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Assessment of vehicle, temperature loads and pavement conditions

Piotr JASKUŁA, Dawid RYS

DEPARTMENT OF TRANSPORTATION ENGINEERING

3rd SIIV International Winter School
December 18th-21st, 2022 – Moena

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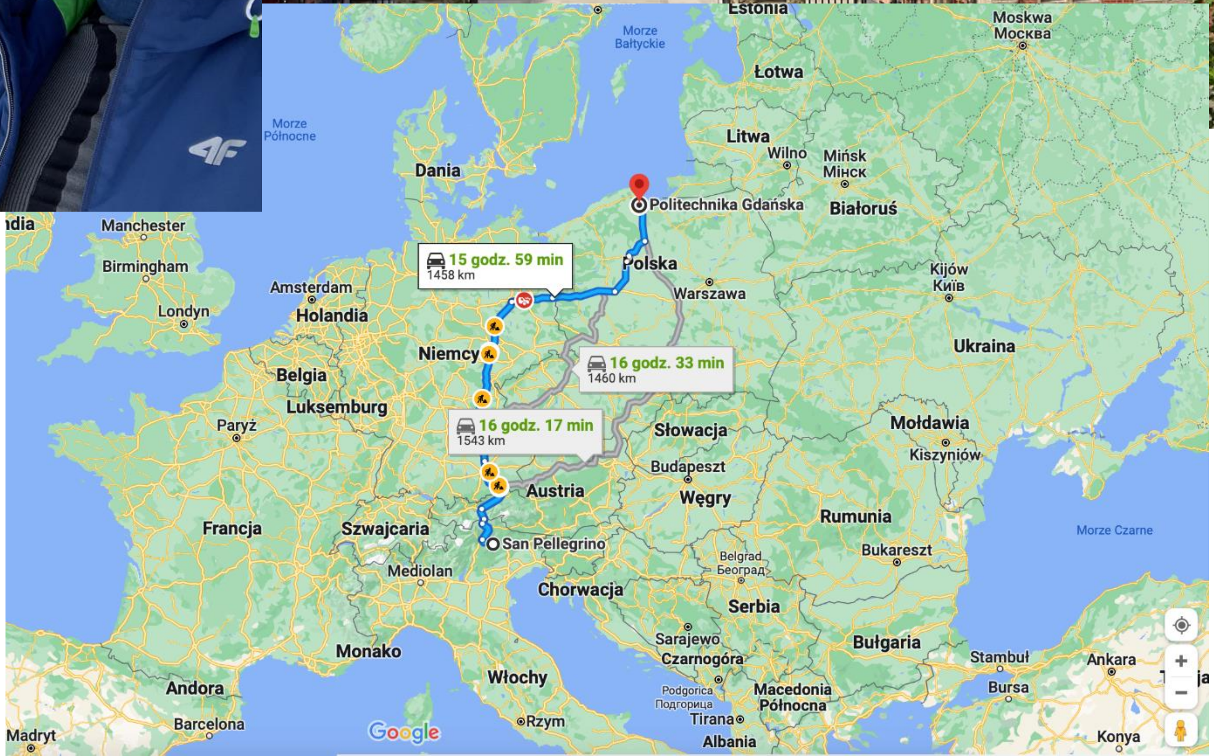
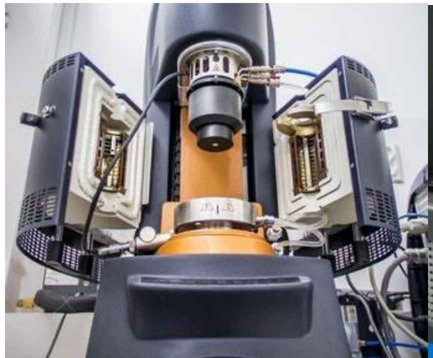


Few words about us...

- GUT – one of the bigest Technical Univ. in Poland
- Faculty of Civil and Enviromental Engineering: aprox. 500 students graduade annually
- Department of Transportation Engineering, HEAD: prof. Piotr Jaskula since 2019
- 3 research teams: Railways, Traffic Engineering, Road Construction
- Field of experiance and research topic: Road materials, Pavement Design, Fatigue life estimation,Pavement Recykling, Traffic load analysis Low-temperatures performance, many more





Assessment of vehicle, temperature loads and pavement conditions – INTRODUCTION

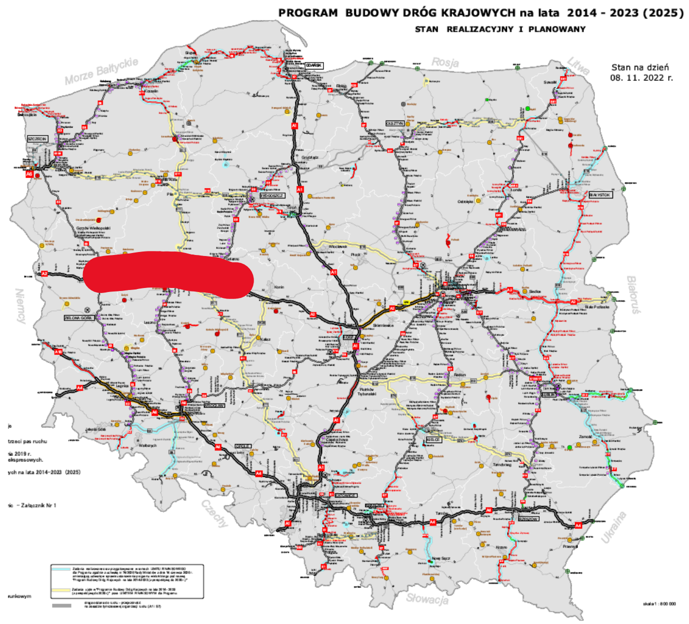
- **Numerous sources of data – how to cope with them?**

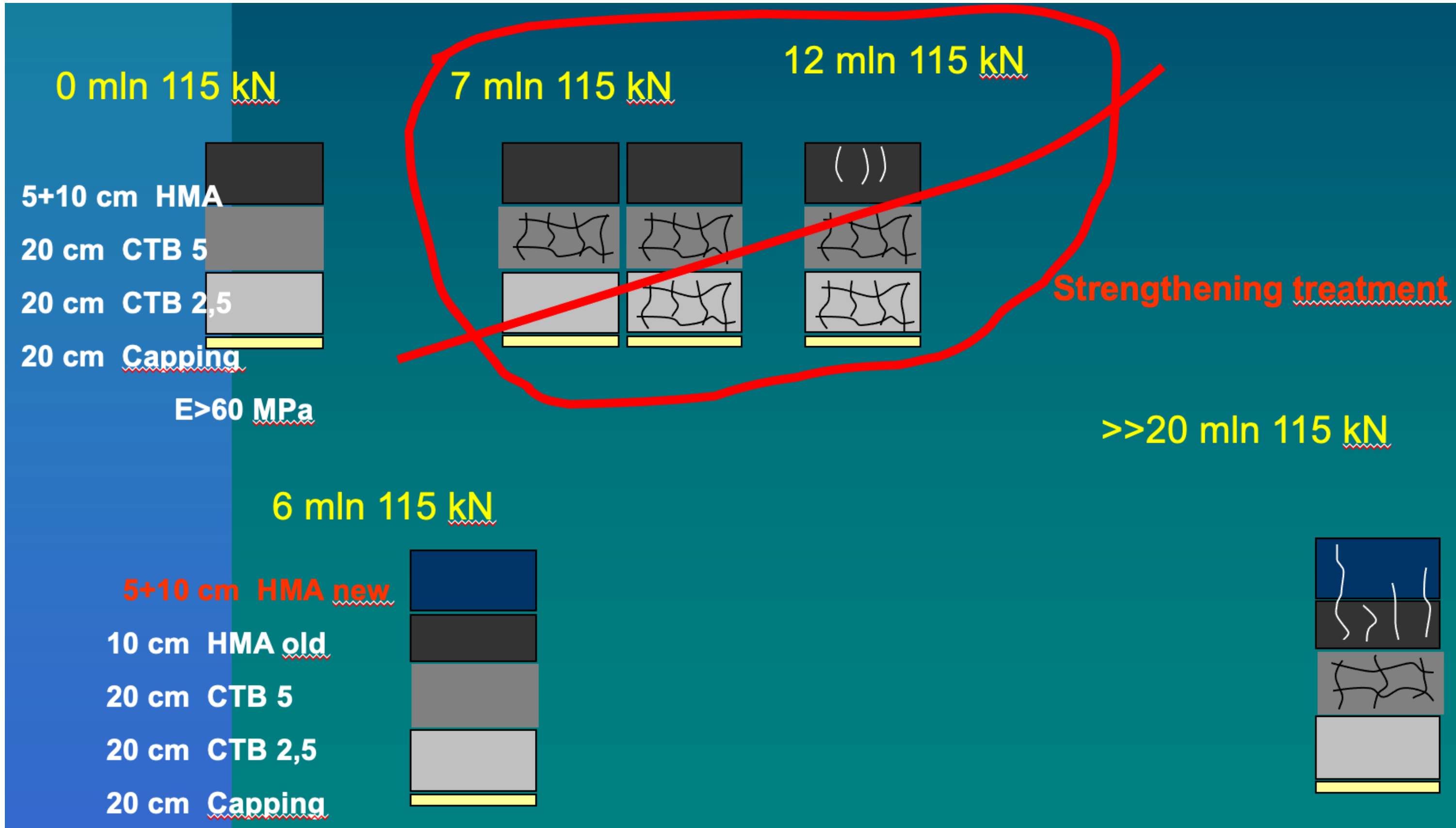
- **VEHICLE LOADS:**
  - WEIGHT IN MOTION SYSTEMS (ESAL, axle load spectra, vehicle overloading)
  - TRAFFIC MANAGEMENT SYSTEMS (Gdansk, Sopot, Gdynia – TRISTAR)
- **TEMPERATURE LOADS:**
  - CLIMATIC DATA (PG climatic zones, low temperature stresses)
  - WINTER MAINTANANCE
- **PAVEMENT CONDITION ASSESSMENT (maintenance scenarios)**

First steps in data age in pavement engineering... the case

Verification of Pavement Design for A2 Toll Motorway in Poland using Heavy Vehicle Simulator, 2002

- A2 is a 152 km toll W-E direction,
- Semi-rigid pavement
- Stage construction project

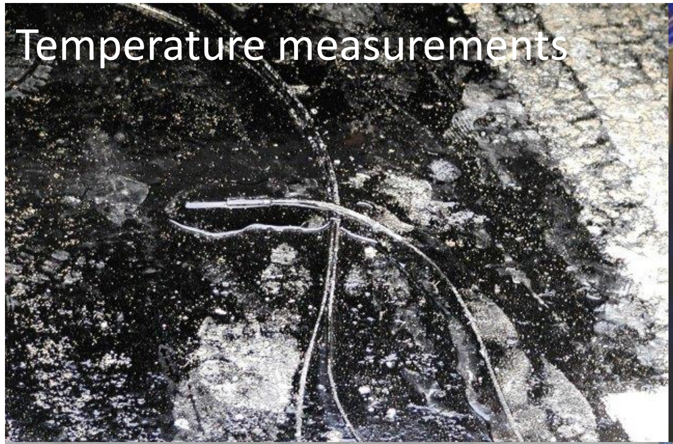


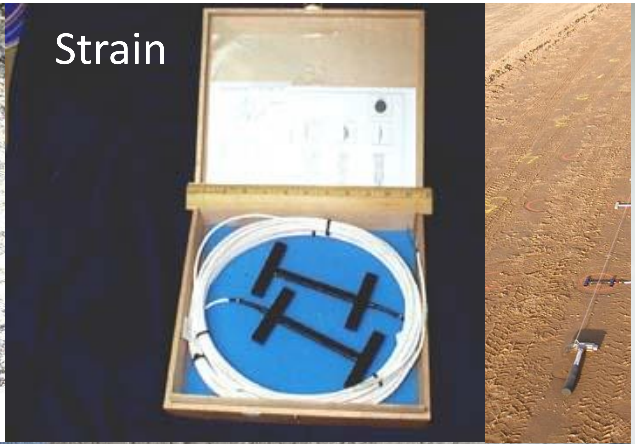


Verification of Pavement Design for A2 Toll Motorway in Poland using Heavy Vehicle Simulator, 2002

- HVS – 0.6 mln 160 kN (1 MPa, 12 km/h) – 30 days : Eqiuvalent to 7 mln of 115 kN standard loads
- Temperature: controled: 15 deg C

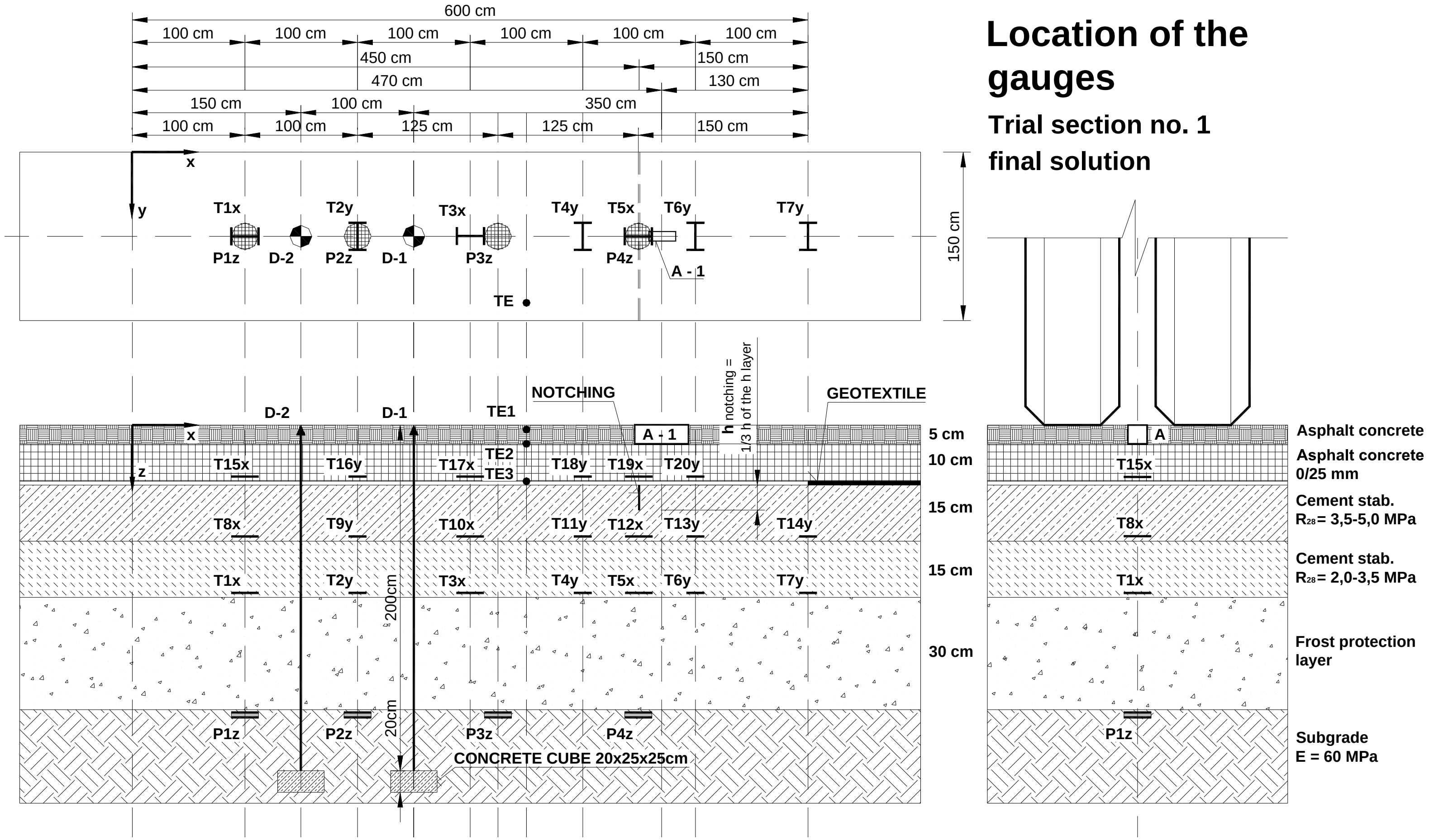
SOURCE of DATA

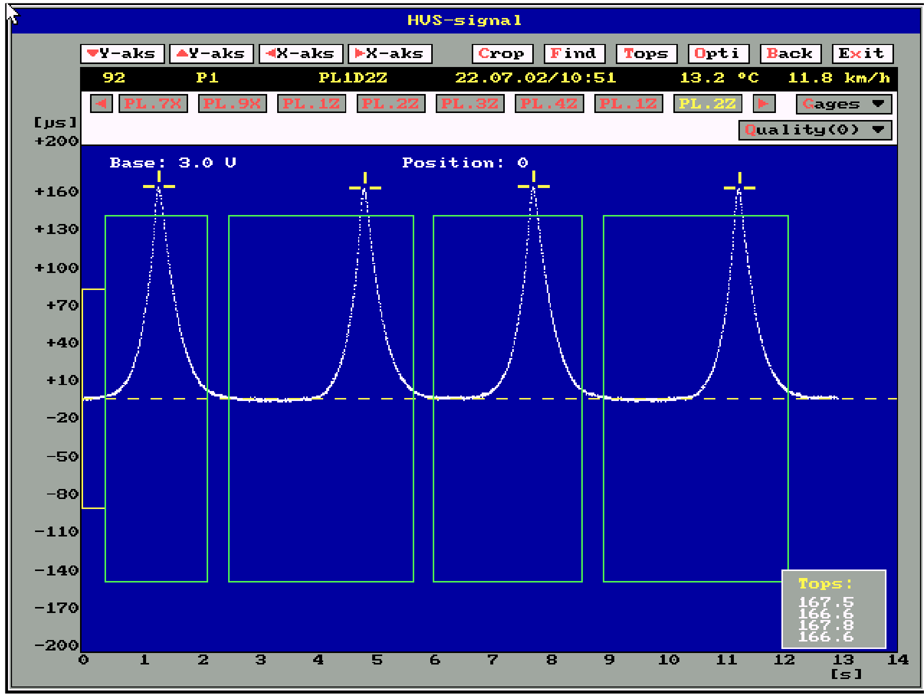




RESULT:

- **Pavement response under successive loads**
- **Fatigue**





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Vehicle loads and Weigh in Motion Systems

Road Materials and Pavement Design

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/trmp20

Determination of equivalent axle load factors with the use of strain energy of distortion

Dawid Rys & Francesco Canestrari

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Consideration of dynamic loads in the determination of axle load spectra for pavement design

Dawid Rys

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Transportation Research Procedia
Volume 14, 2016, Pages 2382-2391

Determination of Vehicles Load Equivalency Factors for Polish Catalogue of Typical Flexible and Semi-rigid Pavement Structures ☆

Dawid Rys, Jozef Judycki, Piotr Jaskula

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https://doi.org/10.1016/j.trpro.2016.05.272

International Journal of Pavement Engineering ›
Volume 17, 2016 - Issue 8

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Articles

Analysis of effect of overloaded vehicles on fatigue life of flexible pavements based on weigh in motion (WIM) data

Dawid Rys, Jozef Judycki & Piotr Jaskula

Pages 716-726 | Received 11 Jul 2014, Accepted 05 Feb 2015, Published online: 11 Mar 2015

Download citation https://doi.org/10.1080/10298436.2015.1019493

Roads and Bridges - Drogi i Mosty 18 (2019) 283 - 302 283

DAWID RYŚ[1)]
PIOTR JASKUŁA[2)]
MARIUSZ JACZEWSKI[3)]
MAREK PSZCZOŁA[4)]

APPLICATION AND EVALUATION OF M-EPDG FOR PERFORMANCE ANALYSIS OF POLISH TYPICAL FLEXIBLE AND RIGID PAVEMENTS

WDROŻENIE I OCENA METODY M-EPDG DO ANALIZY TRWAŁOŚCI POLSKICH TYPOWYCH KONSTRUKCJI NAWIERZCHNI PODATNYCH I SZTYWNYCH

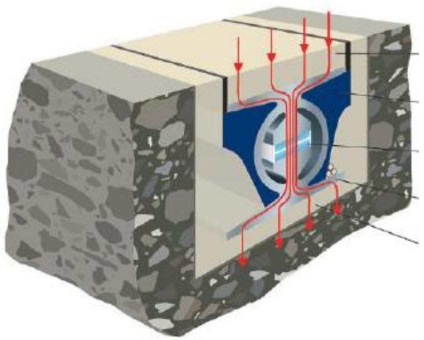
STRESZCZENIE. Głównym celem artykułu jest omówienie zastosowania i ocena przydatności metody M-EPDG oraz oprogramowania AASHTOware do analizy trwałości nowych nawierzchni podatnych i sztywnych zaprojektowanych zgodnie z polskimi katalogami, porównywalnymi z analogicznymi katalogami typowych nawierzchni stosowanymi w innych krajach europejskich. W tym celu określono i opisano lokalne dane wejściowe dla Polski, jak również porównano je z domyślnymi wartościami stosowanymi w USA. Parametry stanu nawierzchni uzyskane z M-EPDG zestawiono z ich granicznymi wartościami określonymi w polskim

