# Impact of Preventive Maintenance on Flexible Pavement Service Life

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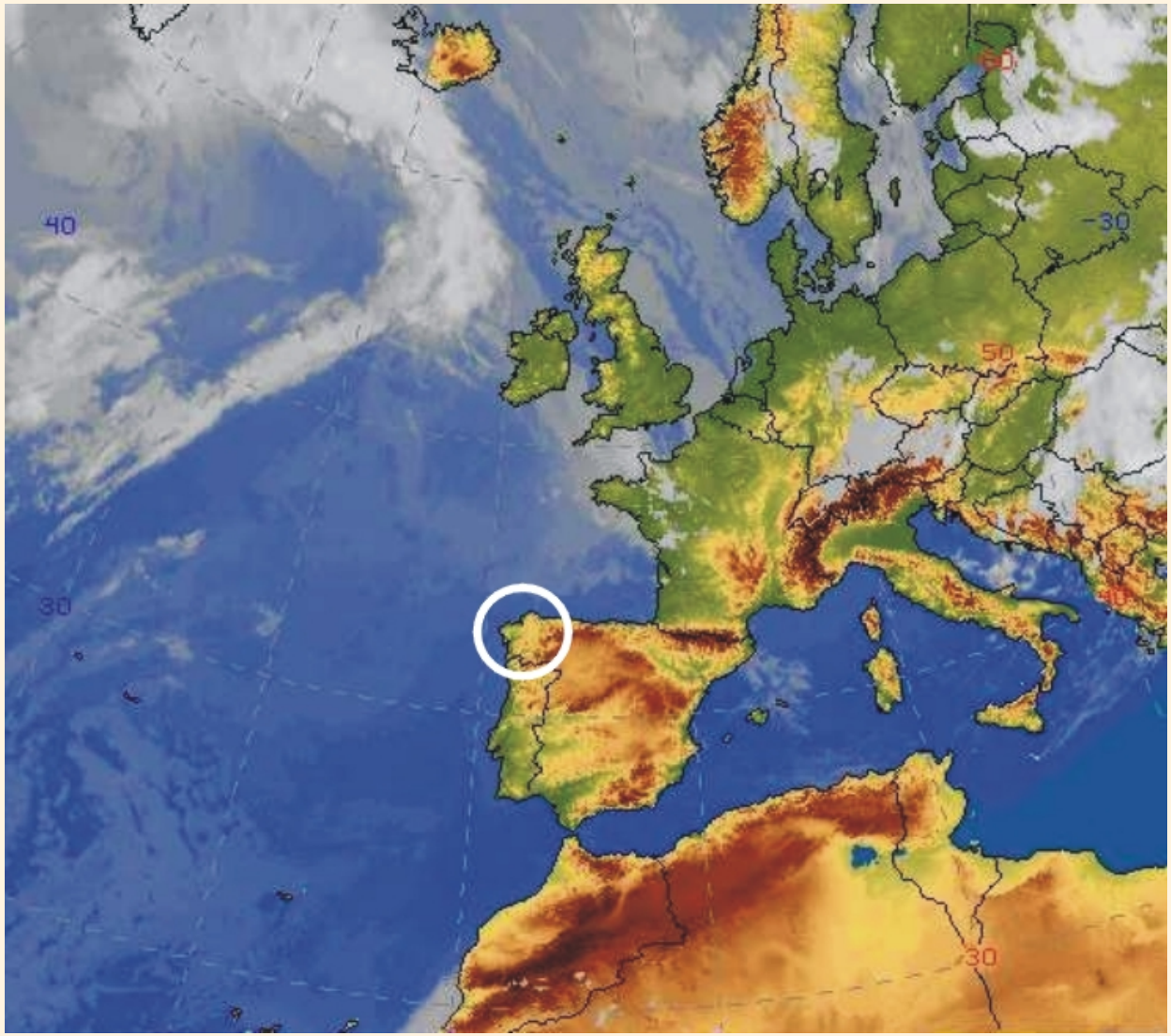
# Background (I)




Stereographic Polar Image of SPAIN, EU — Courtesy of **National Institute of Meteorology**

# Background (II)

Satellite image of GALICIA — Courtesy of **NASA**

# Background (III)

Ribeira Sacra (Sil River Canyon) — Courtesy of **Wikimedia Commons** [by SanchoPanzaXXI]

# Background (IV)

- Road construction and maintenance is a specially relevant issue, due to
  - the dispersion of settlements,
  - the length and density of the secondary road network,
  - the complicated orography, and
  - the rainy weather.

