Fundación Ingeniería Civil de Galicia

European Investment Bank · Institute

Grant under the STAREBEI Programme:

IMPACT OF PREVENTIVE MAINTENANCE ON FLEXIBLE PAVEMENT SERVICE LIFE

— PROJECT SCOPE—

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GMNI — GRUPO DE MÉTODOS NUMÉRICOS EN INGENIERÍA

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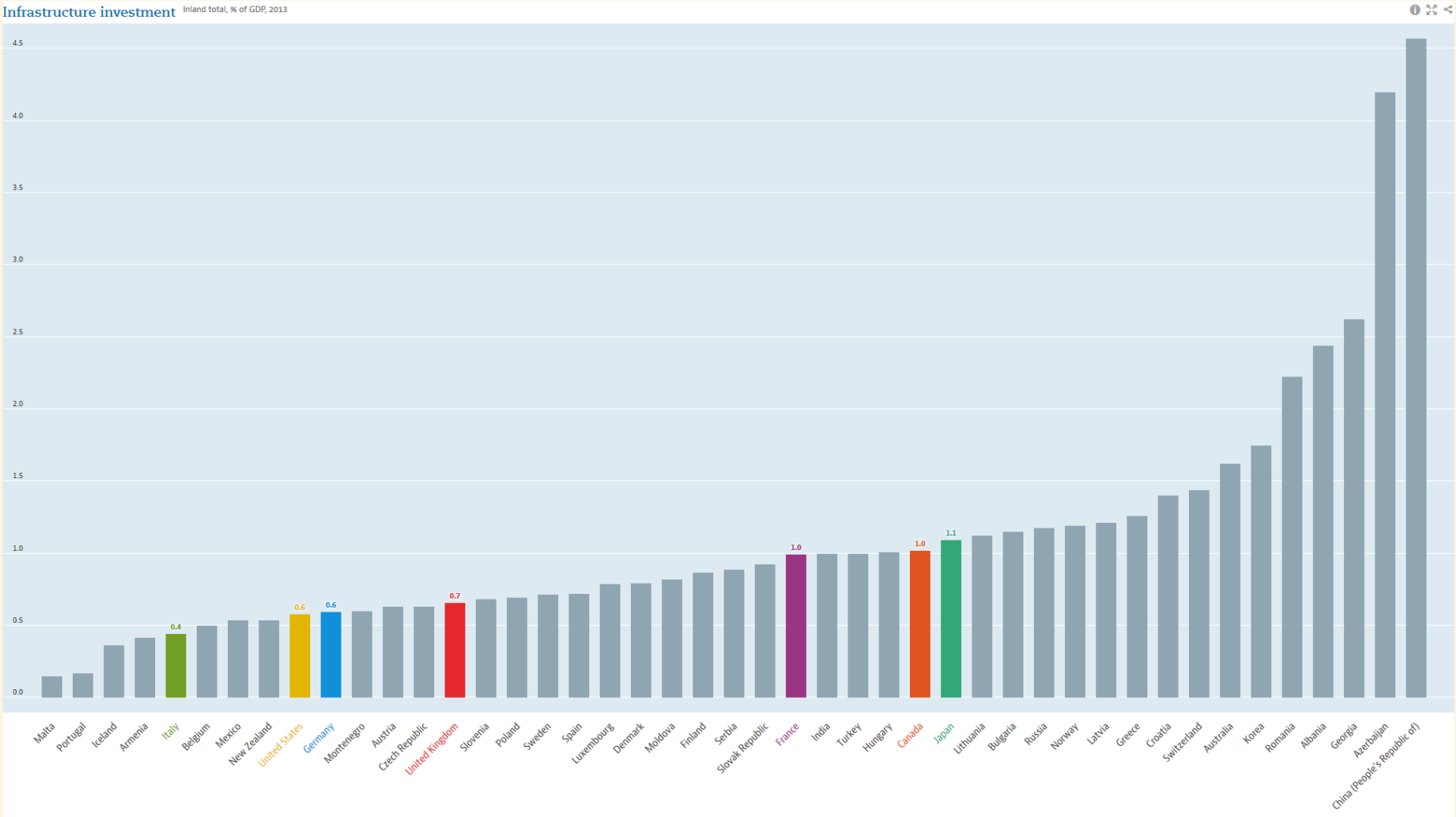
Introduction (I)

TRANSPORT

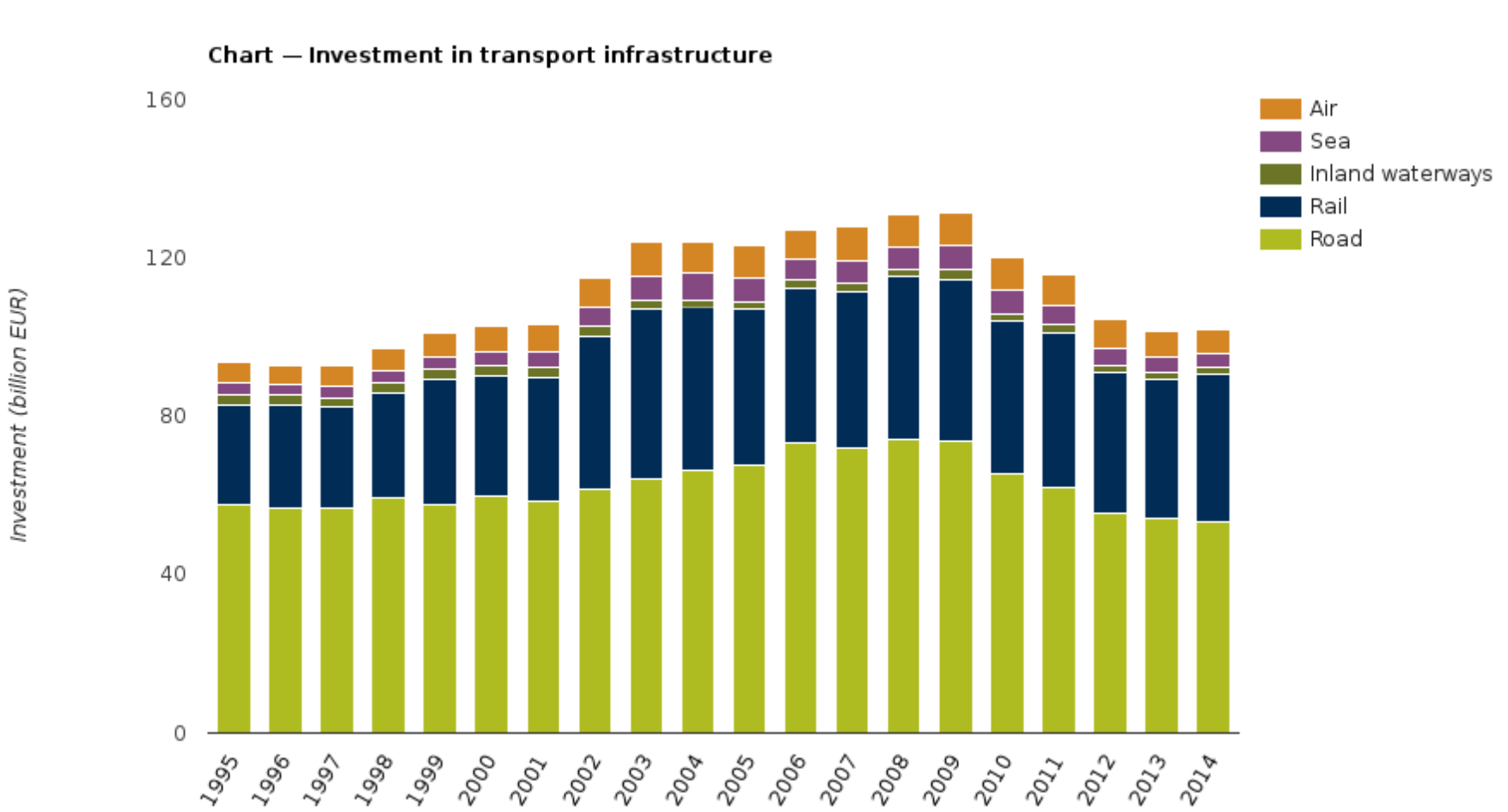
- Standard of living
- Economic growth
- Development
- Communication
- Mobility

Introduction (II)



% of GDP spent in transport infrastructure — Source **OECD Transport Statistics**
[Organization for Economic Co-operation and Development (OECD)]

Introduction (III)



Investment in transport infrastructure — Source **OECD Transport Statistics**
[Organization for Economic Co-operation and Development (OECD)]

Introduction (IV)

- Road transport is a key element for the economic growth and development

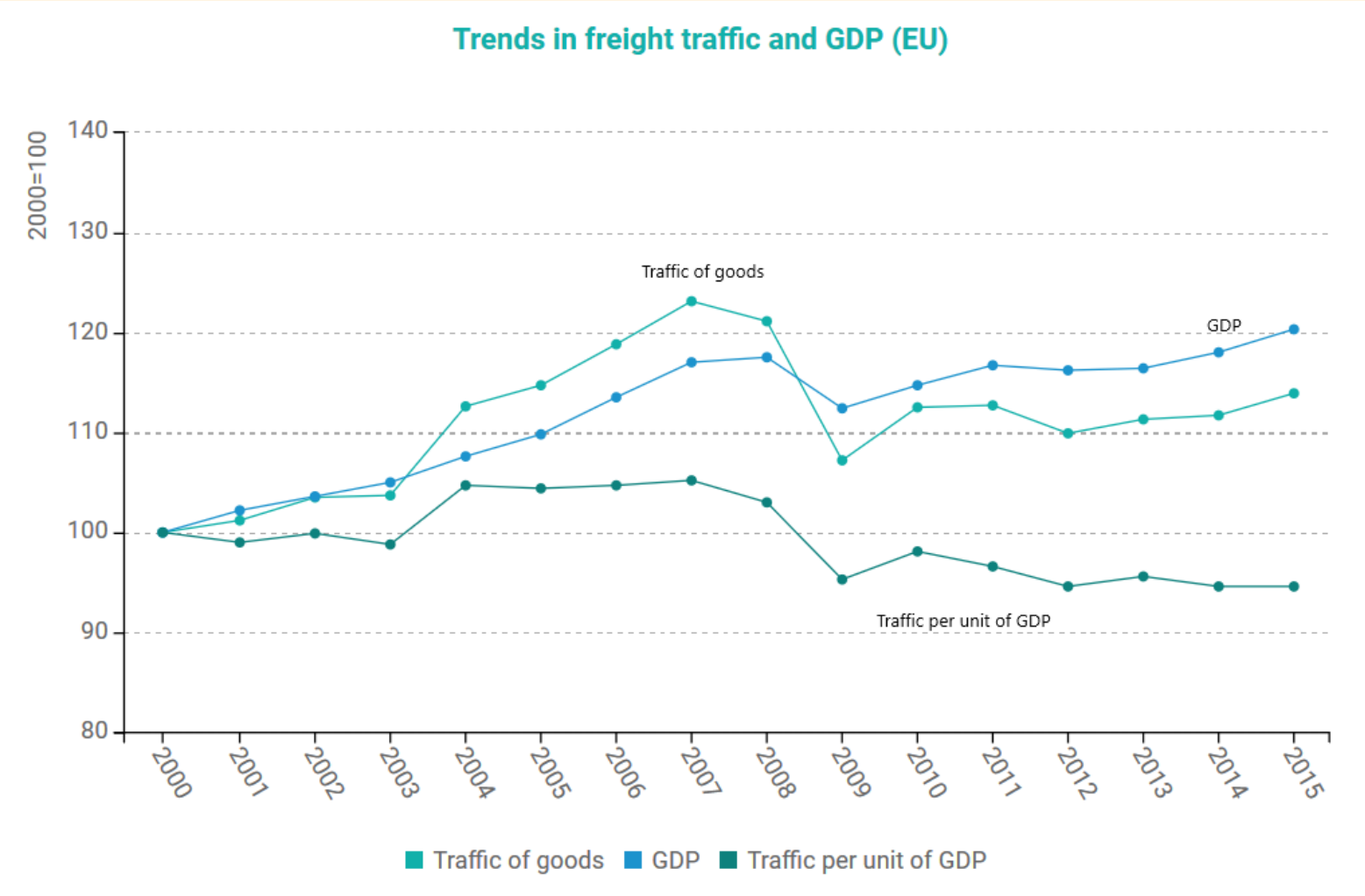
- Importance of the **Road Transport** in the EU
  - About 45% of the transported goods
  - Over 80% of the passengers
  - Generates close to 2% of GDP
  - Employs over 5 million people
  - Investment in infrastructures $\simeq$ 0.6% of the GDP

