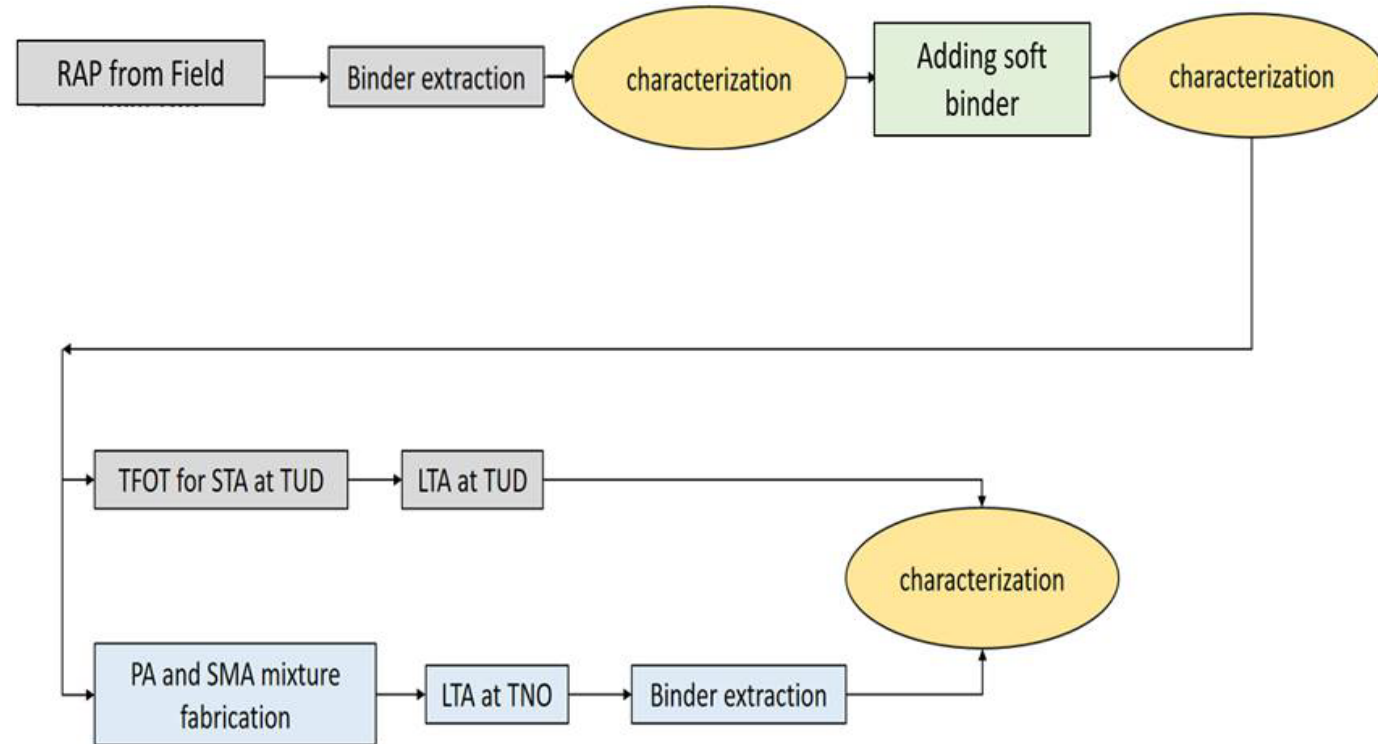
Critical properties/indices



Task 2 Developing lab ageing procedures

- *What are the impacts of developed ageing protocols on the **ageing** characteristics of **alternative binders**, for example RAP binder?*

RAP binder ageing behavior; sustainability benefits; ageing protocol optimization



Outputs:

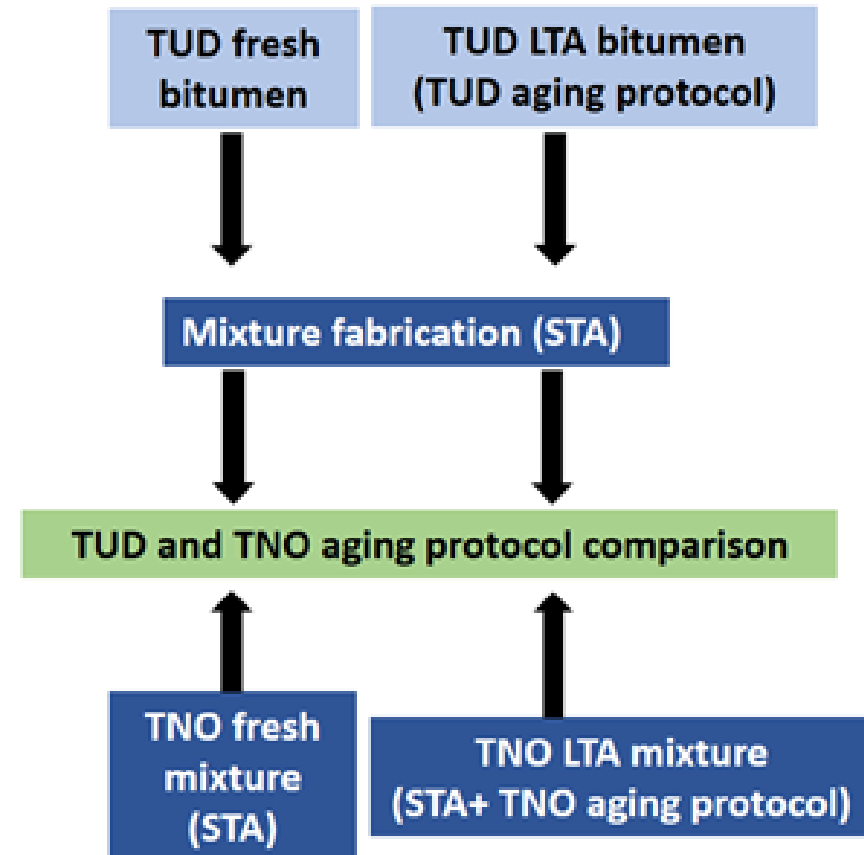
- Field representative accelerated aging protocol
- Multi-scale understanding of ageing phenomena
- Understanding of reclaimed asphalt ageing behaviour
- Proper indices for aging monitoring
- Chemometric tools for future studies

Task 3 Ageing influence on mechanical properties

- **Objective:** Investigate the effect of ageing on the mixture properties using mechanical tests, such as Thermal Stress Restrained Specimen Test (TSRST).

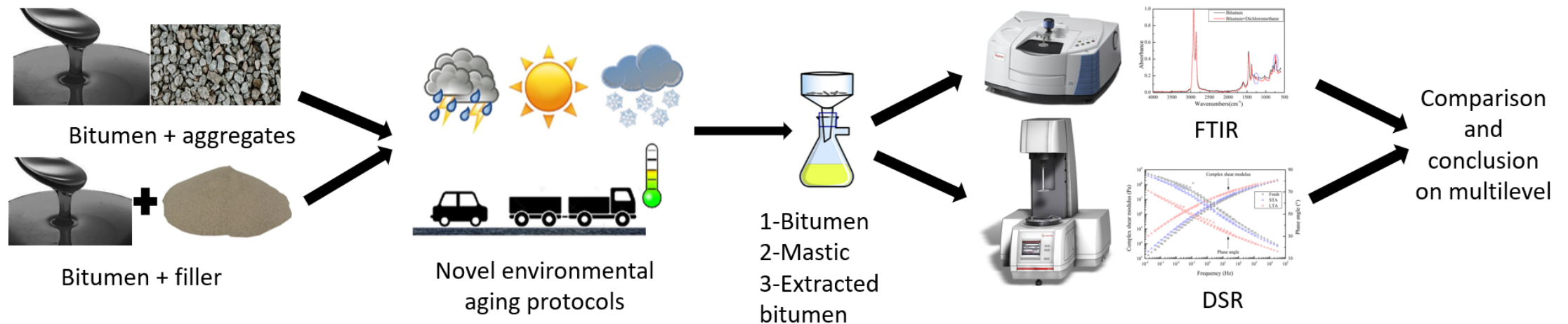
What is the effect of binder and mixture ageing protocols on mixture properties?

Output: Recommendation for a suitable ageing protocol for mixture scale testing (RWS blueprint).



Task 4 Ageing effects from environmental/compositional aspects

- **Objective:** Investigate the effect of individual environmental/compositional aspects on the developed laboratory ageing protocols.
 - What is the effect of **ageing/moisture/ozone/freeze-thaw** conditioning on mixture/binder ageing?
 - What is the effect of mineral **fillers** on binder **ageing/moisture sensitivity**?
 - How does ageing affect **binder-filler/aggregate adhesion** properties?



Output:

- Literature review on effect of filler on binder ageing
- Updates of the laboratory ageing protocols developed in Task 2.

Project outputs – relevance to practice

Provide in-depth insights into **multi-scale ageing phenomena**

Suitable **testing methods** for characterization of **binder/mixture ageing**

AAP+ objective
Develop a comprehensive laboratory ageing protocol that accurately simulates field conditions for both binders and mixtures.

Chemometric tools for binder fingerprinting and classification based on chemo-rheological properties

Refined **ageing parameters** for improving the **reliability** of laboratory ageing protocols

Ageing of Asphalt Pavements (AAP+)

AAP+ towards the next-generation ageing protocols



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Thank you! *Questions?*

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Ravelling Test/Assessment Method

R-TeAM



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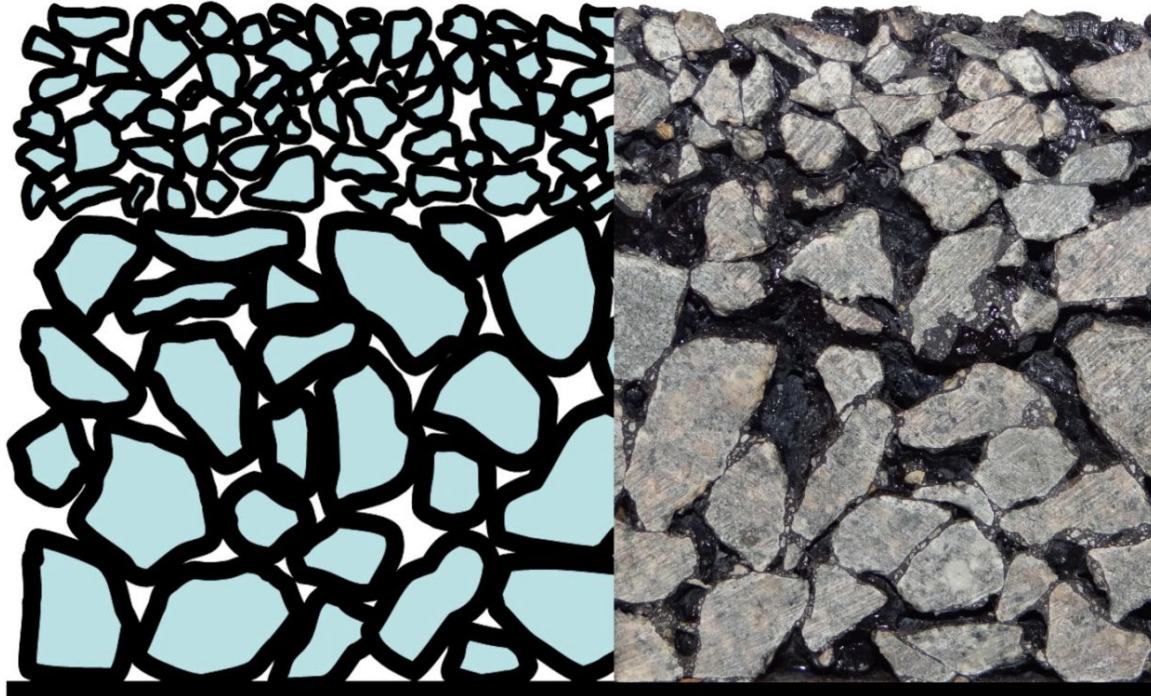
31 oktober 2023

Katerina Varveri
Filip Mastoras
Panos Apostolidis
Mahesh Moeniela
Cor Kasbergen
Dave van Vliet

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Use of porous asphalt in NL



(VBW Asfalt, 2013)

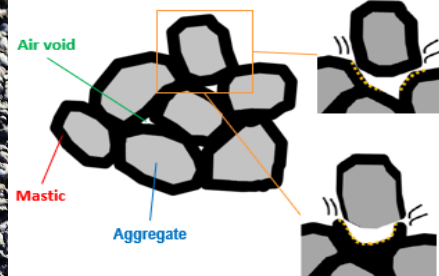
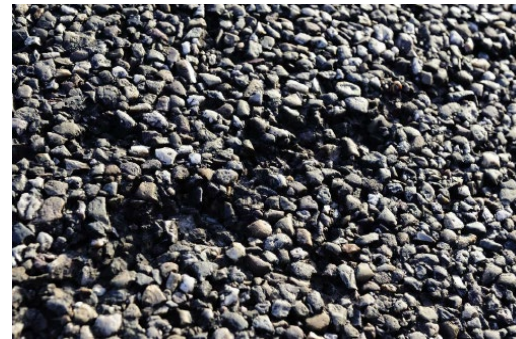
- Dutch highways > 90% ZOAB
- ZOAB 0/16: > 80%

- ✓ Excellent noise reduction characteristics
- ✓ Drainage properties, help avoid “splash and spray” effects and hydroplaning

Problem statement



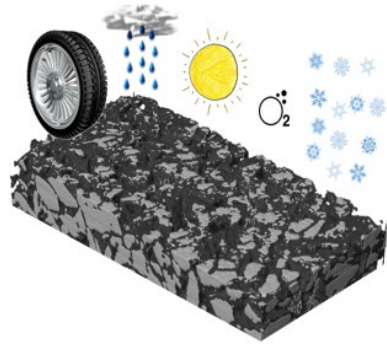
Ravelling (stone loss)



- ✓ Main distress type in NL
- ✓ No reliable and/or complete test method/requirement

Goal of the R-TeAM

Develop a testing protocol for the prediction of ravelling resistance of asphalt mixtures



- ✓ Representative of the field situation
 - Realistic loading states
 - Degradation processes

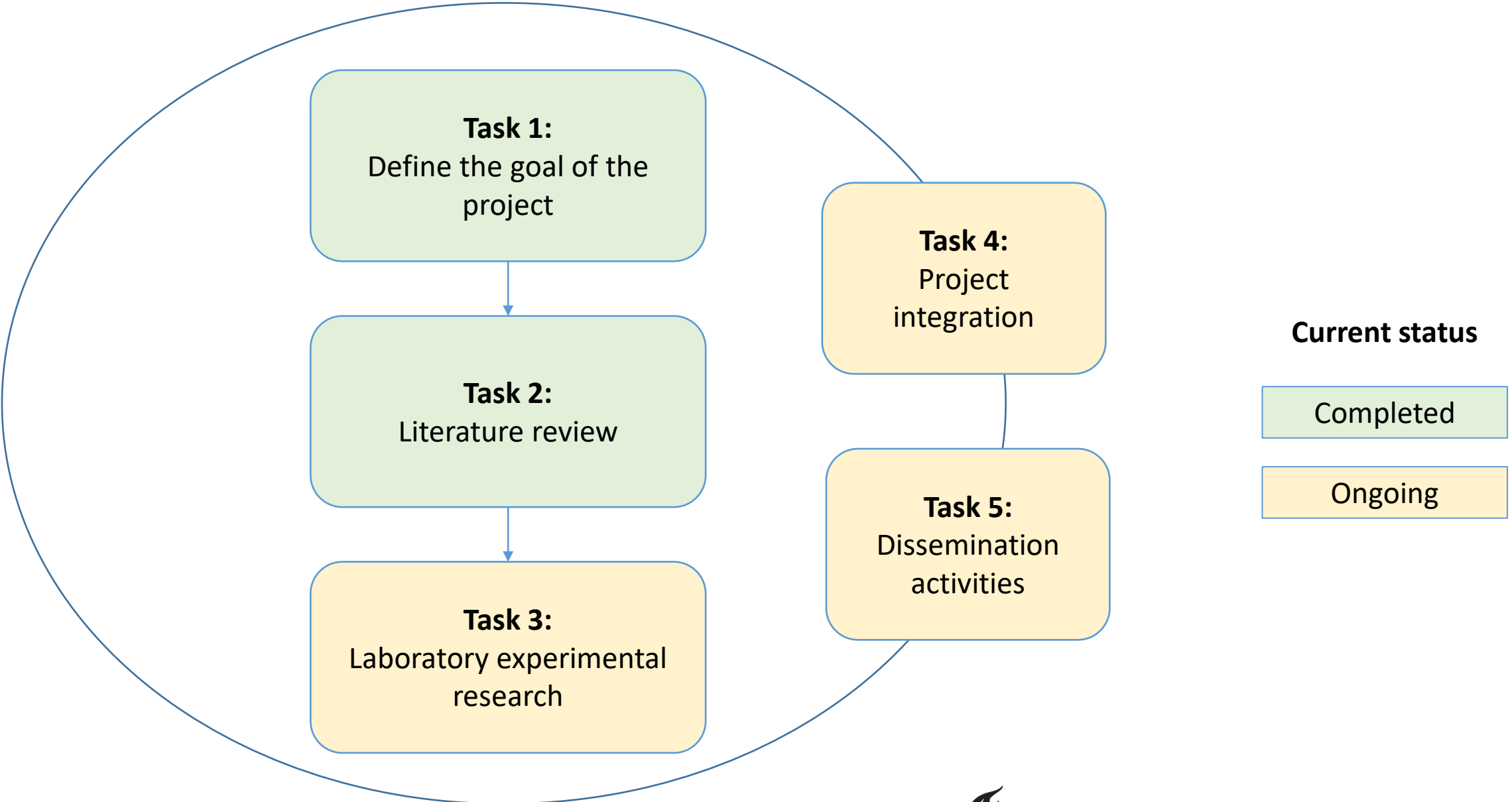


- ✓ Discriminative ability
 - Good and poor performing asphalt mixtures
 - Reference and candidate asphalt mixtures



- ✓ Relatively simple to apply
 - Straightforward set-up
 - Familiar to the sector

Project approach



Task 2: Literature review

Goal: Serve as basis for the design of the experimental research

Focus



- ✓ Identify potential test methods and models to assess ravelling
- ✓ Identify links of these tests/models to field performance
- ✓ Identify reference materials, with expected good and poor performance

Result



- ✓ A proposed assessment method with 4 steps:
 1. Sample preparation
 2. Conditioning
 3. Mechanical testing
 4. Evaluation
- ✓ Most promising materials, procedures, methods and protocols, per step

Task 3: Experimental research Materials – Asphalt mixtures



Reference asphalt mixture		
Bitumen type	Filler type	Compaction temperature
70/100 Pen	Wigro 60K + 1% baghouse dust	145 °C



(Expected) poor performing asphalt mixture 1		
Bitumen type	Filler type	Compaction temperature
70/100 Pen	Baghouse dust	145 °C



(Expected) poor performing asphalt mixture 2		
Bitumen type	Filler type	Compaction temperature
70/100 Pen	Wigro 60K + 1% baghouse dust	110 °C



Task 3: Experimental research Materials – Bituminous mastics

Asphalt mixtures

Reference asphalt mixture		
Bitumen type	Filler type	Compaction temperature
70/100 Pen	Wigro 60K + 1% baghouse dust	145 °C



(Expected) poor performing asphalt mixture 1		
Bitumen type	Filler type	Compaction temperature
70/100 Pen	Baghouse dust	145 °C



Mastics

Reference bituminous mastic	
Bitumen type	Filler type
70/100 Pen	Wigro 60K + baghouse dust



(Expected) poor performing bituminous mastic	
Bitumen type	Filler type
70/100 Pen	Baghouse dust



Task 3: Experimental research Conditioning



AAP+ protocols

Asphalt slabs oven ageing
9 weeks @ 85 °C



Bituminous mastics
TFOT+PAV ageing
with 99% RH in PAV chamber



+



2 different protocols

Frost-Thaw

Protocol	Moisture conditioning	Thermal loading
(I)	 No moisture conditioning	 No thermal loading
(V)	 Vacuum saturation at 25°C	 Sample is sealed and the macro pores are saturated with water