ABSTRACT. The main goal of the paper is to implement and evaluate the M-EPDG and the software AASHTOware to analyse the performance of new flexible and rigid pavements designed according to the Polish catalogues, which are comparable with analogous catalogues used in other European countries. For this purpose the site-specific inputs for Poland were determined and described in the paper as well as compared to the default input data used in the USA. Performance parameters delivered from M-EPDG were compared to limits of pavement distresses given in the Polish Pavement

OVERVIEW of Weigh in Motion Technology

Cameras

Inductive loops

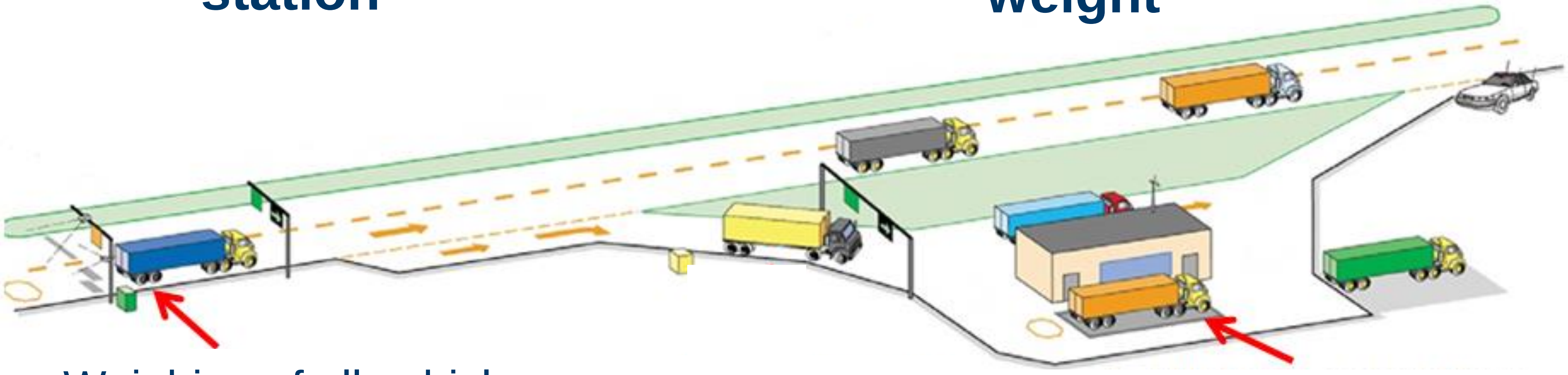


Load sensors

Idea of vehicle preselection

Weigh in motion station

Control on static weight



Weighing of all vehicles
Preselecting
Providing the statistical data

Weighing of preselected vehicles on static, legal weights.
Imposition of punishment

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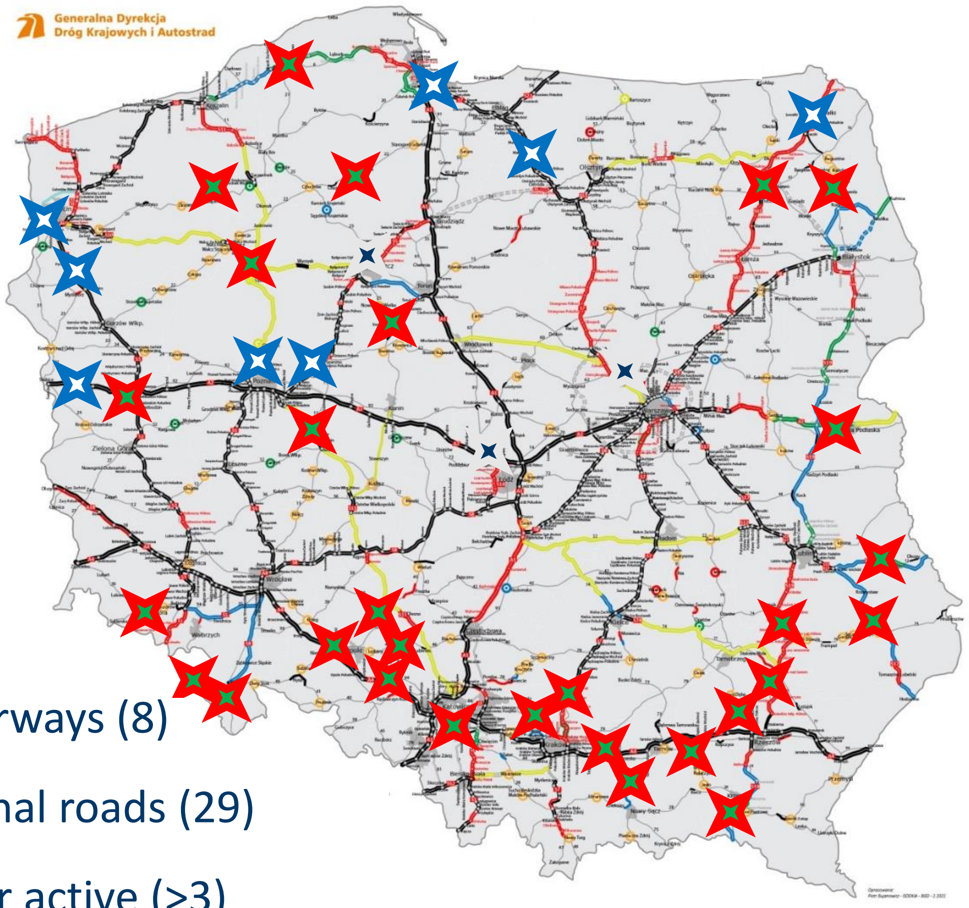
OVERVIEW of Weigh in Motion Technology

Data include:

- gross weight
- axle loads
- distance between axles
- speed
- vehicles class

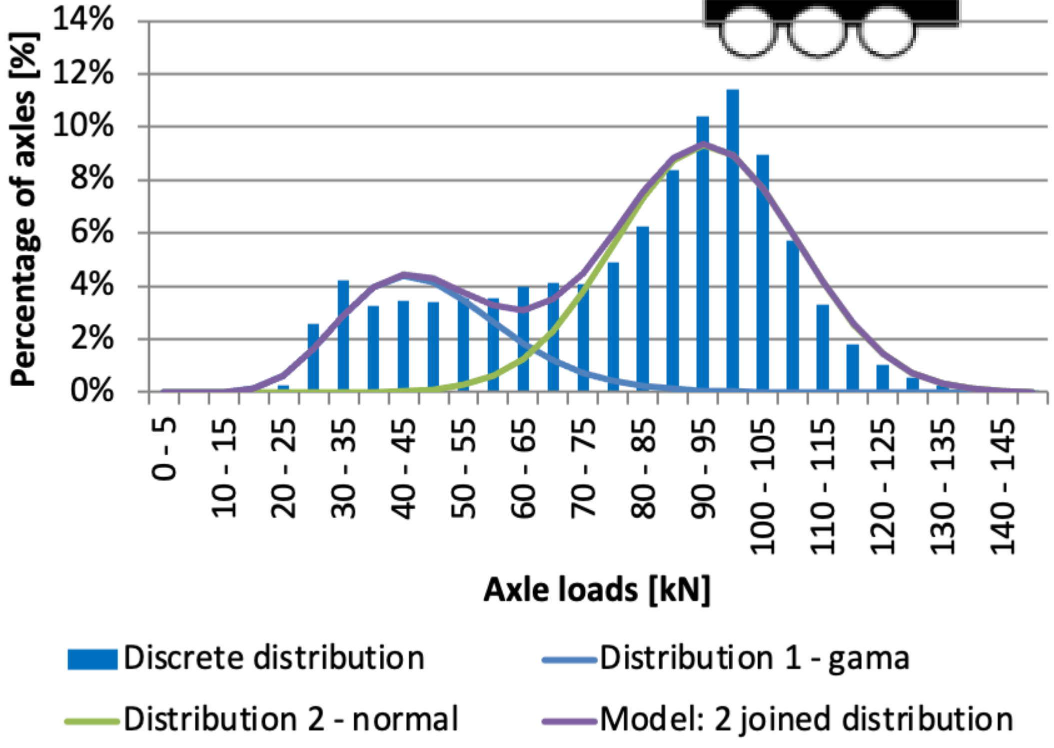


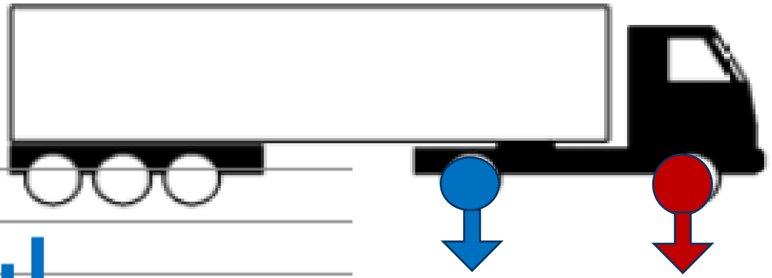
WIM on motorways (8)

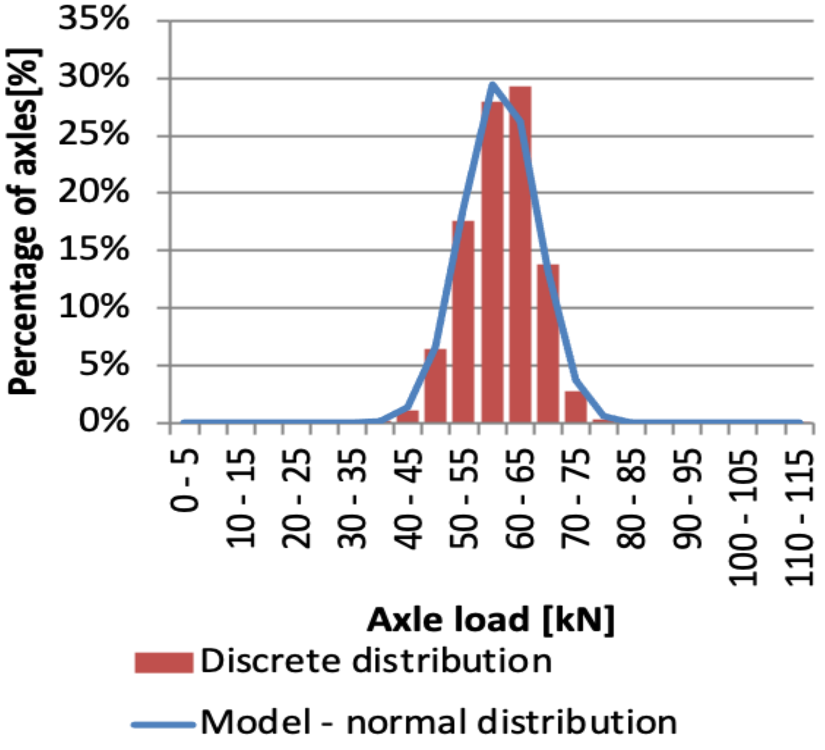
WIM on national roads (29)

WIM no longer active (>3)

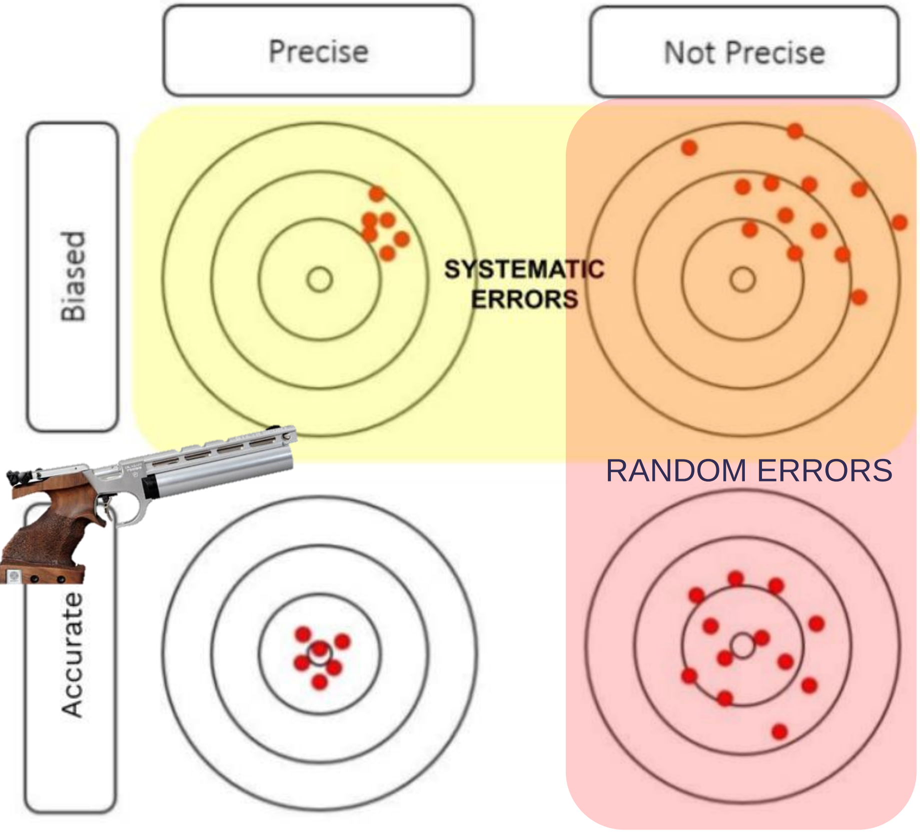
Axle load spectra (ALS) – example

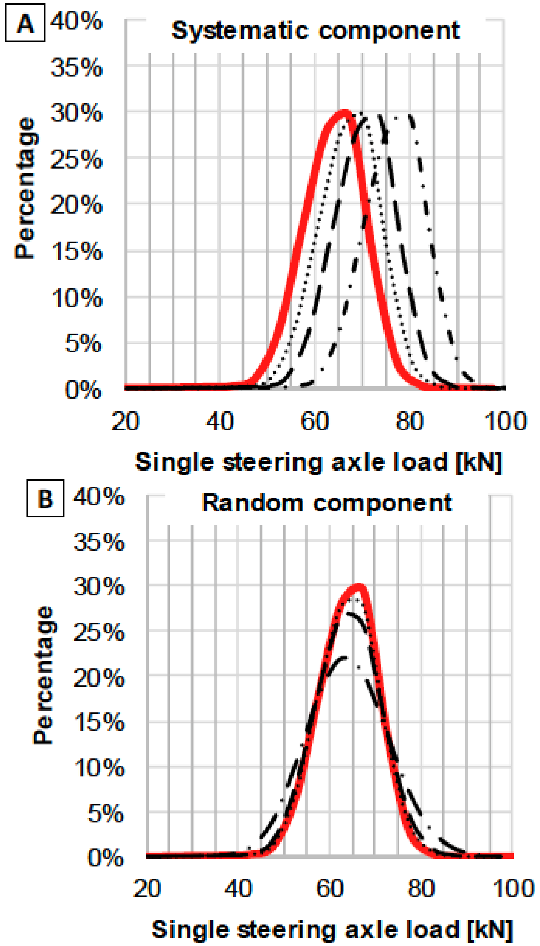






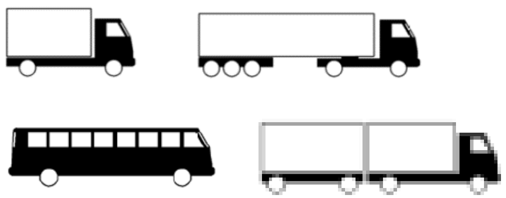
Axle load spectra (ALS) – assesment of system errors

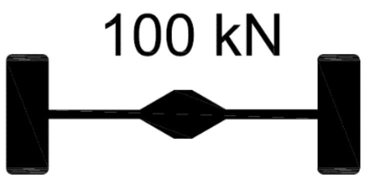




- Steering axle load spectrum can be used to evaluate error
- Systematic error is more serious, can lead to underestimation of traffic loads

Application of WIM data for calculation of the Load Equivalency Factors LEF





Number of trucks or axles × Load equivalency factors F_j = Number of equivalent standard axle loads

Power equation – general level

$$LEF = \left(\frac{Q_j}{Q_s}\right)^n$$

Q_j – an actual axle load

Q_s – the standard axle load

n – exponent (4 – most common)

Mechanistic-empirical approach – site specific level

$$LEF = \frac{d_j}{d_s}$$

d_j – fatigue damage caused by an actual axle load Q_j

d_s – fatigue damage caused by the standard axle load Q_s

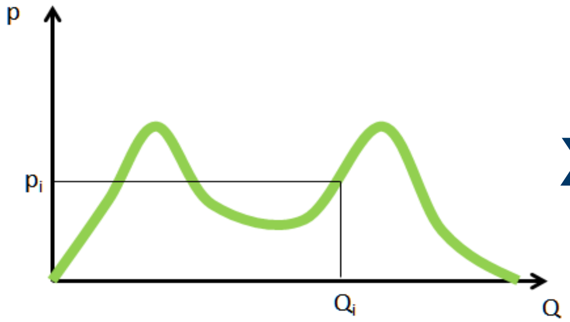
Application of WIM data for calculation of the Load Equivalency Factors LEF

- **Calculation of LEF for particular vehicles (truck factors)**

$$LEF(vehicle) = \sum_{j=1}^{n} LEF(axles)$$

- **Calculation of LEF on the basis of axle load spectra**

Axle load spectra — **Load equivalency function** — **Load Equivalency Factors**



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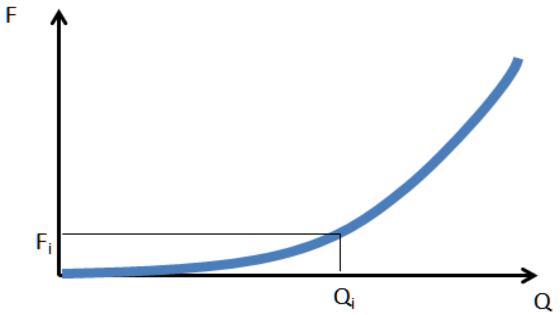

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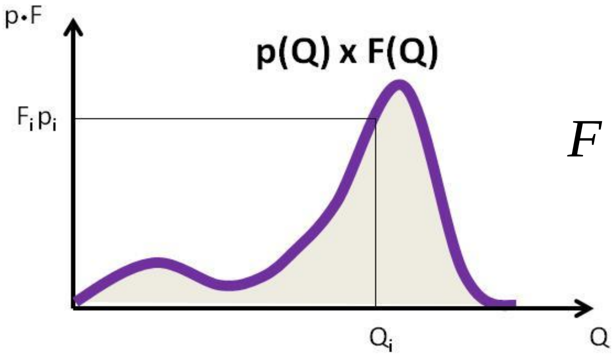


$$F = \int_{0}^{Q\max} p(Q) \cdot F(Q) dQ$$

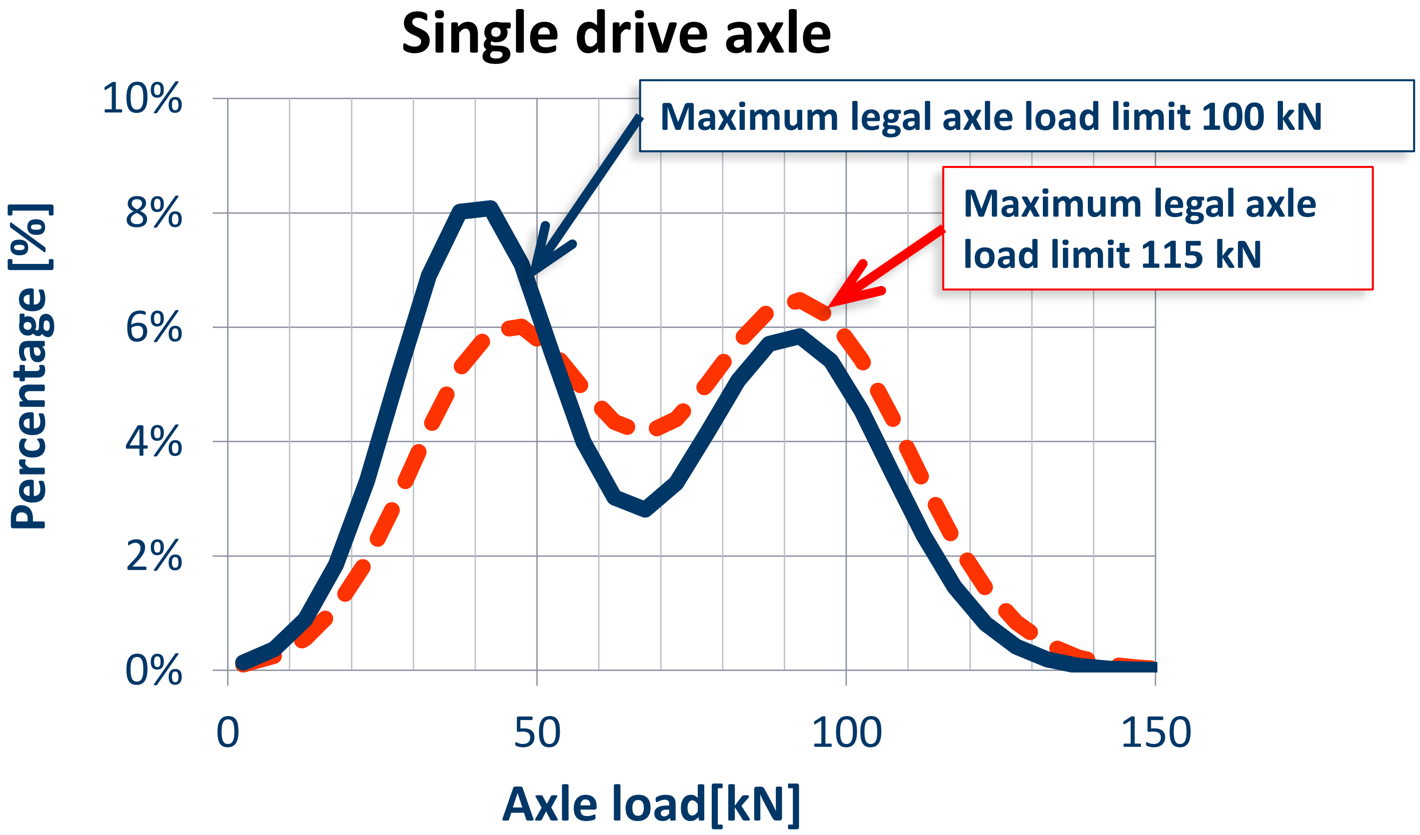
EFFECT OF MAXIMUM AXLE LOAD AND AXLE LOAD INCREASE – K1

Average distributions of axle loads

Different types of axles (single, multiple, drive etc.)