Introduction (V)

Country	Road investments	Road maintenance
Canada	13.086.085.940	3.942.560.656
France	10.297.735.752	2.904.000.000
Germany	11.730.000.000	—
Italy	2.841.000.000	9.134.000.000
Japan	33.129.221.998	16.256.879.830
United Kingdom	6.030.381.536	3.145.313.236
United States	62.415.298.901	36.146.664.659

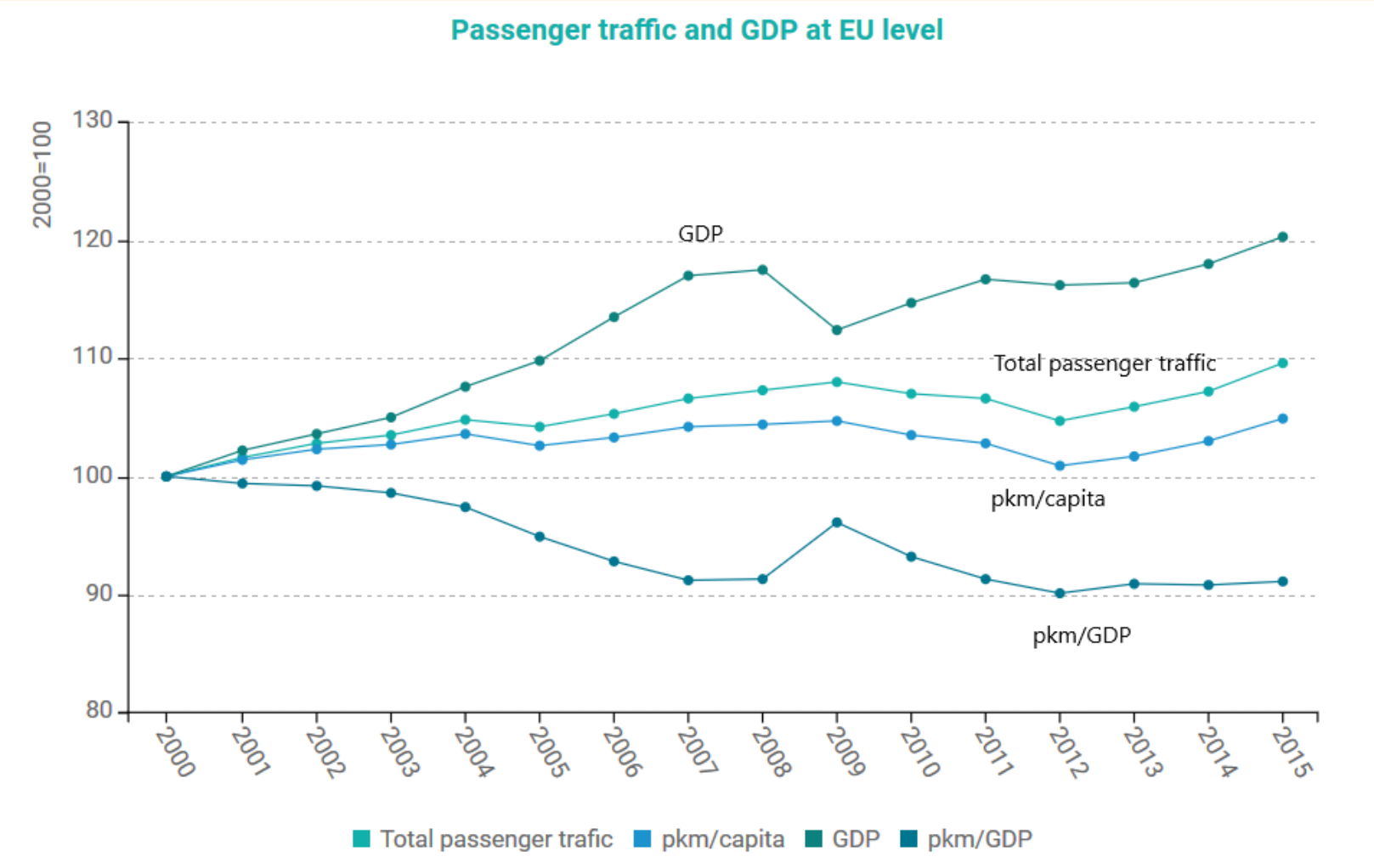
Euros spent in road investments and road maintenance by G7 countries in 2013
Source **OECD Transport Statistics**
[Organization for Economic Co-operation and Development (OECD)]

Introduction (VI)



Trends in freight traffic and GDP (EU)
Source **ODYSEE-MURE**

Introduction (VII)



Passenger traffic and GDP at EU level
Source **ODYSEE-MURE**

Introduction (VIII)

$ $ $ $ $ ECONOMIC CRISIS $ $ $ $ $

↘ Investment in road infrastructures(*)

85.8 billion EUR (2008) ⇝ 63.3 billion EUR (2013)

Reduction ≈ 26%

↘ **Investment in road infrastructure maintenance(*)**

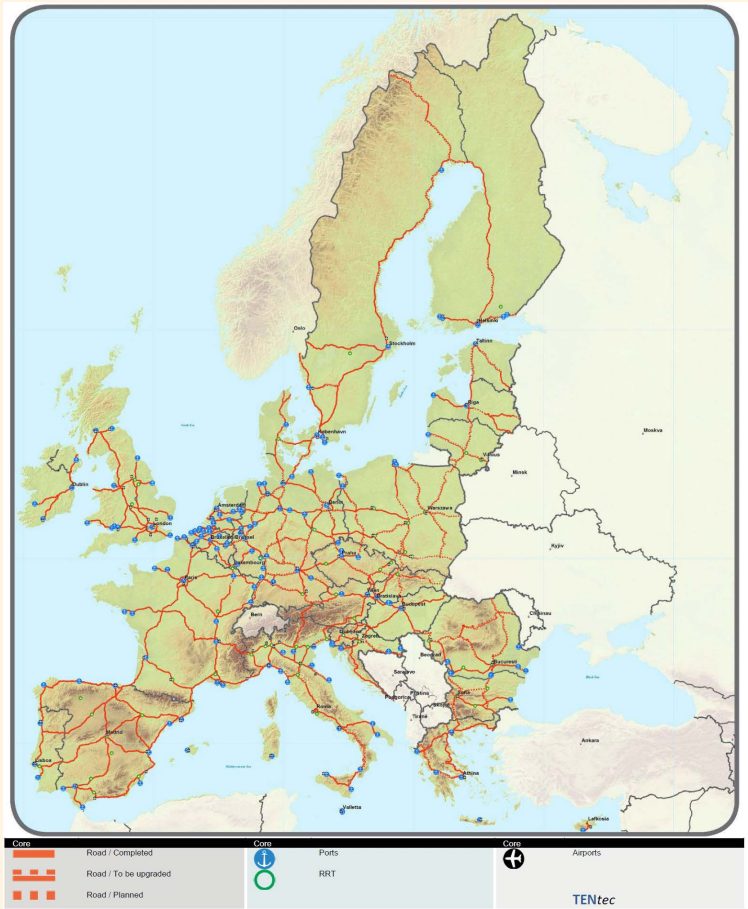
30.2 billion EUR (2008) ⇝ 23.4 billion EUR (2013)

Reduction ≈ 23%

(*)Investment of the EEA-33 countries.Source **OECD.Stat**

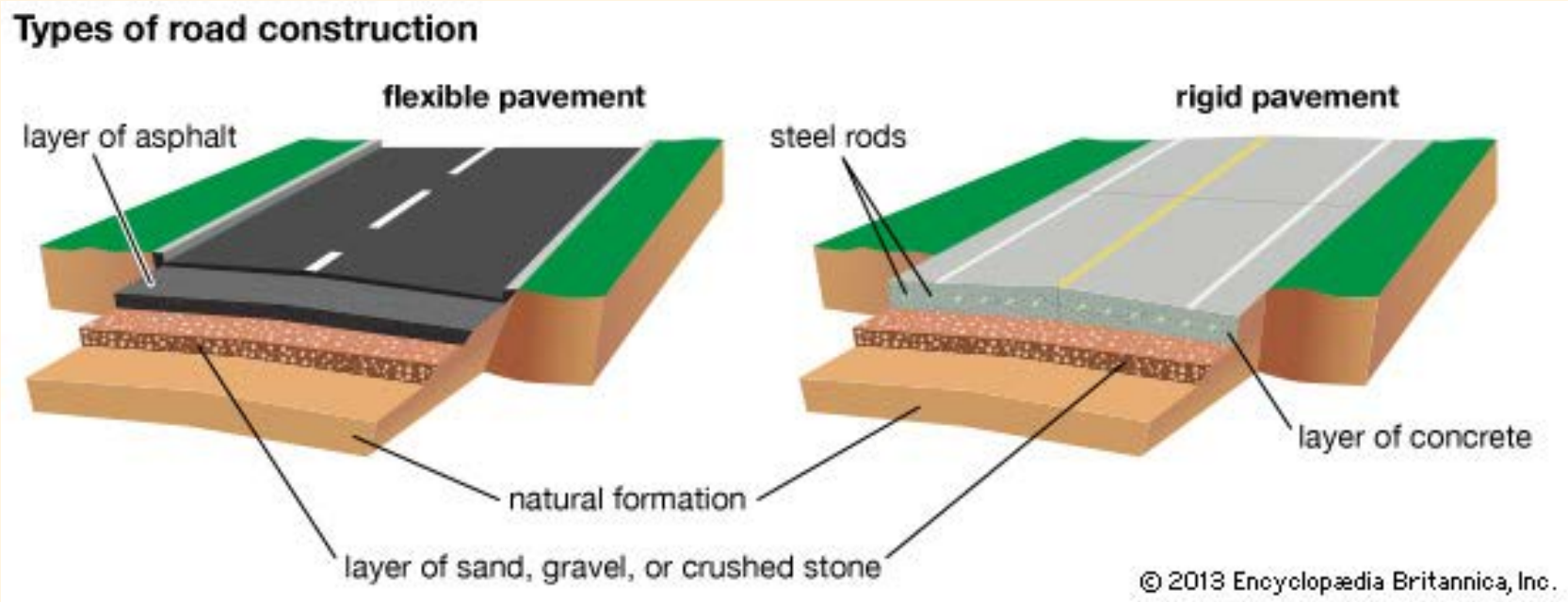
Introduction (IX)

Still work to do...