MIST



Task 3: Experimental research

Mechanical testing

Asphalt mixtures

Ravelling resistance

RSAT



Strength

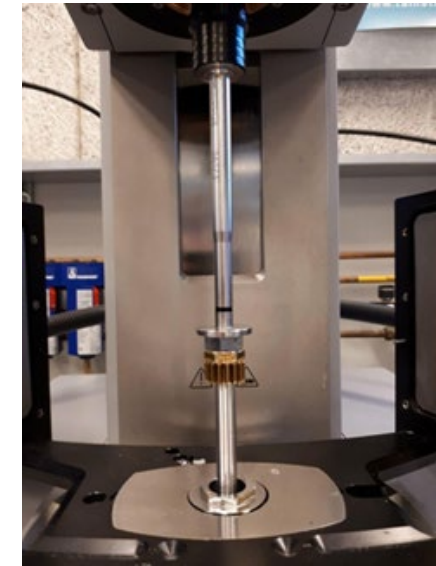
ITT



Mastics

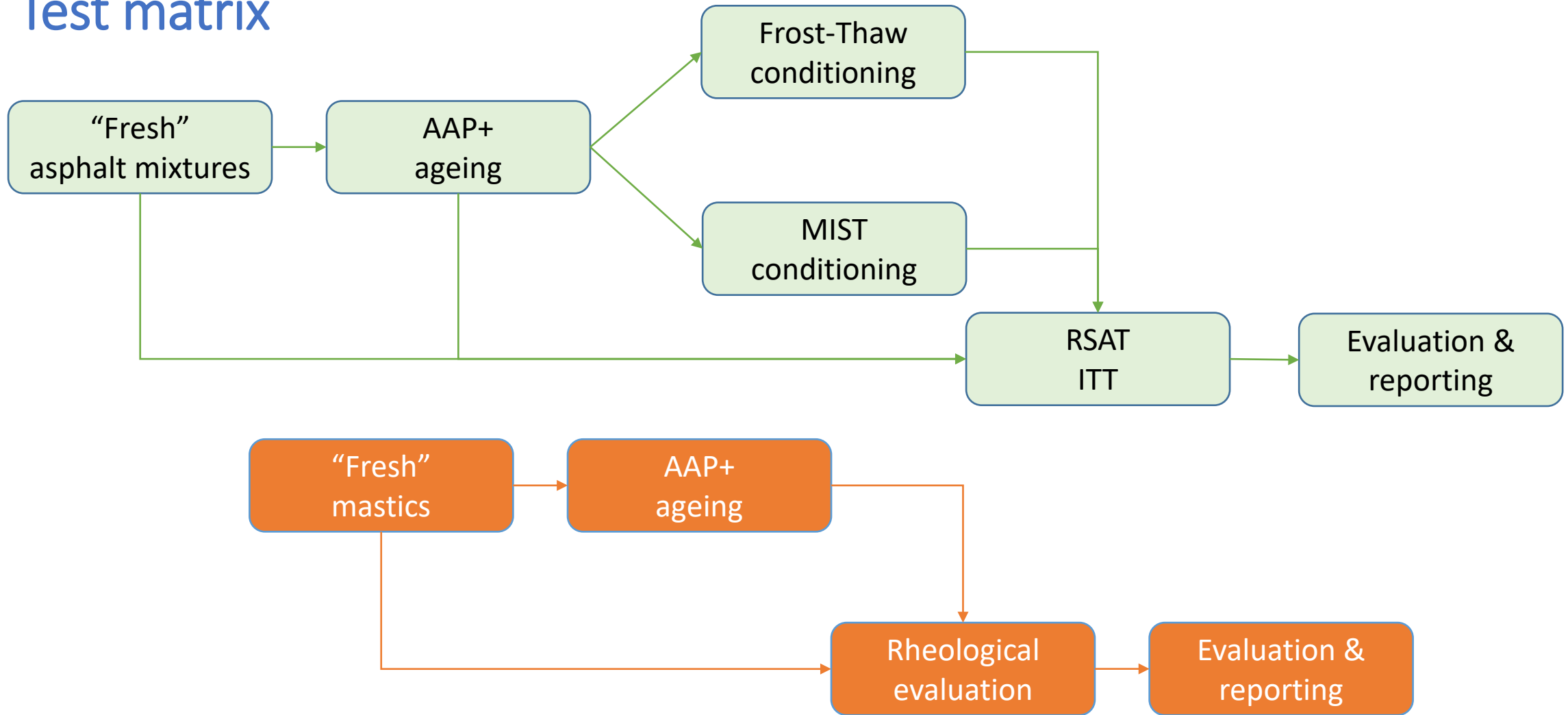
Rheological evaluation

DSR



Task 3: Experimental research

Test matrix



Project conclusion and deliverables



End of 2024

Conclusion of the study and final report:

- Results on asphalt mixture level
- Effect of conditioning on mechanical properties
- Discriminative ability of the protocol
- Possible relations with results on mastic level

End of 2023

Mastics evaluation report:

- Rheological results
- Analysis and interpretation of results

Mid 2023

Literature review

Thank you for your attention!

Questions?

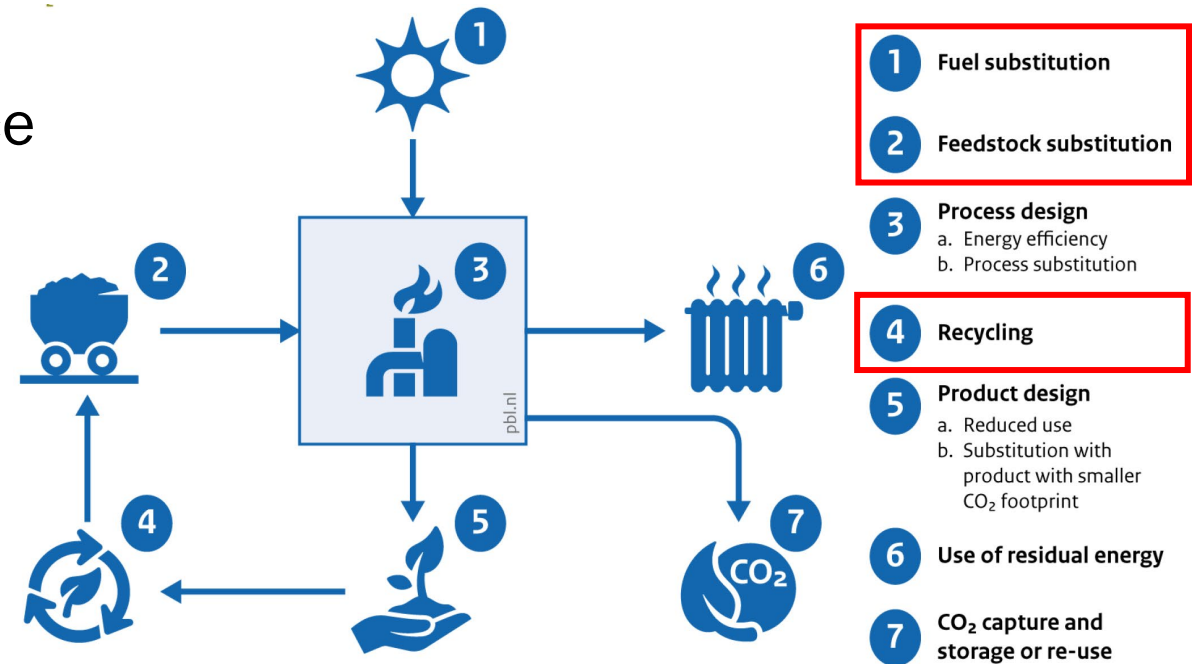


Future outlook



EAPA's goals for climate-neutral asphalt industry

- Decarbonisation
- Sustainable construction & maintenance
- Research and innovation



CO₂ reduction categories

Source: PBL ([Decarbonisation options for the Dutch asphalt industry](#) | [PBL Netherlands Environmental Assessment Agency](#))

Transition path towards 2050 - RWS



2023

2030

2050

Increasing RAP content

- Use of more RAP
- Using RAP at the surface layers (25-30%), even higher ~ 60%
- Overall reduction of using primary materials

Producing asphalt at low temperature

- <140 °C warm mix asphalt
- <110 °C half warm asphalt
- With foaming technology, 100-110 °C

Changes and quality aspects of asphalt binder

- Roadmap- biobased binder
- Alternative binders (waste streams from other sources) → needs further research

Standardization
& validation

Method to assess the effect of healing and aging on fatigue



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**Panos Apostolidis
Greet Leegwater
Xueyan Liu
Diederik van Lent
Filip Mastoras**

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2020-2024**

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Project Ultimate Goal

The goal of RWS is to develop a practical protocol to determine shift factors for the laboratory fatigue life of asphalt mixtures to correct for healing and aging.

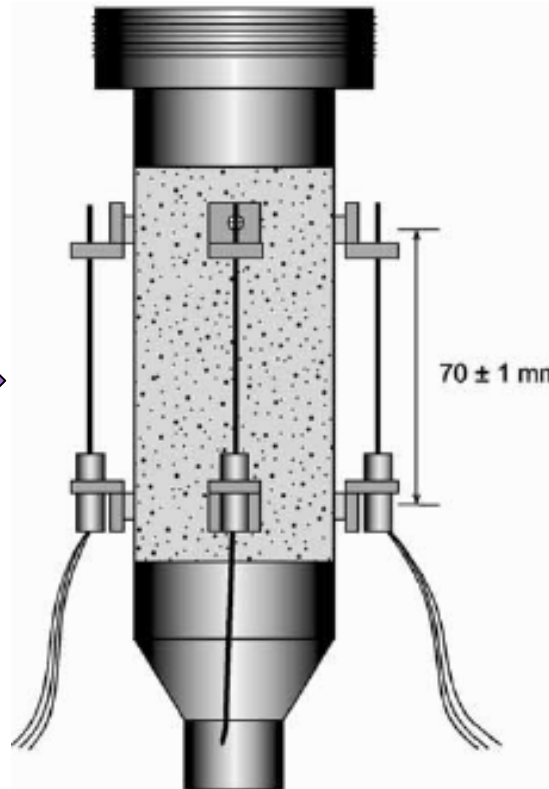
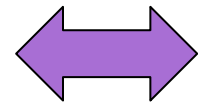
Project Intermediate Goals

- The state-of-the-art on the topic of healing and aging with respect to fatigue
- Study asphalt base layers to assess the impact of changes in design on healing and aging
- Assess variation in healing of binders that are currently in use for asphalt base layer
- Use the viscoelastic continuum damage theory to predict fatigue response considering healing

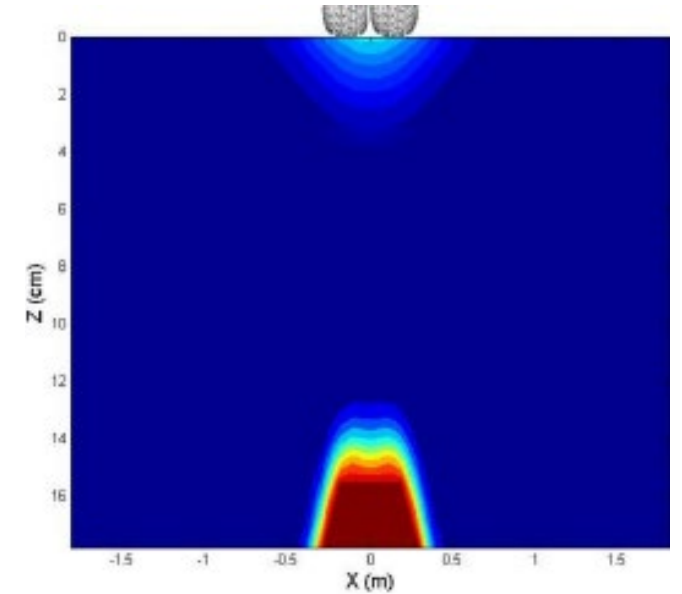
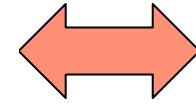
Laboratory program – from binder to pavement



asphalt binder



asphalt concrete



pavement predictions

Binder experiments (Expansion & Two-piece healing)

Two-piece healing tests will address strength recovery after damage.

Expansion tests will address the tendency of cracks to close under the influence of increasing temperatures.

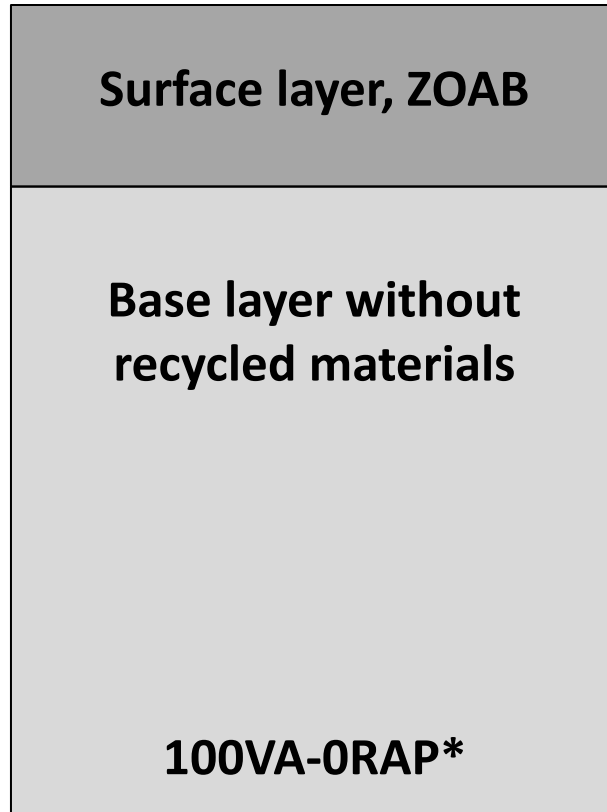
Materials:

- 40/60 (KPE Healing, TUD mixtures)
- 70/100 (KPE Healing, TUD mixtures)
- 160/220 (KPE Healing, TUD mixtures)
- Anova 1817 (KPE Healing, TUD mixtures)
- Q8 10/20, Q8 40/60, Q8 70/100
- Styrelf 40/100-65 A AP, CQPMB 2

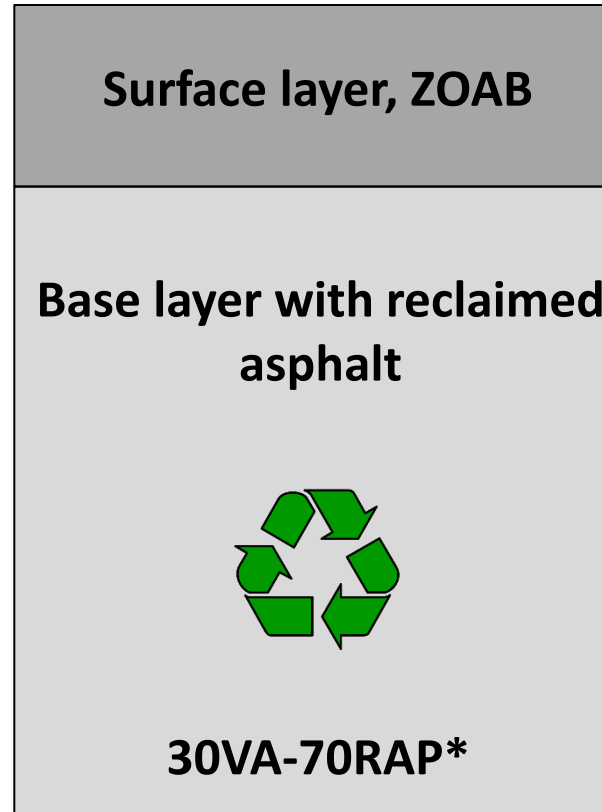


Material cases – the Dutch asphalt base mixtures

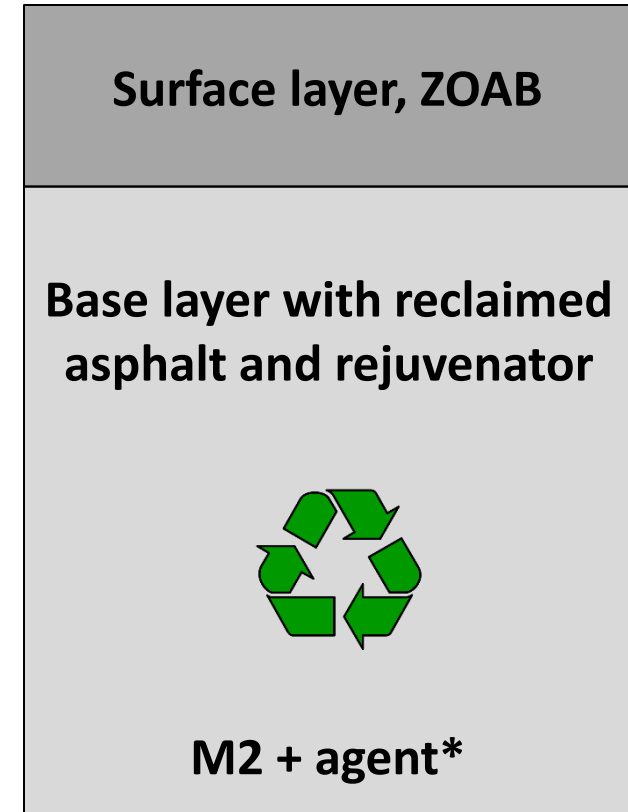
Mixture 1



Mixture 2



Mixture 3



* Aggregate Gradation: AC16 OL/TL 40/60 + PR (DTT537)

Laboratory produced mixtures and drill cores



Study in ageing and healing of asphalt base-layers

- Cores are drilled from older pavements with and without RA
- Expert workshop organized (June 27th 2023) to discuss test approach
- Tests plans on two levels:
 - Binder: FT-IR testing on slices of the cores to determine aging indexes
 - Mastic: Granulating cores, sieving them and DSR testing and DSC



Uniaxial test methods for asphalt mixtures

Standard Method of Test for
Determining Dynamic Modulus
of Hot

Standard Method of Test for

Determining the Damage
Characteristic

AASHTO
Technical
of Asphalt
Release: C

Standard Method of Test for
Determining the Damage
Characteristic

Mixture

Cyclic F

AASHTO Desi

Standard Method of Test for
Determining the Damage
Characteristic Curve and Failure
Criterion Using the Asphalt Mixture
Performance Tester (AMPT) Cyclic
Fatigue Test

AASHTO Designation: TP 107-18¹

Technical Subcommittee: 2d, Proportioning
of Asphalt-Aggregate Mixtures

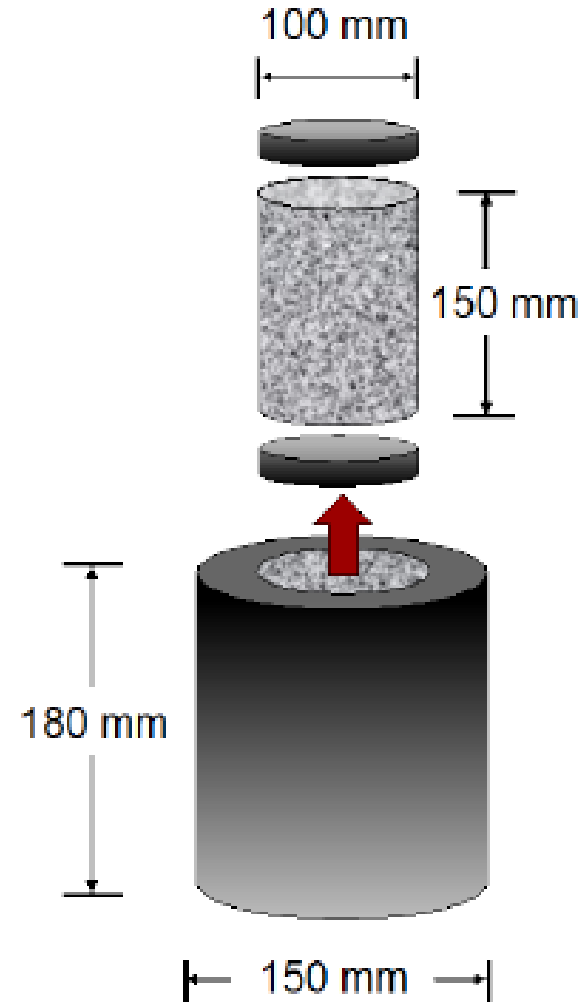
Release: Group 3 (July)

AASHTO
American Association
444 North Capitol
Washington, D.C.

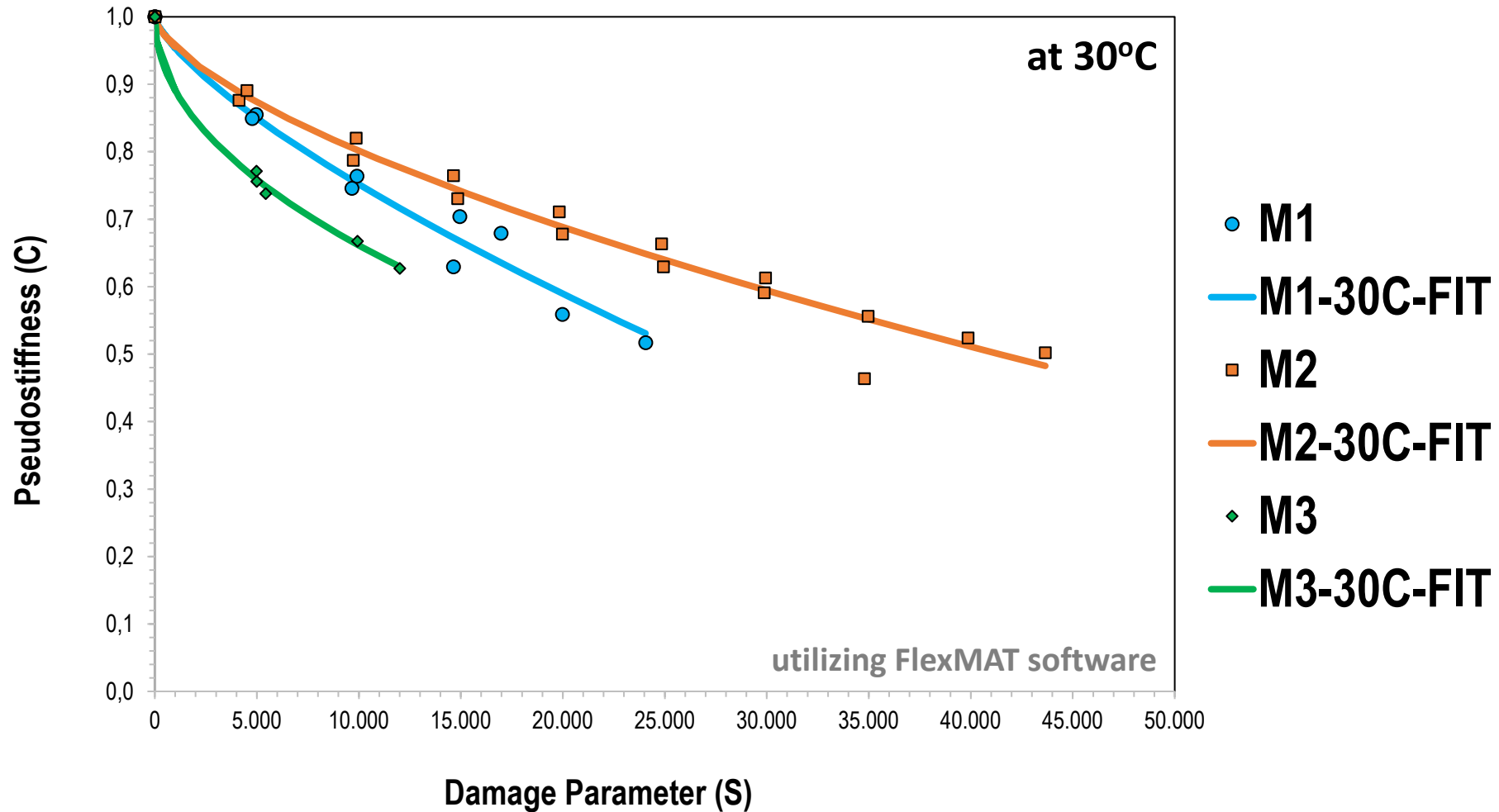
AASHTO
American Association
444 North Capitol
Washington, D.C.