- Almost 100% of roads in the region are made of **FLEXIBLE** type **Hot Mix Asphalt (HMA)** pavements.

# Outline

- Introduction
- Problem Statement
- Objectives
- Preliminary results
- Expected Outcome

# Introduction

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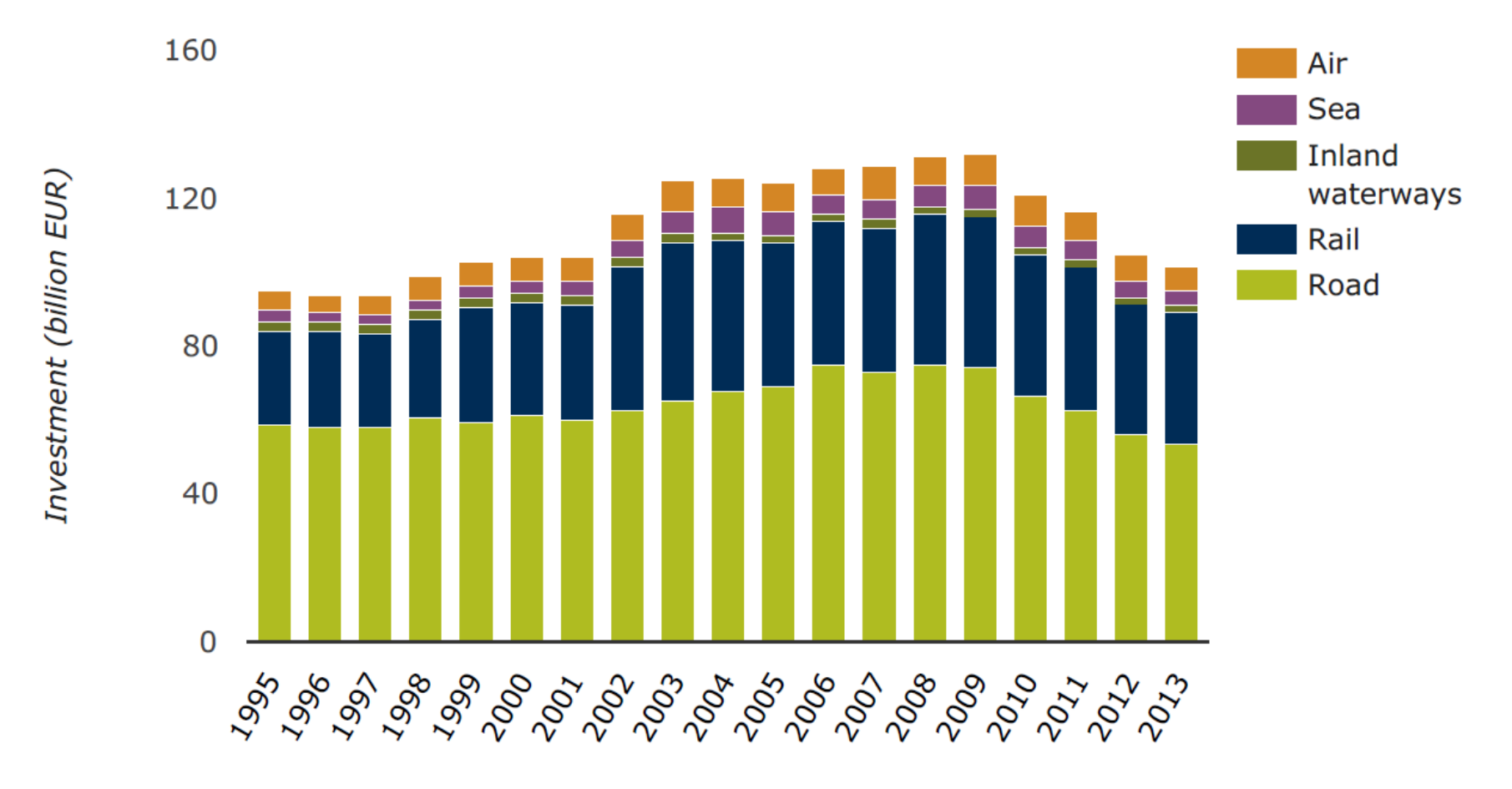
# Introduction (I)

- 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 (II)




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

# Introduction (III)

In Europe, since about 7–8 years. . .

$ $ $ $ $ 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 (IV)

- Civil Engineering Public Works:
  - ♣ increasing pressure for **optimizing operations** and **reducing costs**,
  - ♠ economic & political decisions prevail against technical reasons.