Roads completed, to be upgraded and planned in the trans-European transport network (TEN-T)
Source **European Commission**

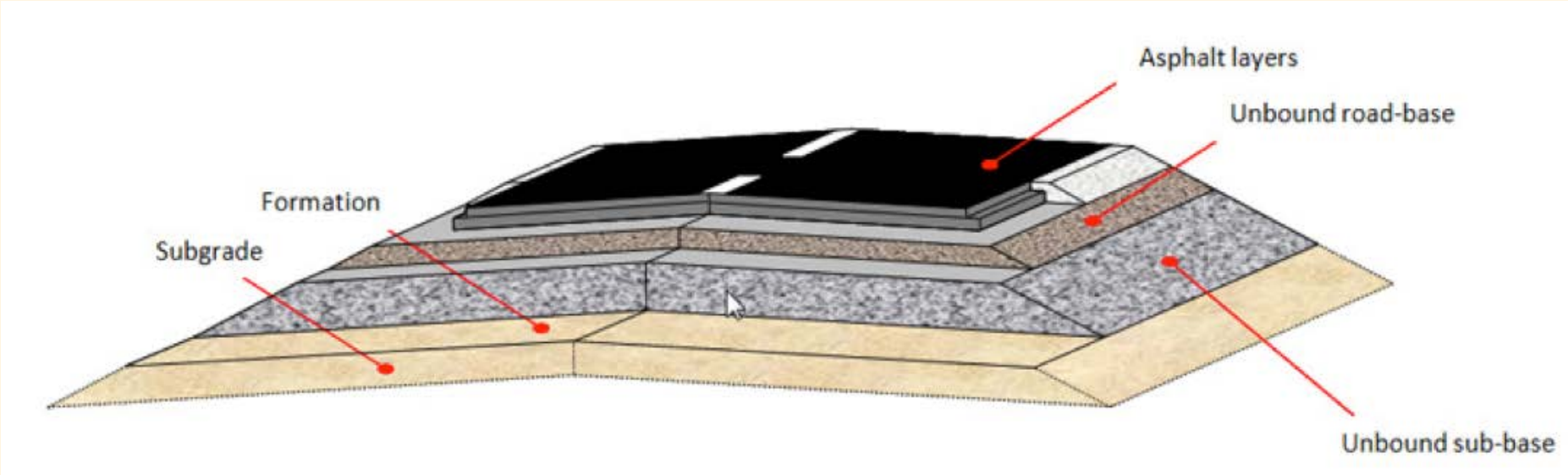
Flexible pavements
vs
Rigid pavements



Flexible pavement and rigid pavement — Source **Encyclopædia Britannica**

Roads (II)

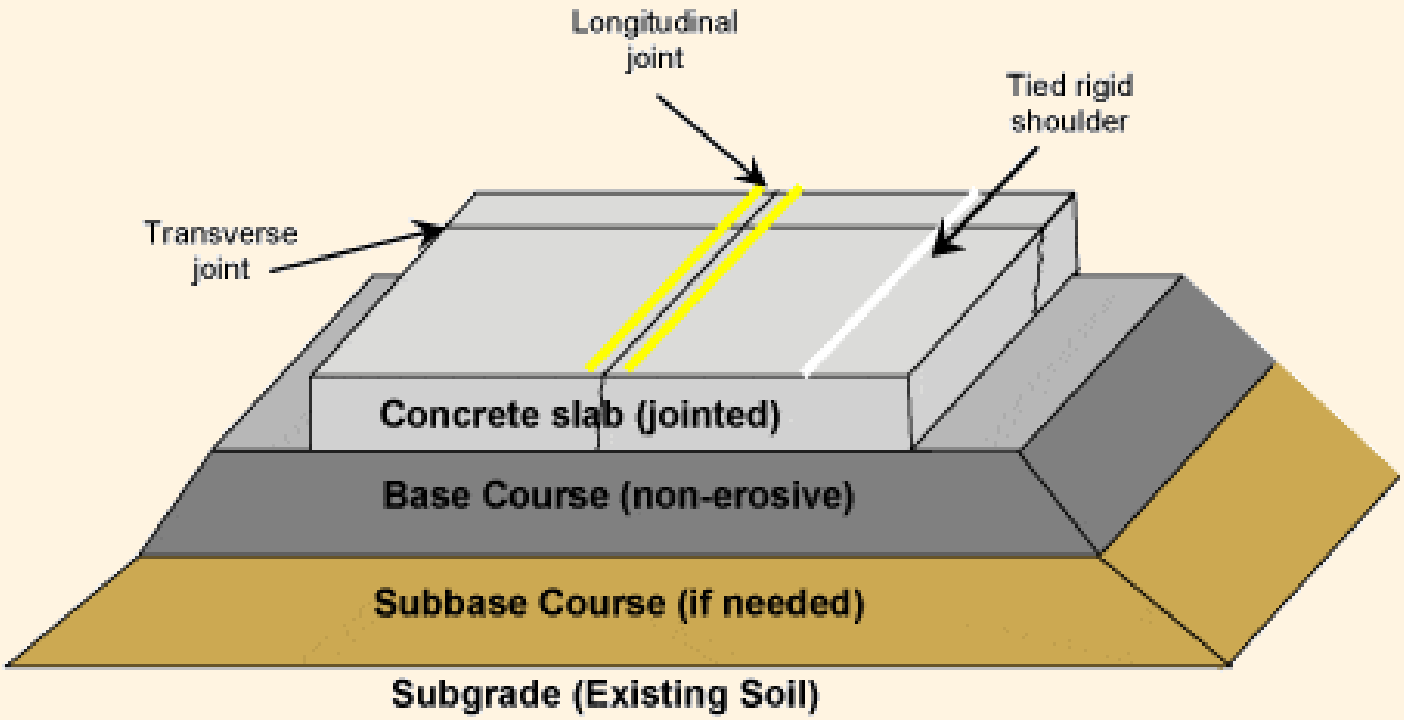
Flexible pavements: Those which are surfaced with bituminous (or asphalt) materials. These types of pavements are called “flexible" since the total pavement structure “bends" or “deflects" due to traffic loads. A flexible structure is generally composed of several layers of materials which can accommodate this “flexing".



Flexible pavement cross section — Source **EAPA**
[European Asphalt Pavement Association (EAPA)]

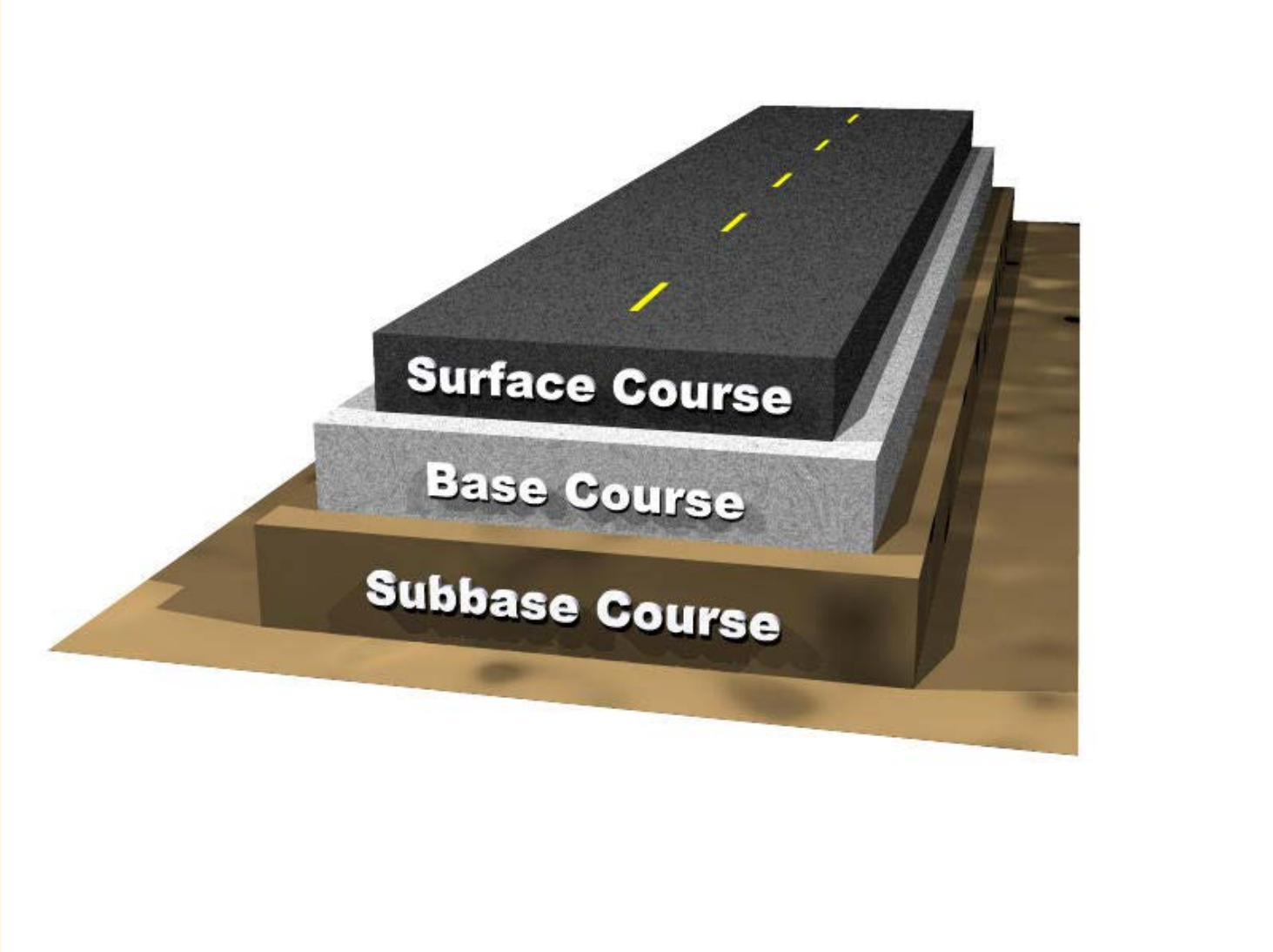
Roads (III)

Rigid pavements: Those which are surfaced with portland cement concrete (PCC). These types of pavements are called “rigid" because they are substantially stiffer than flexible pavements due to PCC’s high stiffness.



Rigid pavement cross section — Source **theconstructor.org**

Roads (IV)



Basic flexible pavement structure — Source **pavementinteractive.org**

Roads (VI)

Flexible pavement:

1.- Surfaced with bituminous or asphalt materials.

2.- Have low flexural strength.

3.- No stresses due to temperature variations.

4.- Have low completion cost but high repairing cost.

Rigid pavement:

1.- One layer of Portland cement concrete slab or similar.

2.- Have high flexural strength.

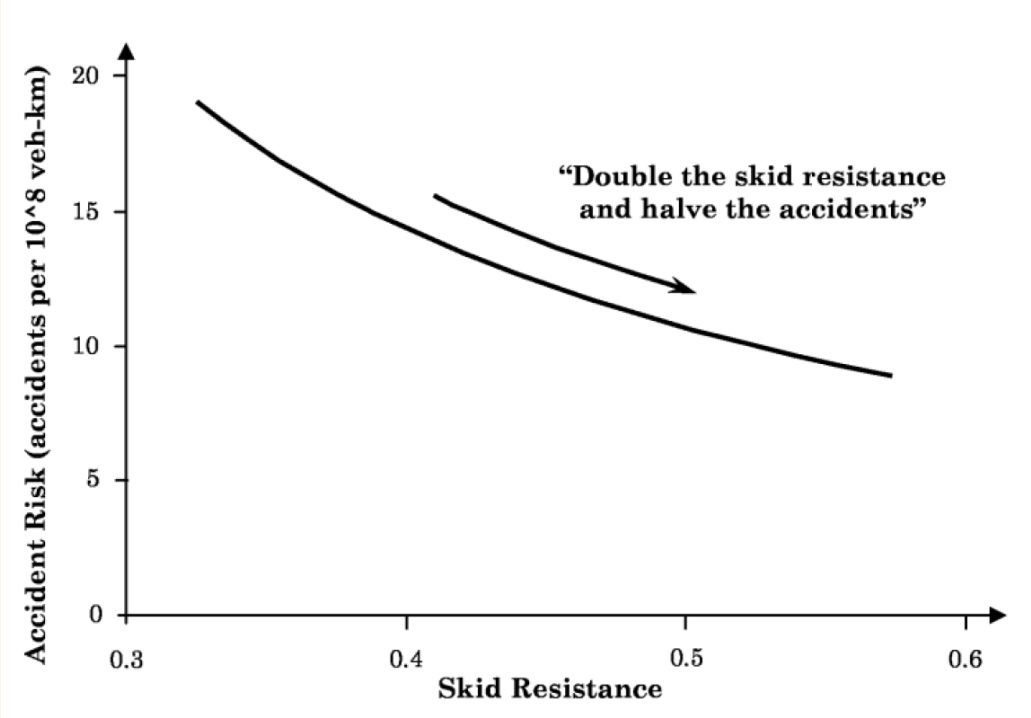
3.- Heavy stresses due to temperature variations.