Legal axle load limits in Poland:

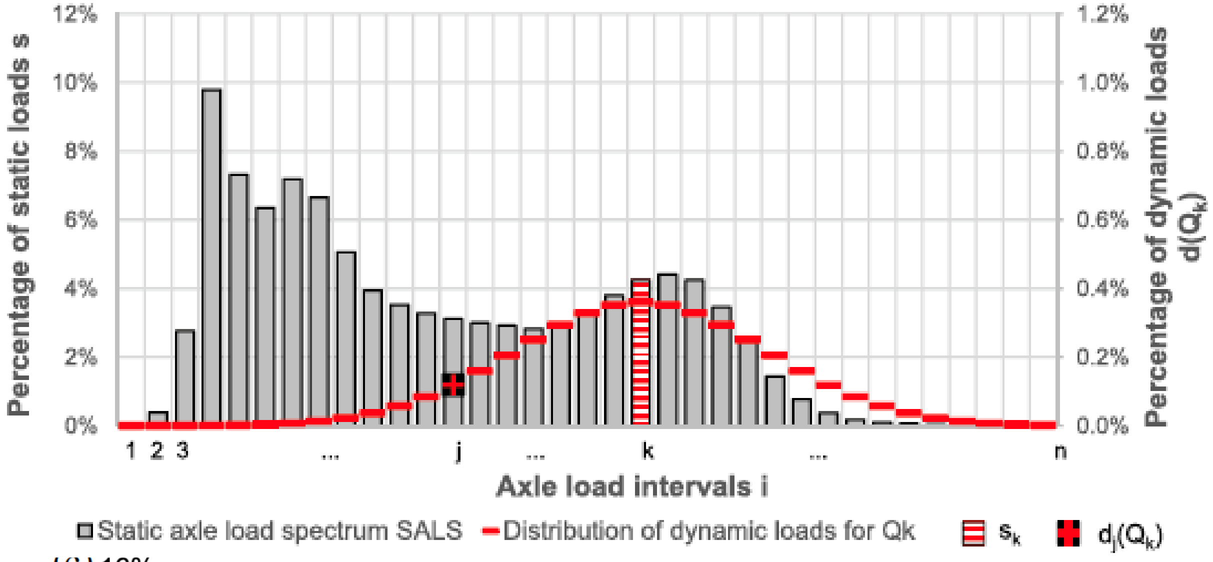
115 kN, ~~100 kN, 80 kN~~

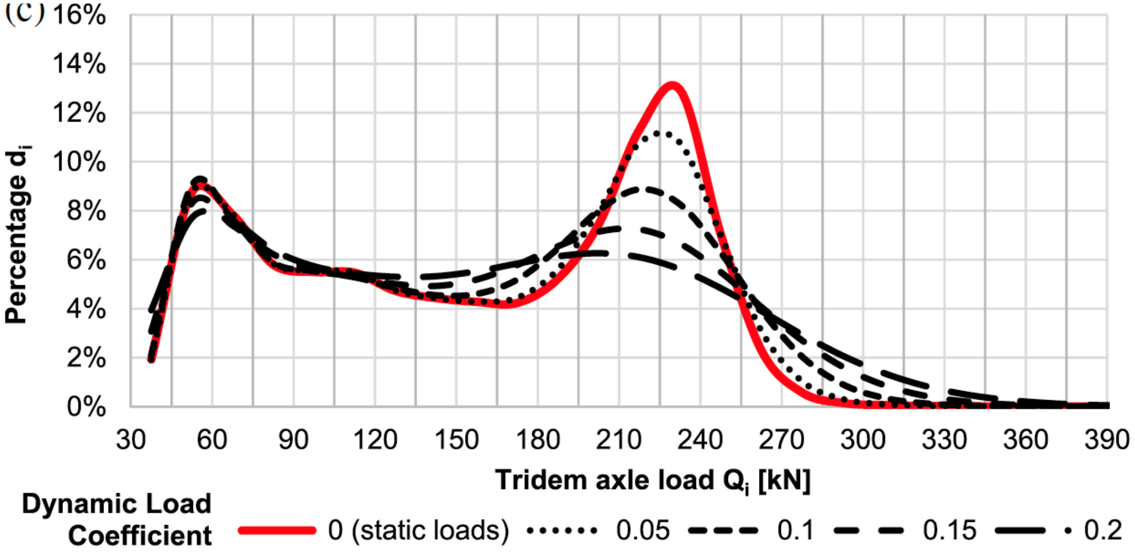


EFFECT OF DYNAMIC LOADS – K2

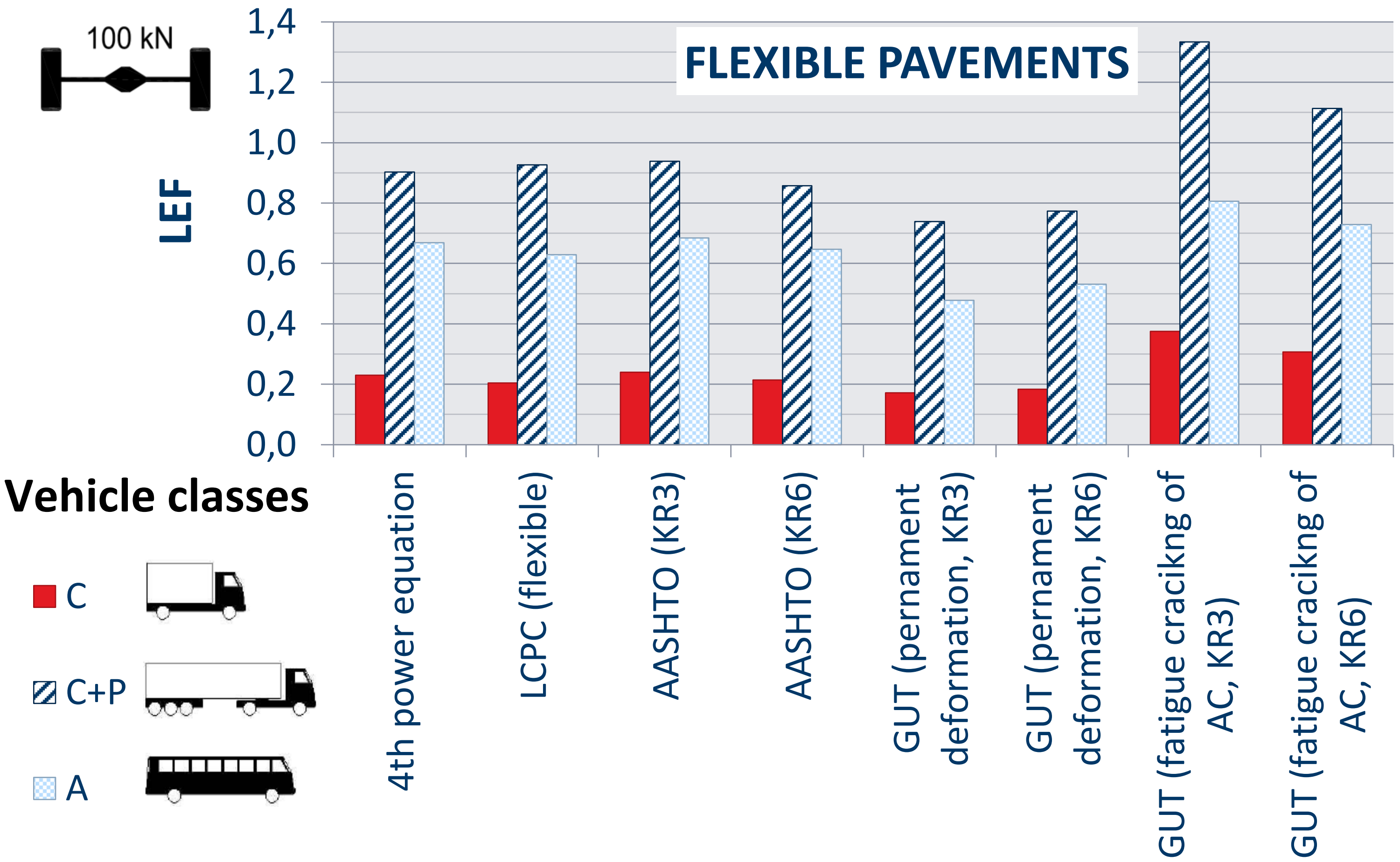
- **Dynamic Load Coefficient DLC**
- **Increase of pavement roughness (IRI) and vehicle speed causes increase of DLC**
- **Increase of DLC causes ”flattening” of ALS**
- **Higher amount of heavier, dynamic loads causes faster pavement deterioration**

$$k_d = \frac{LEF_{dyn}}{LEF_{stat}}$$

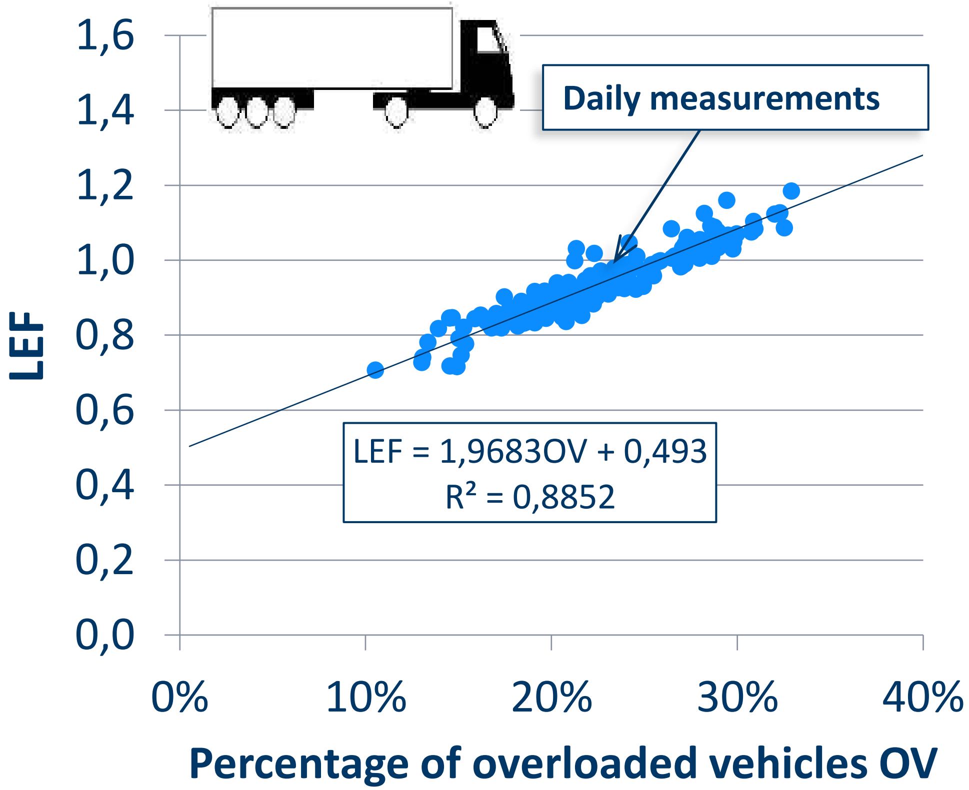




LOAD EQUIVALENCY FACTORS – OLEF



EFFECT OF OVERLOADED VEHICLES – K4



FINAL VALUES OF LOAD EQUIVALENCY FACTORS (100 kN)

Average and operative values delivered from analysis of WIM data **OLEF**

Effect of maximum legal axle load limit **K1**

Impact of dynamic loads **K2**

Possibility of increase of axle loads in the future **K3**

Impact of overloaded vehicles **K4**

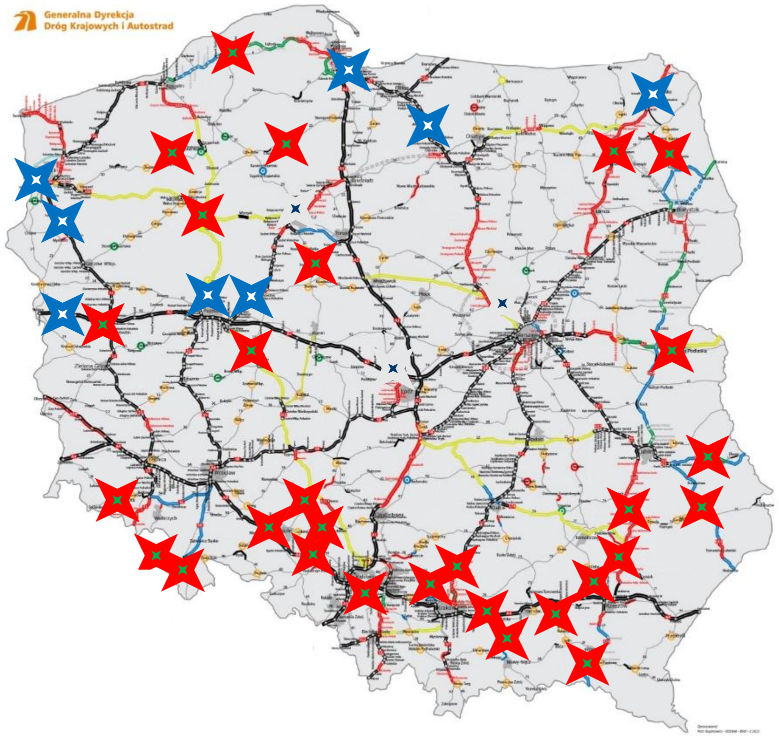
CORRECTION COEFICIENTS

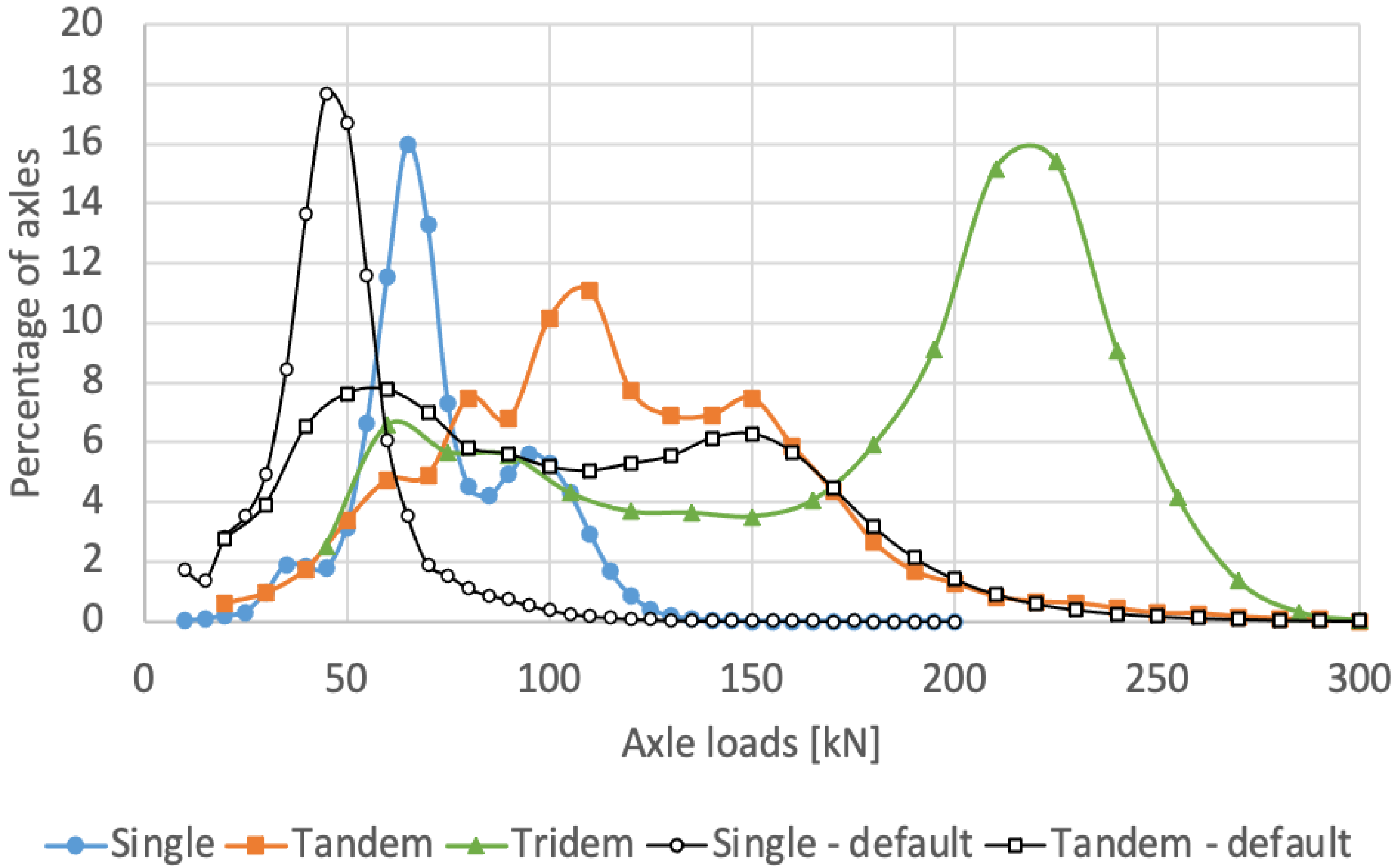
Vehicle category	Group of roads		
	Motorways and expressways	National roads	Other roads
	Maximum legal axle load limit, assumed for pavement design		
	115 kN	115 kN	115 kN
C	0,50	0,50	0,45
C+P	1,95	1,80	1,70
A	1,25	1,20	1,15

$$LEF_{FINAL} = OLEF \cdot K1 \cdot K2 \cdot K3 \cdot K4$$

WEIGHT IN MOTION STATION – load spectra to M-EPDG

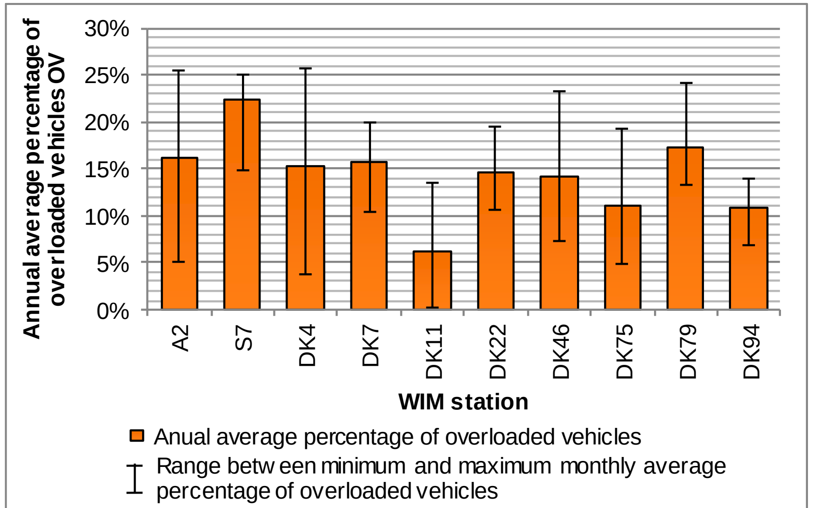
- **No equivalent axle, and load equivalency factors**
- **Axle load spectra – crucial data**