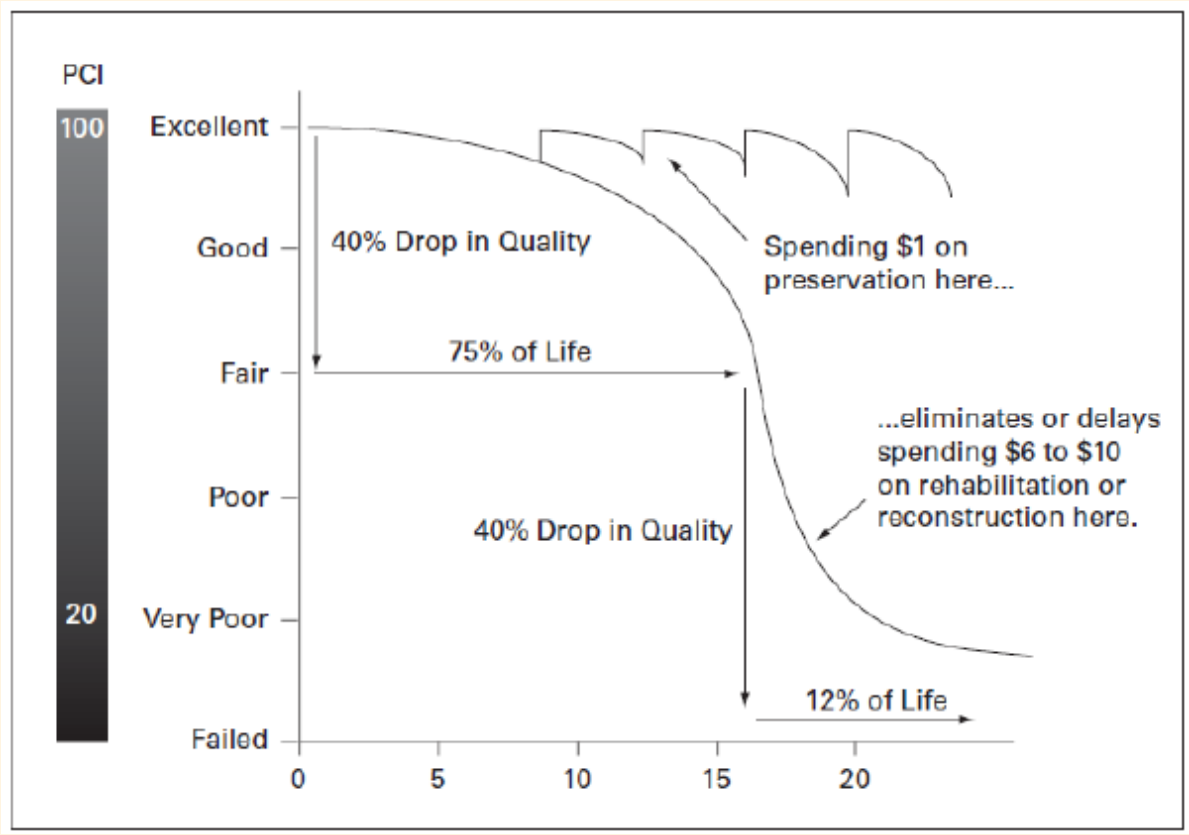
Old questions are posed, once again. . .

Which would be the effects of delaying
(temporarily, during this crisis period)
**"non–essential"** maintenance operations? (*)

(*) This question stands mainly for the secondary road network.

# Introduction (V)

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]

# Introduction (VI)

- As pointed by the European Parliament...

1.-*"The **quality** of road infrastructure is a key factor in road accidents"*

2.-*"There is a direct relationship between **pavement condition** and transport fuel consumption"*

# Problem Statement

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# Problem Statement (I)

REDUCTION IN ROAD MAINTENANCE

$\Downarrow$

NEW OPPORTUNITIES IN MANAGING

$\Downarrow$

**LONG-TERM MAINTENACE**

# Problem Statement (Ia)

REDUCTION IN ROAD MAINTENANCE

$\Downarrow$

NEW OPPORTUNITIES IN MANAGING

$\Downarrow$

**LONG-TERM MAINTENACE**

*Impact of Preventive Maintenance on Flexible Pavement Service Life*

# Problem Statement (II)

- One of the key factors in the design construction and maintenance of road infrastructures is the definition of the **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 ANALYSIS

# Fatigue Analysis of Flexible Pavements (I)

**Strain-based fatigue model** for Hot Mix Asphalt (HMA) pavements:

$$\epsilon_r = K \cdot N^{-\alpha} \qquad \Longleftrightarrow \qquad N = (K/\epsilon_r)^{1/\alpha},$$

where

| | |
|---|---|
| $N$ | = number of load cycles to failure, |
| $\epsilon_r$ | = reference strain, |
| $K, \alpha$ | = coefficients that depend on the HMA type. |

# Fatigue Analysis of Flexible Pavements (II)

Fatigue damage is cumulative and grows with the number of load cycles.