AASHTO
THE VOICE OF TRANSPORTATION

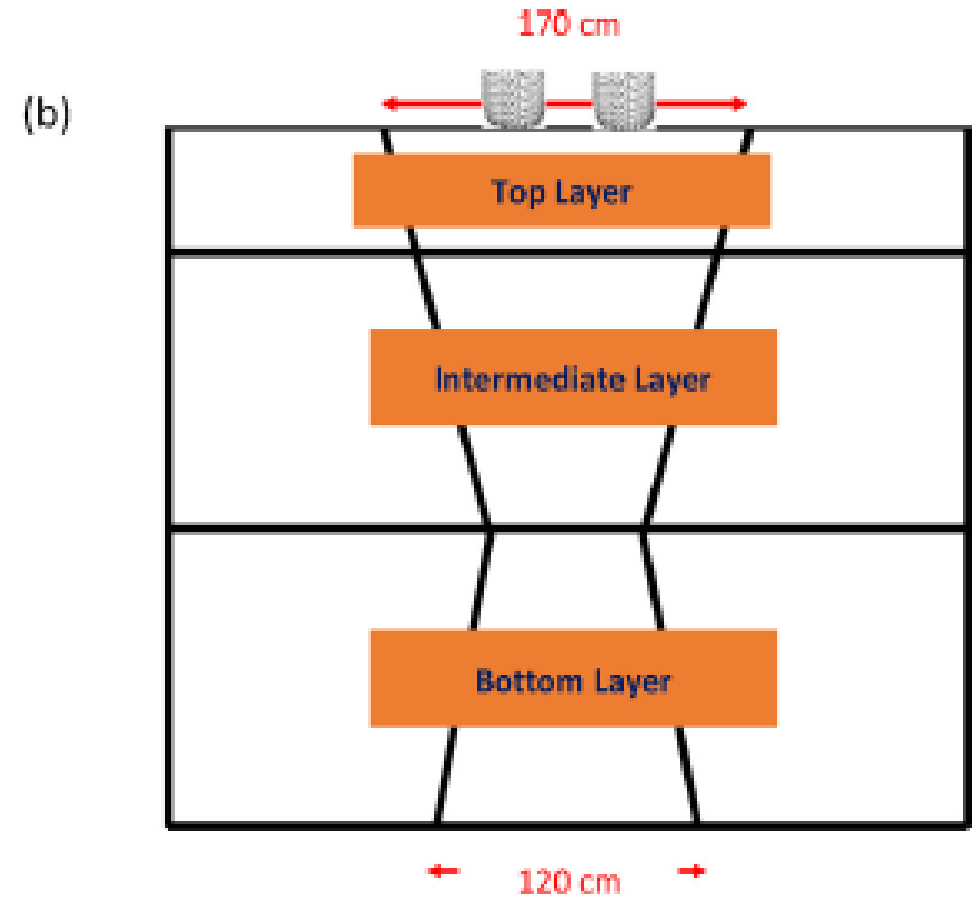
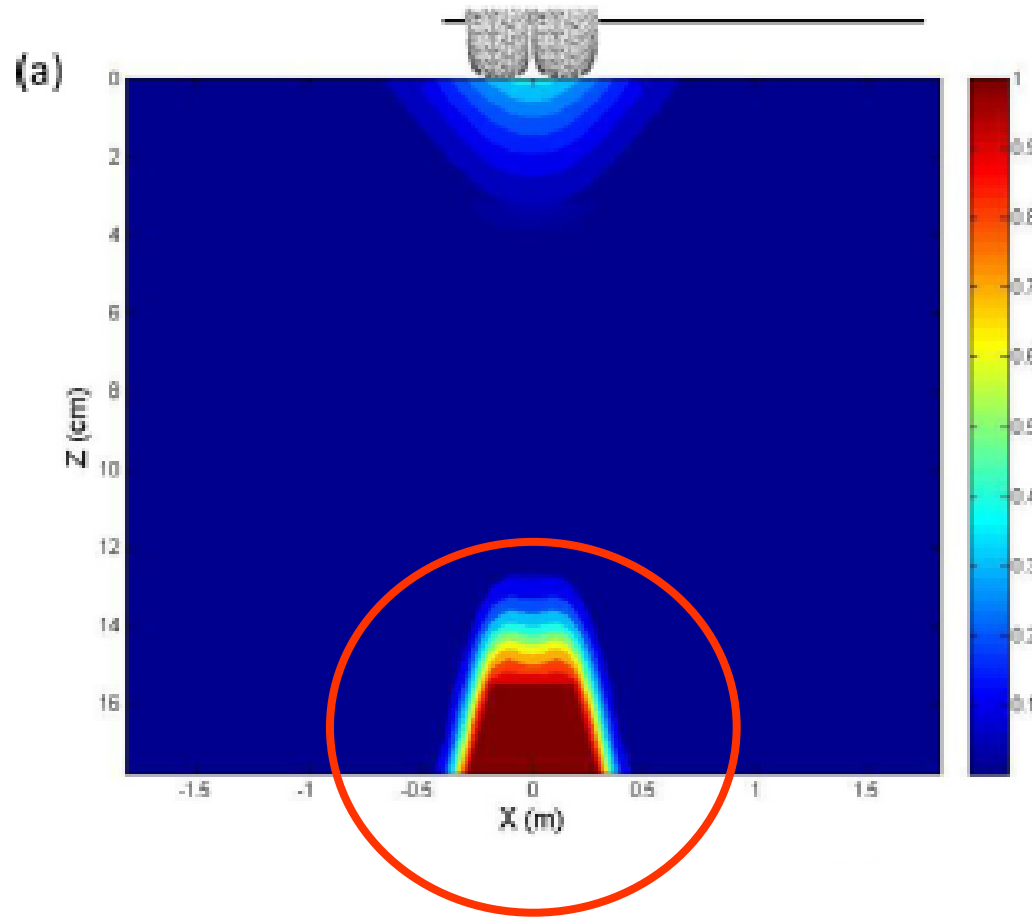
American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001



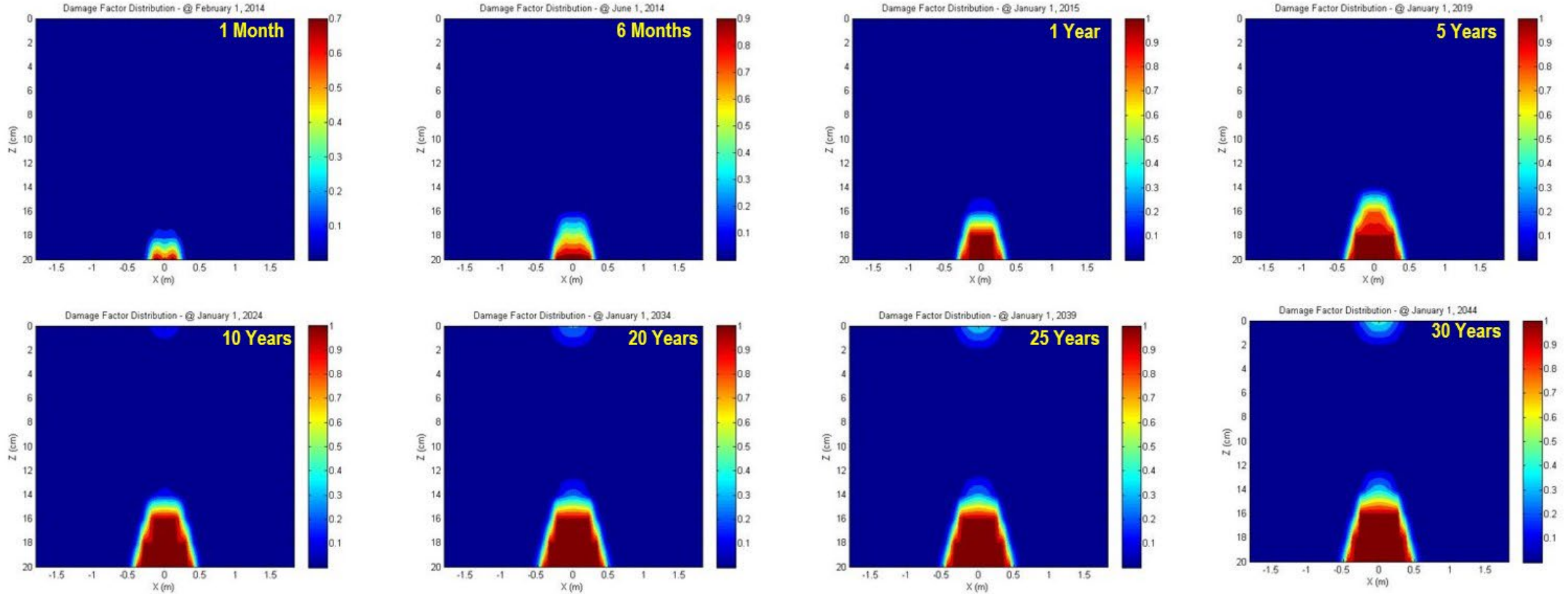
Laboratory test results (select.) – fatigue damage



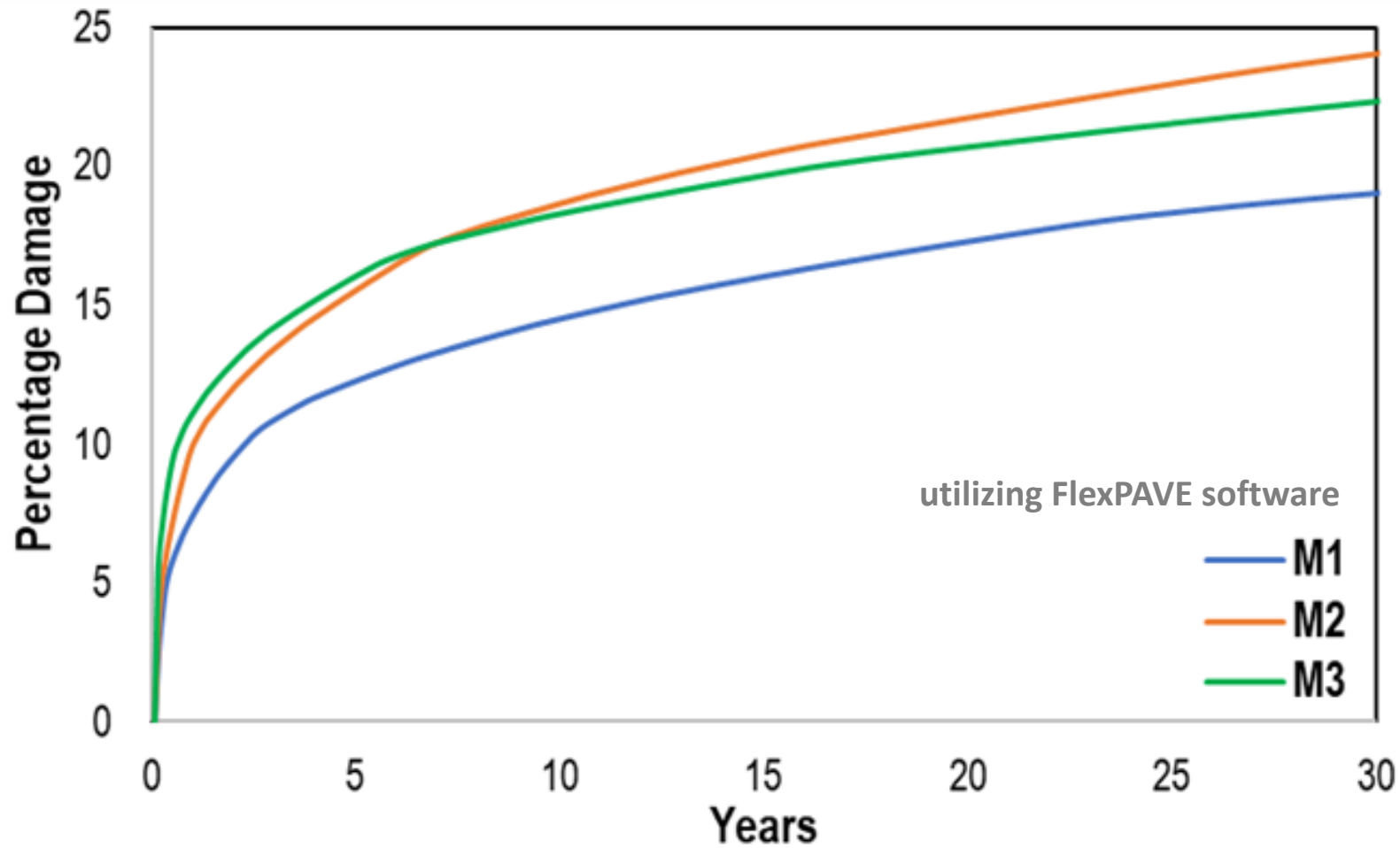
Pavement damage predictions - FlexPAVE



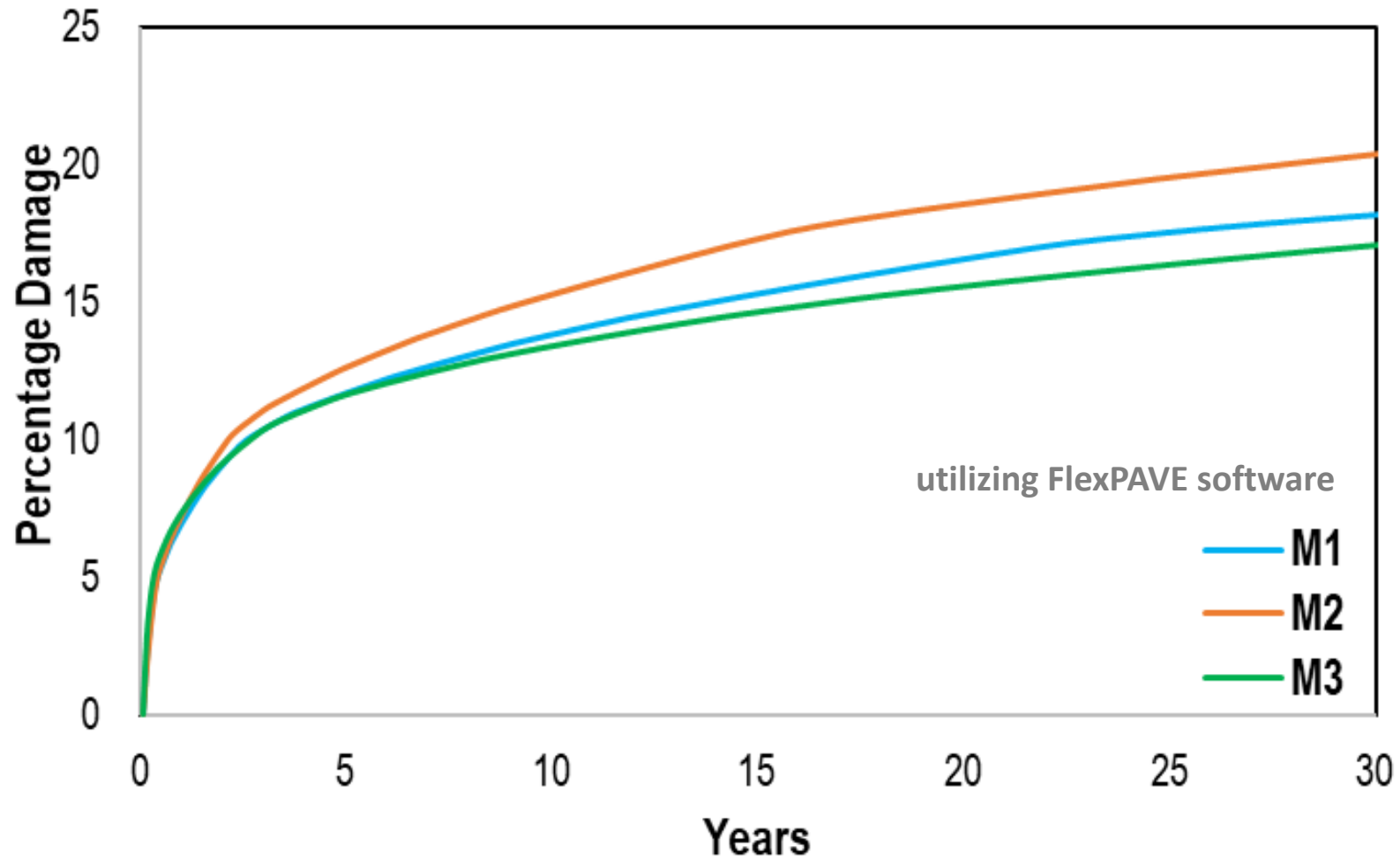
Pavement damage predictions - FlexPAVE



Pavement damage predictions (fatigue)



Pavement damage predictions (including healing)



Potential applications



Findings in combination with CEAB to decide on the need for extra requirements in contracts in the design of base layer mixtures.

Use of VECD method for a practical protocol to determine shift factors for laboratory fatigue life of asphalt mixtures to correct healing and aging.



Towards Green Road Infrastructure: Investigating and Improving Rolling Resistance Prediction



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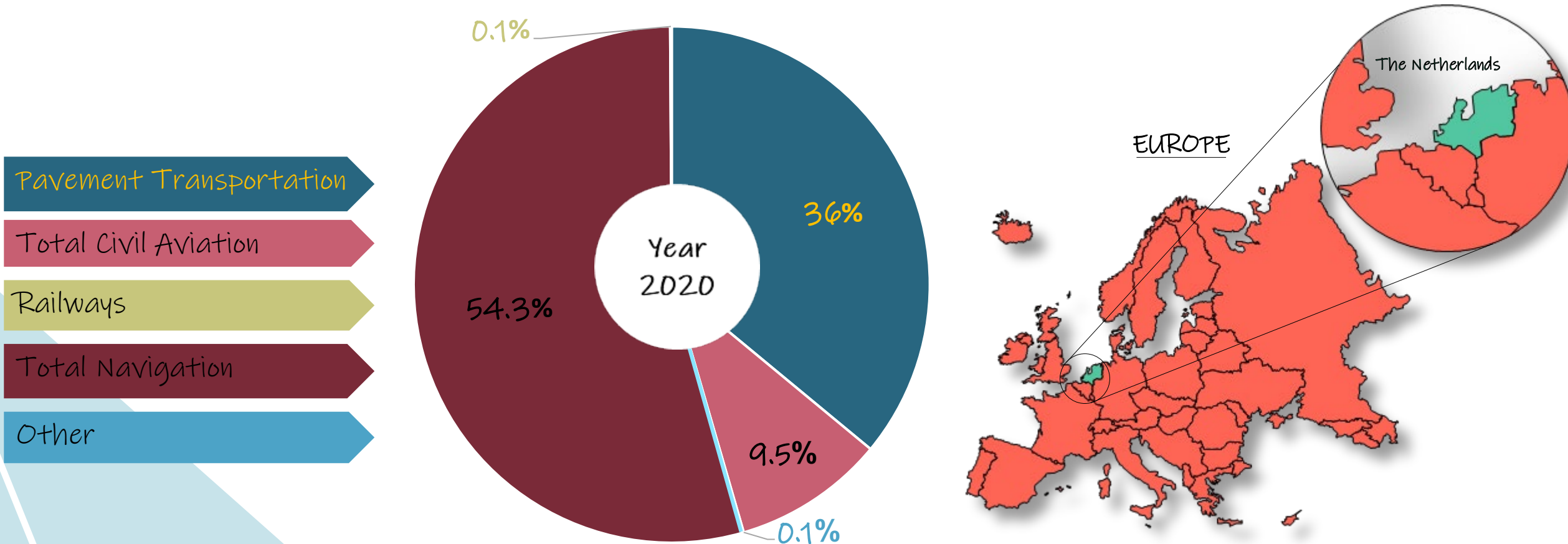
**Saranga Premarathna
Mahesh Moeniela**

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GHG emissions The Netherlands from the Transport sector



(EU Energy in Figures: Statistical Pocketbook, 2022)

Why do we need a better prediction of rolling resistance?

- To assess the environmental cost due to rolling resistance.
- To include rolling resistance in the prioritization of pavement maintenance strategies.
- To assist pavement construction practices to create lower rolling-resistant pavements.
- To support the pavement management policies.

Drawbacks of the conventional models

Tested Pavements

DA and PCC

Country

USA, Minnesota

R^2

$R^2 < 0.4$

Models

Tested Pavements

Asphalt (SMA, etc.)