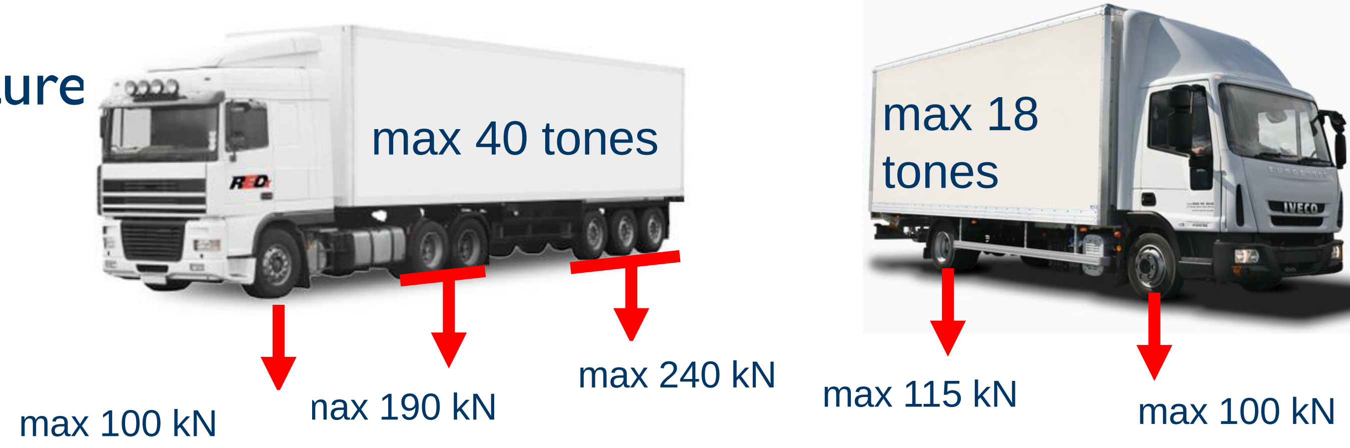




WEIGHT IN MOTION STATION – overloads

- There are set legal limitations of gross weigh and axle loads of vehicles
- Some vehicles exceed this legal limits
- Overloaded vehicles have much higher detrimental effects on pavement structure than properly loaded vehicles

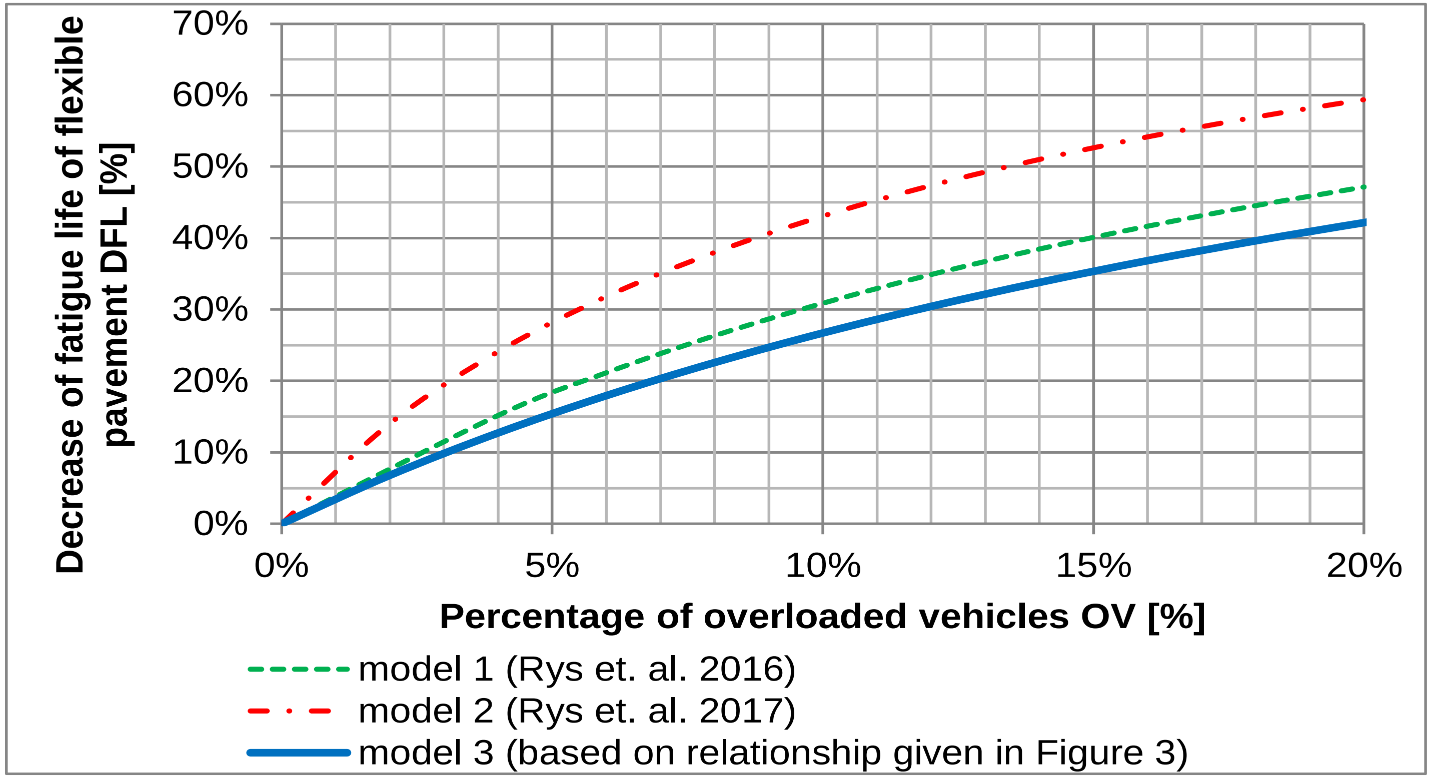




$$OV = \frac{Number\ of\ overloaded\ vehicles}{Total\ number\ of\ trucks}\ [\%]$$

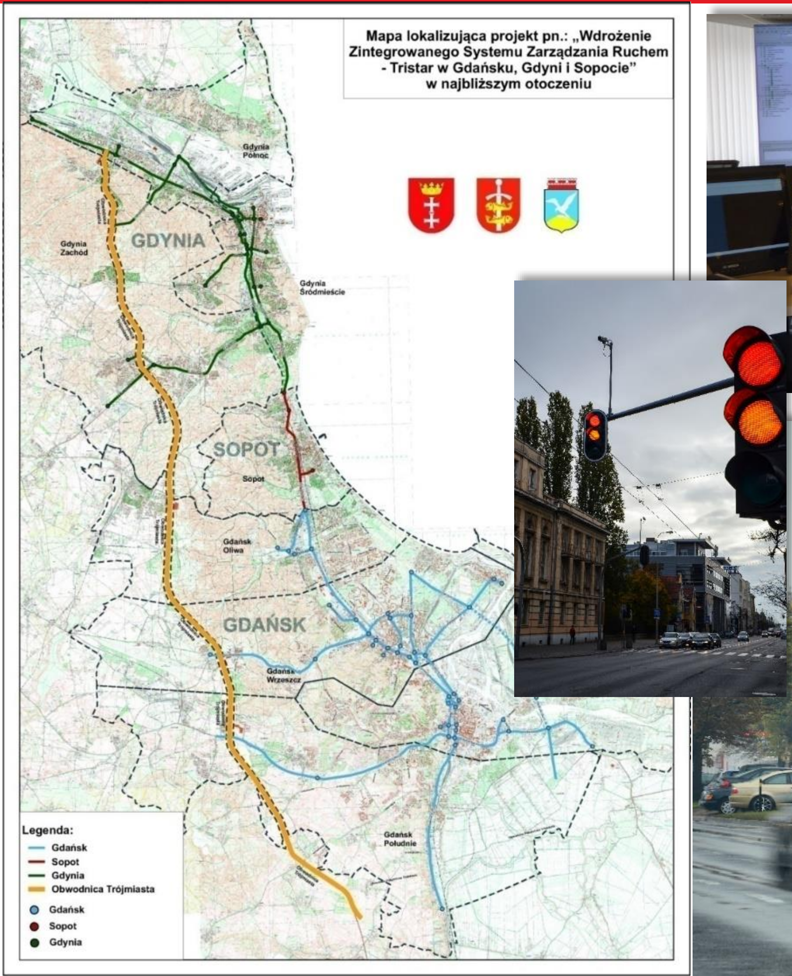
WEIGHT IN MOTION STATION – overload

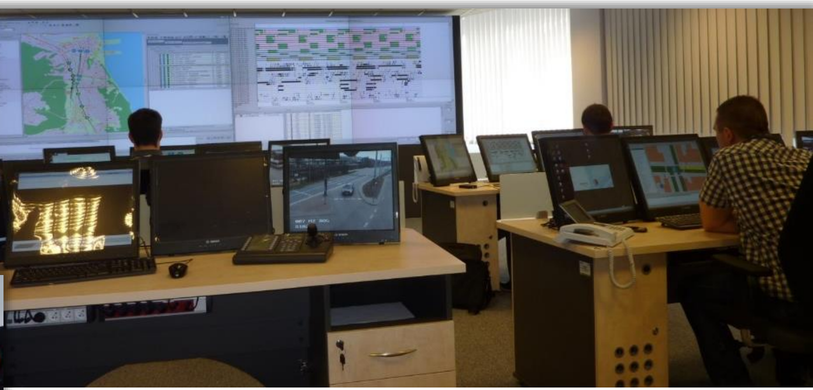
Fatigue Life drops down approximately twice when OV=20

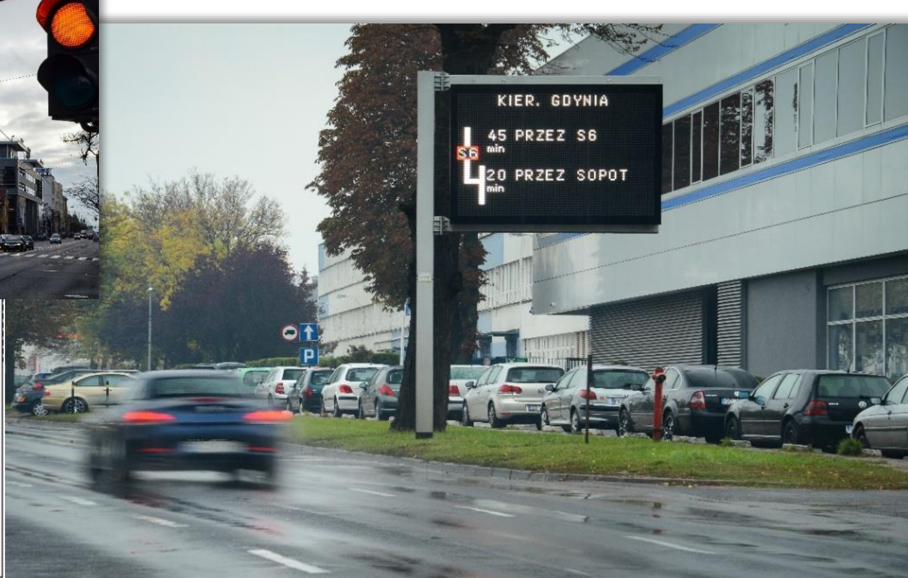


TRAFFIC CONTROL – TRISTAR system

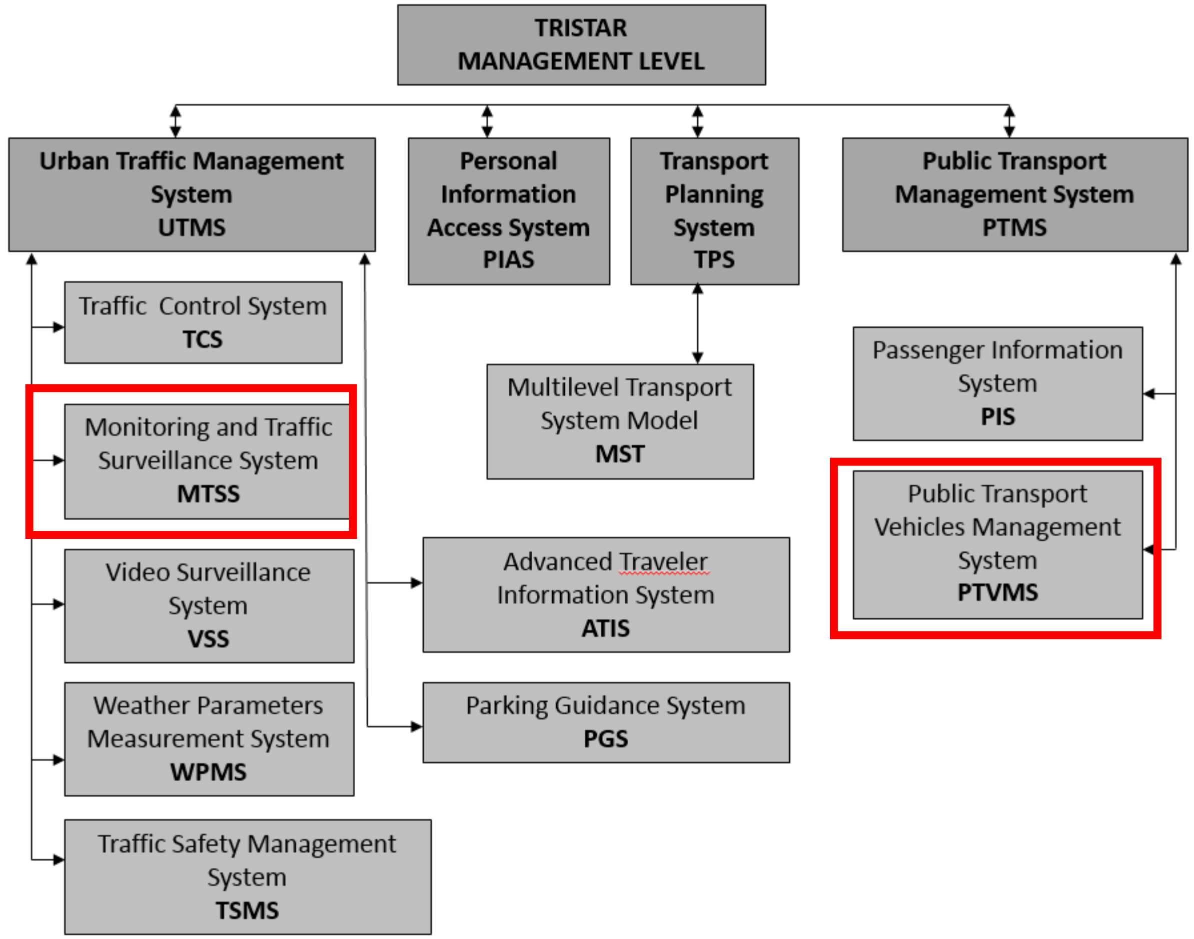
- 148 km of fiber optic connections
- 161 intersections with traffic lights (BALANCE/EPICS system)
- 73 video surveillance cameras
- 61 points with ANPR cameras
- 36 guidance parking information signs
- 34 Passenger Information boards
- 22 Bluetooth/WiFi scanners
- 19 Variable Message Boards
- 16 Tripplanners
- 14 Weather stations
- 7 Variable Message Signs
- 1 Weigh in Motion







TRISTAR System Architecture

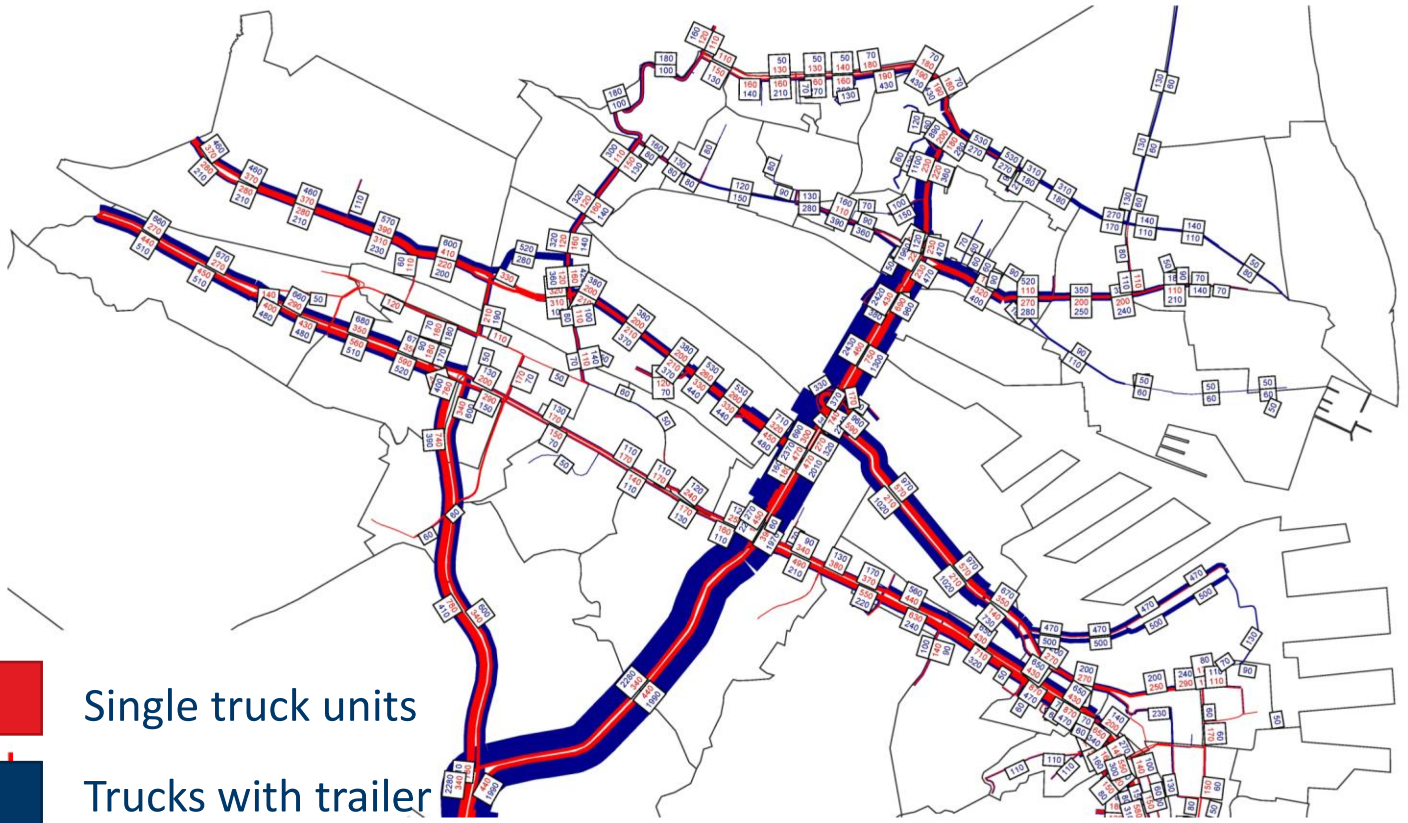


Public transport priority

Monitoring and Traffic Surveillance System - MTSS

Examples of detection systems in TRISTAR:

- Traffic measurement stations – 161 intersections – inductive loops
- Traffic Control System - inductive loops or video detection
- Bluetooth and Wi-Fi sensors - incident detection algorithms
- ANPR cameras – Driver Information System / Traffic Safety Management System
- Public Transport Vehicles – PT Vehicles Management System / priorities for PT vehicles in TCS