- Seminal idea: **LINEAR RULE** (Palmgren, $\approx$ 90 years ago).
- Mathematical formulation: **MINER'S RULE** ($\approx$ 70 years ago).

$$\boxed{\psi = \sum_i \left( \frac{n_i}{N_i} \right)}$$

$\psi \equiv$ total accumulated fatigue damage
$n_i \equiv$ actual number of cycles of each load
$N_i \equiv$ number of cycles to failure

$$\boxed{\psi \geq 1 \Rightarrow FAILURE}$$

# Fatigue Analysis of Flexible Pavements (III)

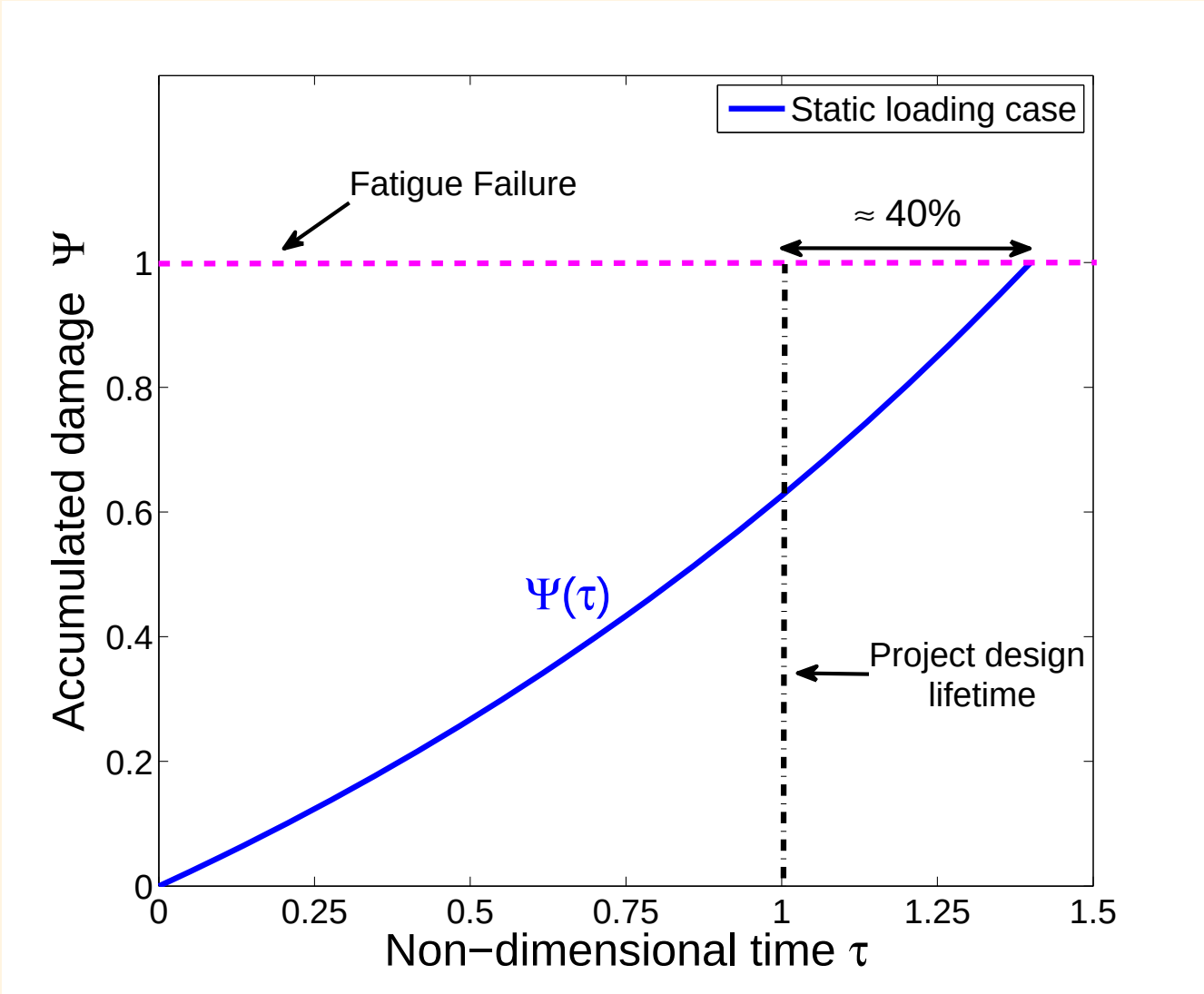
Then:

- $\tau = 1 \longrightarrow$ the end of the project design life period.
- $\psi(1) \begin{cases} < 1 \longrightarrow \text{pavement section is oversized,} & (*) \\ = 1 \longrightarrow \text{pavement section is strictly well sized,} \\ > 1 \longrightarrow \text{pavement section is undersized.} & (**) \end{cases}$
- If section is undersized, non dimensional time $\tau_s$ such that $\psi(\tau_s) = 1$ marks the end of the structural service life at real time $T_s = \tau_s T_p < T_p$.

(*) Expected to be in good condition beyond the project design life period.

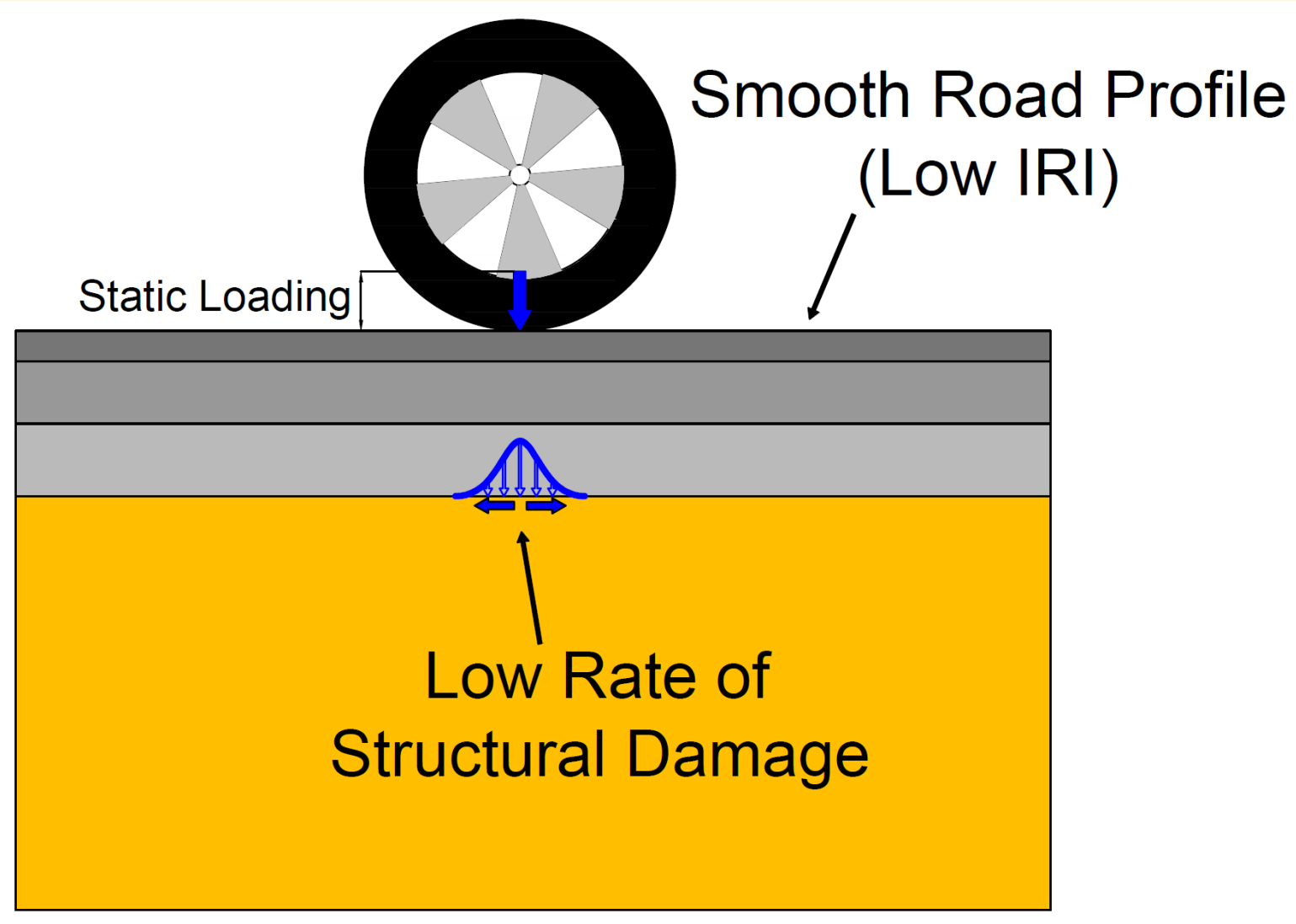
(**) Expected to collapse before the project design life period is over [UNACCEPTABLE].