4.- Have low repairing cost but high completion cost.

PAVEMENT FRICTION

Skid resistance — Source **Daily Mail**

SKID RESISTANCE

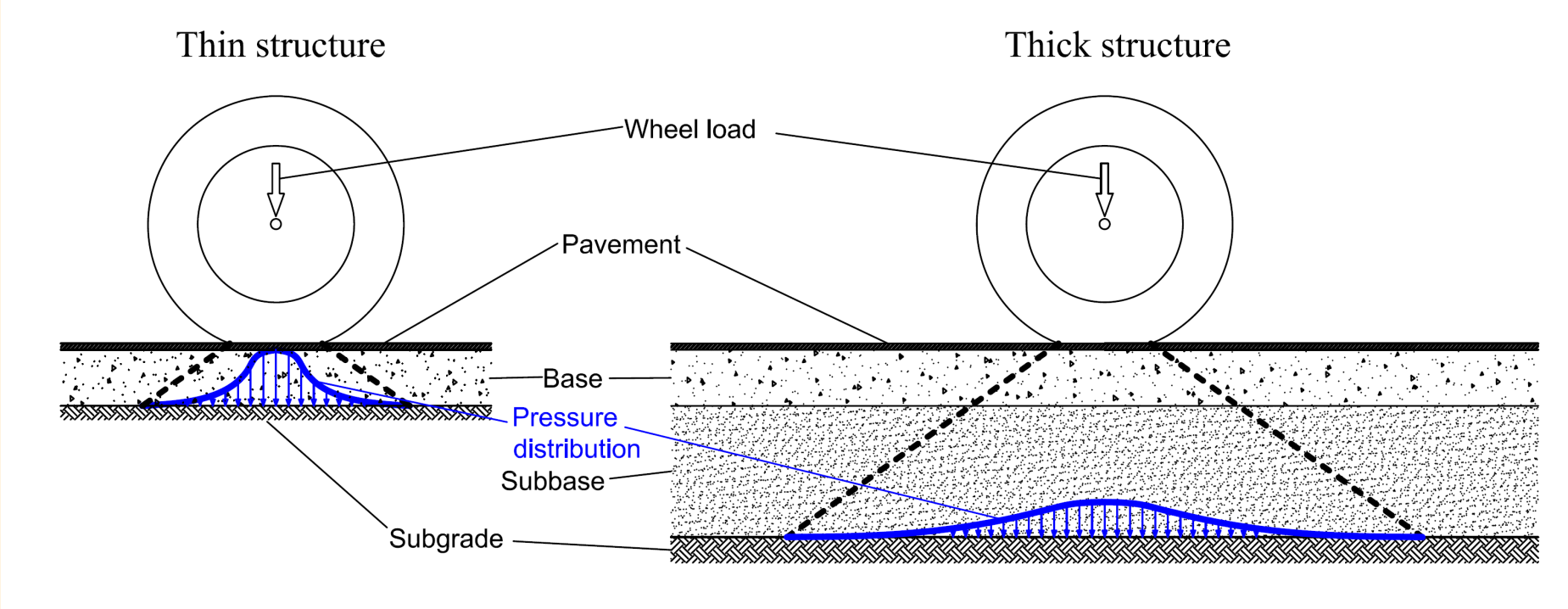


Accident risk and skid resistance — Source **Viner et al., 2004**

STRUCTURAL STRENGTH

Structural strength — Source **qespavements.com**

STRUCTURAL STRENGTH



Pressure distribution along a pavement structure — Source **theconstructor.org**

Quantification

Skid Resistance

- **Friction Factor**
- Skid Number

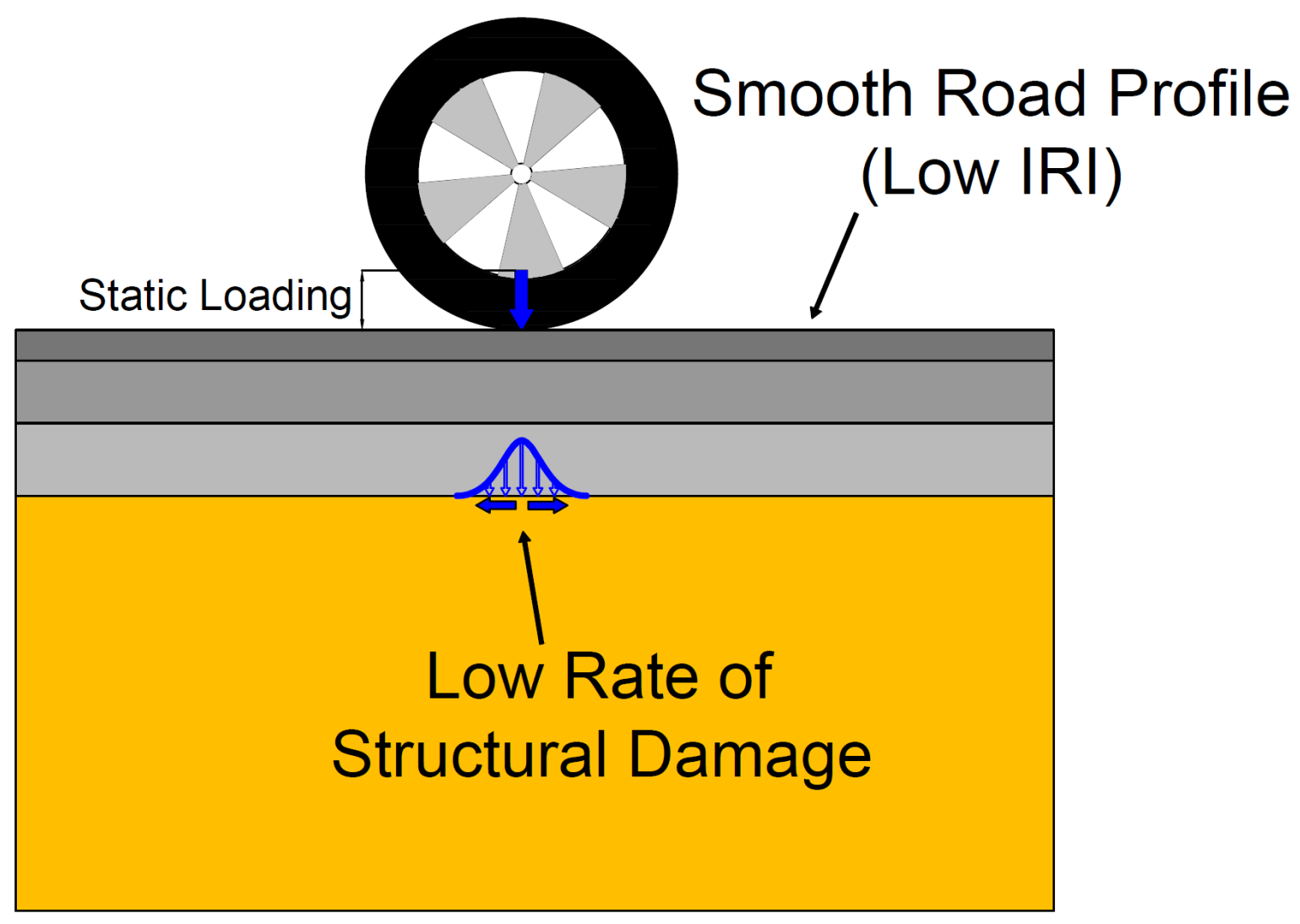
Roughness

- **International Roughness Index (IRI)**
- Profilograph Index
- Ride Number
- Mays Ride Number
- Cumulative Straightedge Index
- Ride Quality Index

Deterioration (I)

≫TIME≫

Deterioration (II)



Low rate of structural damage when road profile is smooth.

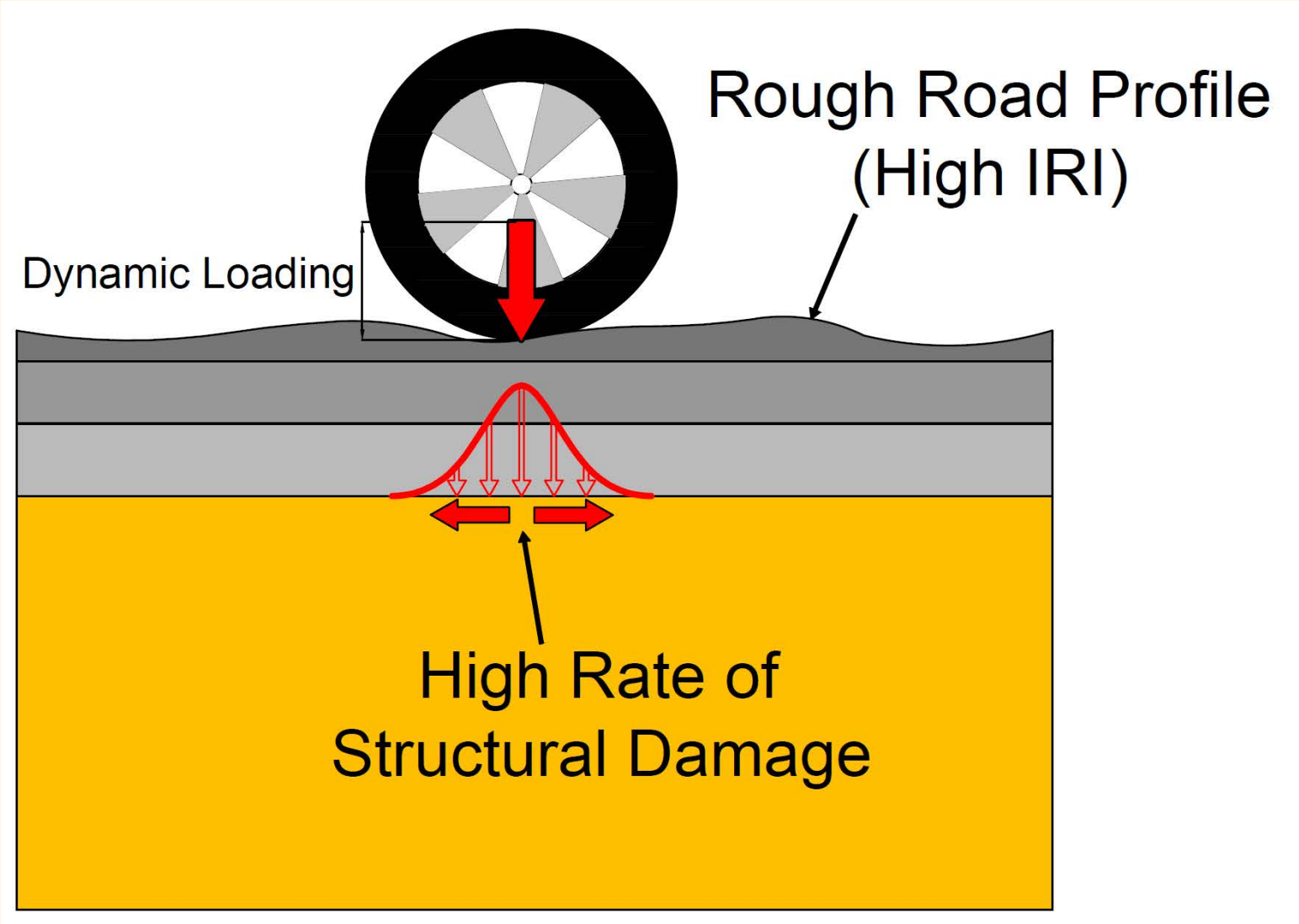
Fourth Power Law

The relationship between axle weight and pavement damage is not linear but exponential.

- A 8 tons single axle (truck) does about **3.000 times more damage** to a pavement than a 0,9 tons single axle (car).
- A 13,5 tons single axle (heavy truck) does about **26.000 times more damage** to a pavement than a 0,9 tons single axle (car).