Single truck units

Trucks with trailer

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TEMPERATURE LOADS

Roads and Bridges - Drogi i Mosty 16 (2017) 245 - 264 245

MAREK PSZCZOŁA[1]
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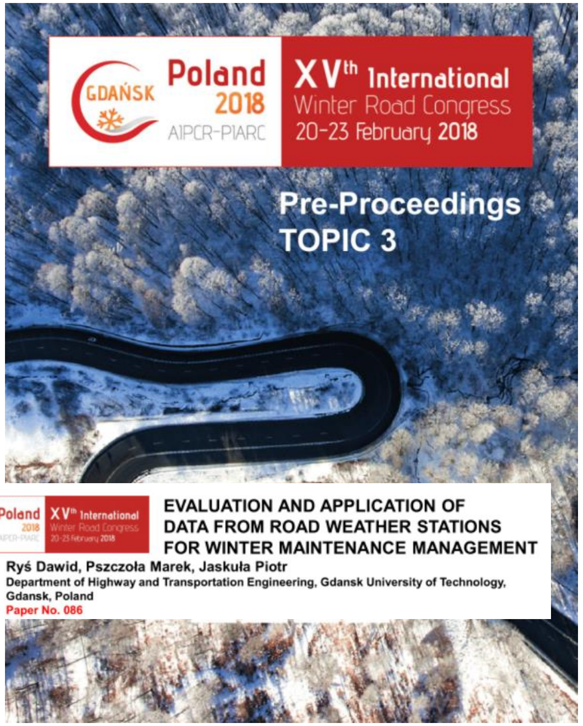
ANALYSIS OF CLIMATIC ZONES IN POLAND WITH REGARD TO ASPHALT PERFORMANCE GRADING

ANALIZA STREF KLIMATYCZNYCH W POLSCE Z UWZGLĘDNIENIEM KLASYFIKACJI FUNKCJONALNEJ ASFALTÓW PERFORMANCE GRADE

STRESZCZENIE. Pod koniec ubiegłego wieku w ramach amerykańskiego programu SHRP opracowano i wdrożono nowy system klasyfikacji asfaltów. Jego ideą była potrzeba lepszego dostosowania metod badań oraz wymagań dla asfaltów drogowych

ABSTRACT. Towards the end of the last century a new system of bitumen grading was developed and implemented as part of the American Strategic Highway Research Program (SHRP). Its aim was to better adjust the testing methods and requirements



EVALUATION AND APPLICATION OF DATA FROM ROAD WEATHER STATIONS FOR WINTER MAINTENANCE MANAGEMENT

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Department of Highway and Transportation Engineering, Gdansk University of Technology, Gdansk, Poland

Paper No. 086

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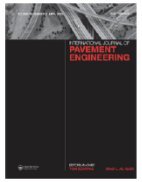

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International Journal of Pavement Engineering

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Factors affecting low-temperature cracking of asphalt pavements: analysis of field observations using the ordered logistic model

Dawid Rys, Mariusz Jaczewski, Marek Pszczola, Agnieszka Kamedulska & Bartosz Kamedulski

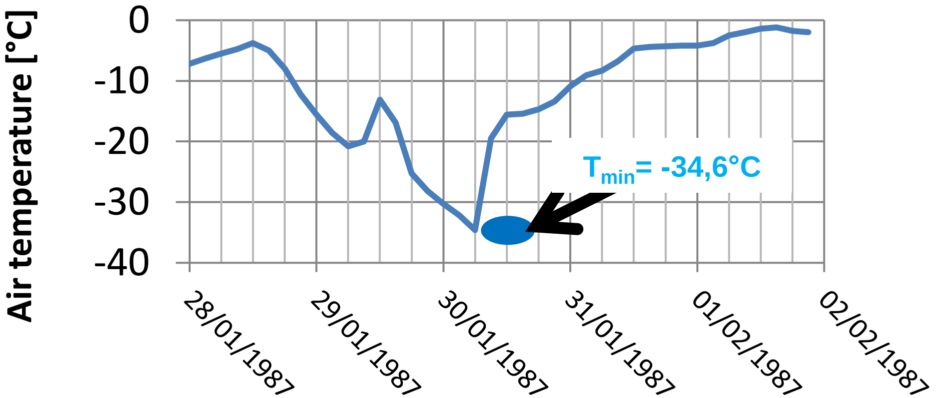
To cite this article: Dawid Rys, Mariusz Jaczewski, Marek Pszczola, Agnieszka Kamedulska & Bartosz Kamedulski (2022): Factors affecting low-temperature cracking of asphalt pavements: analysis of field observations using the ordered logistic model, International Journal of Pavement Engineering, DOI: 10.1080/10298436.2022.2065273

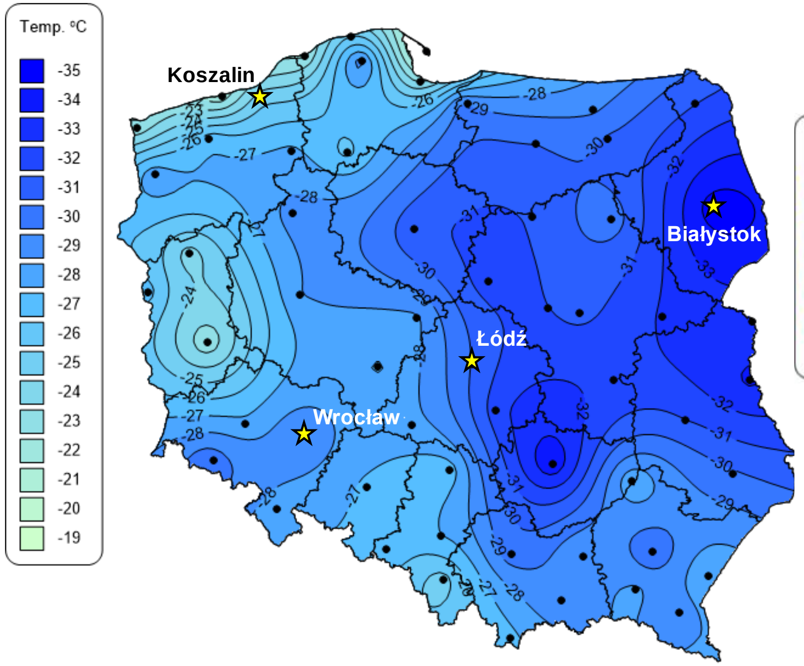
To link to this article: https://doi.org/10.1080/10298436.2022.2065273

CLIMATIC DATA - PG ZONES IN POLAND

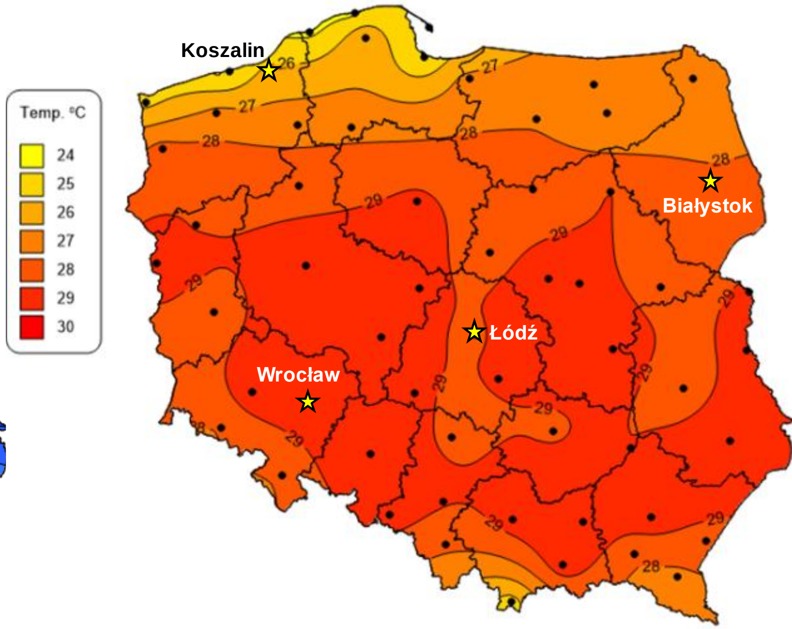
- **Data from 1986 to 2015, 30 years**
- **Air temperature – 2 m from ground**
- **Finally 61 meteo stations of IMiGW**
- **Data from meteorological stations, hour by hour**
- **Air temperature, wind speed, humidity, precitipiator, cloud cover (sunshine)**

CLIMATIC DATA - PG ZONE IN POLAND





WINTER
minimum



SUMER
7- days average

PERFORMANCE GRADE (PG) OF BITUMEN ACCORDING TO SHRP

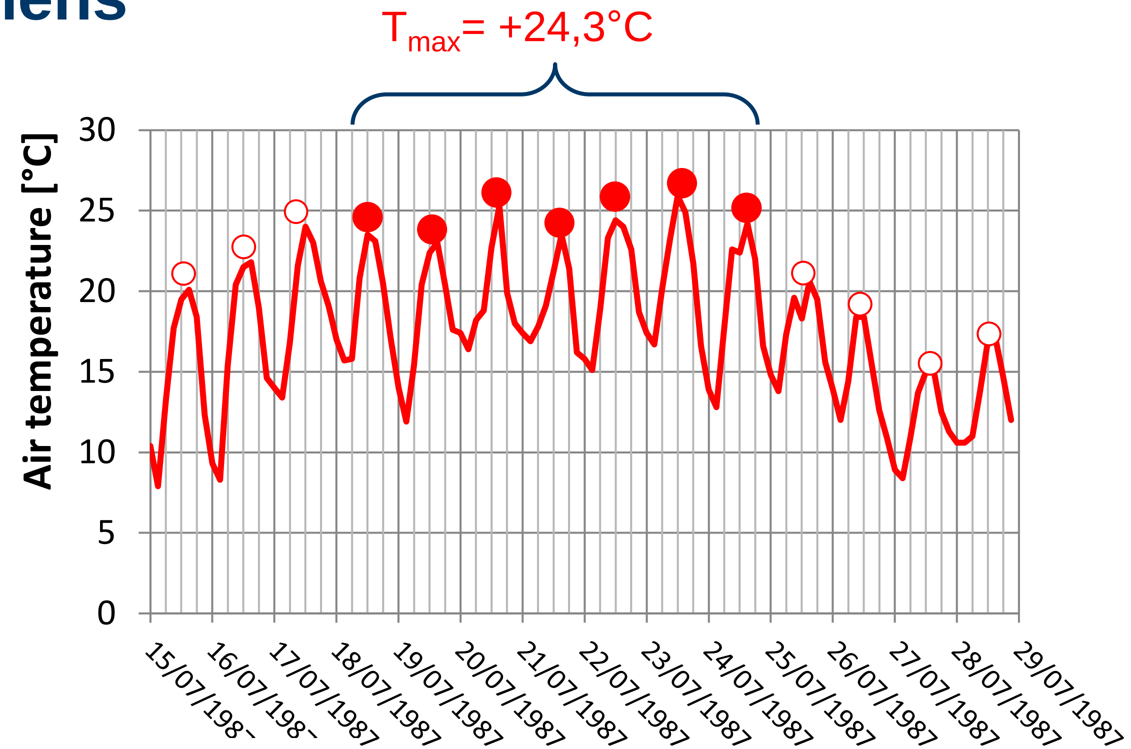
The grading system of bitumens

PG 58 -28

Performance Grade

Average 7-day max pavement temperature

Min pavement temperature



$$T^{d}_{max} = 54{,}32 + 0{,}78 \cdot T_{air} - 0{,}0025 \cdot \phi^2 - 15{,}14 \cdot \log_{10}(H + 25) + z\,(9 + 0{,}61(\sigma_{air})^2)^{0{,}5}$$

$$T^{d}_{min} = -1{,}56 + 0{,}72 \cdot T_{air} - 0{,}004 \cdot \phi^2 + 6{,}26 \cdot \log_{10}\,(H + 25) - z(4{,}4 + 0{,}52 \cdot (\sigma_{air})^2)^{0{,}5}$$

EXAMPLE FOR WEARING COURSE – P=90% and P=50%

7-days max average temperature

Meteo station	T air, °C (mean 30 years of 7-days max. average air temperature)	Standard deviation, 30 years	T pavement, °C P=98%	PG X P=98%	T pavement, °C P=50%	PG X P=50%
Białystok	28,1	2,22	51,3	PG 52	44,2	PG 46
Gdańsk	24,9	1,49	48,0	PG 52	41,3	PG 46
Szczecin	28,3	2,07	51,3	PG 52	44,2	PG 46
Warszawa	29,2	2,15	52,3	PG 58	45,2	PG 46
Wrocław	29,5	2,09	52,8	PG 58	45,8	PG 46

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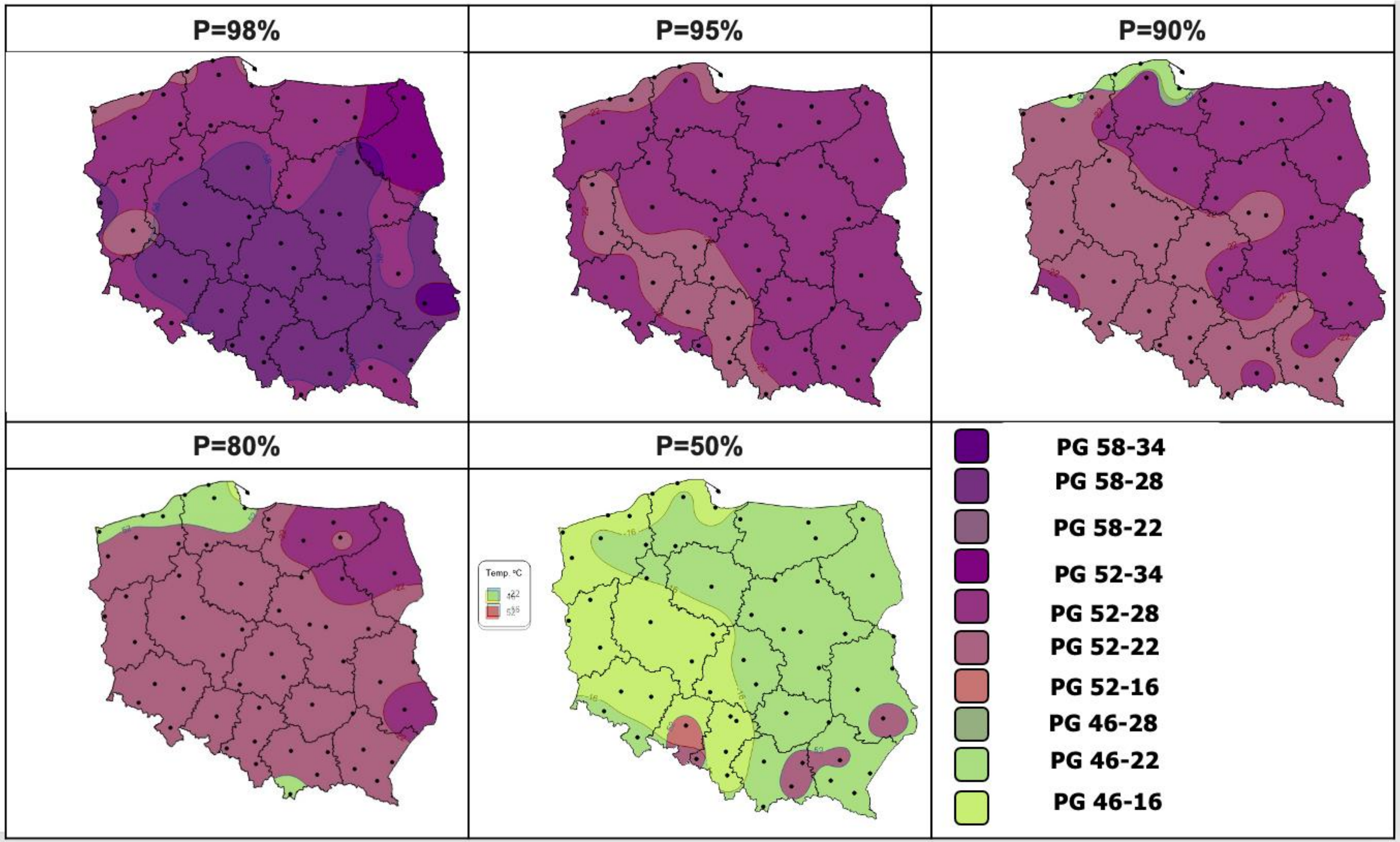
EXAMPLE FOR WEARING COURSE



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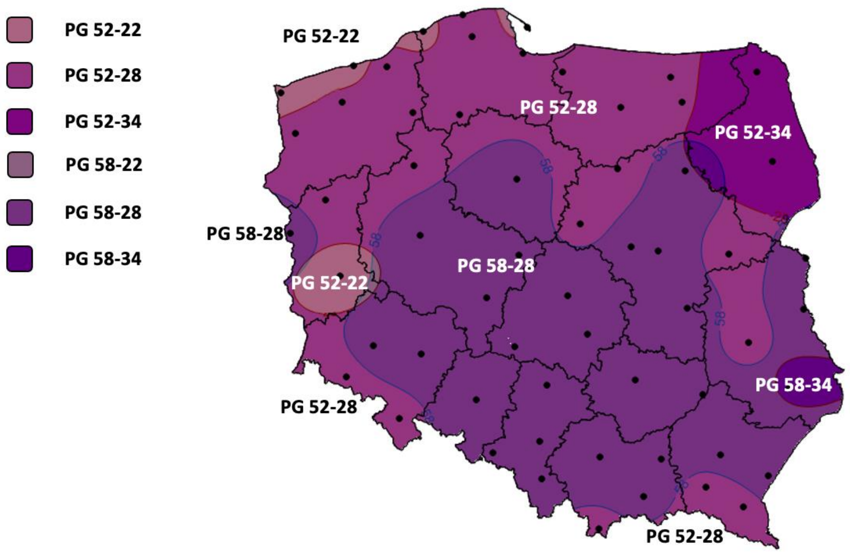
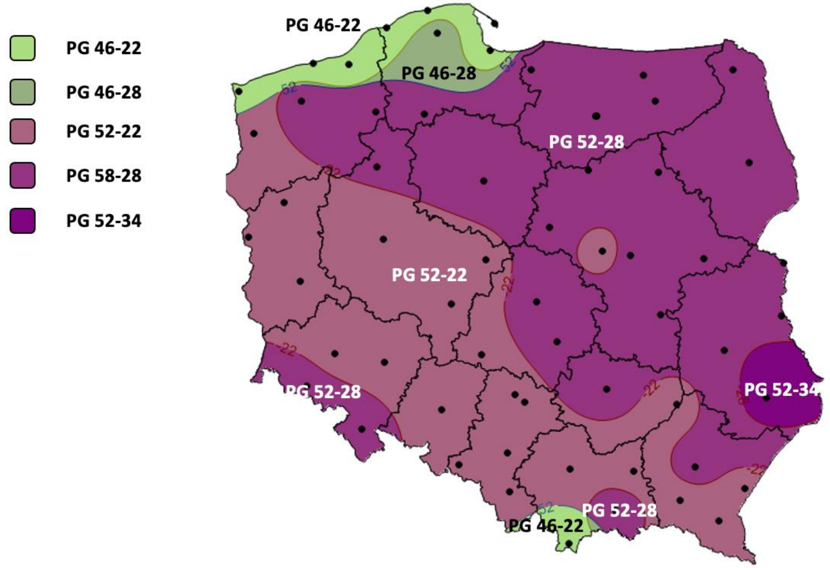
PG ZONES - POLAND