Country

Ireland

R^2

$R^2 < \text{Not reported}$

Models

Tested Pavements

DA (new, old), PA, PCC

Country

France

R^2

$R^2 < 0.6$

Models

$$CRR = \beta_2 MPD + \beta_1 IRI + \beta_0 + \beta_q \text{Road}$$

(Sohaney and Rasmussen, 2013)

$$CRR = a + b \times MPD + c \times IRI + d \times IRI \times (v - 20)$$

(Sandberg et al., 2011)

$$CRR = a + b \times MPD$$

(Bergiers et al., 2011; Anfosso-Ledee et al., 2016)

- DA:** Dense asphalt
- PA:** Porous asphalt
- PCC:** Portland cement concrete
- SMA:** Stone matrix asphalt
- MPD:** Mean profile depth
- IRI:** International roughness index
- CRR:** Coefficient of rolling resistance
- V:** Velocity

Single/Multi-variable linear regressions

Should the available knowledge be directly imported into the Netherlands?

- Existing models have low R^2 values.
- Existing models, tools, techniques and data originate from other countries, for example, USA. - *This inherently limits the application in the Dutch conditions.*
- Porous asphalt and Twin layer porous asphalt are specific pavement materials that set Dutch infrastructure apart from many other countries.
- These characteristics may not be included in the existing trained models. Hence, these models may not work in Dutch conditions.

Goal of the research

To reduce uncertainty in the Environmental Cost Indicator (ECI) computation of **rolling resistance** while enhancing rolling resistance predictive performance by employing **critical tire-pavement** interaction characteristics, under the Dutch conditions.



Roadmap of work packages



Task 1

- Background & existing data collection



Task 2

- Data Collection and preliminary analysis



Task 3

- Development of a Big-data analysis framework to incorporate LCMS and M+P data



Task 4

- Conduct laboratory tests to obtain physics-based information



Task 5

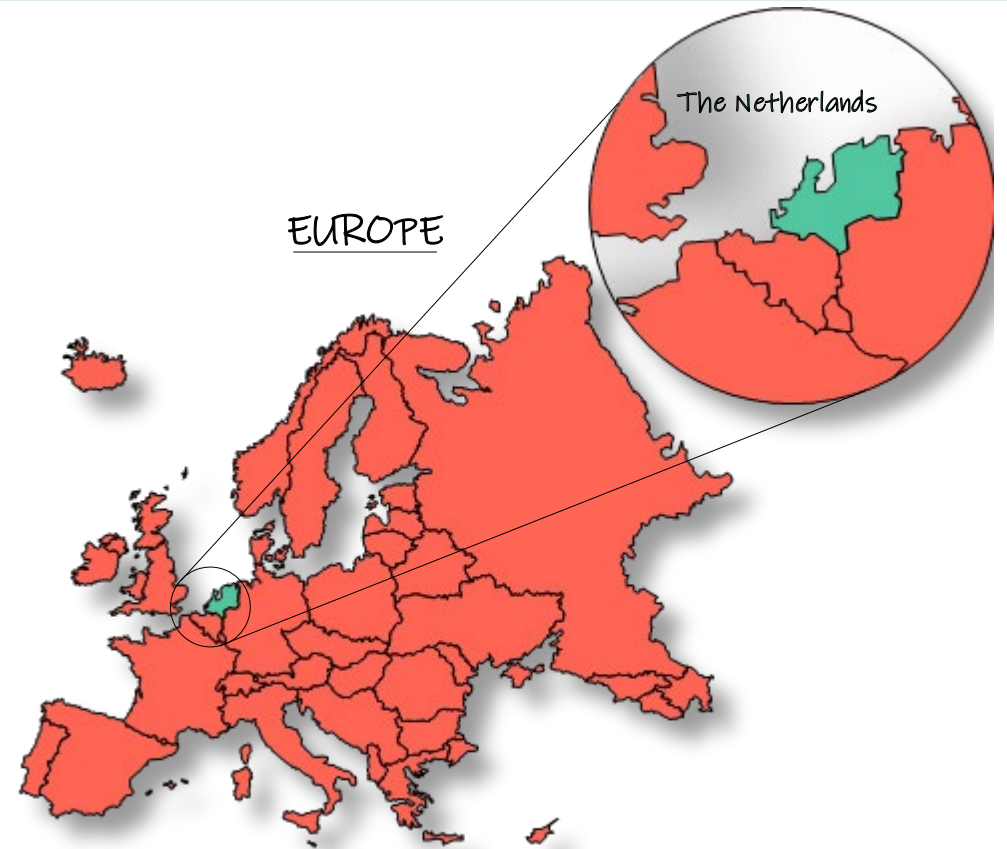
- Numerical tools to study the physics information



Preliminary investigations of datasets

Overview of initial dataset

	MPD	Skewness	Tire_inflation_P	Tire_temperature :	RR_coefficient
0	1.682720	-1.302599	212.62	24.04 ;	0.010014
1	1.600175	-1.200616	212.62	24.04 ;	0.010003
2	1.521199	-1.121326	212.62	24.04 ;	0.009992
3	1.473313	-1.175466	212.62	24.04 ;	0.009982
4	1.554195	-1.253199	212.62	24.04 ;	0.009972
...



RR prediction: Conventional statistical models

- i. Based on the Empirical model developed by Rajaei and his team:

$$RRC = 0.0022 \times RMS + 0.007$$

$$R^2 = 0.36$$

(Ref: Rajaei et al., 2018)

- ii. Based on the Empirical model developed by Hooghwerff and his team:

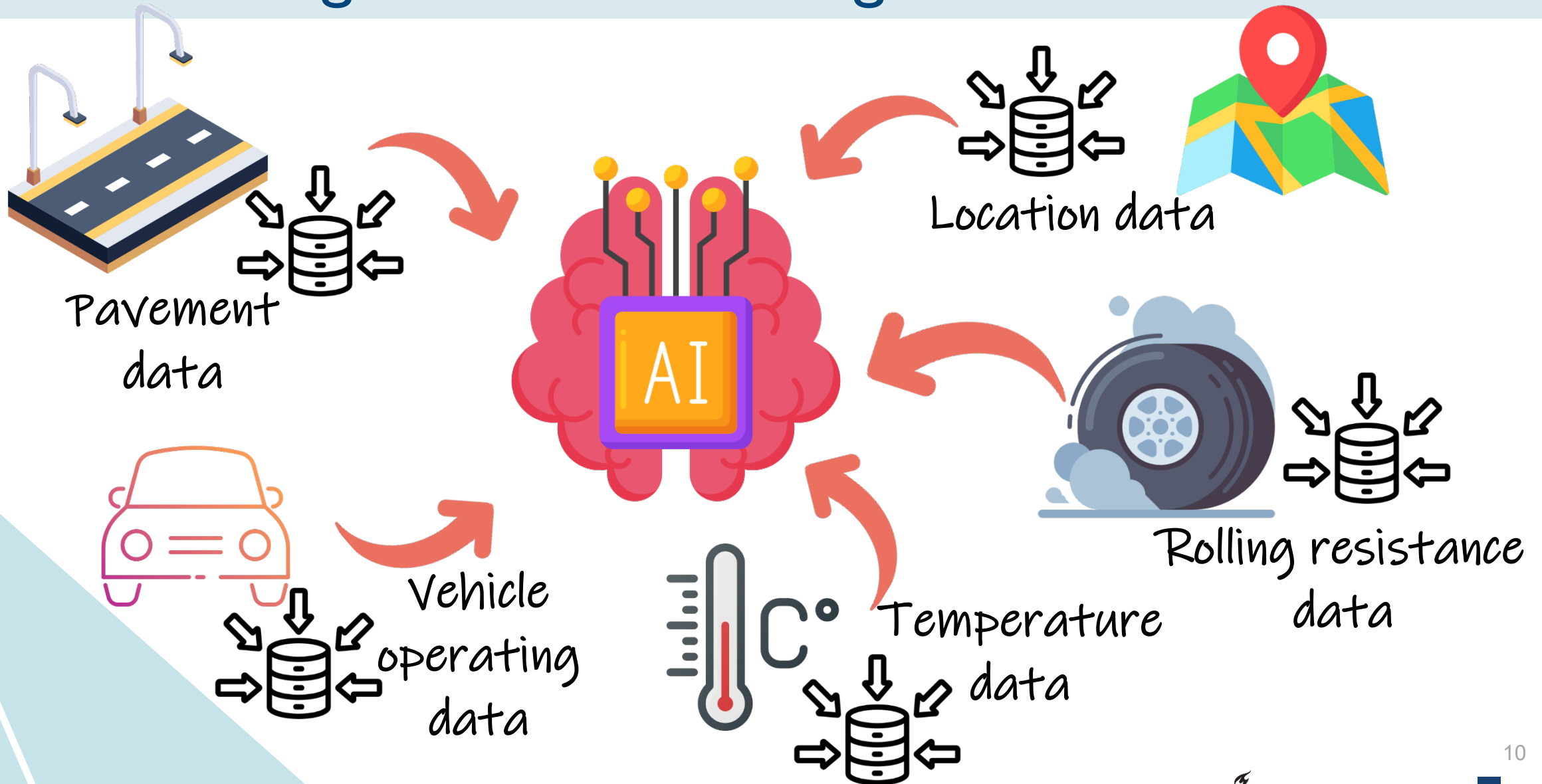
$$RRC = 0.89 \times MPD + 2.68 \left(\frac{MPD}{RMS} \right) + 5.45$$

$$R^2 = 0.65$$

(Ref: Hooghwerff et al., 2013)

Conventional Models

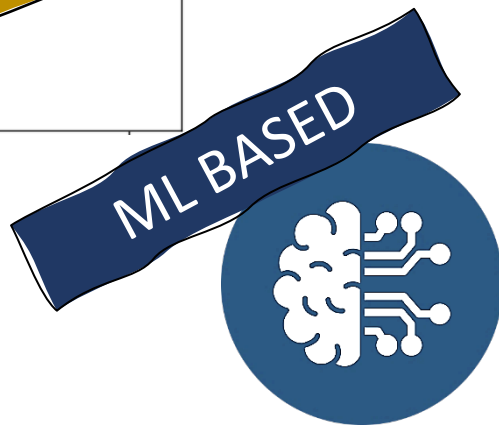
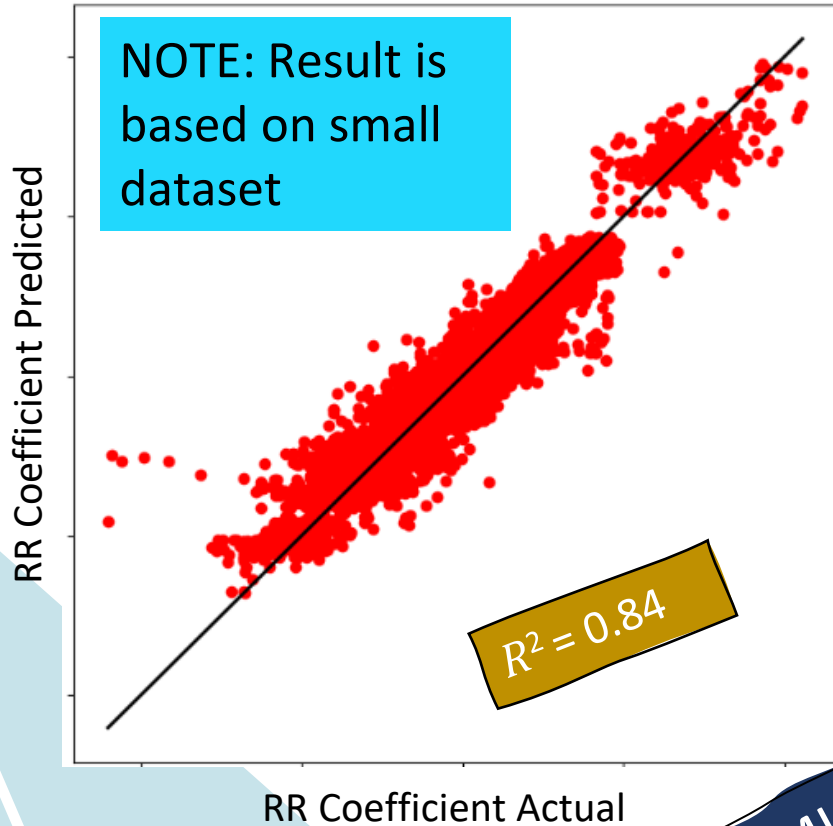
Shifting to artificial intelligence



Comparison with conventional statistical models

- Machine learning based approach

RR Actual vs Predicted



- Conventional approach

- Based on the Empirical model developed by Rajaei and his team:

$$RRC = 0.0022 \times RMS + 0.007$$

$$R^2 = 0.36$$

(Ref: Rajaei et al., 2018)

- Based on the Empirical model developed by Hooghwerff and his team:

$$RRC = 0.89 \times MPD + 2.68 \left(\frac{MPD}{RMS} \right) + 5.45$$

$$R^2 = 0.65$$

(Ref: Hooghwerff et al., 2013)

AI-based toolkit: Under development

Pave the Way

Road to Net-Zero Emission

ROLLING RESISTANCE PREDICTOR



MPD(<3 mm)

Skewness(between +1.5 and -1.5 mm)

Tyre Temperature?(°C)

Tyre Pressure?(between 190 and 240 kPa)

Choose data file to upload (only .csv format) & submit.

No file chosen

Predict RRC

About:

Rolling Resistance Predictor uses a data driven AI approach to predict the coefficient of rolling resistance on a given pavement surface, particularly, under the Netherlands condition. This AI tool considers factors that can be directly affected by tire properties, temperatures, and also by pavement related factors such as Mean Profile Depth (MPD), Root Mean Square (RMS), Skewness and type of the asphalt layer. The project has been conducted in collaborate with RWS and TNO under the projects of Knowledge-based Pavement Engineering (KPE), specifically, project of Environmental Cost Indicator of Rolling Resistance (ECIRR).

Predicted RRC using RandomForest Reg. model is 0.1298

Field Data:

A measurement Developers: Premarathna Saranga, Anupam Kunnar, Erkens Sandra, Kasbergen Cor, Zhaojie Sun, Mahesh Moenielal, Bram Vreugdenhil, & Harco Kersten

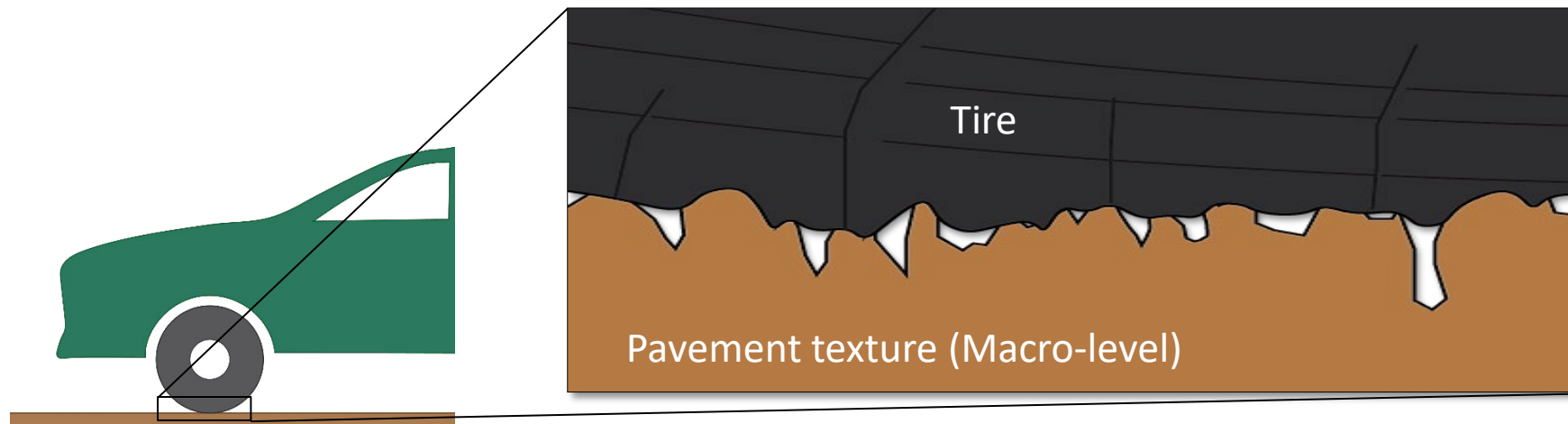
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Ongoing progress

Include physics-based parameter which could improve the prediction.



How? by including physics-based parameter



Observed challenges

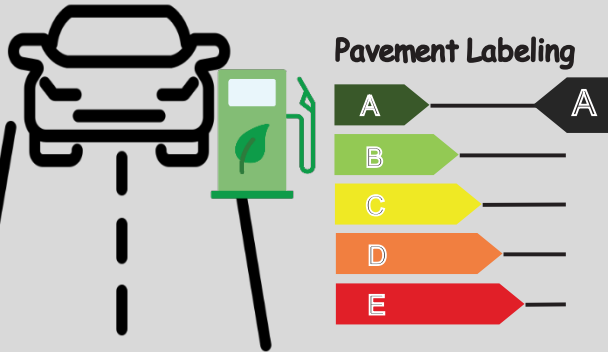
- Complexity of the phenomenon (Non-Linearity).
- Lack of standardized testing procedures.
- Reporting inconsistencies.
- Data availability and quality.
- Incomplete synchronizations occur when combining data from various sources.



15

Our pavements in year 2050: Pavement labeling

In order to develop a system of pavement labeling, we need information:



Environment related data

- Temperature
- Moister, etc.

Pavement related data

- Type of the pavement
- Characteristics of the pavement
- Raveling and rutting related information, etc.

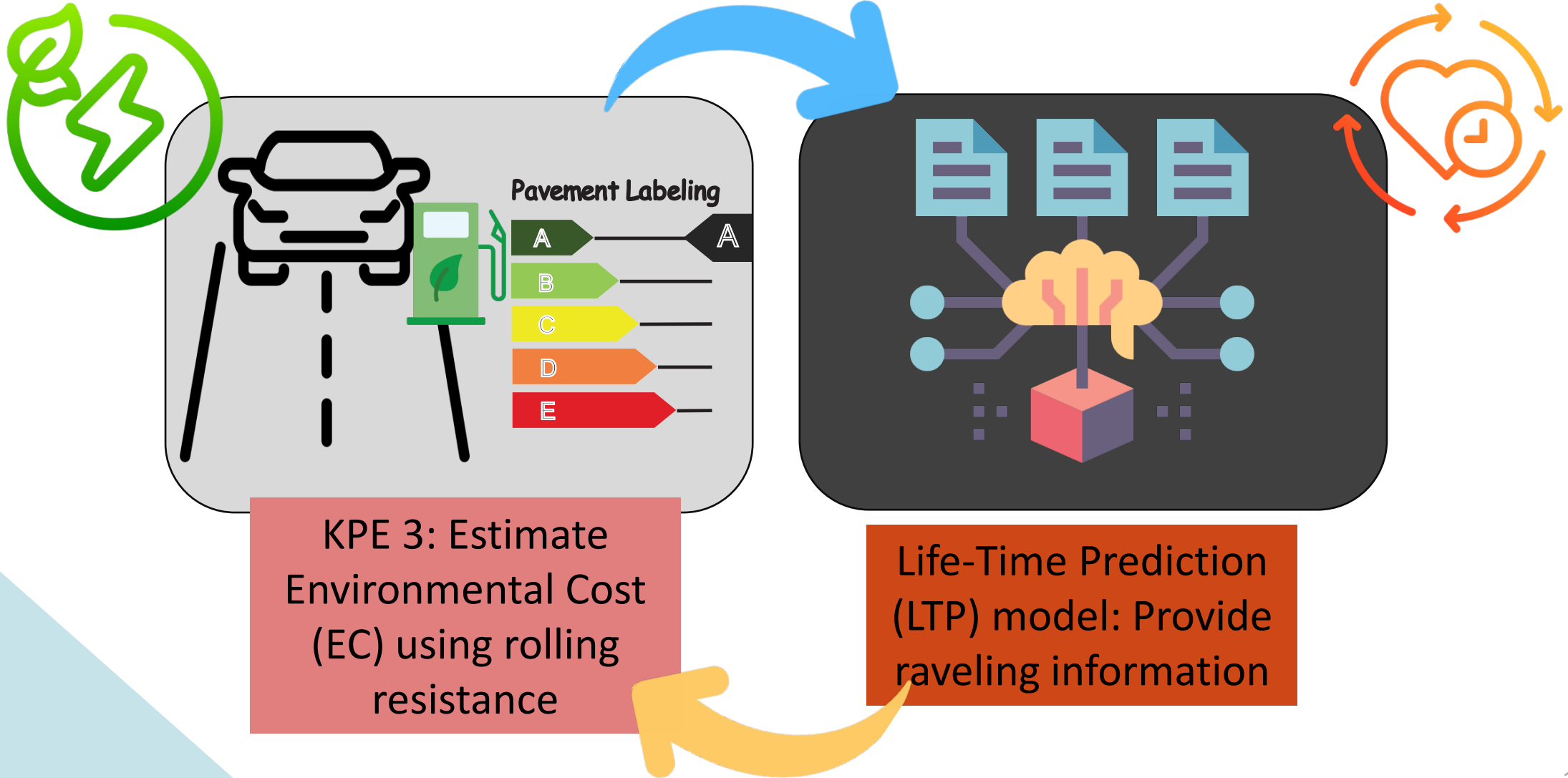
Tire and vehicle operation-related data

- Construction of the tire
- The material behaviour of the tire
- Vehicle Load
- Tire-inflated pressure
- Temperature of the tire
- Speed, etc.