Heavy trucks and buses are responsible for a majority of pavement damage

Deterioration (IV)



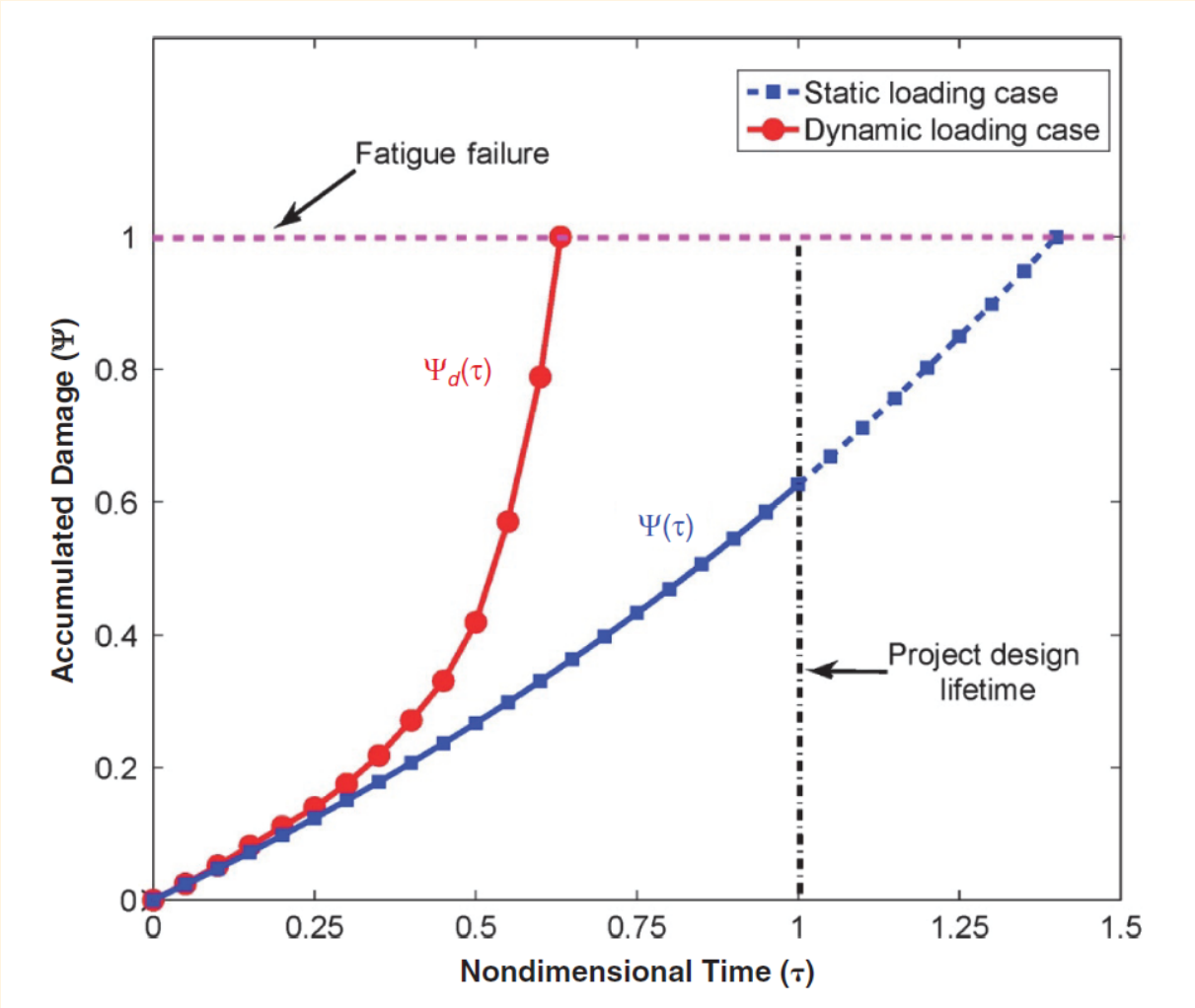
High rate of structural damage when road profile is rough.

PAVEMENT LIFETIME

- Directly determined by the number of axles of vehicles rolling on each section and the load carried by each axle to the pavement

FATIGUE $\Rightarrow$ MINER's RULE

Deterioration (VI)



Evolution of accumulated fatigue damage indicator $\Psi(\tau)$.
Source **Previous GMNI work**

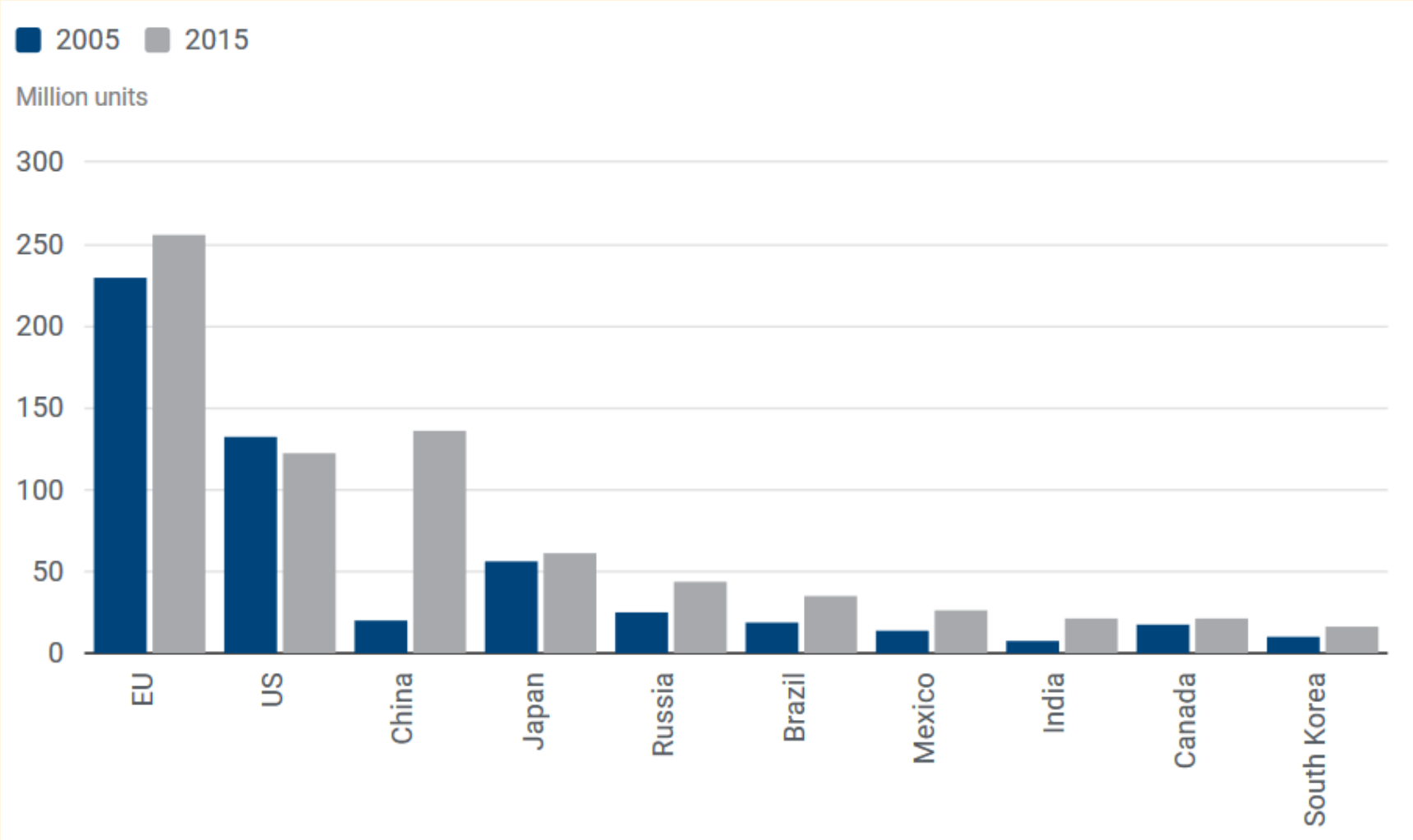
Traffic (I)

Vehicle type	2012	2013	2014	2015
Passenger cars	304.349.924	308.332.988	317.497.306	323.584.629
Light commercial vehicles	38.901.972	39.296.021	39.817.663	40.727.091
Medium and heavy commercial vehicles	13.158.496	13.063.573	13.091.936	13.048.717
Buses	970.182	954.871	943.192	957.597

Vehicles in use in Europe.

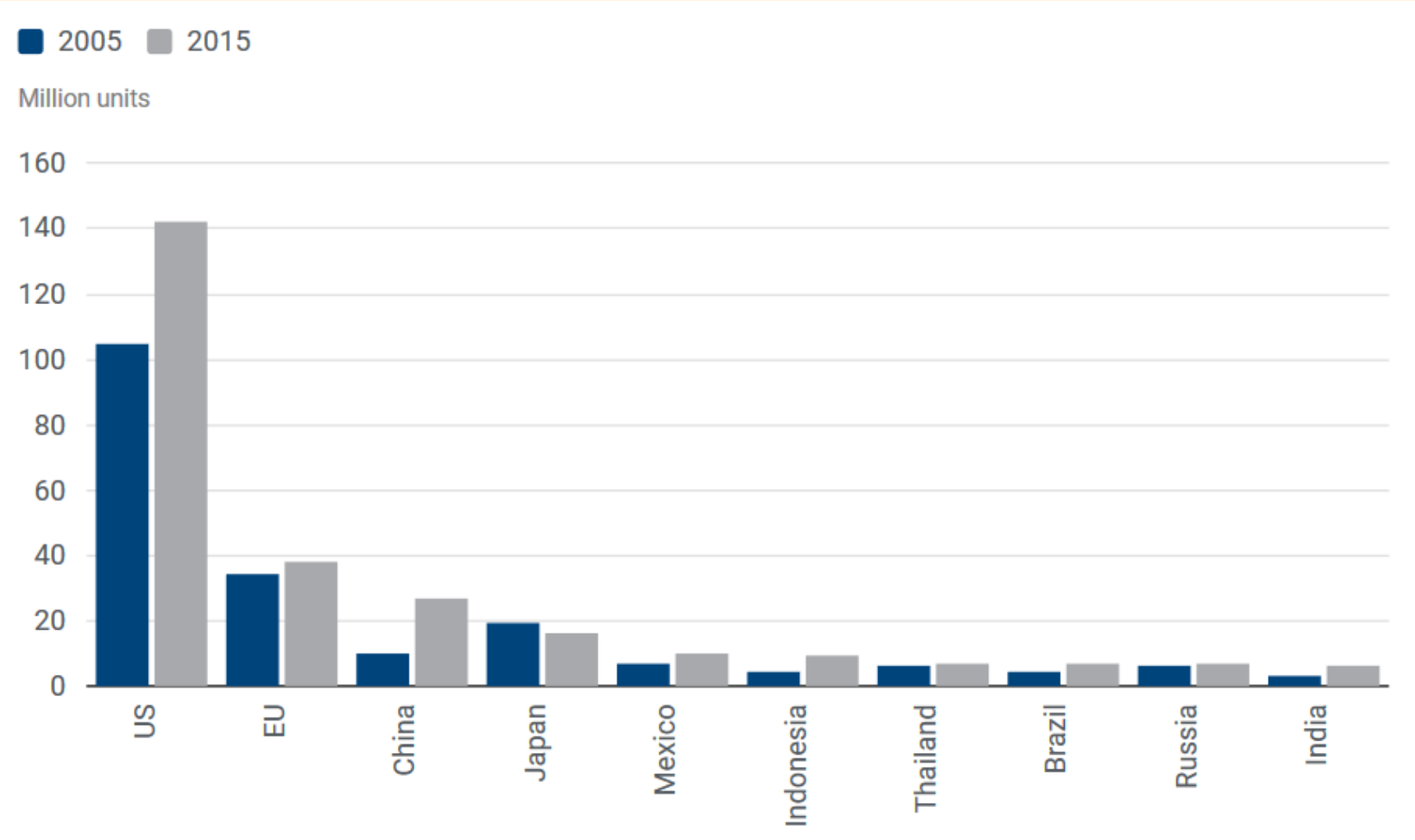
Source **European Automobile Manufacturers Association**