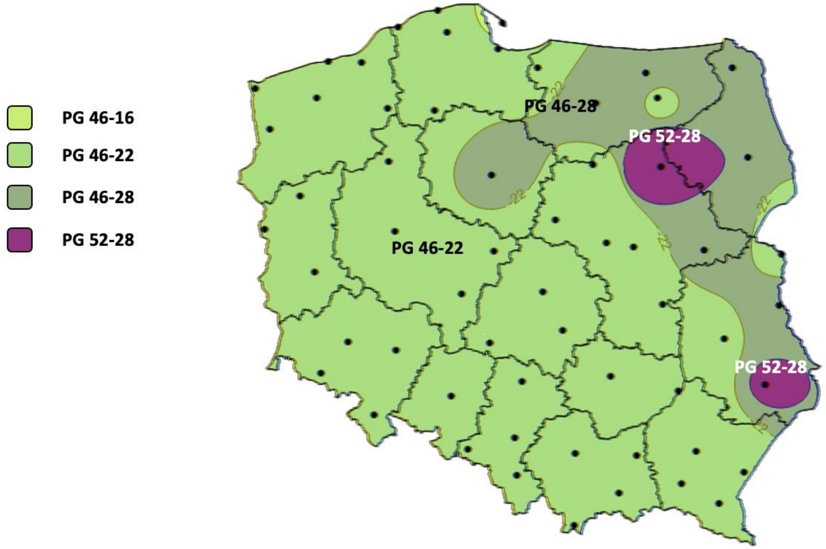
P=98% warstwa ścieralna



P=98% warstwa wiążąca

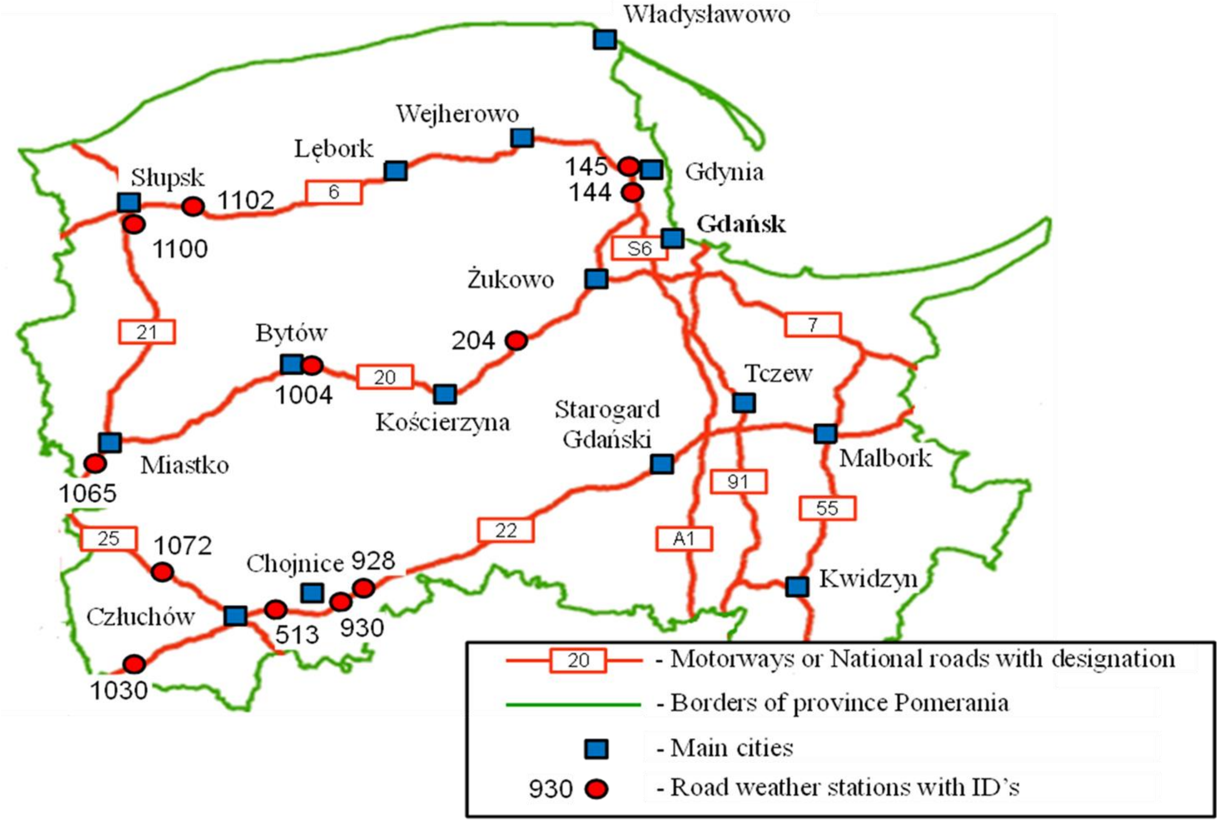


P=98% warstwa podbudowy



Probality level	Belarus			Estonia		Poland			Ukraine		
	Zone 1 N-E	Zone 2 C and W	Zone 3 S-E	Zone 1 E	Zone 2 N-E W and S	Zone 1 E, N-E	Zone 2 C, S, W	Zone 3 Coast	Zone 1 S and S-E	Zone 2 W	Zone 3 E
98%	52-34	52-28	58-28	58-34 58-40	58-28 58-34	52-34 58-34	52-28 58-28	52-22	64-28	58-34	64-34

CLIMATIC DATA – WINTER MAINTENANCE



Data were collected from 12 road weather stations located in national roads of Pomerania District.

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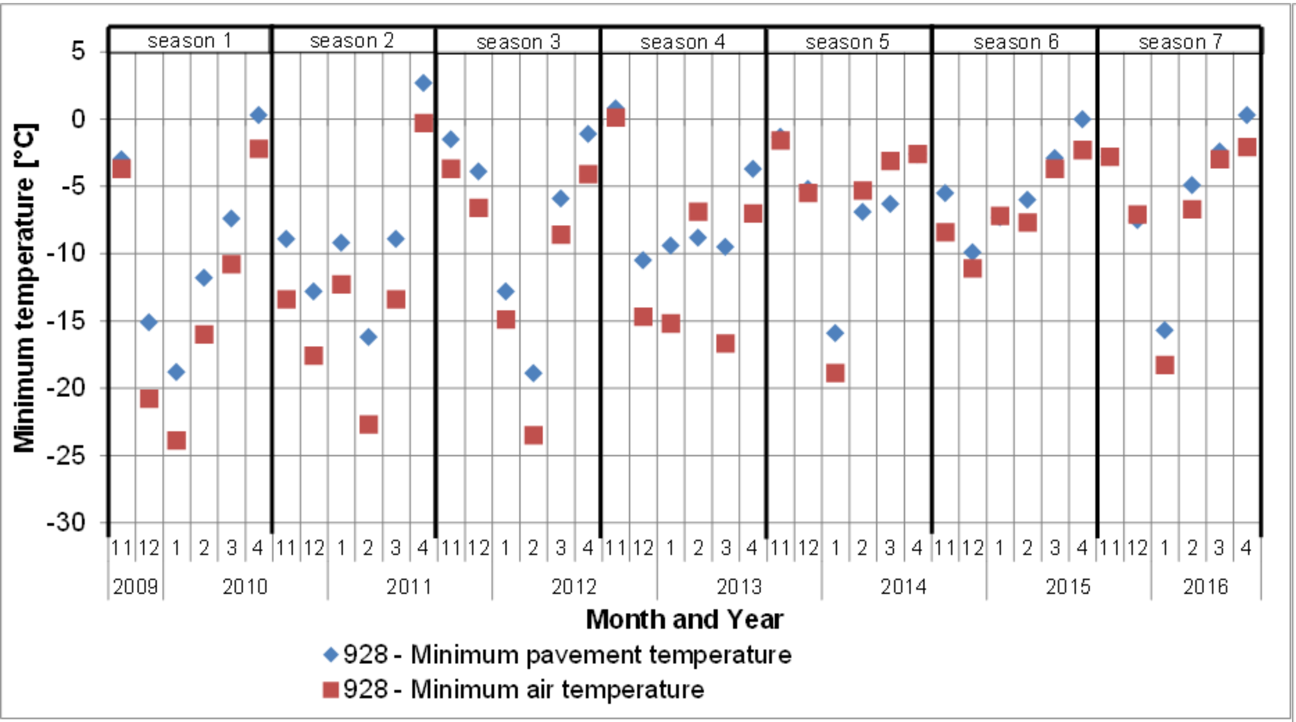
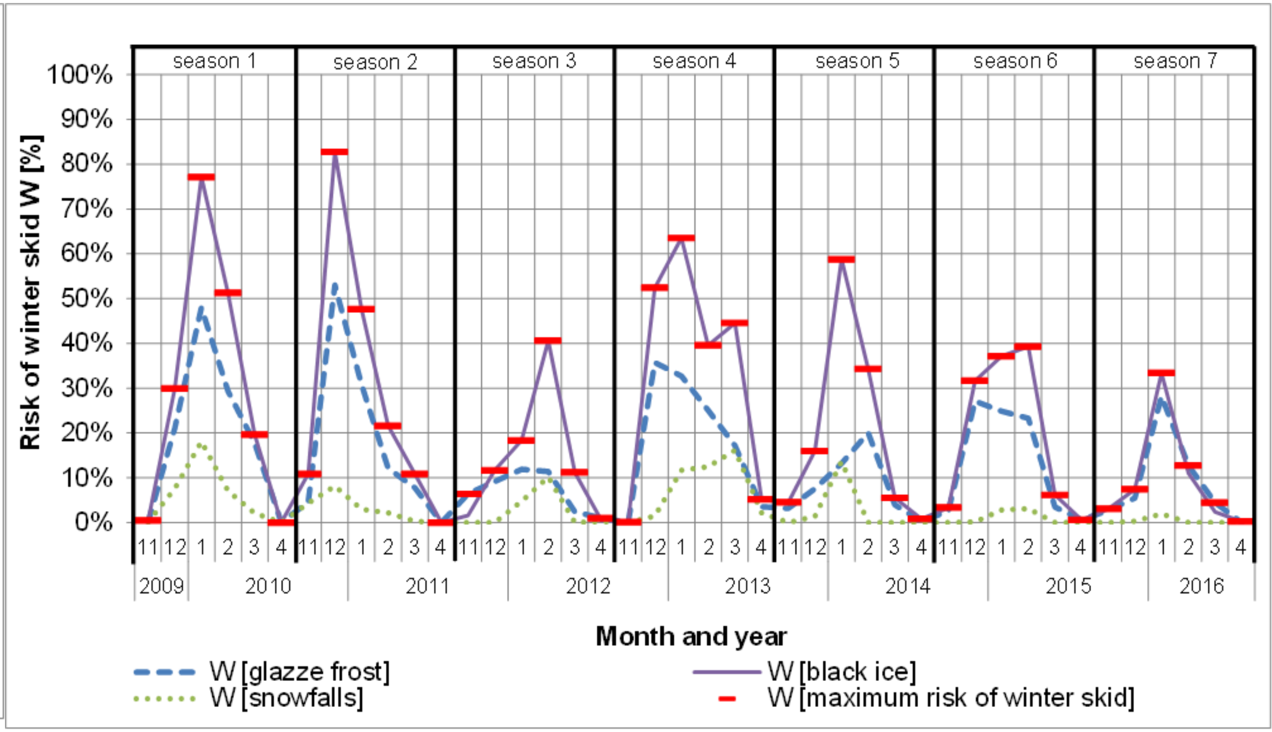
SELECTED FACTORS DELIVERD FROM DATA ANALYSIS

MINIMUM PAVEMENT TEMPERARURE – CRACKING



RISK OF WINTER SKID



The maximum transition trough 0°C, which in Pomerania District equals maximally to 124 times, indicate the problem of winter skid.

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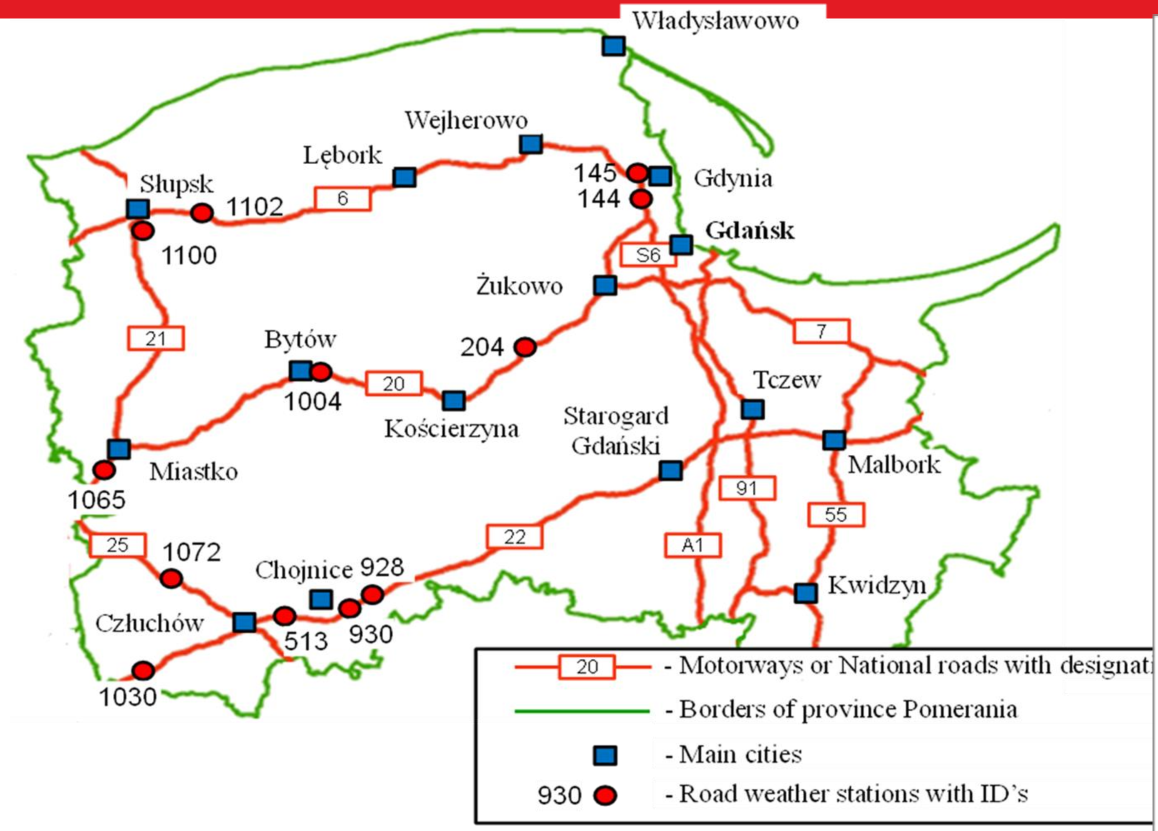
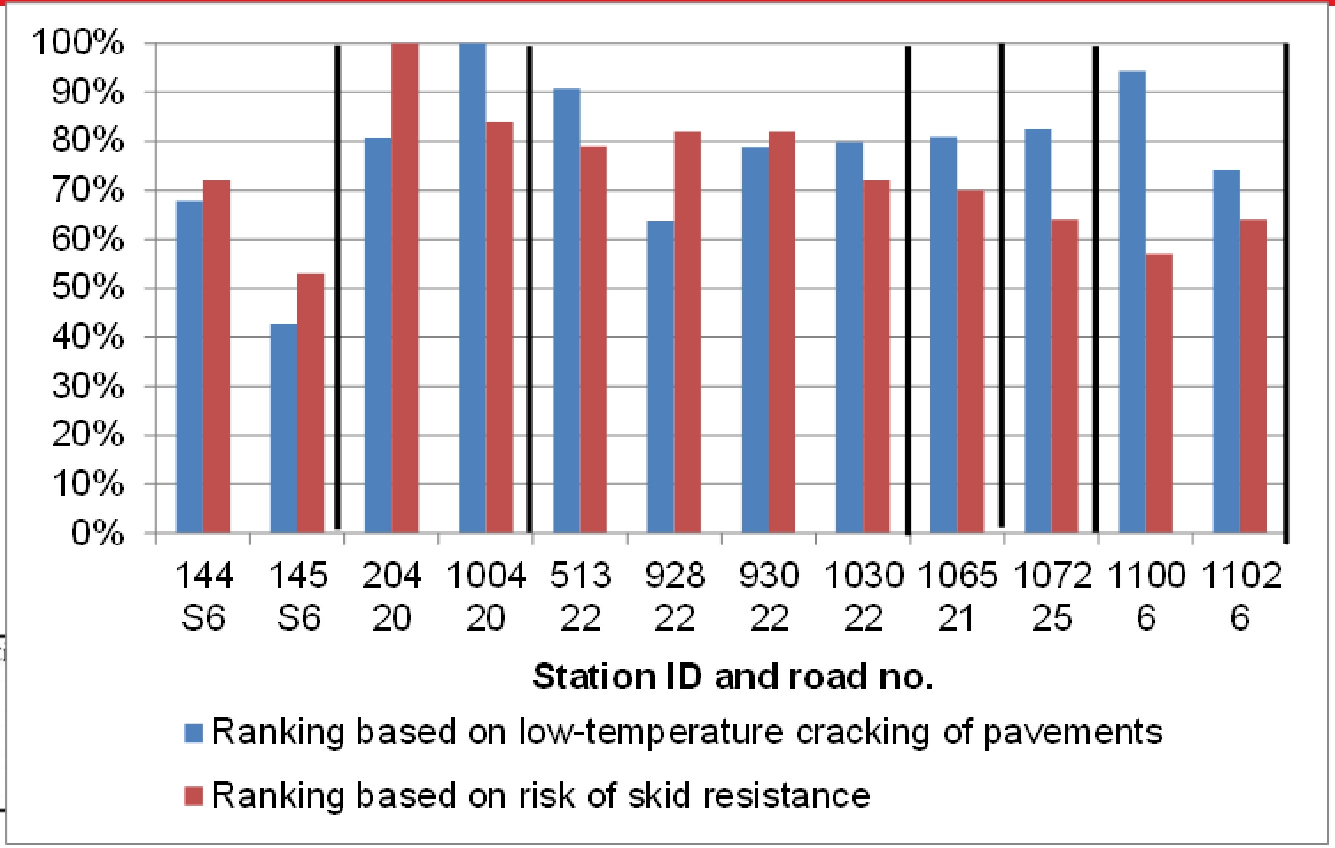
ROAD RANKING





CLIMATIC DATA FOR ANALYSIS OF LOW TEMPERATURE STRESSES IN PAVEMENT

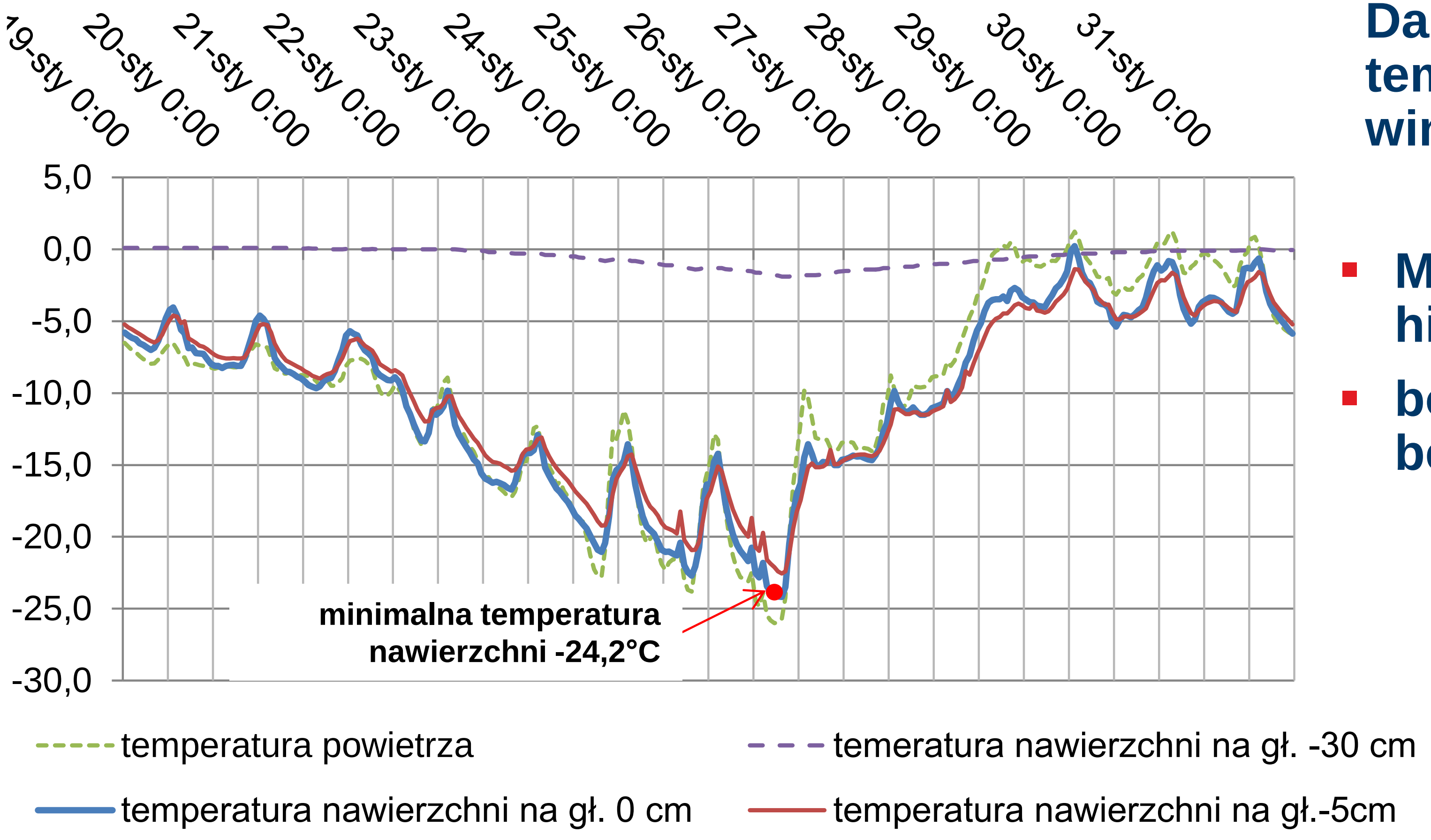
Temperatures:

- AIR (2 above terrain)
- PAVEMENT (0cm, -5 cm, -30 cm)

Remianing data:

- Rainfalls, humunudity
- Surface conditions (wet, dry, ice)
- Speed and direction of wind