Database

- Environment-related data
- Pavement-related data
- Tire and vehicle operation-related data
- Location related-data

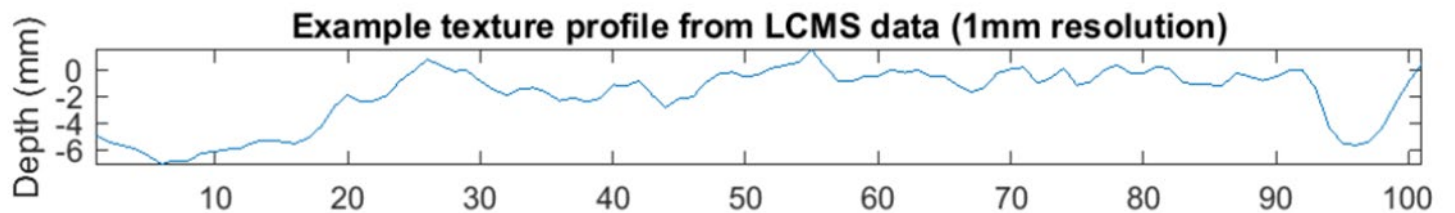
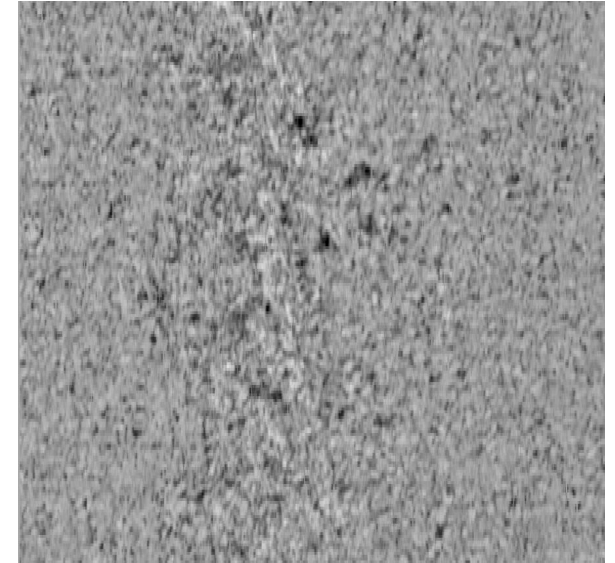
KPE-3 within KPE



Learning from LCMS

RR and LCMS data

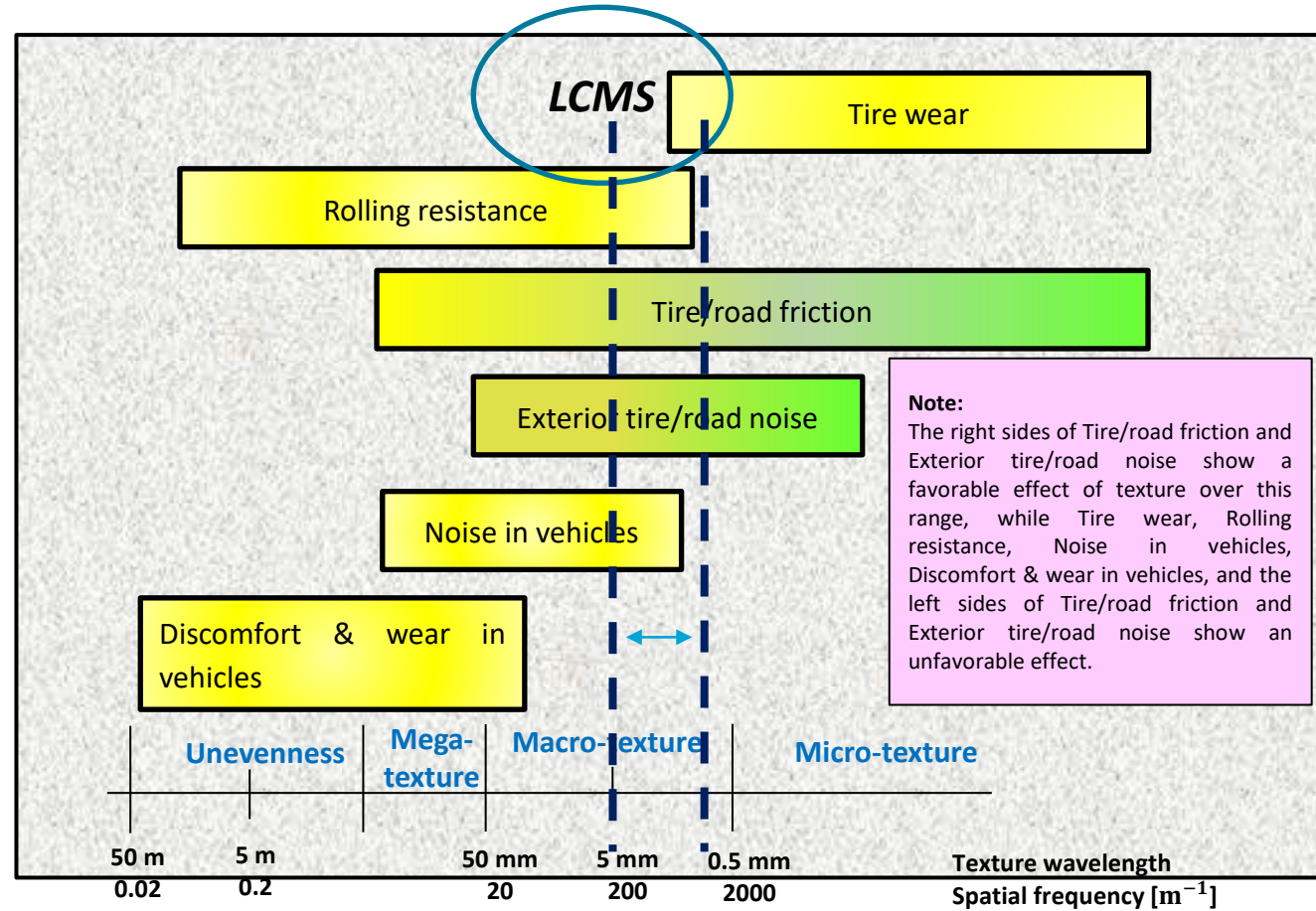
- Measurements TU Gdansk trailer 2013 (M+P)
- Monitoring condition pavements Dutch highways 1x/year (2013-now).
- High resolution LCMS1 (1x5 mm) and LCMS2 (1x2 mm).
- Generating 3D texture profiles from raw LCMS data.



LCMS and Coefficient of rolling resistance

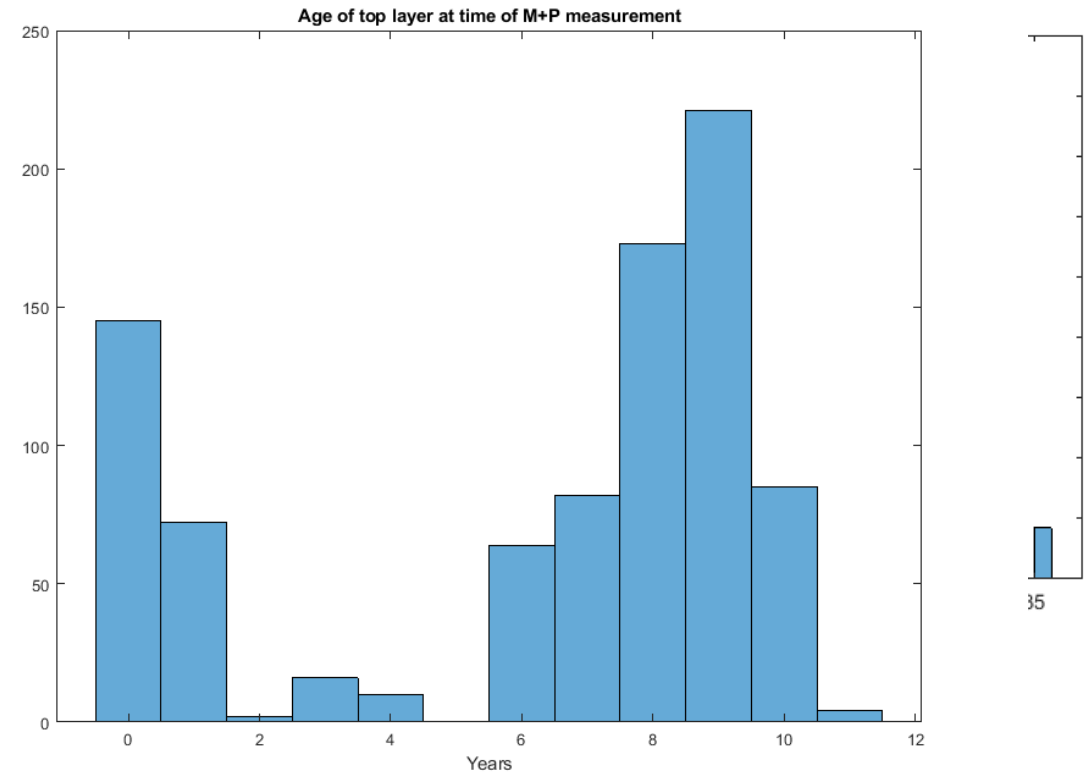
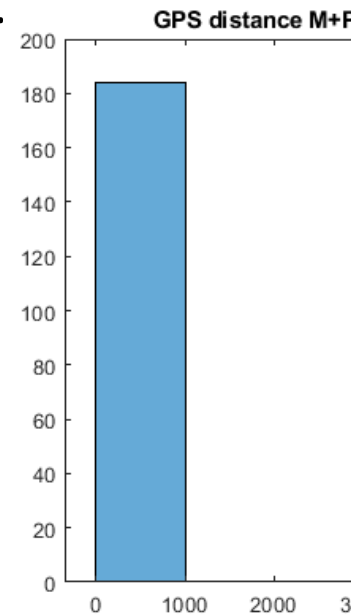


- TU Gdansk trailer

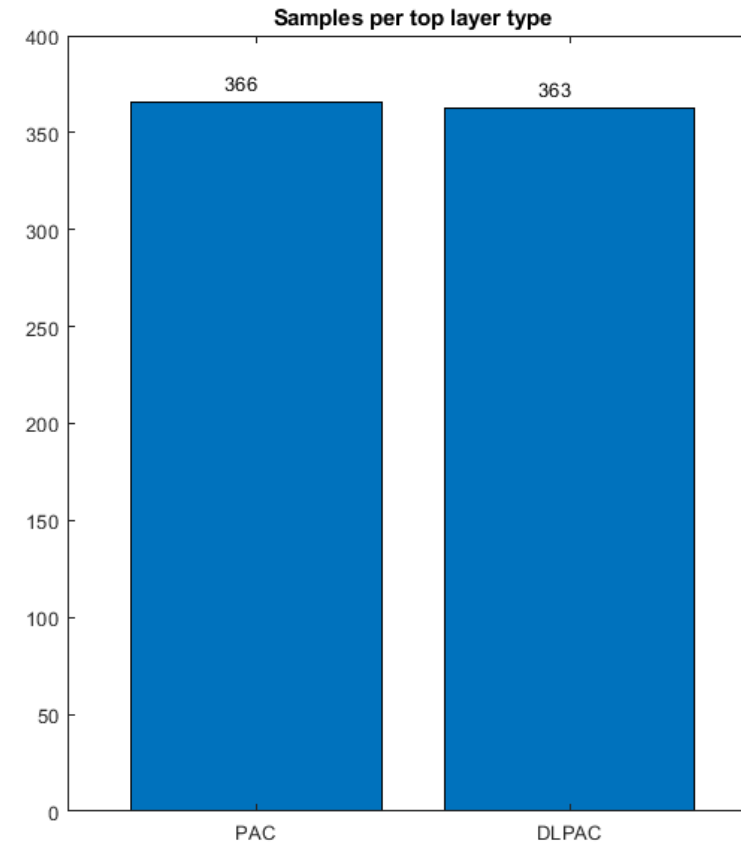
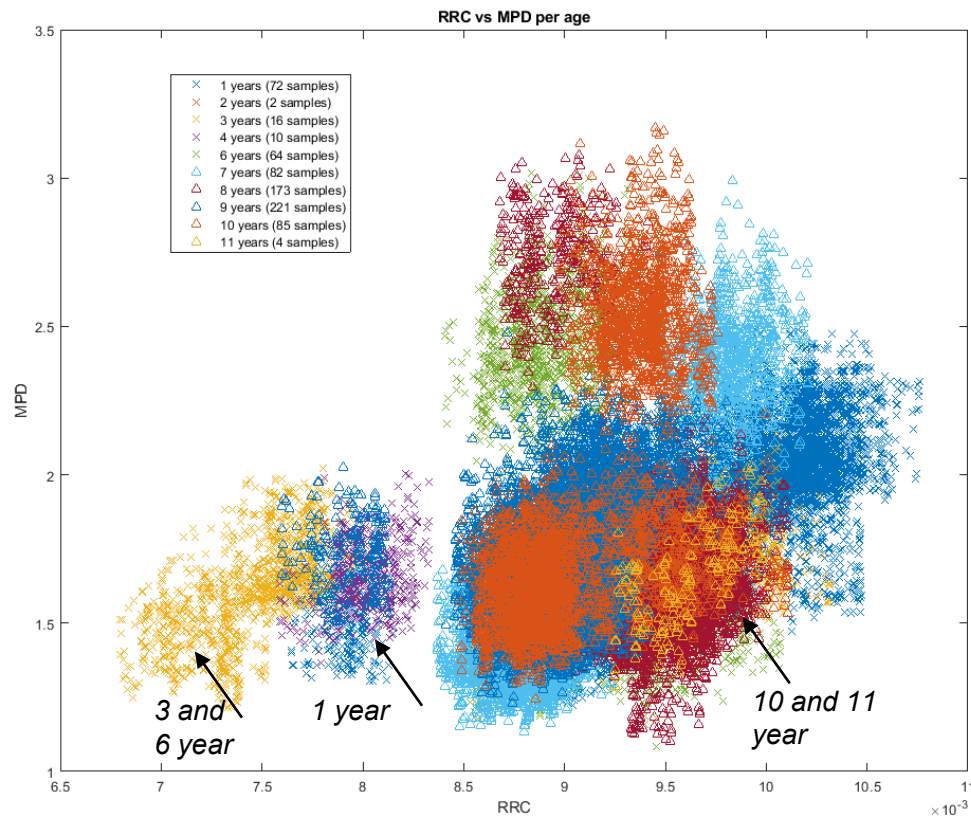


Selection road sections

- Criteria for filtering datasets RR measurements 2013
 - Type top layer asphalt.
 - GPS.
 - Age top layer.
 - Variance hm.



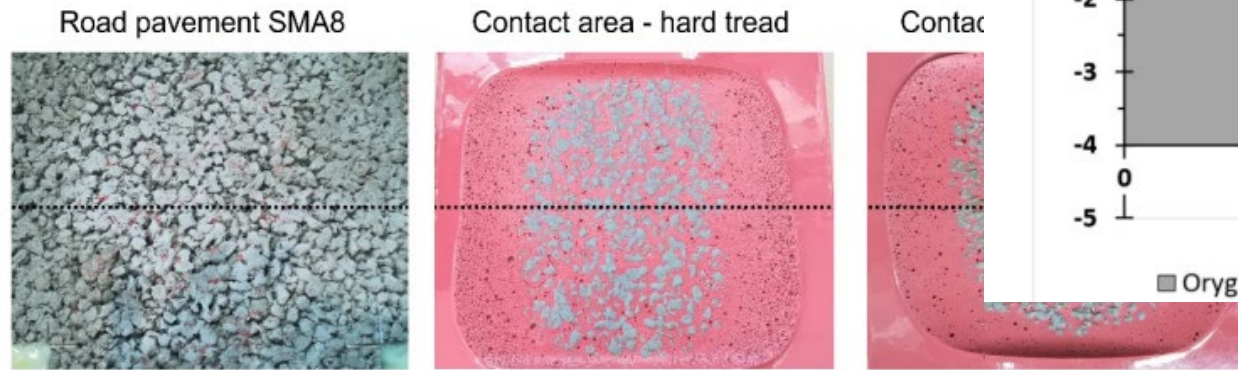
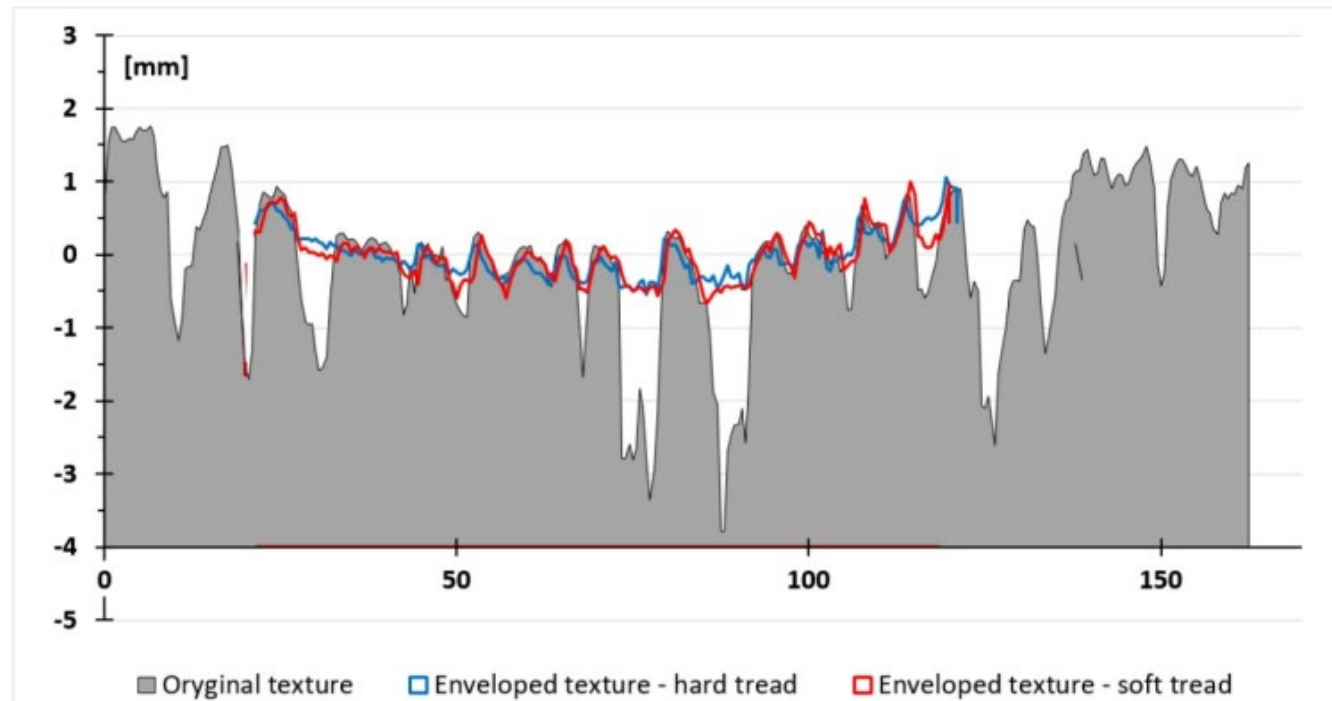
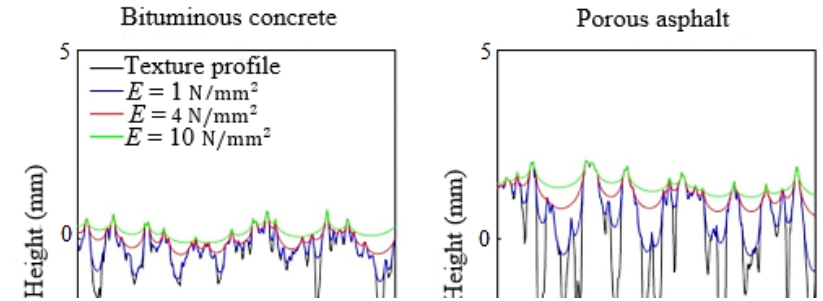
Rolling resistance – MPD & age top layer



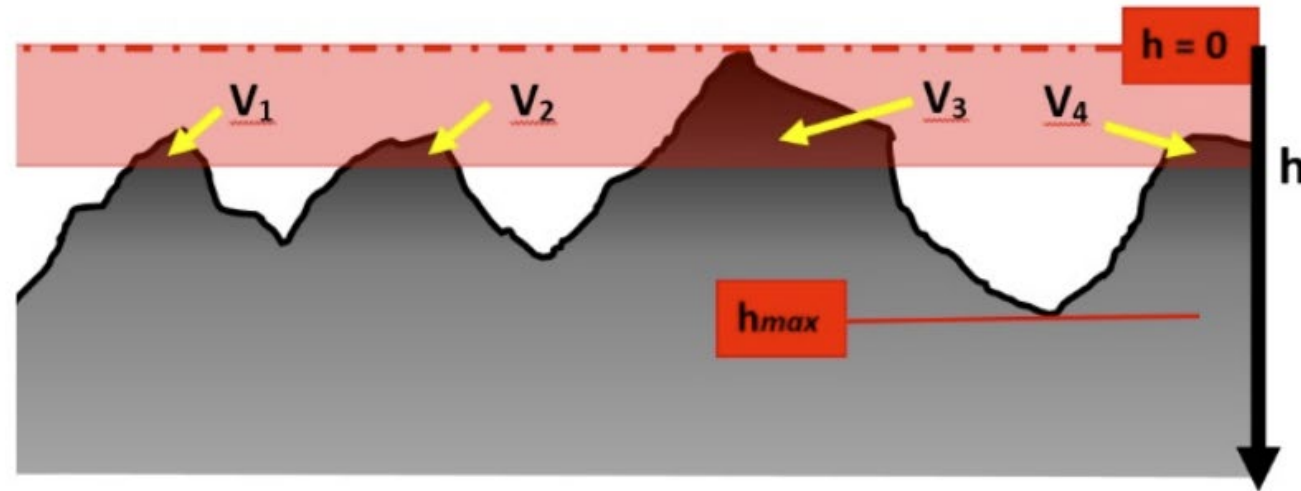
- Clustering RR for MPD and age top layer, poor correlation.
- High variation in relation MPD-RR, difference in number of samples for age top layer.