Traffic (II)



Global number of passenger cars
Source **European Automobile Manufacturers Association**

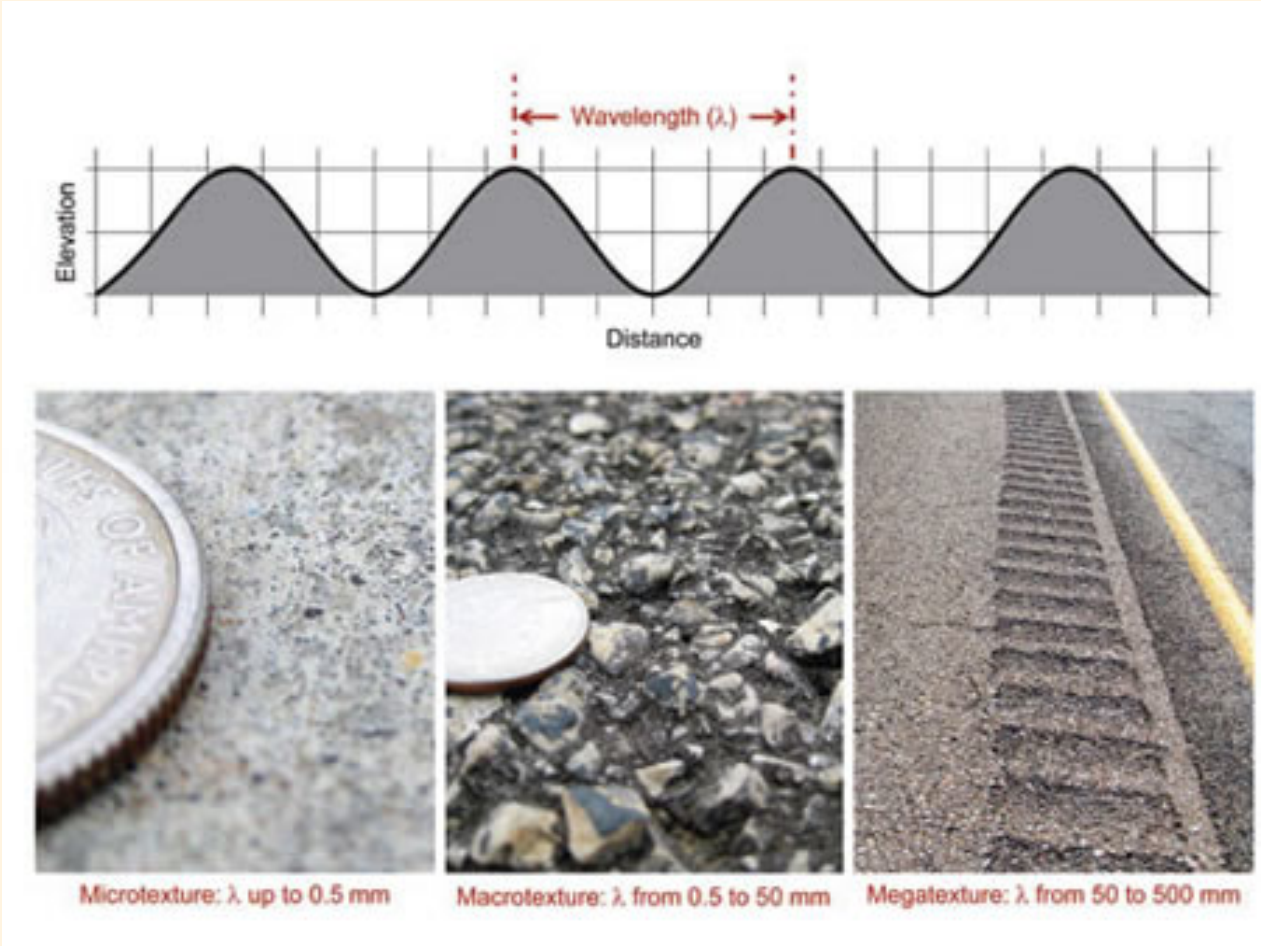
Traffic (III)



Global number of commercial vehicles
Source **European Automobile Manufacturers Association**

Deterioration Effects (I)

Safety (Direct)

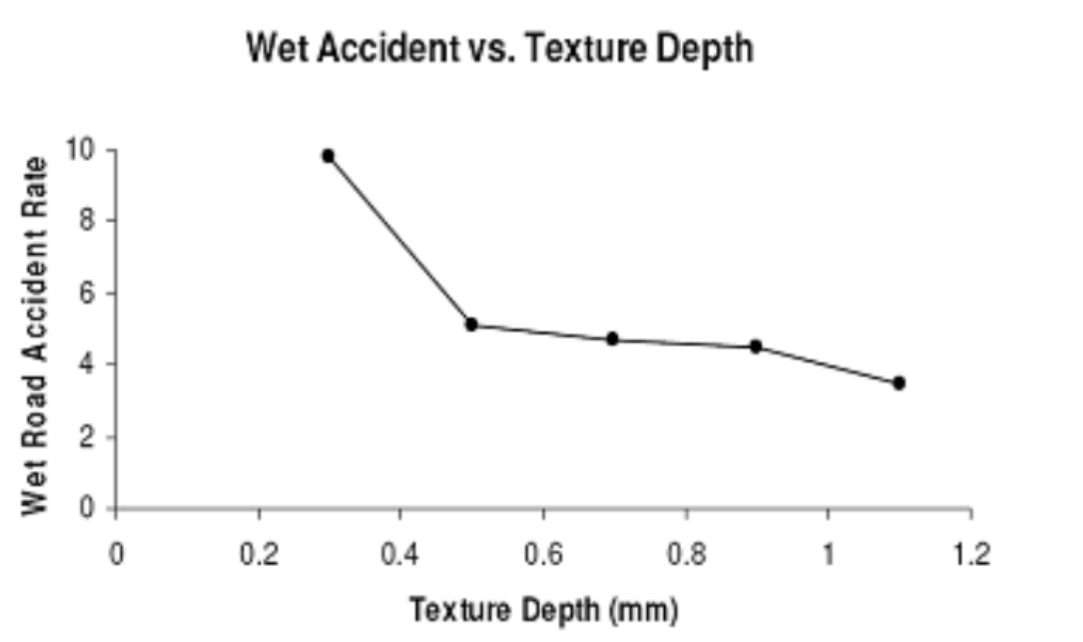


Micro, Macro and Megatexture

Safety (Direct)

- Microtexture

$$\uparrow \text{Microtexture} \quad \Rightarrow \quad \uparrow \text{Safety}$$



Relationship between Wet-Accident and Surface Texture Depth
Source **Gothie 1991**

Safety (Direct)

- Macrotexture

$\uparrow$ Macrotexture $\Rightarrow$ $\downarrow$ Less Friction surface $\Rightarrow$ $\downarrow$ Safety

Safety (Direct)

- Megatexture

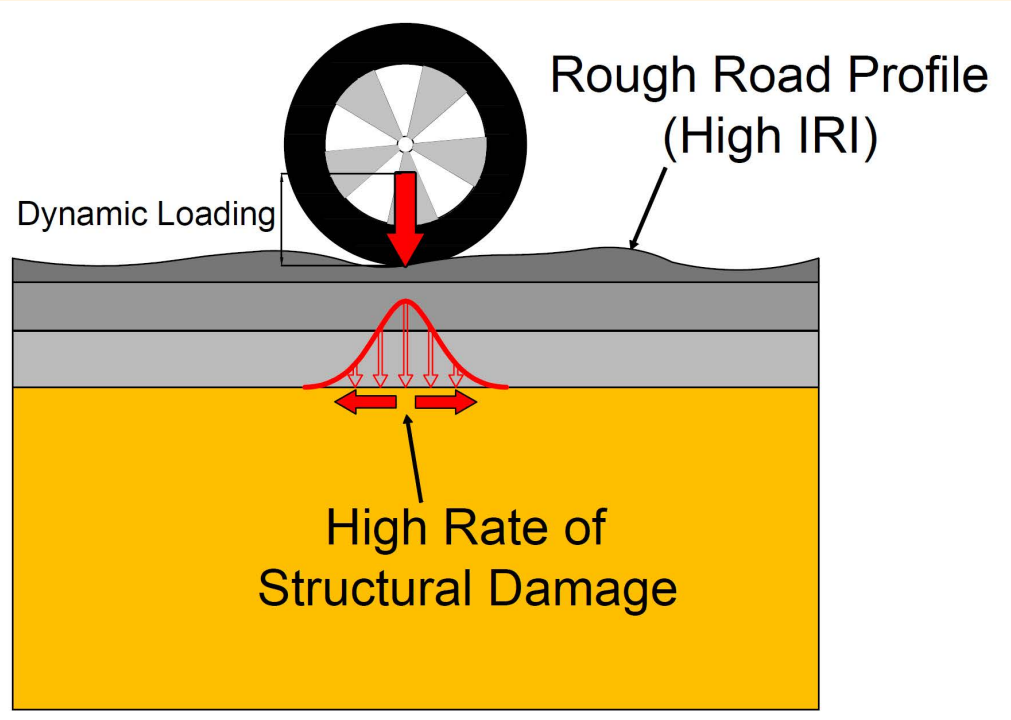
$$\uparrow \text{Megatexture} \quad \Rightarrow \quad \downarrow\downarrow \text{Safety}$$

$$\boxed{IRI}$$

Damage (Direct)

- Megatexture

$$\uparrow \text{Roughness (IRI)} \quad \Rightarrow \quad \uparrow \text{Structural Damage}$$



Fuel Consumption (Indirect)

- Roughness (Megatexture)
- Macrotexture
- Structural Responsiveness

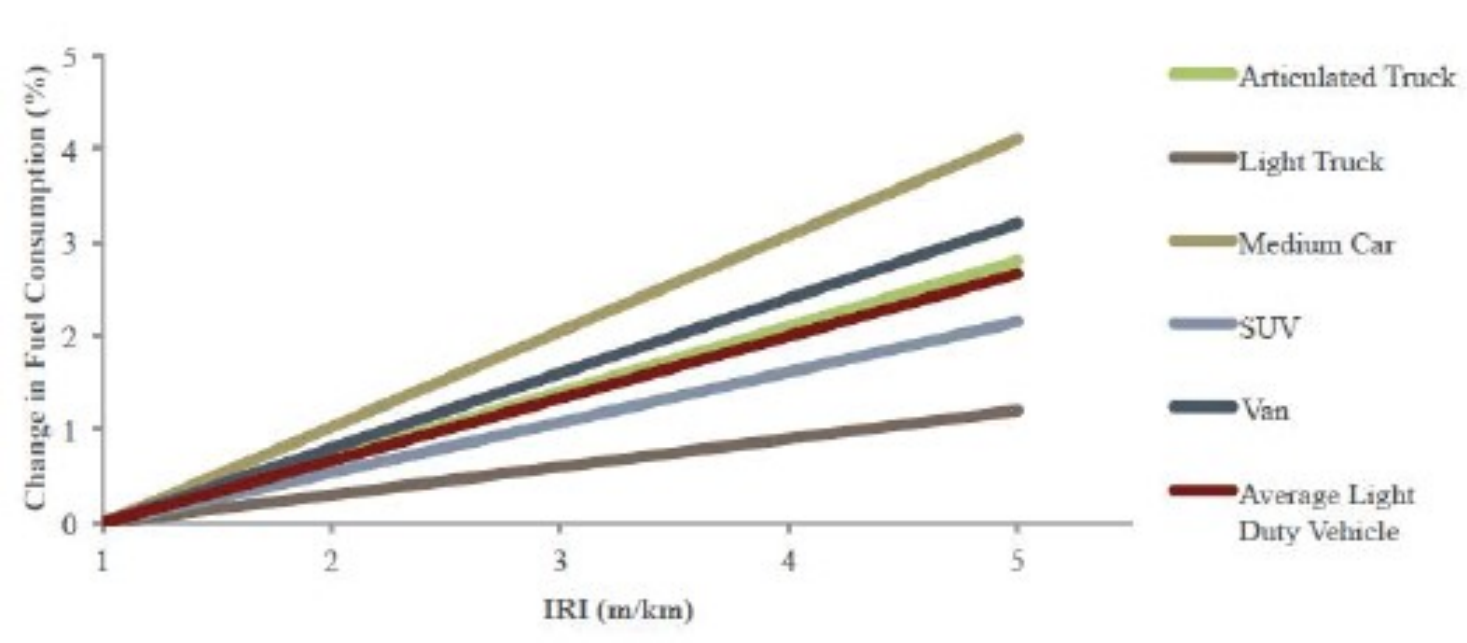
$$CO_2$$

Fuel Consumption (Indirect)