CLIMATIC DATA – LOW TEMPERATURE STRESSES



Daily changes of pavement temperature – an example period at winter season

- Minimum pavement temperature is higher than min air temperature,
- both occur at the same time, most often between 5 and 7 AM

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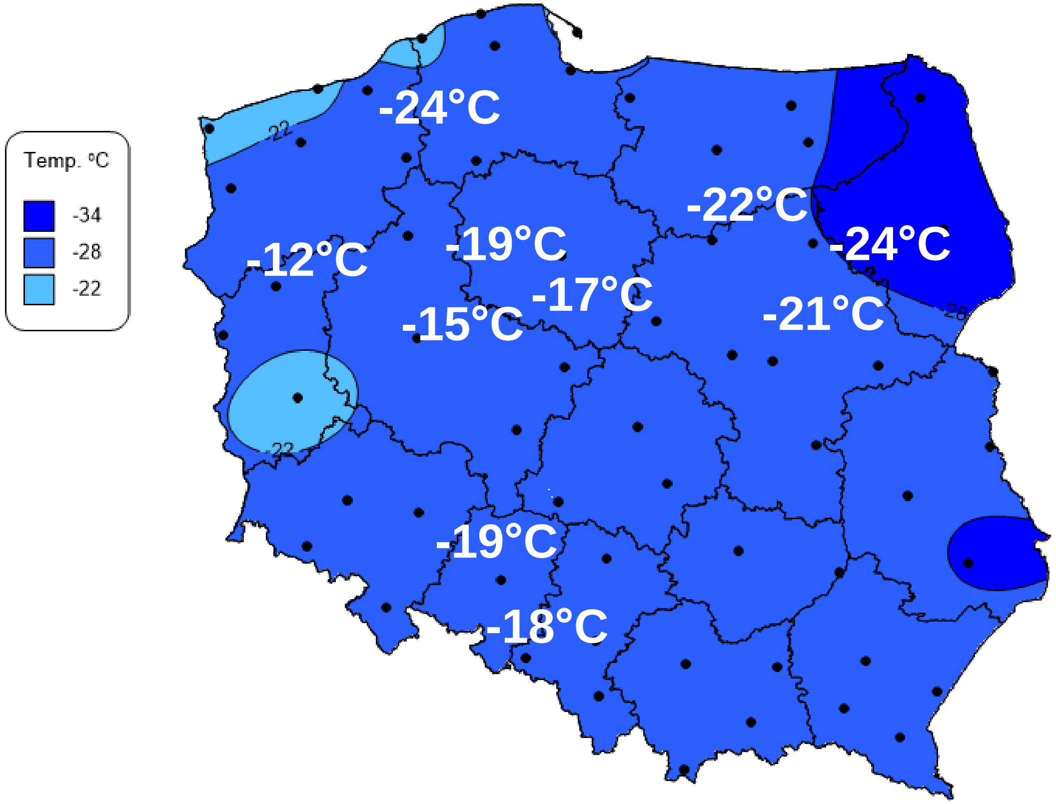
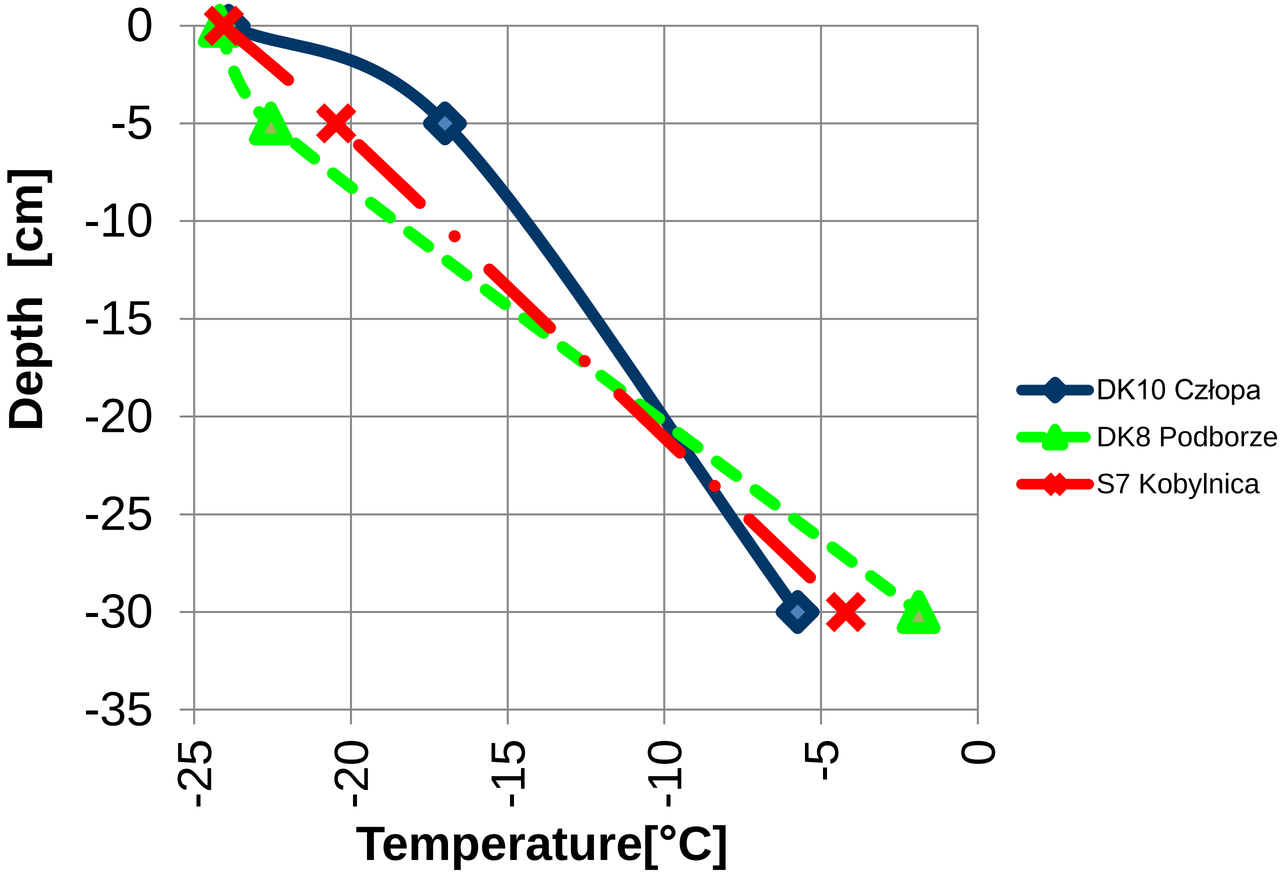
Comparison of minimum measured pavement temperature to PG lower temperature

- **There were not deteced lower pavement temperature on the surface than the lower PG of asphalt (wearing course, p=98%)**





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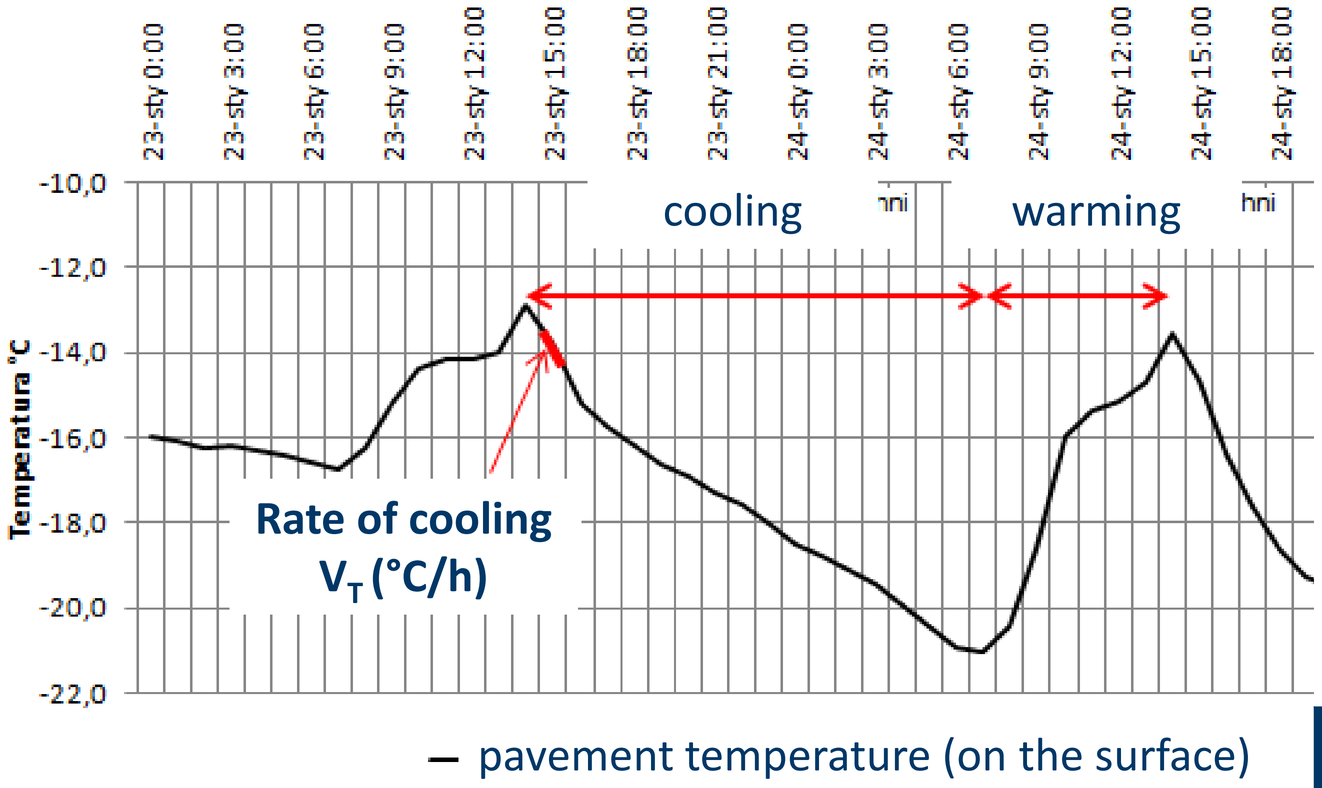
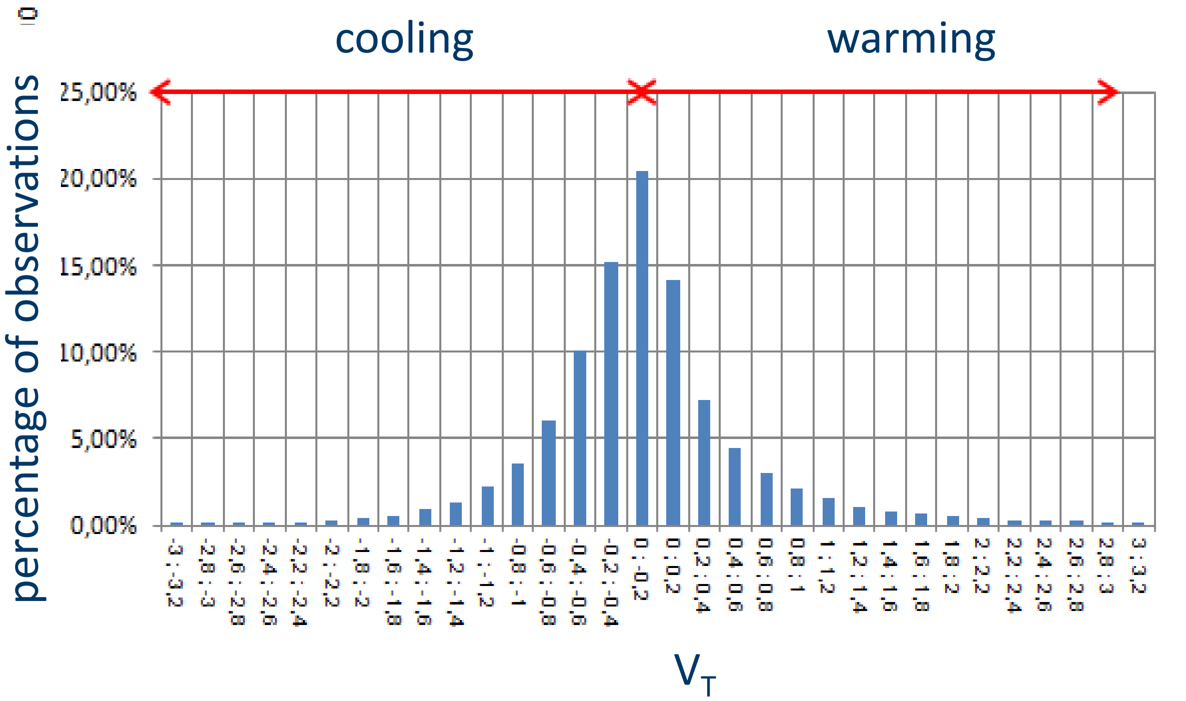
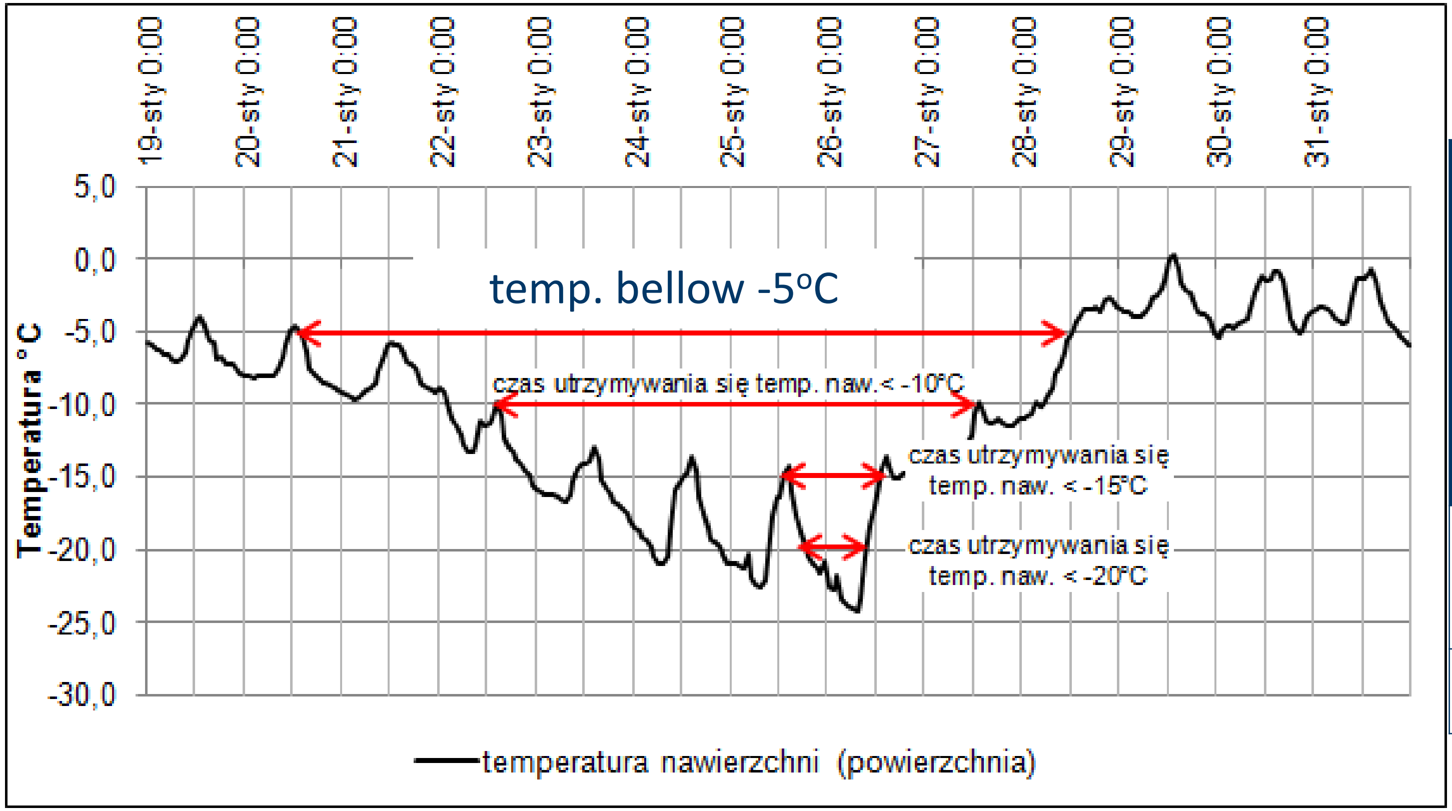
The rate of pavement cooling





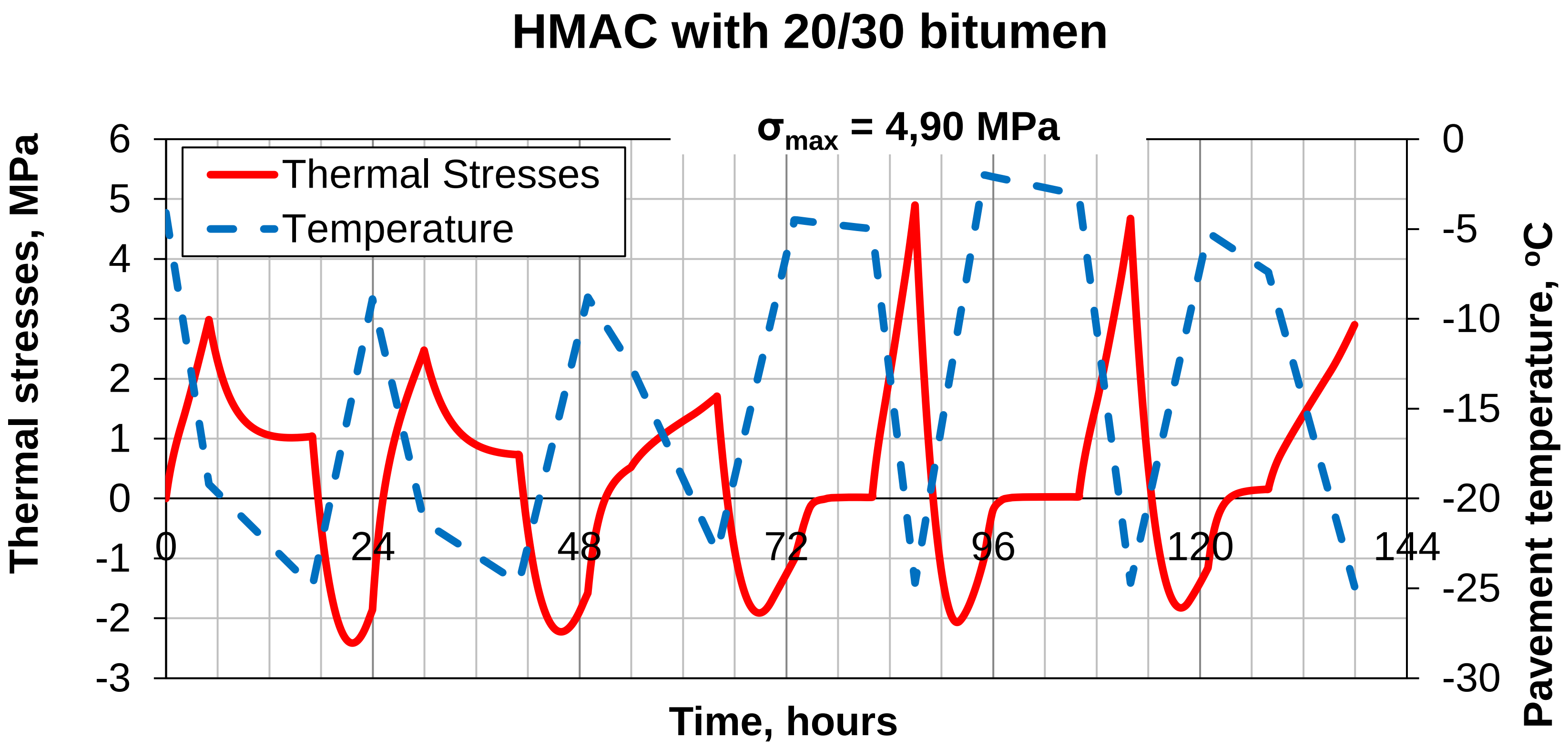
Relability	Rate of cooling V_T (°C/h)
99,9%	≤ 3,7
90%	≤ 0,8

The low temperatures duration



The longest period when temperature remained bellow: DK8 Podborze (woj. Mazowieckie) 19-31 January 2010 r. [hours]				
0°C	-5°C	-10°C	-15°C	-20°C
746	261	143	85	18

Calculation of low-temperature stresses according to actual pavement temperatures