Enveloping

- MPD not suitable for Porous Asphalt
- Enveloping method more suitable for texture parameter tire-road contact → removing deep pore
- Method Esjmont:
 - Texture properties relevant for energy loss
 - Penetration depth texture summits vs valleys
 - Experiments SMA8 and surface dressing

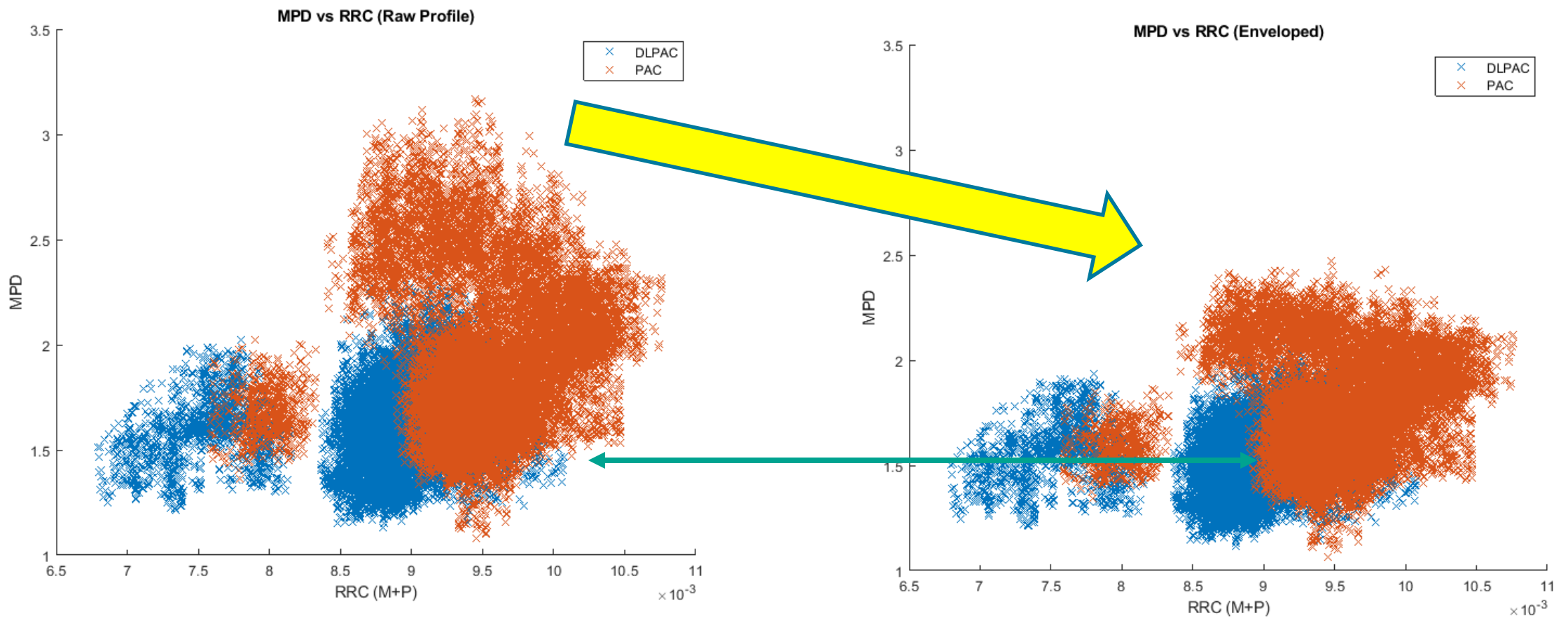


Characterization texture for RR

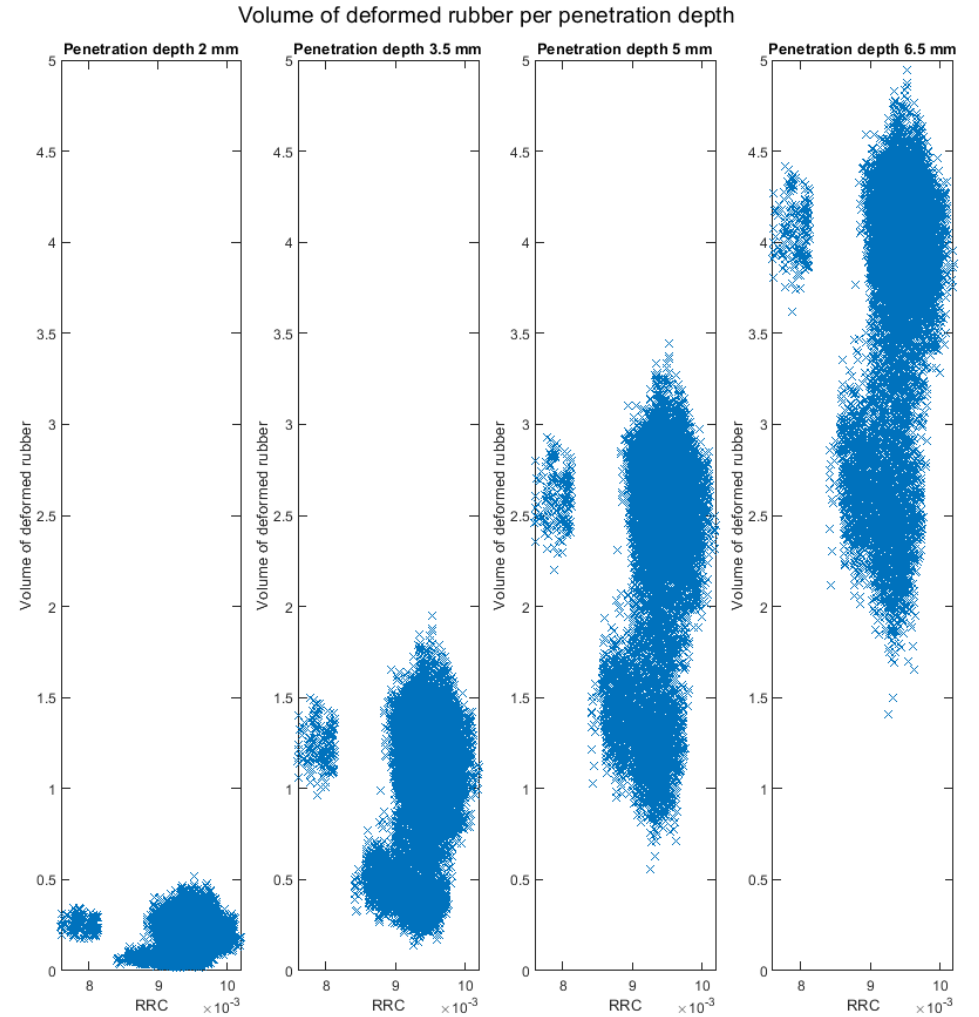
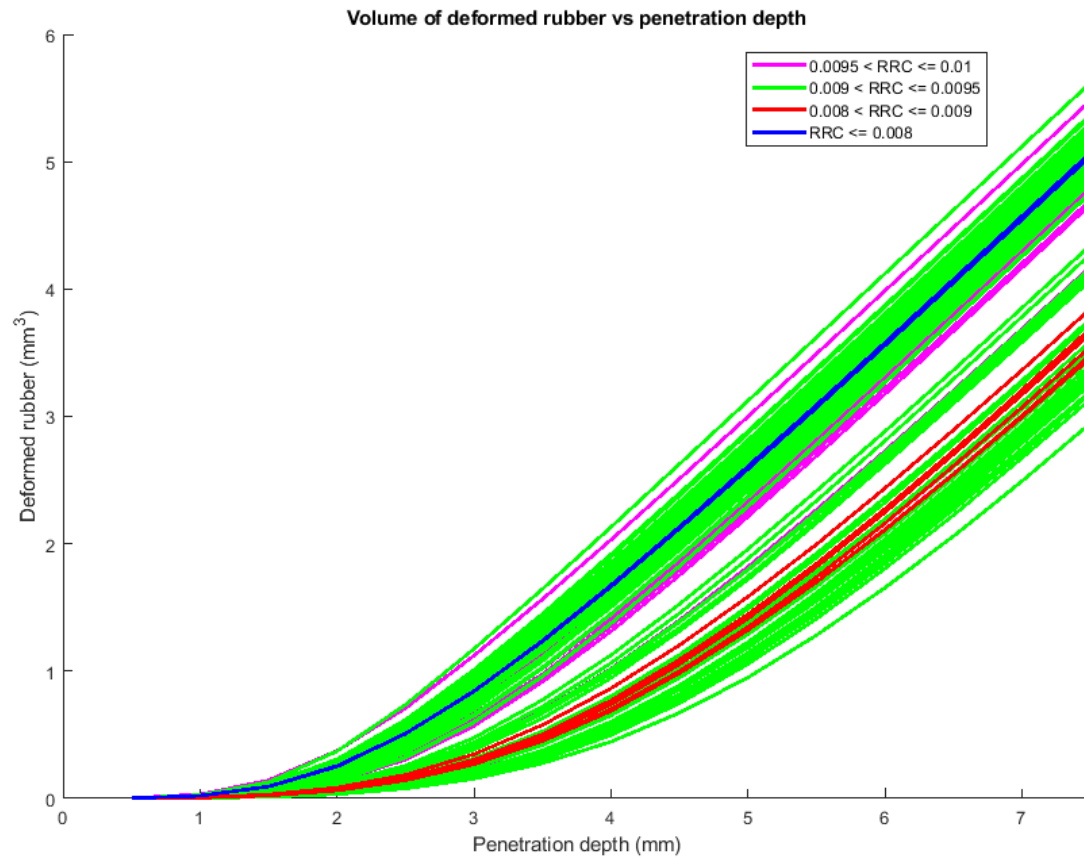


- 50x50 mm² in centre tire imprint using 3D recording pavement texture.
- Level highest summit ($h=0$) and lowest pit (h_{max}) by enveloped tire imprint.
- Calculation of deformed rubber for several penetrations in steps of 0.5 mm.
- Deformed rubber volume indicator to classify road surfaces influencing RR
- Enveloped MPD from raw LCMS data

MPD and enveloped MPD



Volume deformed rubber



Lessons learned using LCMS data for rolling resistance

1. Clustering for RR vs MPD & age asphalt top layer but poor correlation (PA16/PA16+).
2. Poor correlation between MPD and RR; same correlation for enveloped MPD.
Volume deformed rubber → poor correlation RR data 2013 PA/PA+
3. Combination LCMS and RR measurements 2013 not reliable.

Recommendations

- Perform LCMS and RR measurements at the same time, conditions, and positions.
- New RR measurements → sufficient 'samples'.
- Enveloping analysis for texture profile contact tire-pavement

Topics for discussion

Discussion

- Do you all agree that there is a need to predict rolling resistance to assess environmental costs?
- Do you agree that we need to develop a rolling resistance framework suited to our conditions? For example, devices that could be more suitable, conducting field tests on our test sections, etc.
- Do you see anything in common with what we try to achieve?
- Can we generate the necessary data?
- How can we collaborate to make improvements?



Publications

Publications and workshops

- Sun, Z., Premarathna, W.A.A.S., Anupam, K., Kasbergen, C. and Erkens, S.M.J.G. (2023). A state-of-the-art review on rolling resistance of asphalt pavements and its environmental impact. *Journal of Construction and Building Materials*.
- Modeling of Pavement Surface in Road Safety and Rolling Resistance: Keynote Speech by K. Anupam at the Conference on Pavement Functional Design Management (PFDM), 2023.
- KPE Knowledge Sharing workshop - August 2023.



Lifetime Prediction

KPE-6



Rijkswaterstaat
Ministry of Infrastructure
and Water Management



Seminar: 'Bouwen op Kennis'

*Met KPE naar een
klimaatneutrale weg*

31 oktober 2023

Sandra Erkens

&

Mohammadjavad Berangi

Bernardo Mota Lontra

Dave van Vliet

Kumar Anupam

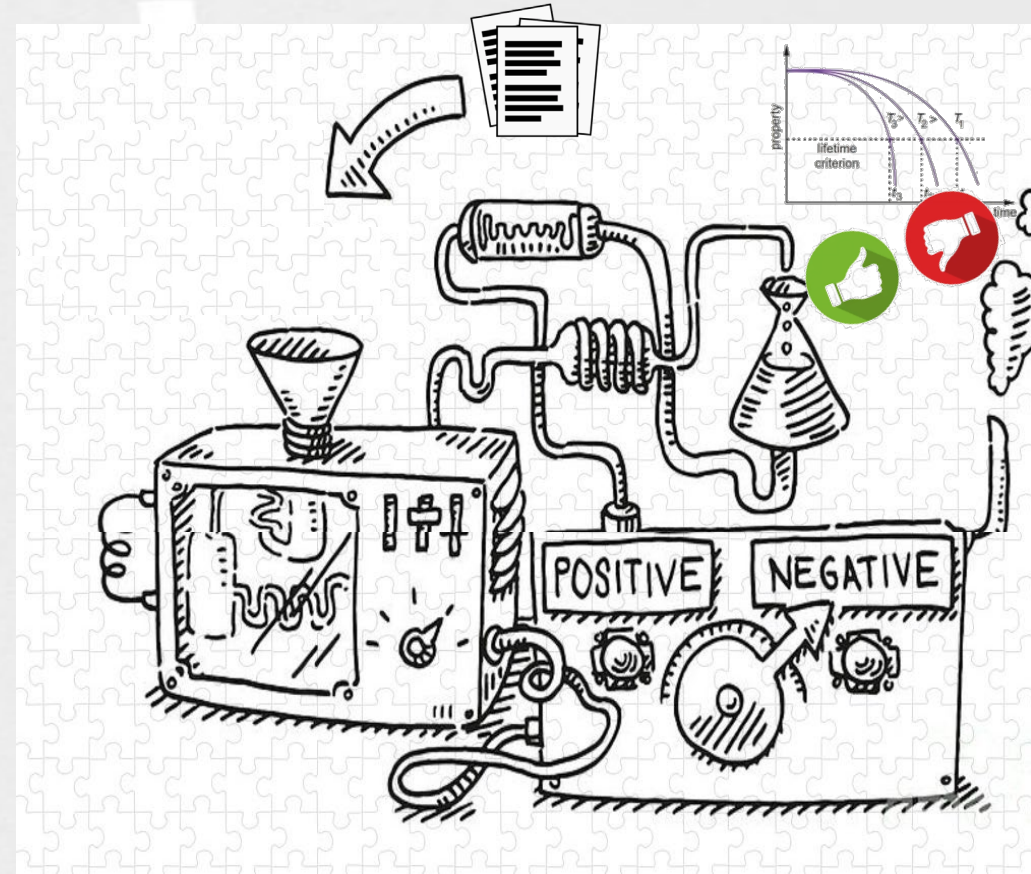
**Knowledge-based
Pavement
Engineering
2020-2024**

Lifetime Prediction

- Lifetime prediction:
 - Assess quality
 - Validate innovations
 - Predict budgets
 - Update requirements
 - Etc

Lifetime Prediction

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 - Assess quality
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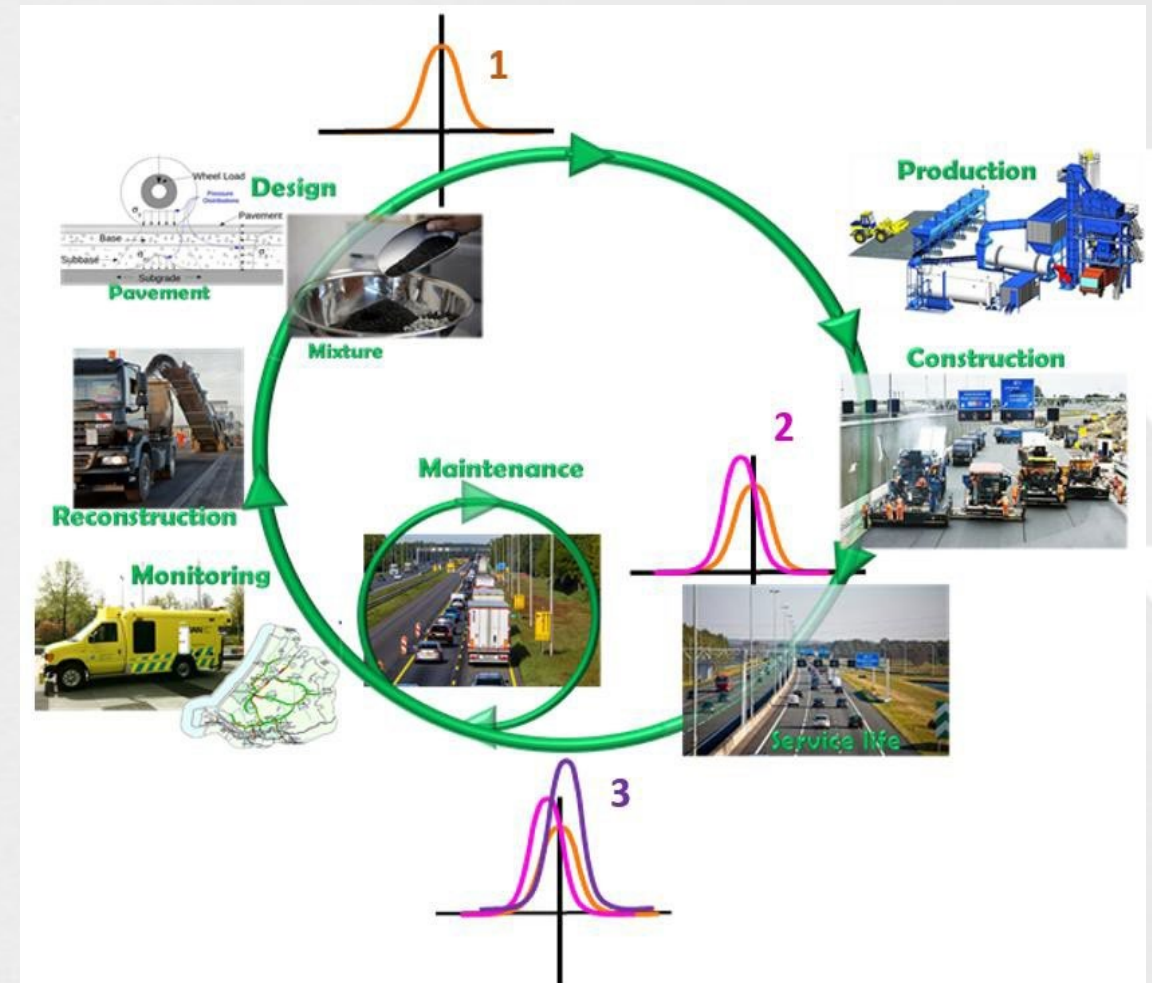


Lifetime Prediction

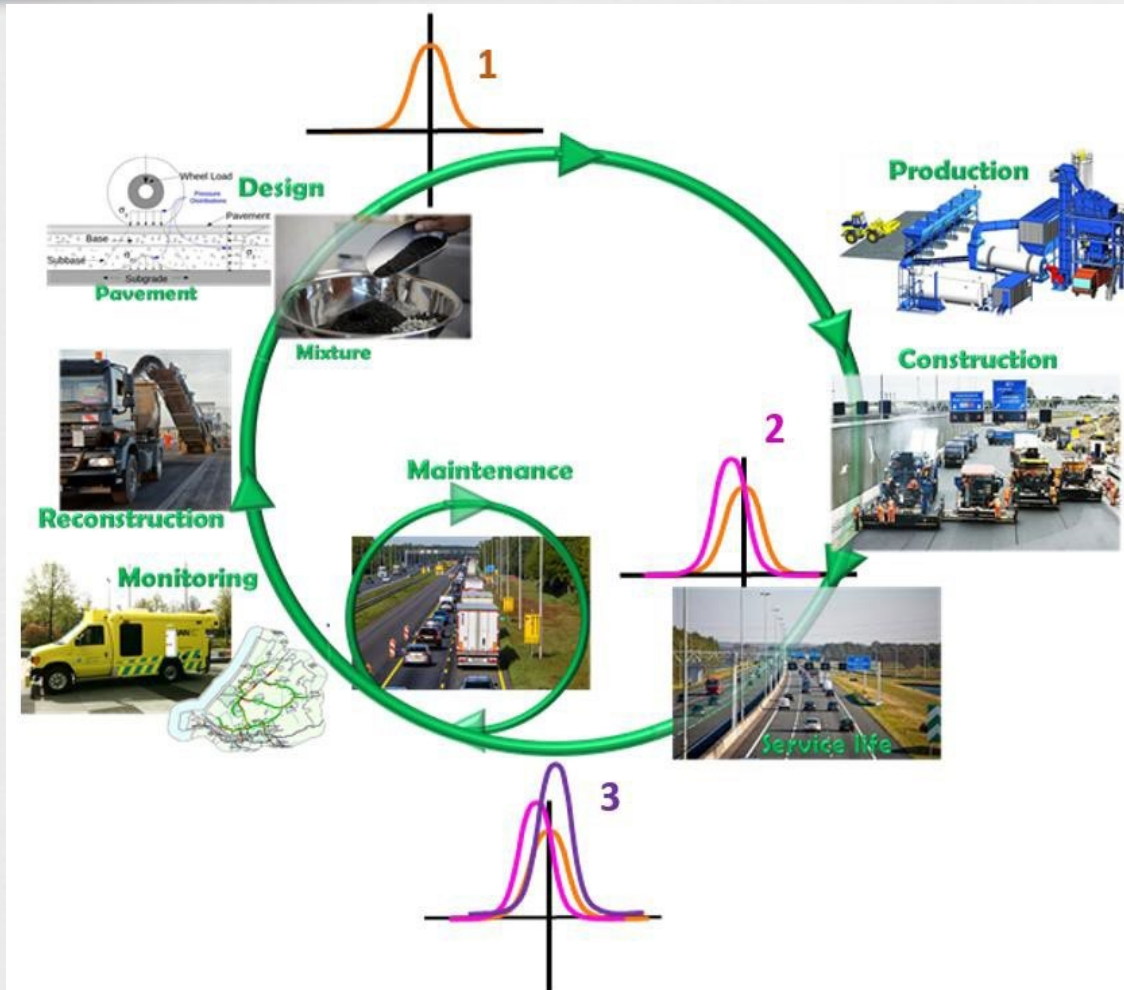
- KPE Lifetime prediction:
 - No miracles
 - Combine available information and knowledge
 - Add potential from KPE projects
 - KPE: adding to RWS toolbox