Transport type	MtCO_2	%
Road	852	95,2
Domestic air	16,2	1,8
Rail	14,9	1,7
Inland waterways	6,12	0,7
Other transportation	5,79	0,6

Emissions from transport in 2015 (EU)
Source **European Environment Agency**

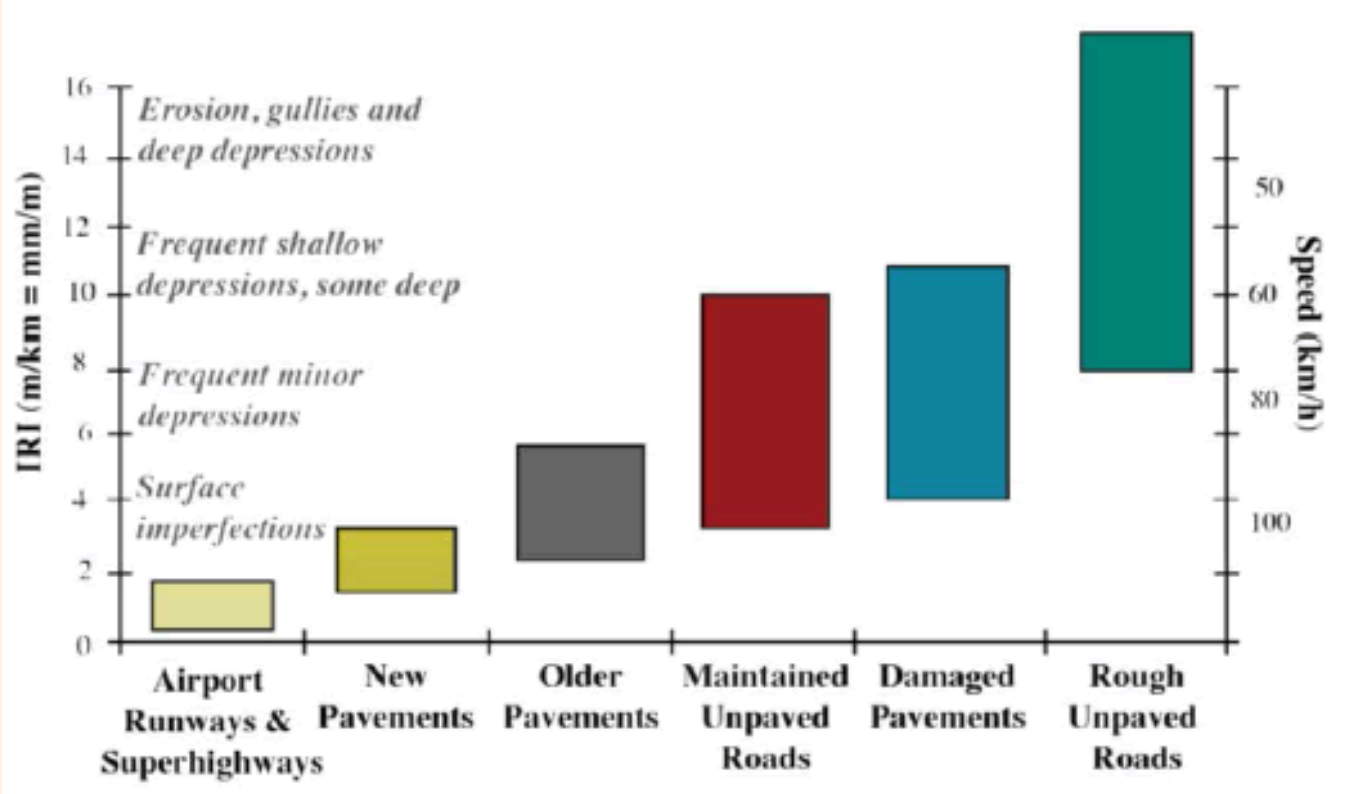
Fuel Consumption (Indirect)



Effects of pavement roughness on fuel consumption
Source **Zaabar and Chatti 2010**

Deterioration Effects (IX)

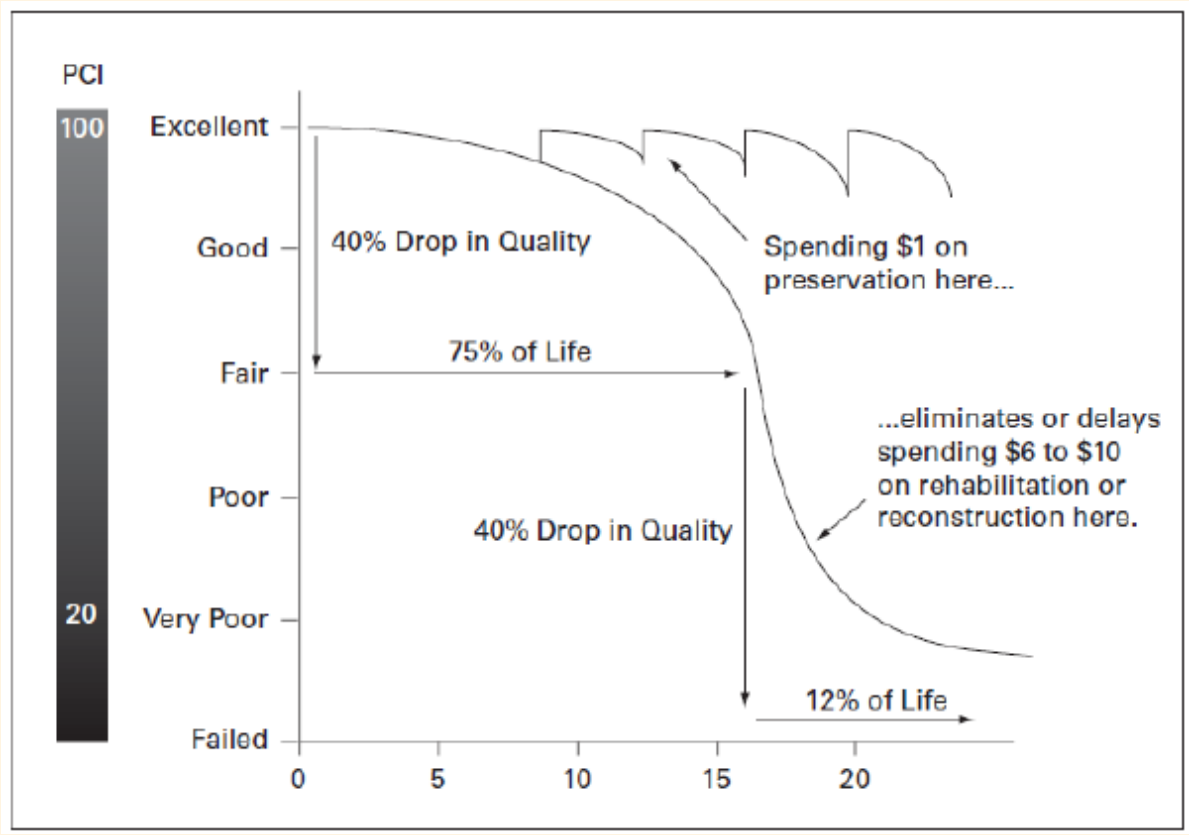
Speed (Indirect)



Effects of pavement roughness on speed
Source **Sayers 1986**

Maintenance Operations (I)

Lack of maintenance ⇒ Expensive Future

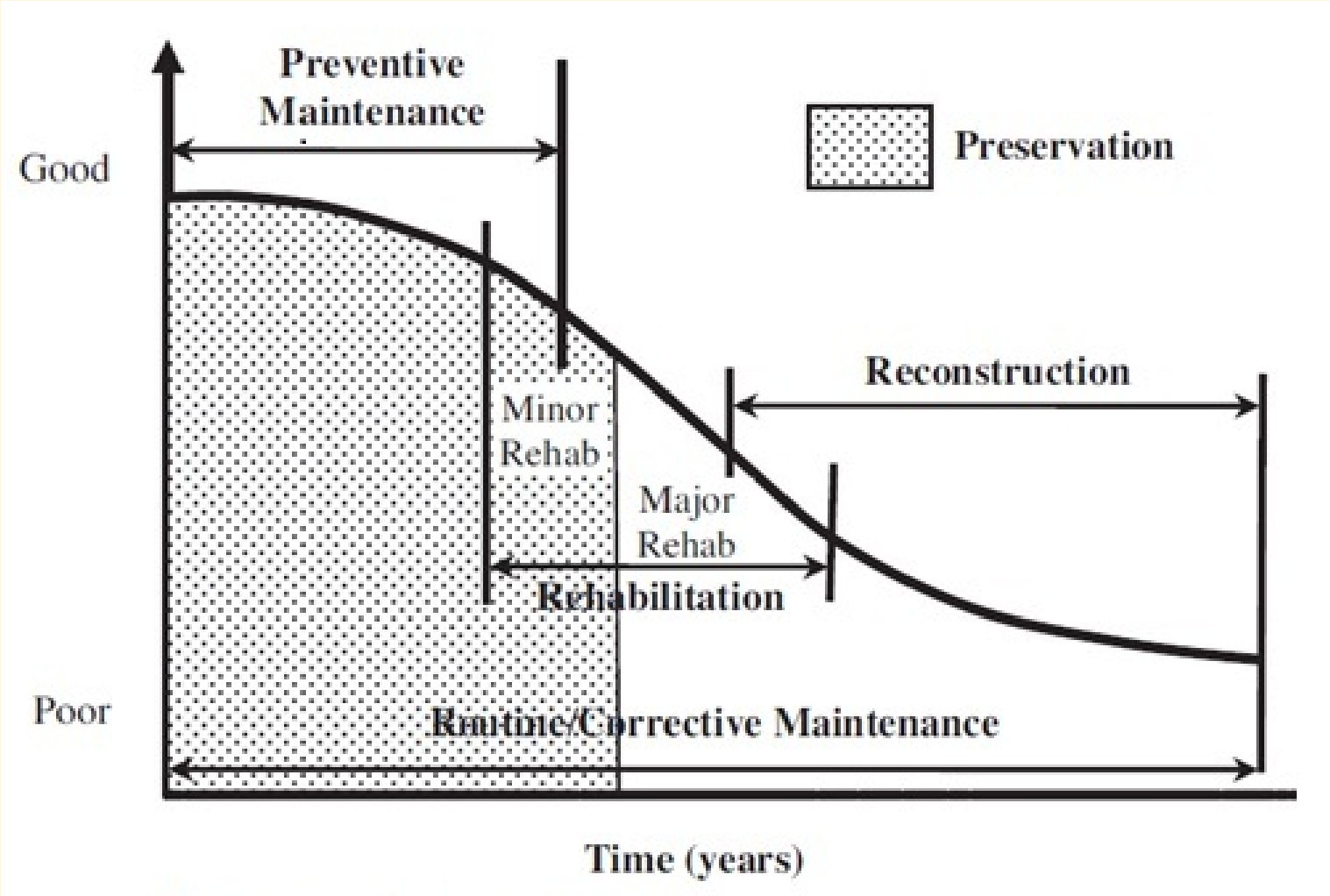


Pavement deterioration curve along its lifetime.PCI stands for Pavement Condition Index
Source **US Department of Transportation**
[Federal Highway Administration]

Categories of Pavement Maintenance:

- Pavement preservation
  - Preventive maintenance
  - Corrective maintenance
  - Routine maintenance
- Pavement rehabilitation
- Pavement reconstruction

Maintenance Operations (III)



Different types of operations related to pavement condition
Source **Peshkin et al. 2007**

ECONOMIC BALANCE

It is believed that if preventive maintenance is programmed to be applied too infrequently the maintenance and user costs will increase. On the contrary, if it is applied too frequently the maintenance program cost will be reduced, but due to the traffic interruption there are costs in terms of user delay and inconvenience.