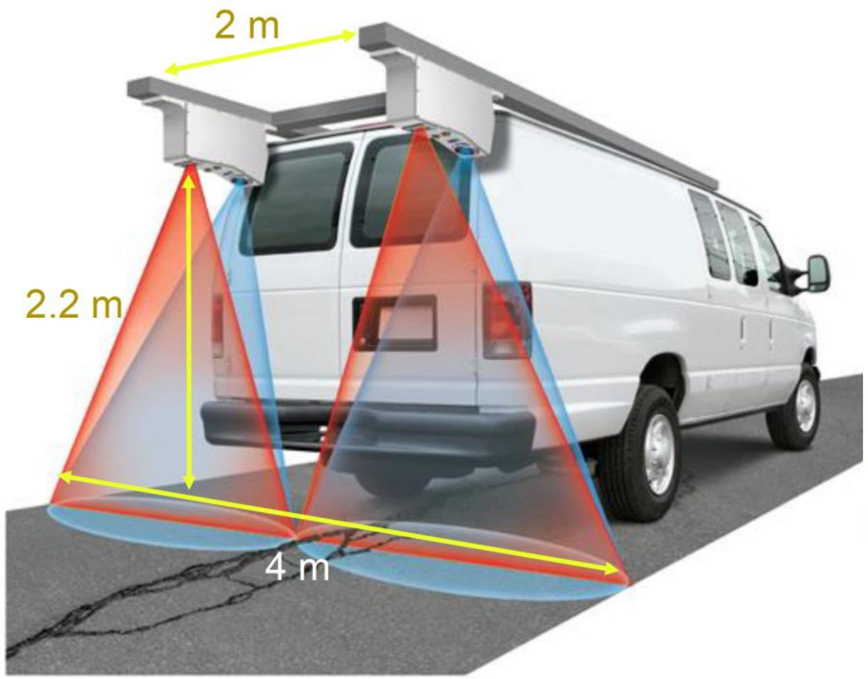


Judycki J., **A new viscoelastic method of calculation of low-temperature thermal stresses in asphalt layers of pavements**, *International Journal of Pavement Engineering*, 2016

Judycki J., **Verification of the new viscoelastic method of thermal stress calculation in asphalt layers of pavements**, *International Journal of Pavement Engineering*, 2016

PAVEMENT CONDITION ASSESSMENT – MAINTENANCE SCENARIO

LCMS-2



FWD

GPR

TSD

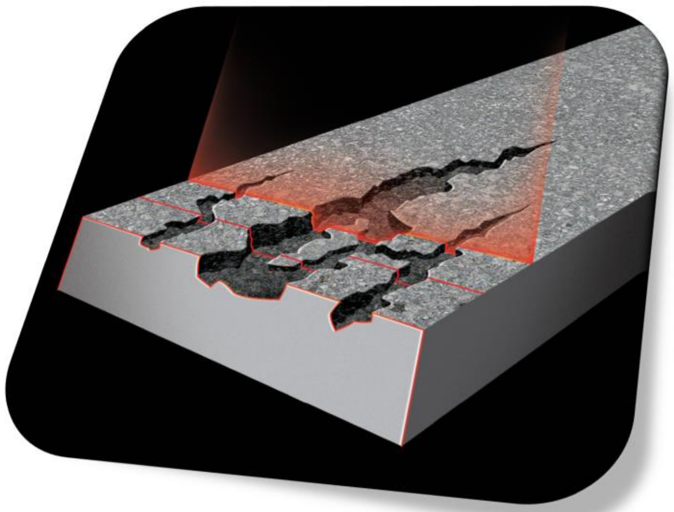
LCMS – LASER CRACK MEASURMENT SYSTEM

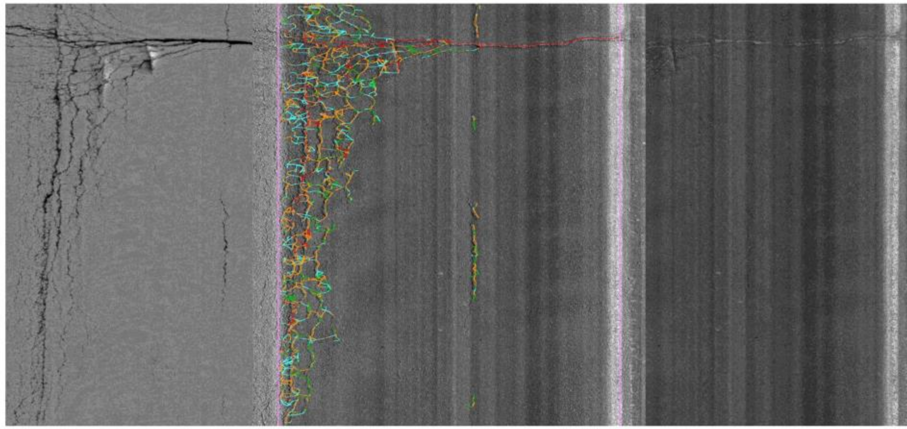
DATA delivered from LCMS

-all types of joints and crack (longitudinal, aligator, transversal)

-potholes and Surface repairs

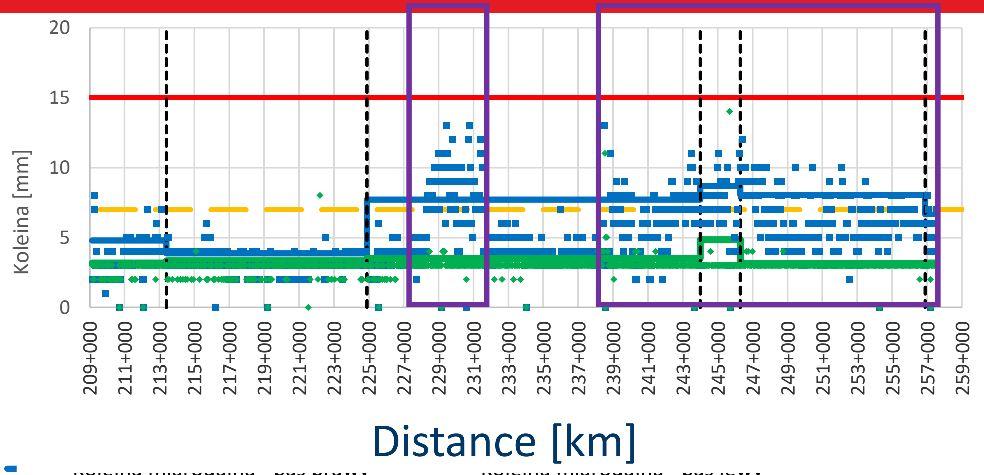
-IRI

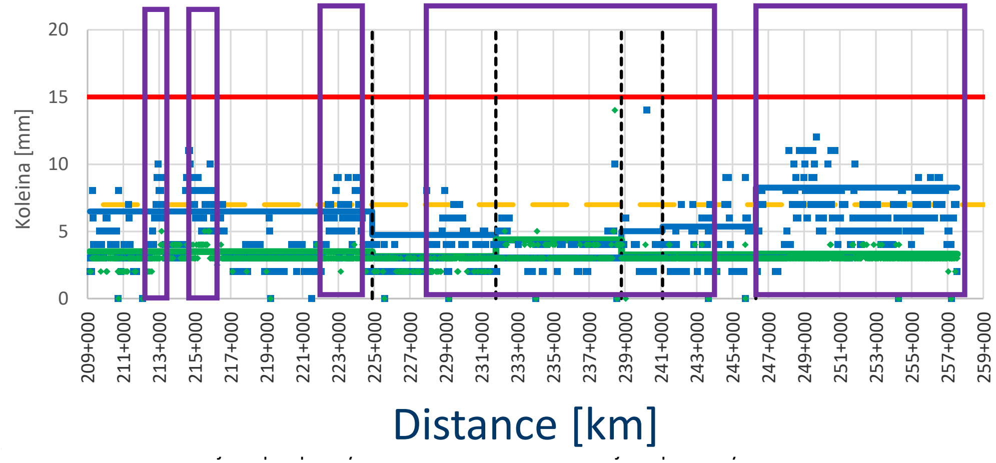




Range Merged Intensity

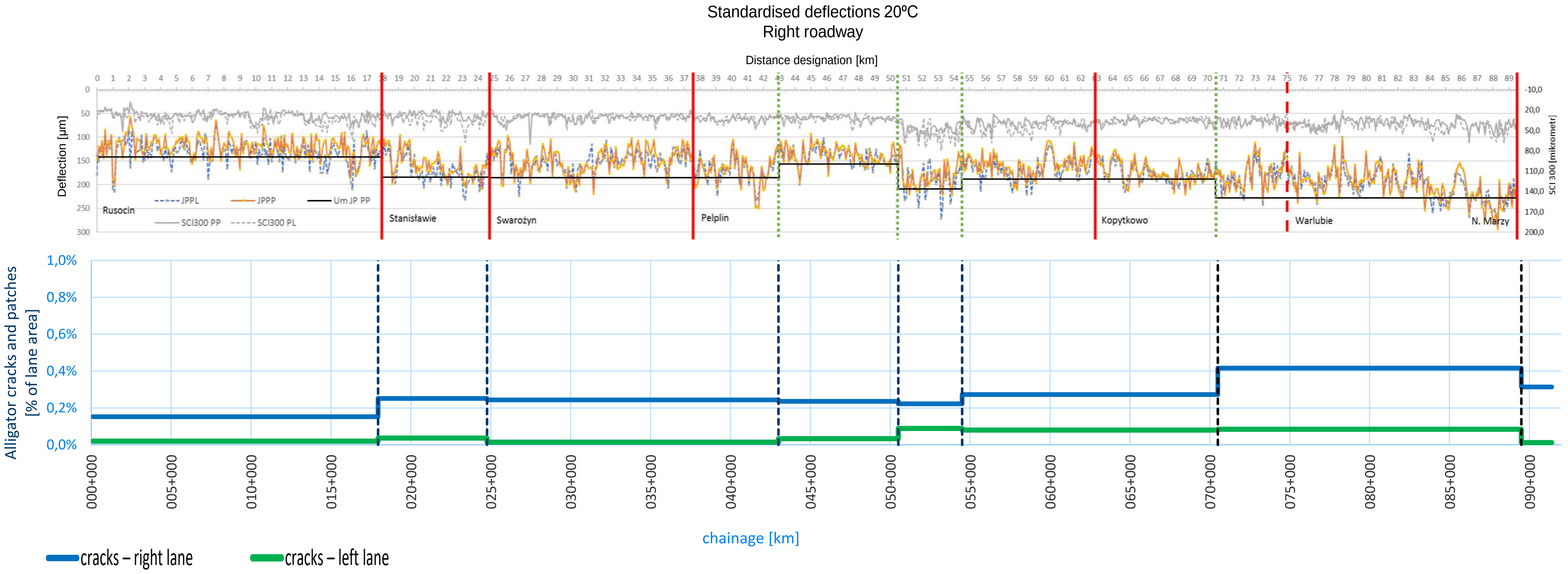
LCMS – Case study 1





- Rut depth:
- blue lines / dots (50m) represents rigth lane
- green lines / dots (50m) – left line
- yellow and red lines – limits: warning/critical
- two types of HMA for binder course
- One type of HMA included some additive, another one not
- HMA with aditive was much more sensitive on plastic deformation

LCMS – Case study 2 – comparison of FWD results with alligator cracks



Building of pavement maintanance scenarios

- MEPDG – Mechanicstic Empirical Pavement Design Guide is one of method to predict pavement conditions
- Traffic data, climatic data, and material properties are combined
- LCMS data is using to verify results and to calibrate M-EPDG models

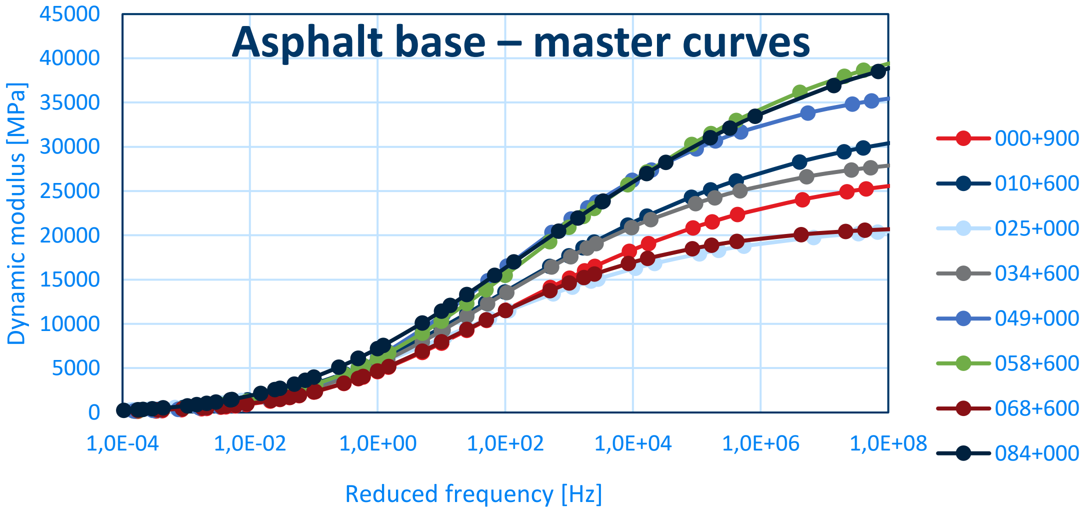
Load spectrum
q = 850 kPa

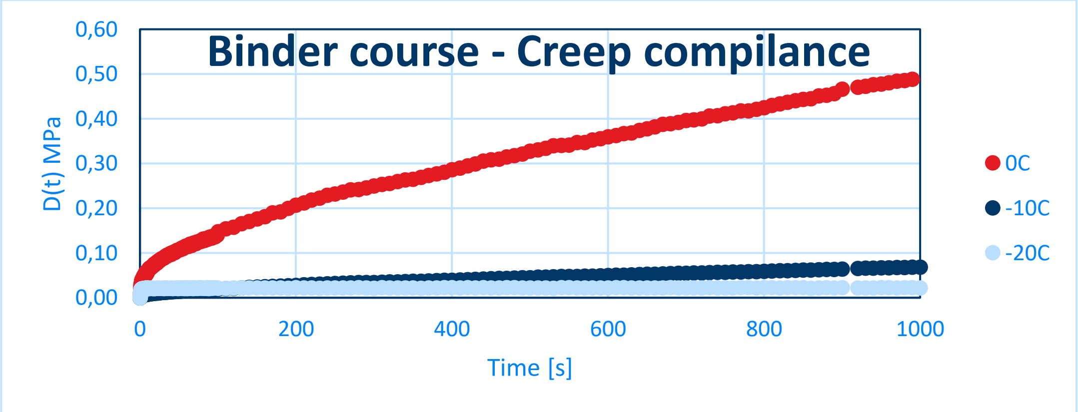
Layer system:

Layer type	Material	Thickness [cm]	Basis of the adopted stiffness moduli
Wearing course	SMA11 with DE 80 B bitumen	3.5	SPT – tests of the SMA mixtures from the 2021 expert analysis
Binder course	BA0/20 asphalt concrete with DE 30 B bitumen	8.0	SPT – tests of cored samples
Asphalt base	BA0/25 asphalt concrete with 35/50 bitumen	15.5	SPT - tests of cored samples
Granular base	Crushed aggregate 0/31.5 C 90/3	20	FWD deflection measurements – the 90th percentile E2 modulus from backcalculations
Remaining lower layers and the subgrade	-	∞	FWD deflection measurements – the 90th percentile E3 modulus from backcalculations

Materials properties used in M-EPDG analysis

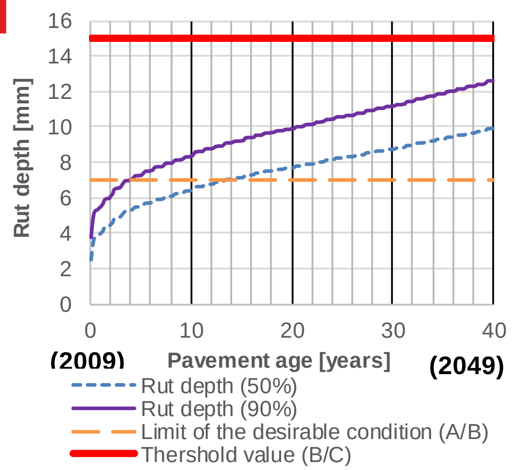
- **Dynamic modulus: Master curves for each uniform section**
- **Creep compliance and indirect tensile strength – performance in low temperatures**
- **Polish mixtures are much stiffer than default mixtures used in the method**
- **Crushed stone base and subgrade – on the basis of FWD tests and back calculations**

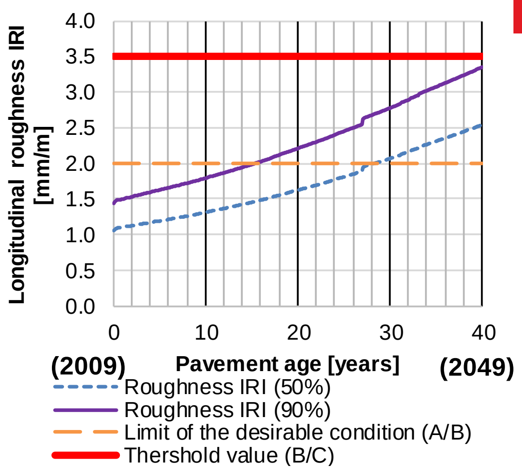


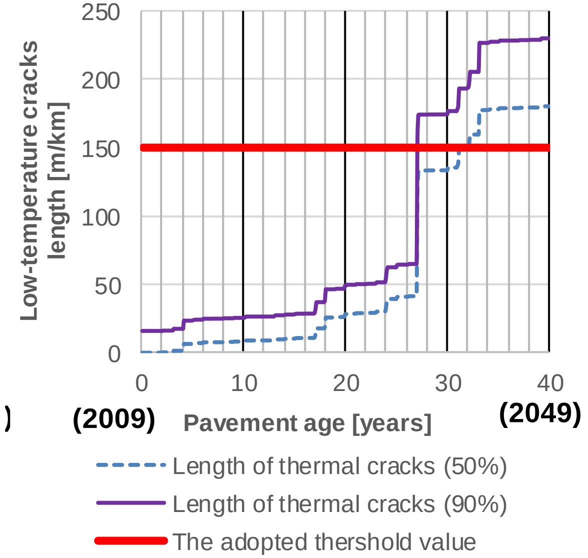


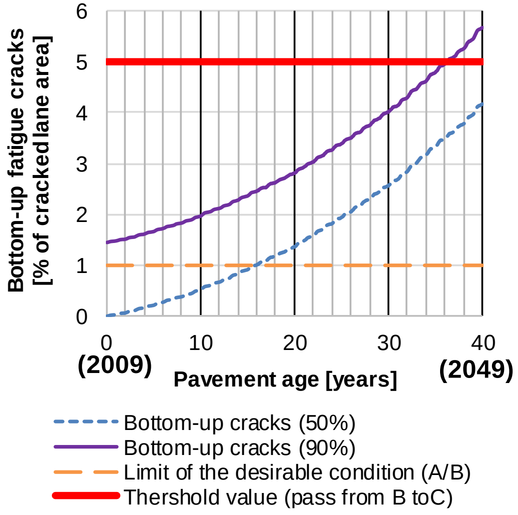
MEPDG – analysis results – example for one of uniform sections

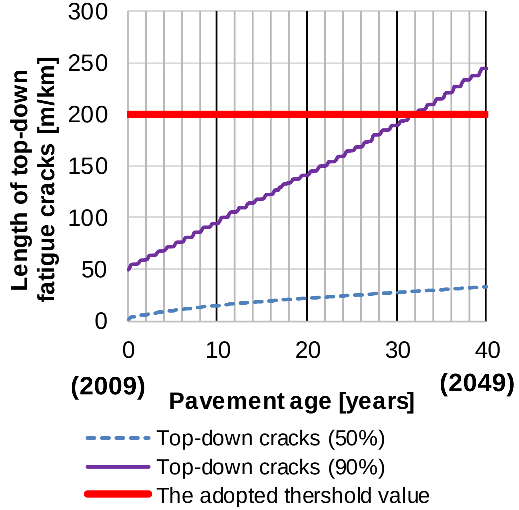
- **Analyzes were run at the year of motorway opening**
- **Calibration coefficient were set to achieve distresses in 2022 on the same level as results from LCMS**
- **The method allows to predict, what level of distresses will be achieved in the future,**
- **The maintenance treatments can be planned**
- **Replacement of wearing course is recommended**
- **Overlays are not necessary at this stage**











CONCLUSIONS

- Numerous sources of data are available,
- Data can be adopted to communicate with road users (smart pavements) as well as they are necessary for appropriate road network management
- it is advisable to ensure as high data accuracy as it is possible, or to be aware of the scale of potential errors
- Multilevel verification approach allows to indicate potential errors and confirms of the correctness of the result

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