Lifetime Prediction

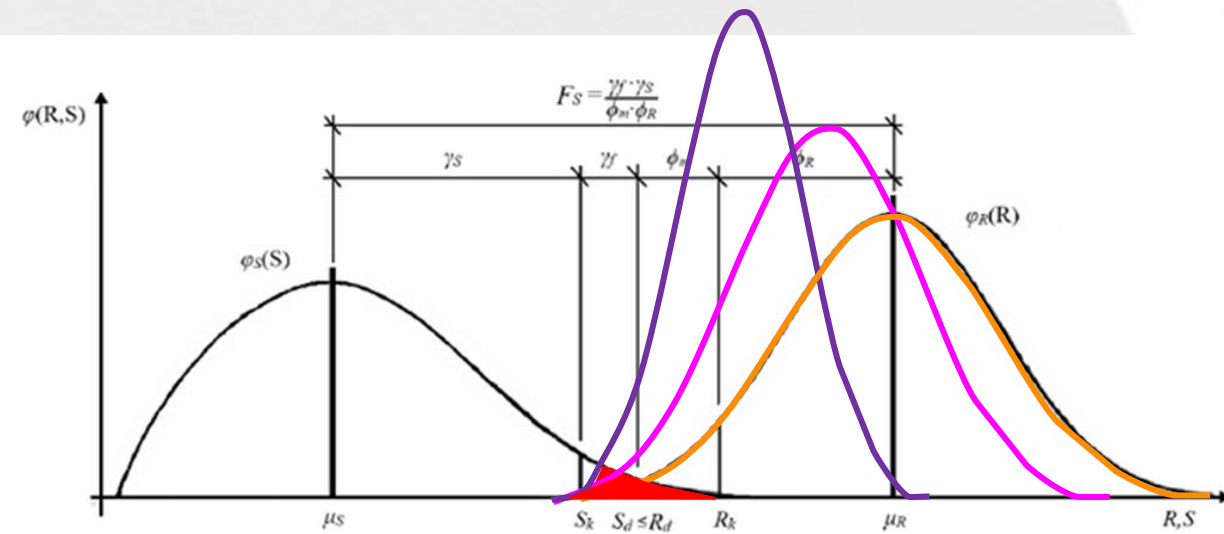
	1	2	3
raveling			
transversal cracks			
longitudinal cracks			
alligator cracks			
rutting			
longitudinal unevenness			
skid resistance			
transversal unevenness			
rolling resistance			



Lifetime Prediction



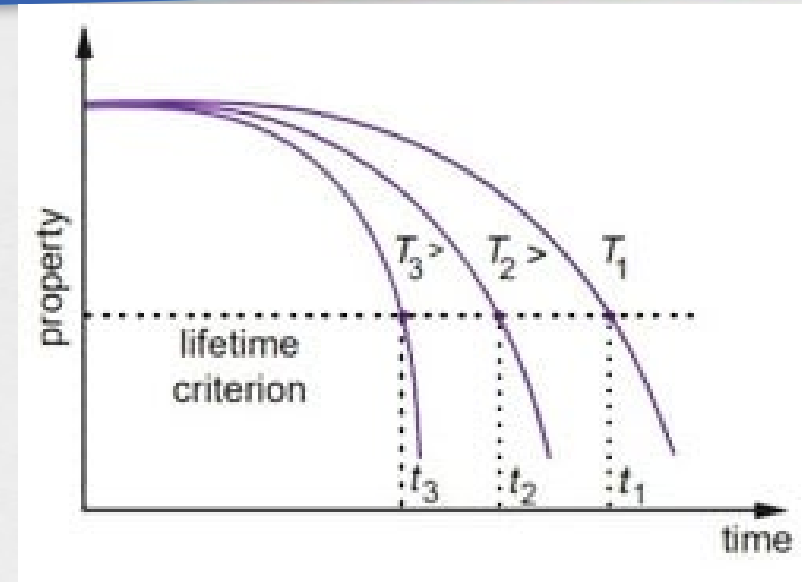
Material variability
 production and construction effects
 aging (material & weather)
 mechanical degradation (repeated loading)



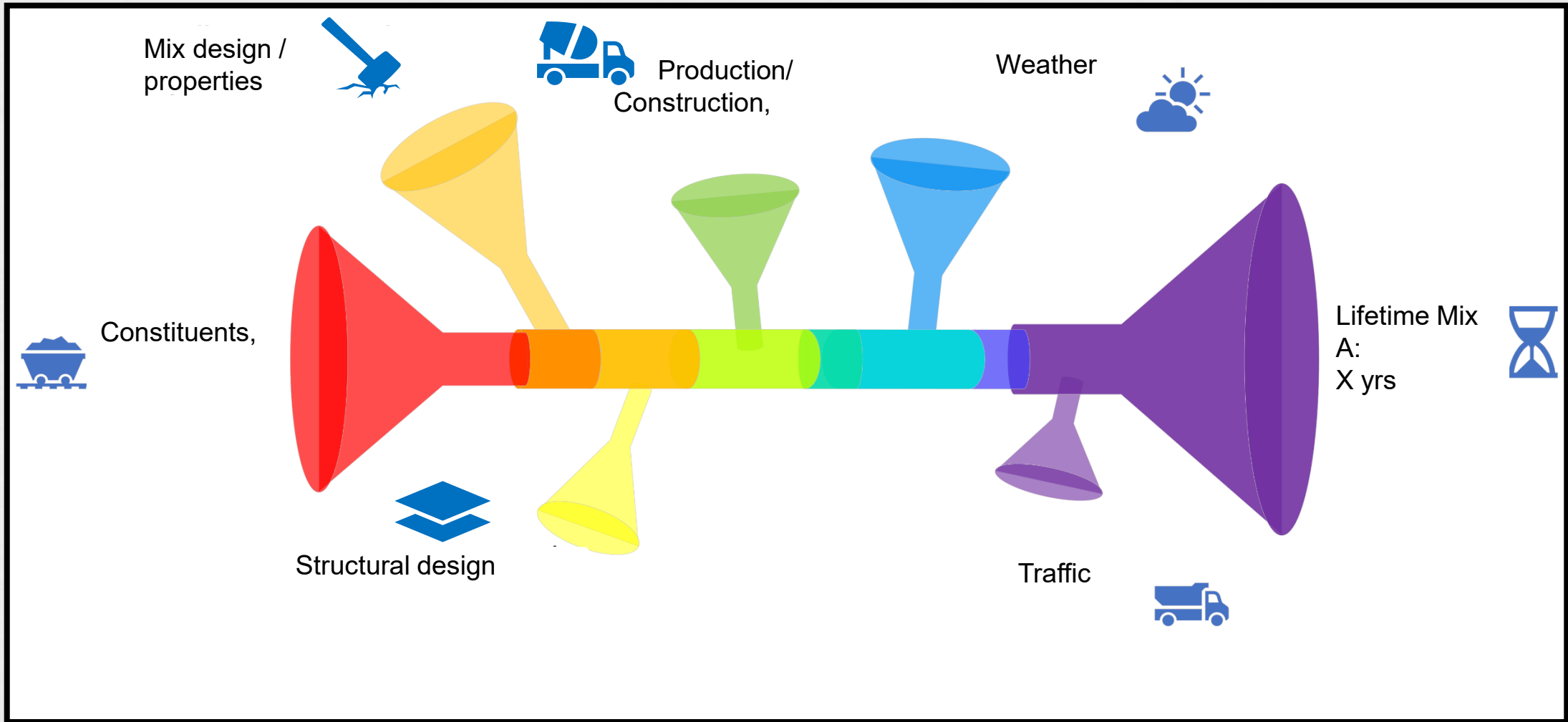
Yukio, Carlo & Neto, Nilson & Prazeres, Plinio & Rodrigues Júnior, Sandoval & Sampaio, Regina. (2017).
 Software Development on the MATLAB for Structural Reliability and Sensitivity Analysis.
 10.20906/CPS/CILAMCE2017-0570.

Lifetime Prediction

- KPE Lifetime Prediction
 - Lifetime in specific standard conditions
 - With an ontology to facilitate exchange & analyses
 - Minimum: standard info, where possible with improvements/extensions



Lifetime Prediction



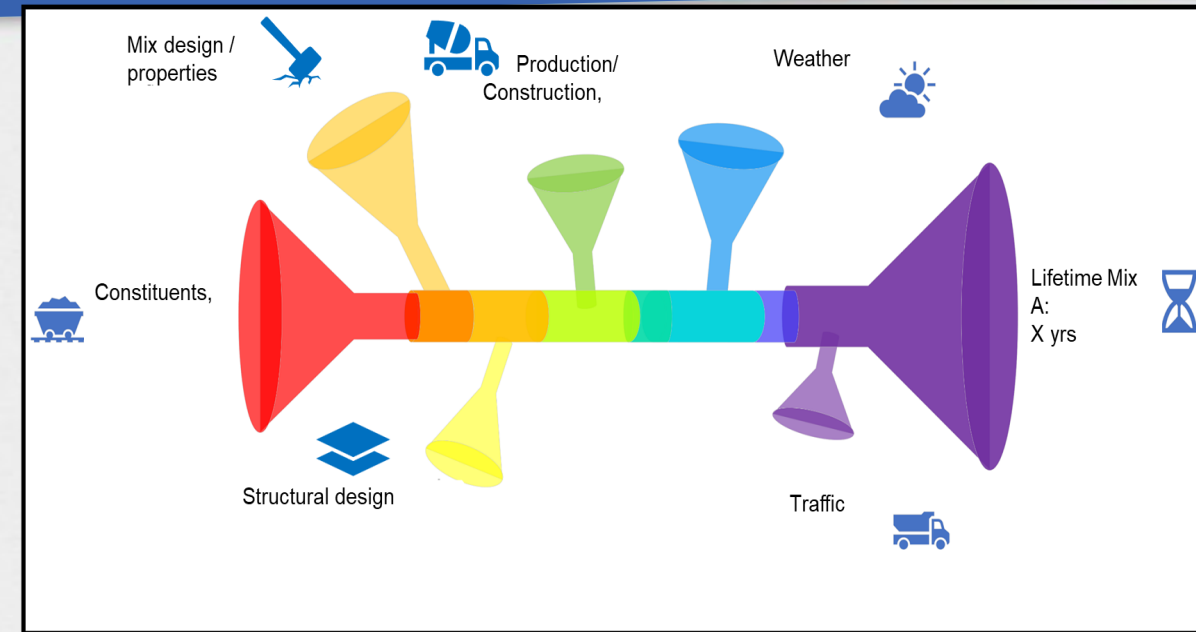
Lifetime Prediction

- Some information readily available: standard
- Some information rare but interesting
- Some conditions need to be assumed/standardised

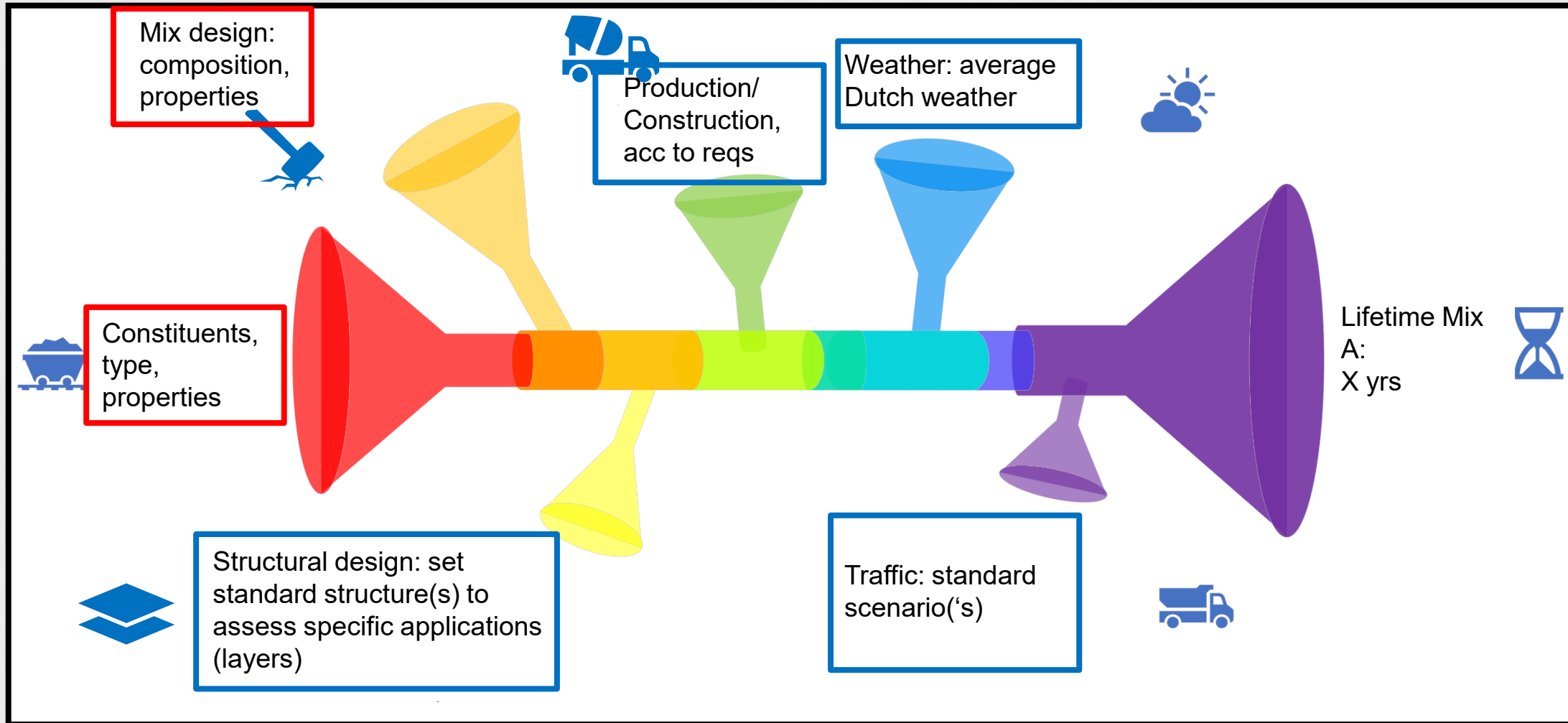
Distress type → Phase ↓	fatigue	ravelling
Constituent materials	<ul style="list-style-type: none"> • Penetration • DSR mastercurve • xxx 	<ul style="list-style-type: none"> • Penetration • DSR mastercurve • DSR-adhesion/mastic
Mix design	<ul style="list-style-type: none"> • bitumen content • stiffness • resistance to fatigue 	<ul style="list-style-type: none"> • bitumen content • RA content • Type and amount rejuvenator • void content • Dmax • ITSr • effect aging • RSAT
Structural design	<ul style="list-style-type: none"> • standard structure • layer in which the material is used 	<ul style="list-style-type: none"> • standard structure, proper adhesion to binder layer
Production	<ul style="list-style-type: none"> • xxx 	<ul style="list-style-type: none"> • xxx
Construction	<ul style="list-style-type: none"> • density/degree of compaction • bitumen content • homogeneity 	<ul style="list-style-type: none"> • density/degree of compaction • bitumen content • void content • pen after construction? • homogeneity
Service life	<ul style="list-style-type: none"> • traffic intensity • weather (standardized expectation, no extremes?) 	<ul style="list-style-type: none"> • traffic intensity • weather (standardized expectation, no extremes?)
maintenance	<ul style="list-style-type: none"> • No maintenance? 	<ul style="list-style-type: none"> • No maintenance?

Lifetime Prediction

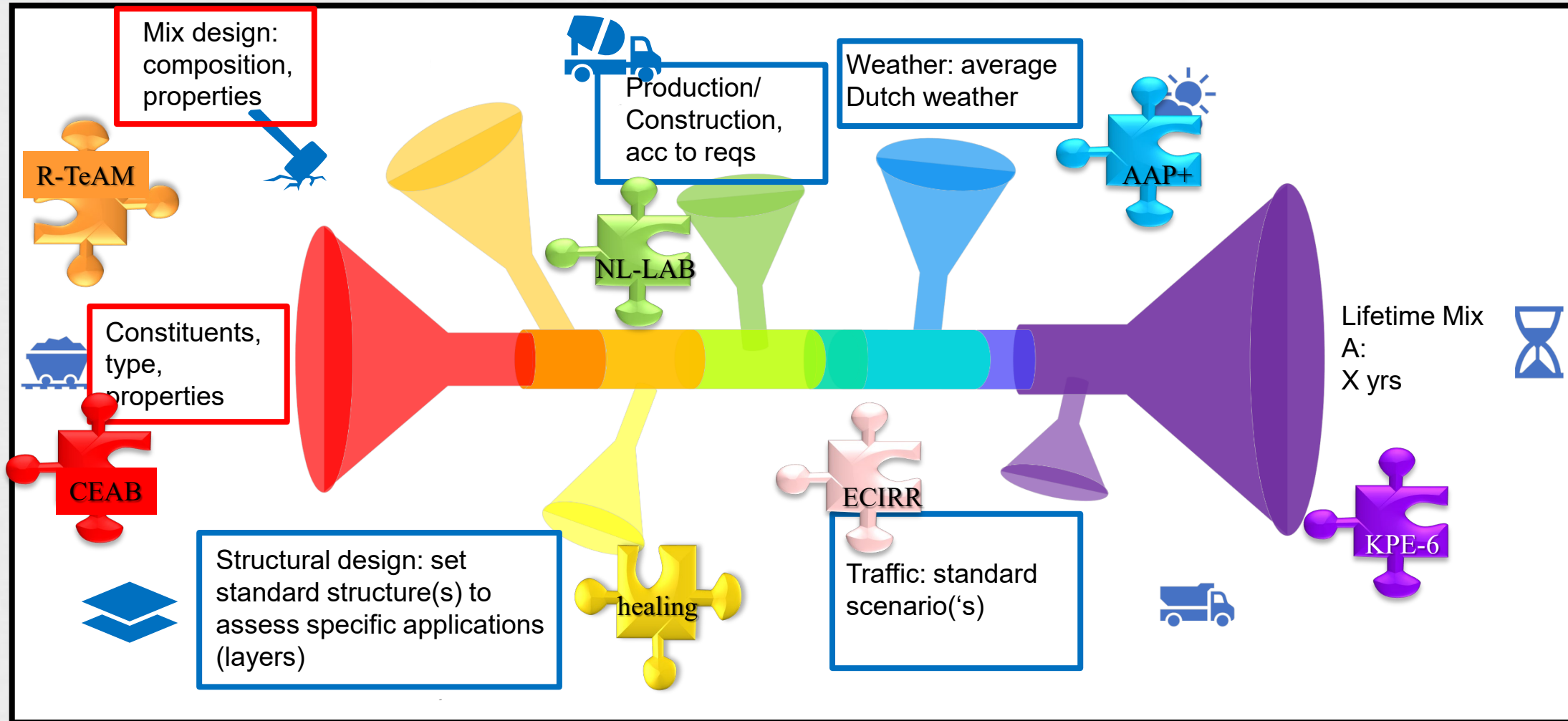
- Structural Design:
 - Assume standard structure(s):
 - Base, bind, proper tack coat
 - Extra's:
 - Additional information per available data, i.e. old binder layer



Lifetime Prediction



Lifetime Prediction



Lifetime Prediction

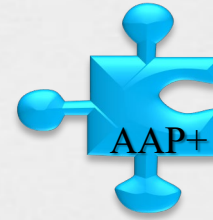
- Overview ravelling resistance assessment methods & applicability



- Models to predict functional properties of asphalt mixtures



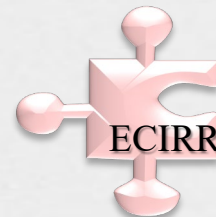
- Aging conditions/ parameters for bitumen and mixtures
- Chemical characteristics linked to aging sensitivity



- Assessment effect changes in design/material on ageing and healing



- Binder performance indicators for durability and recyclability
- Framework for binder properties in relation to variation of quality

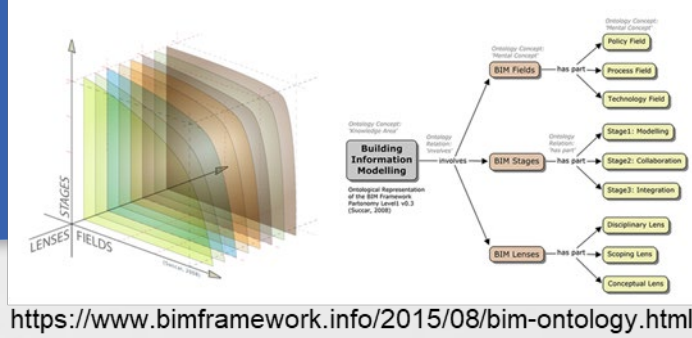


- Tool to compare the rolling resistance of different pavement structures under Dutch conditions in the design phase



- Framework for the lifetime prediction of asphalt mixtures

Lifetime Prediction



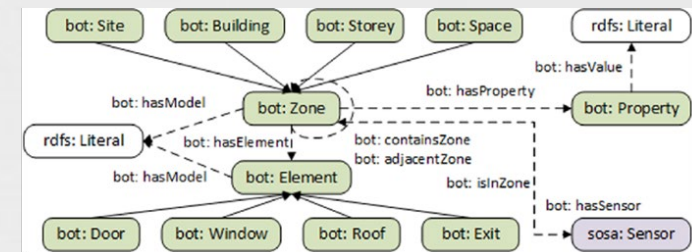
• Ontology

– What is it?