# Fatigue Analysis of Flexible Pavements (IV)




Evolution of the accumulated fatigue damage indicator $\psi(\tau)$ for Section T3121.

# Fatigue Analysis of Flexible Pavements (V)




Low rate of structural damage when road profile is smooth (low–IRI conditions).

# Dynamic Axle Loads (I)

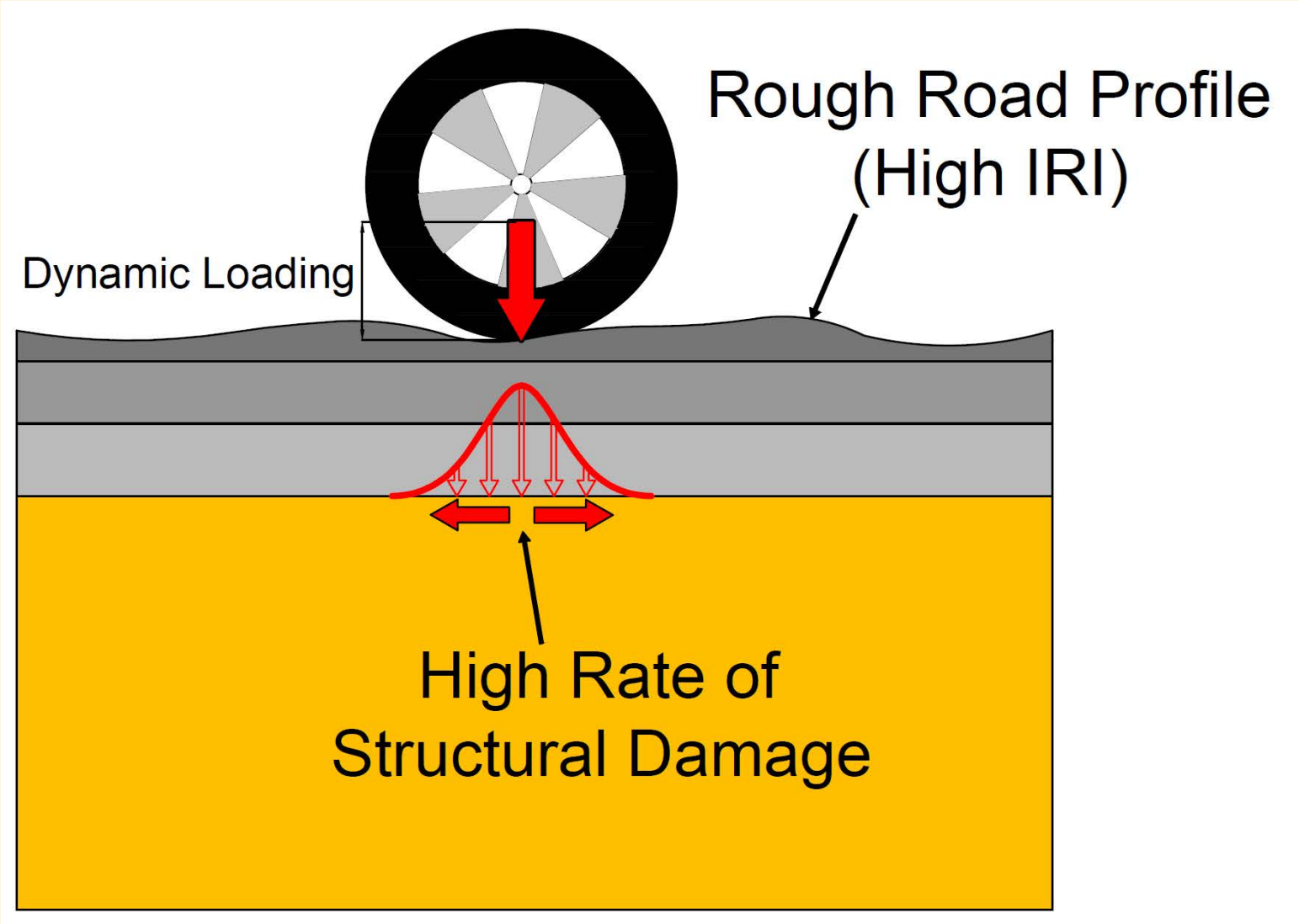
- In 2013 **EUROVIA** awarded a project to our research group by its subsidiary firm *OVISA Pavimentos y Obras S.A.*
- Objective:

**QUANTIFY THE REDUCTION IN THE STRUCTURAL SERVICE LIFE OF FLEXIBLE PAVEMENTS DUE TO THE RISE OF THE DYNAMIC AXLE LOADS AS THE PROGRESSIVE DETERIORATION OF THE ROAD PROFILE OCCURS.**

♡ The main results of that project are presented in :

- F. Navarrina et al., *A Comprehensive Model for the Fatigue Analysis of Flexible Pavements Considering the Effects of Dynamic Axle Loads* Transportation Research Record (TRR), Journal of the Transportation Research Board 2524: 110–118, 2015.

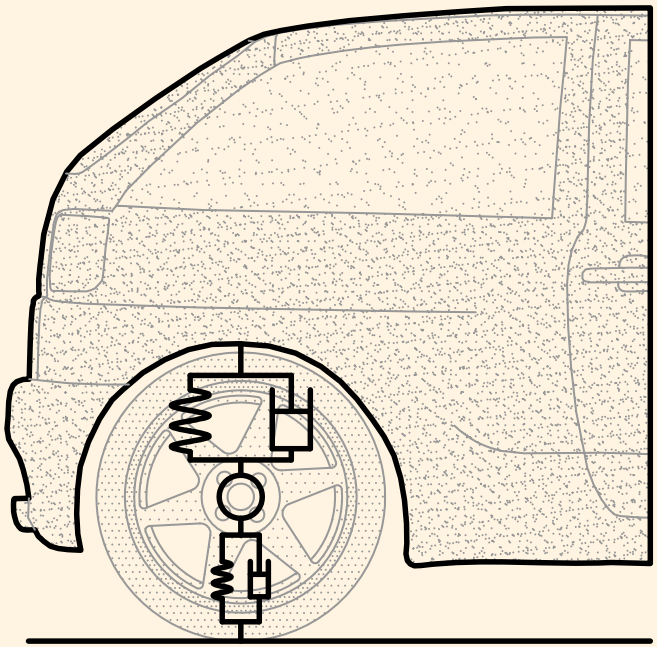
# Dynamic Axle Loads (II)

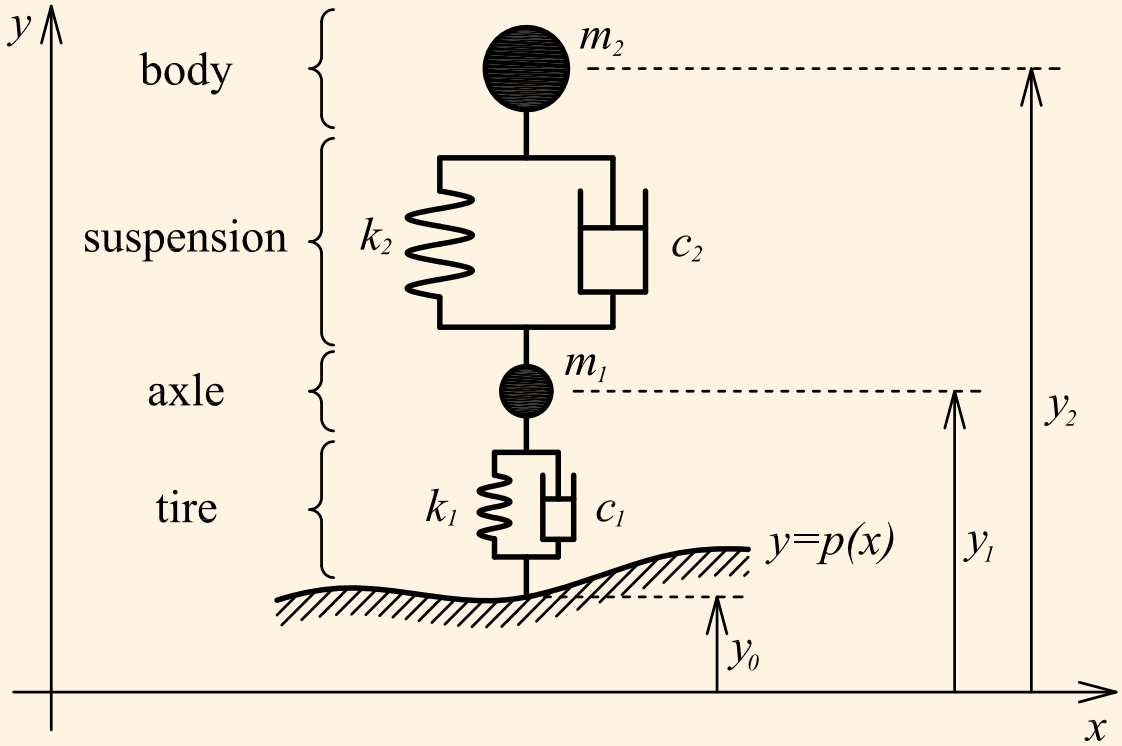



High rate of structural damage when road profile is rough (high–IRI conditions).