ECONOMIC BALANCE

Project Objectives (I)

ANALYZE

UNDERSTAND

IMPROVE

Project Objectives (II)

INPUTS

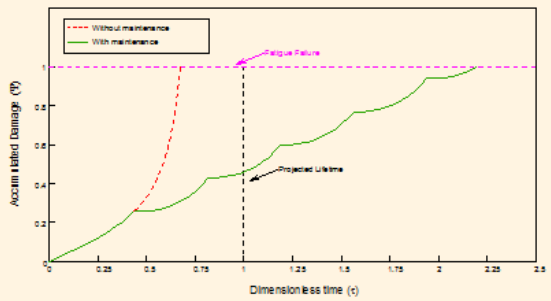
-Pavement Characteristics:
- -Materials
- -Number of layers
- -Pavement Condition Index (PCI)
- -Projected Service Lifetime
- -Current IRI

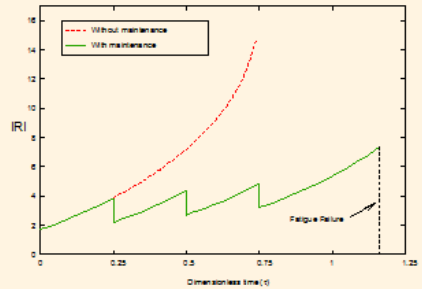
-Average daily traffic of heavy vehicles (ADT_h)

-Maintenance Strategy

MATHEMATIC MODEL

OUTPUTS





Project Results (I)

Report No.1

STAREBEI Project — Fundación de la Ingeniería Civil de Galicia :

Impact of Preventive Maintenance on Flexible Pavement Service Life

Report No.1

State of Knowledge

M. Ruíz, L. Ramírez, F. Navarrina & M. Aymerich

Grupo de Métodos Numéricos en Ingeniería (GMNI)
Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos,
Universidad de A Coruña — Fundación de la Ingeniería Civil de Galicia

A Coruña, February the 28th, 2017

Project Results (II)

Report No.2

STAREBEI Project — Fundación de la Ingeniería Civil de Galicia :

Impact of Preventive Maintenance on Flexible Pavement Service Life

Report No.2

Mathematical Model and Sample Results

M. Ruíz, L. Ramírez, F. Navarrina, M. Aymerich & D. López-Navarrete

Grupo de Métodos Numéricos en Ingeniería (GMNI)
Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos,
Universidad de A Coruña — Fundación de la Ingeniería Civil de Galicia

A Coruña, October the 15th, 2017

Project Results (III)

Report No.3

STAREBEI Project — Fundación de la Ingeniería Civil de Galicia :

Impact of Preventive Maintenance on Flexible Pavement Service Life

Report No.3

Dynamic & Maintenance Simulation App: User's guide

M. Ruíz, L. Ramírez, F. Navarrina, M. Aymerich & D. López-Navarrete

Grupo de Métodos Numéricos en Ingeniería (GMNI)
Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos,
Universidad de A Coruña — Fundación de la Ingeniería Civil de Galicia

A Coruña, December the 22nd, 2017

DMSA

- **New tool** developed in the context of this project.
- **Specific** for the evaluation of projects financed by the EIB.
- **Financed** by the EIB Institute under a STAREBEI grant.
- Including the **latest advances** in Civil Engineering.

Fast

User-friendly

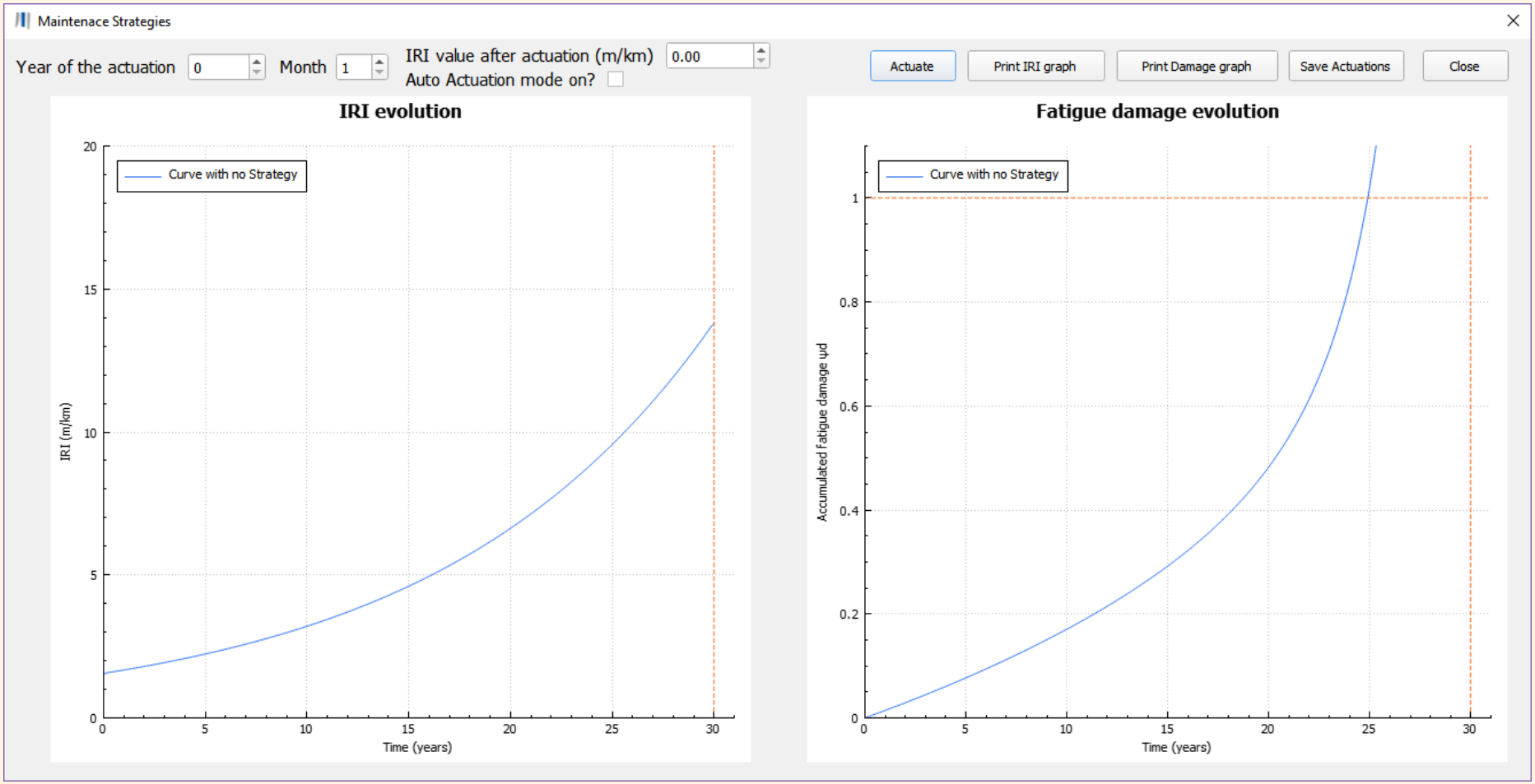
Comparison between Results

Technical

DMSA (I)

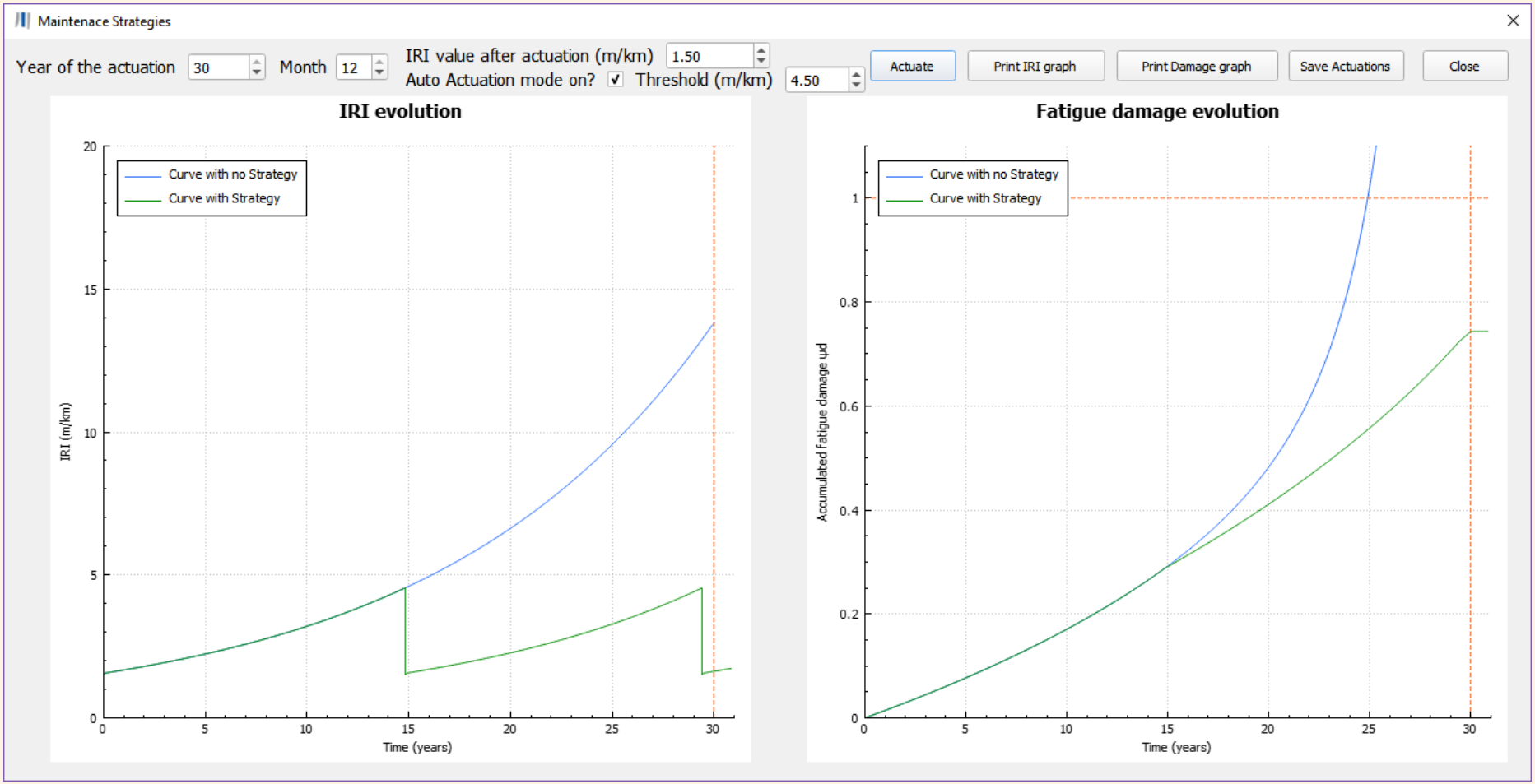
Main window of the DMSA

DMSA (II)



Sample result obtained with DMSA

DMSA (II)



Sample maintenance strategy simulated with DMSA

Outcome

1.- The project will contribute to understand the importance of considering the dynamic load effects on the pavement lifetime.

2.- The results of this project can be used to define a set of recommendations on how to evaluate different maintenance strategies by road project promoters.

3.- The tool developed in this project can be used as an evaluation tool for projects financed by the EIB.