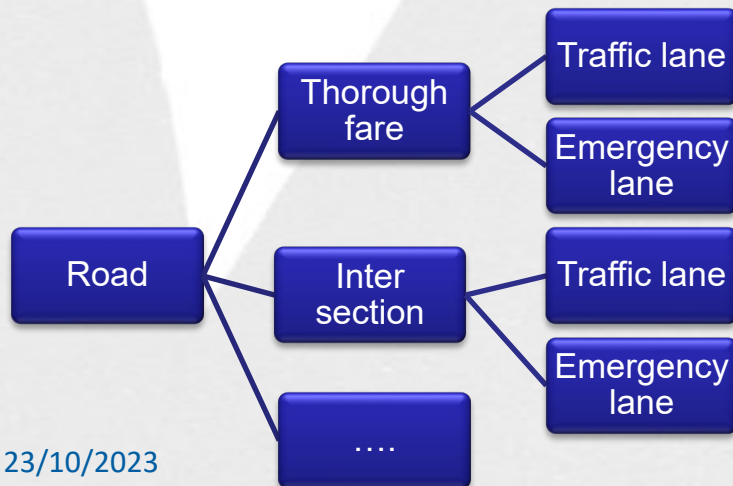
- “the study of being and existence” (Studer et al., 1998) or, in other words, “categories of things that exist” (Sowa, 1999)

– How does it work?

- Set of classes (pieces of information) and relationships (how different pieces of information are associated with one another) (Taher et al., 2017, 2019)

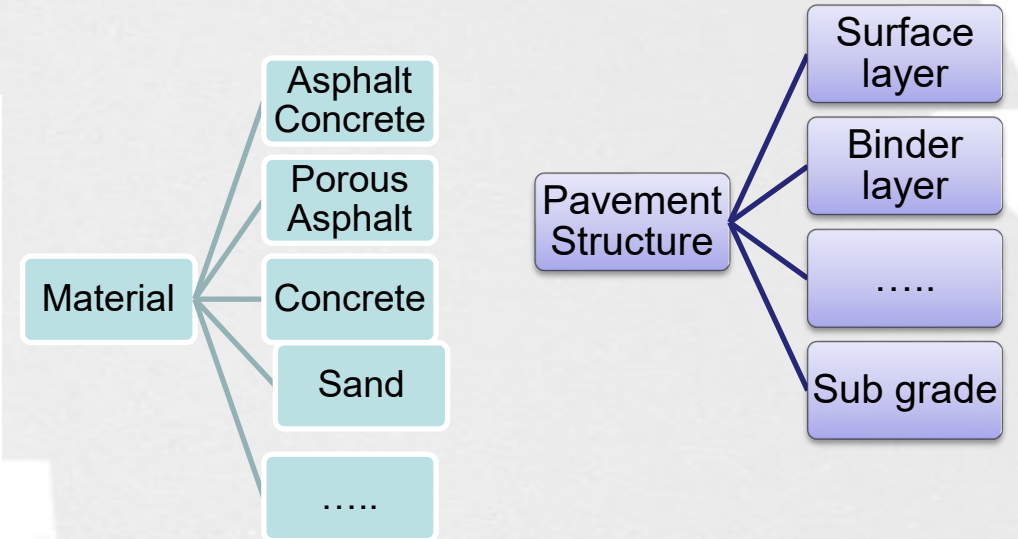


Zhang, Yun-Yi & Hu, Zhen-Zhong & Lin, Jia-Rui & Zhang, Jian-Ping. (2021). Linking data model and formula to automate KPI calculation for building performance benchmarking. Energy Reports. 7. 1326-1337. 10.1016/j.egy.2021.02.044.



23/10/2023

KPE



Lifetime Prediction

• Ontology

– What is it?

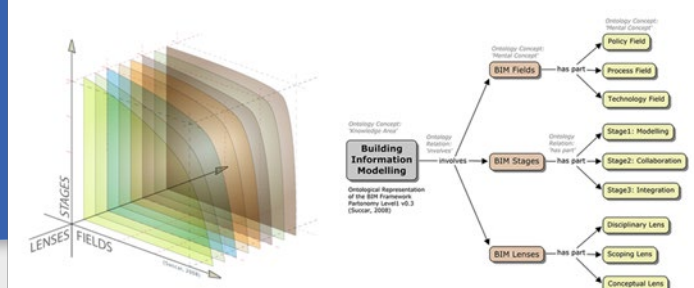
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– How does it work?

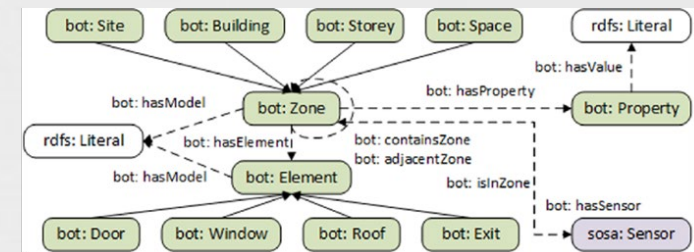
- Set of classes (pieces of information) and relationships (how different pieces of information are associated with one another) (Taher et al., 2017, 2019)

– How will we develop it?

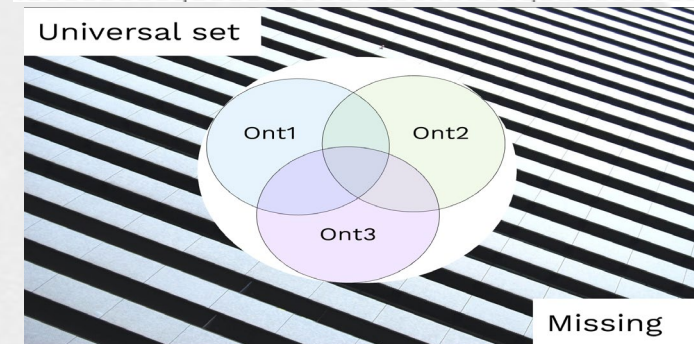
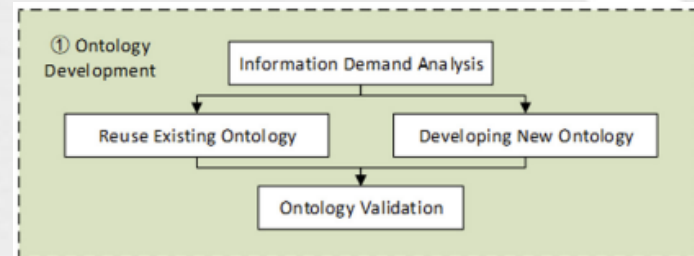
- For example utilizing SABIO(Systematic Approach for Building Ontologies) method
- Integrate/build on developed ontologies from LAM project (Asfalt Impuls), Wegen OTL and Ontology developed at University of Twente



<https://www.bimframework.info/2015/08/bim-ontology.html>

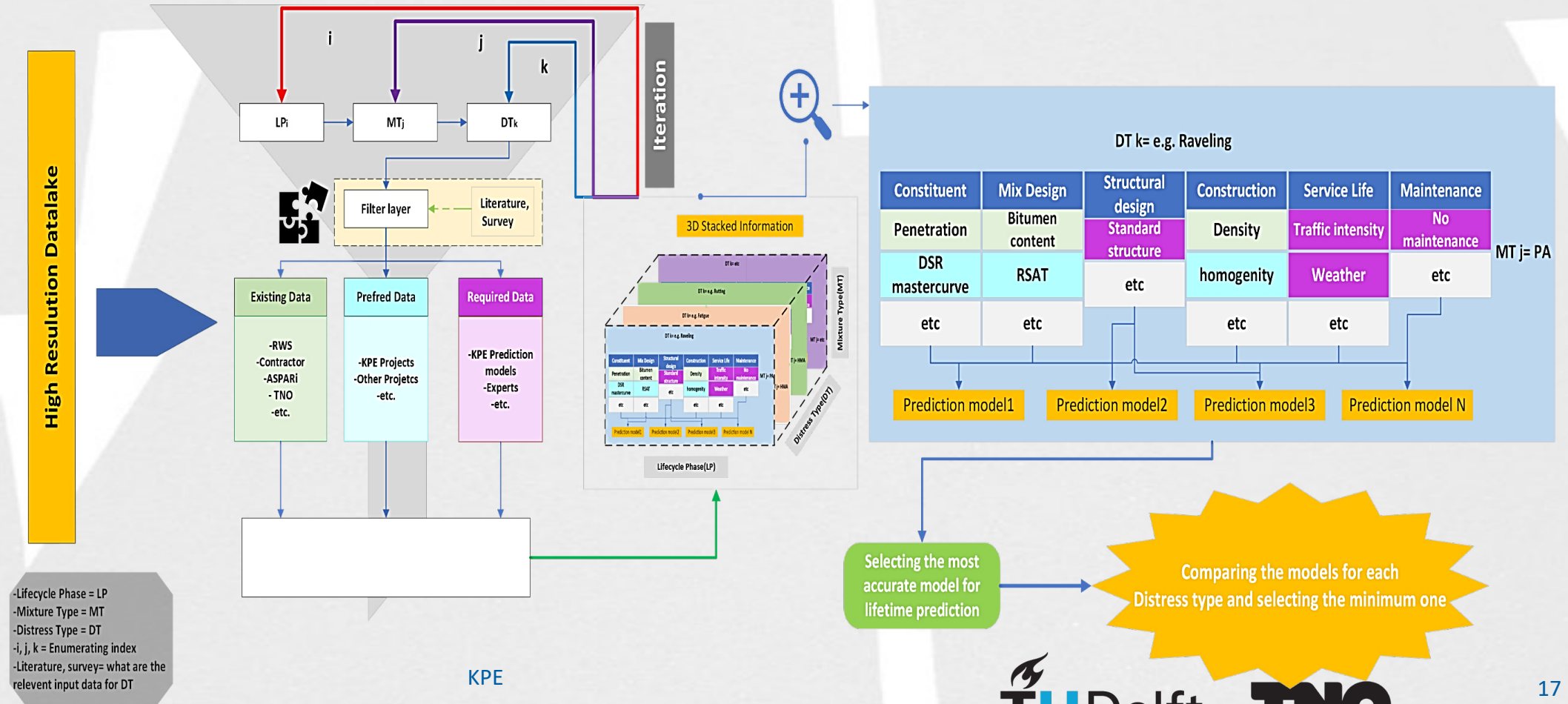


Zhang, Yun-Yi & Hu, Zhen-Zhong & Lin, Jia-Rui & Zhang, Jian-Ping. (2021). Linking data model and formula to automate KPI calculation for building performance benchmarking. Energy Reports. 7. 1326-1337. 10.1016/j.egy.2021.02.044.

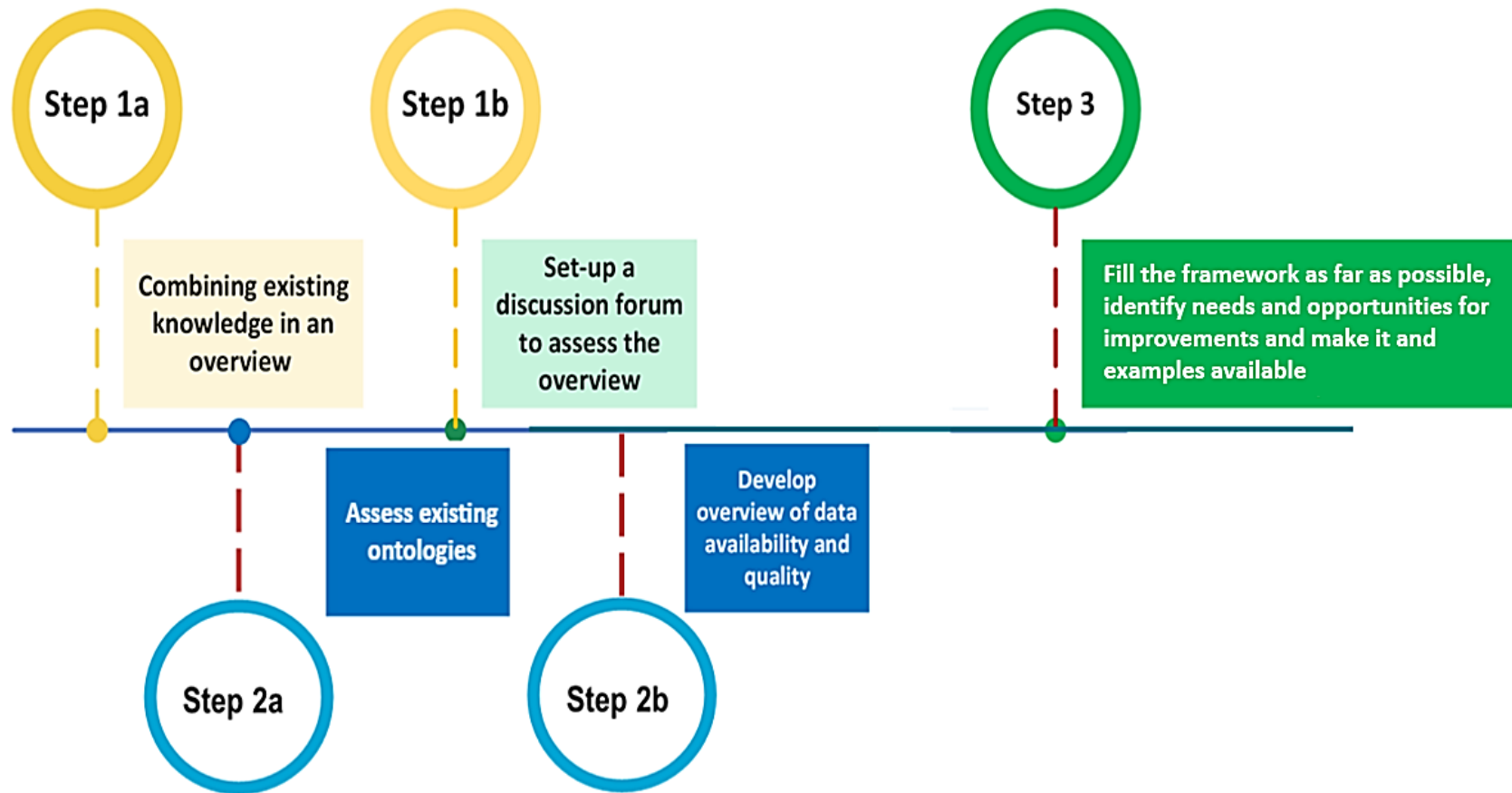


Lifetime Prediction

- Additional information KPE together with existing info



Lifetime Prediction



Lifetime Prediction

- Questions to the audience

- Approach & available data:

- Can you already indicate data/sources of information we missed?

- Expert sessions:

- If you are willing to participate in the experts session and/or to share data, information etc, pls send a message to: M.Berangi@tudelft.nl Mohammadjavad Berangi, PhD linked to LAM – Asphalt Impuls and KPE-6

The End

KPE day 2023

WRAP UP



Rijkswaterstaat
Ministry of Infrastructure
and Water Management



Seminar: 'Bouwen op Kennis'

*Met KPE naar een
klimaatneutrale weg*

31 oktober 2023

Dineke van de Burg
Dave van Vliet
&
Sandra Erkens

**Knowledge-based
Pavement
Engineering
2020-2024**



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Engineering
2020-2024**

TNO  **TU Delft**

Wrap Up

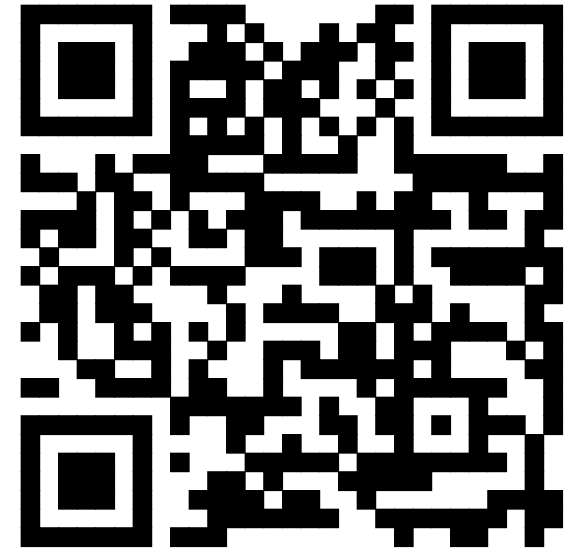
- Lot of information shared this afternoon, some examples of (expected) results:
 - parameters and tools that allow grouping (and distinguishing) binders based on expected aging performance
 - mix aging protocol for example for validations
 - binder performance indicators that indicate the suitability of binders for asphalt construction, quality, durability and recyclability
 - Tools to provide recommendations for the optimal type and amount of rejuvenator for a given RA
 - tool to predict rolling resistance of asphalt pavements under Dutch conditions
- These, and other results from KPE will be embedded in a framework that shows how we can bring together information from all stages of the pavement life cycle, both readily available and more rare, and use it to assess the potential of materials in lifetime

Join the Vevox session

Go to **vevox.app**

Enter the session ID: **119-307-209**

Or scan the QR code





Of the expected KPE results I am most interested in:

parameters and tools that allow grouping (and distinguishing) binders based on expected aging performance

mix aging protocol for example for validations

binder performance indicators that indicate the suitability of binders for asphalt construction

tool to predict rolling resistance of asphalt pavements under Dutch conditions

framework to assess the potential of materials in lifetime

Tools to provide recommendations for the optimal type and amount of rejuvenator for a given RA



Of the expected KPE results I am most interested in:

framework to assess the potential of materials in lifetime

mix aging protocol for example for validations

parameters and tools that allow grouping (and distinguishing) binders based on expected aging performance

binder performance indicators that indicate the suitability of binders for asphalt construction

Tools to provide recommendations for the optimal type and amount of rejuvenator for a given RA

tool to predict rolling resistance of asphalt pavements under Dutch conditions

RESULTS SLIDE



I expect the KPE results to also be applicable to alternative materials

Yes

0%

Yes, but

0%

No, unless

0%

No

0%



I expect the KPE results to also be applicable to alternative materials

Yes



Yes, but



No, unless



No



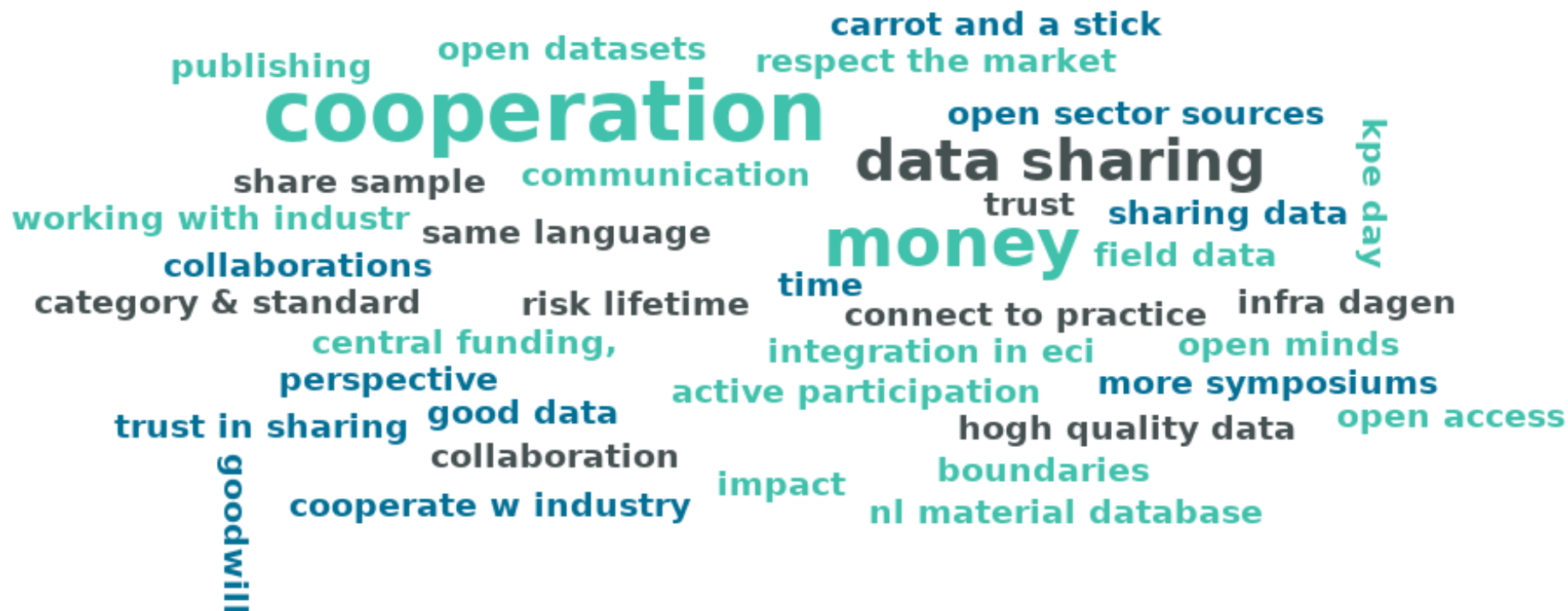
RESULTS SLIDE



What is needed to improve collective knowledge development and sharing?



What is needed to improve collective knowledge development and sharing?



RESULTS SLIDE



Are you willing to contribute your knowledge, experience and data to the development of the lifetime assessment tool?

Yes

0%

No

0%

Maybe, depends on the conditions

0%



Are you willing to contribute your knowledge, experience and data to the development of the lifetime assessment tool?





Looking towards the future, what do you see as the knowledge gaps for the coming 5 to 10 years?



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