# Dynamic Axle Loads (III)

Quarter-Vehicle (QV) Model.






Quarter-Vehicle (QV) Model.

# Dynamic Axle Loads (IV)

By applying Newton's second law, we get the system of ordinary differential equations

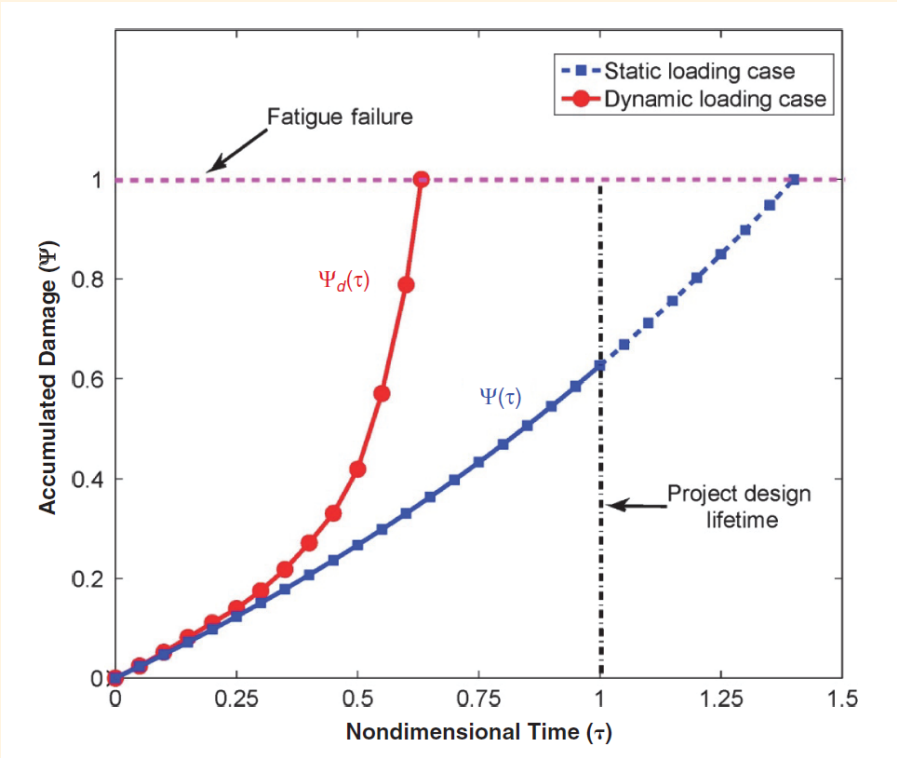
$$\boxed{\underset{\sim}{M}\,\ddot{\bar{u}}(t) + \underset{\sim}{C}\,\dot{\bar{u}}(t) + \underset{\sim}{K}\,\bar{u}(t) = \bar{b}\,\ddot{y}_0(t),}$$

$$\underset{\sim}{M} = \begin{bmatrix} (m_1+m_2) & m_2 \\ m_2 & m_2 \end{bmatrix}, \quad \underset{\sim}{C} = \begin{bmatrix} c_1 & 0 \\ 0 & c_2 \end{bmatrix}, \quad \underset{\sim}{K} = \begin{bmatrix} k_1 & 0 \\ 0 & k_2 \end{bmatrix}, \quad \bar{b} = -\begin{Bmatrix} (m_1+m_2) \\ m_2 \end{Bmatrix},$$

$$\bar{u}(t) = \begin{Bmatrix} u_1(t) \\ u_2(t) \end{Bmatrix}, \qquad u_1(t) = y_1(t) - y_0(t) - \delta_1, \qquad u_2(t) = y_2(t) - y_1(t) - \delta_2.$$

# Dynamic Axle Loads (V)

Dynamic axle loads $\longrightarrow \begin{cases} \Uparrow \text{Damage} \\ \Downarrow \text{Lifetime} \end{cases}$




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

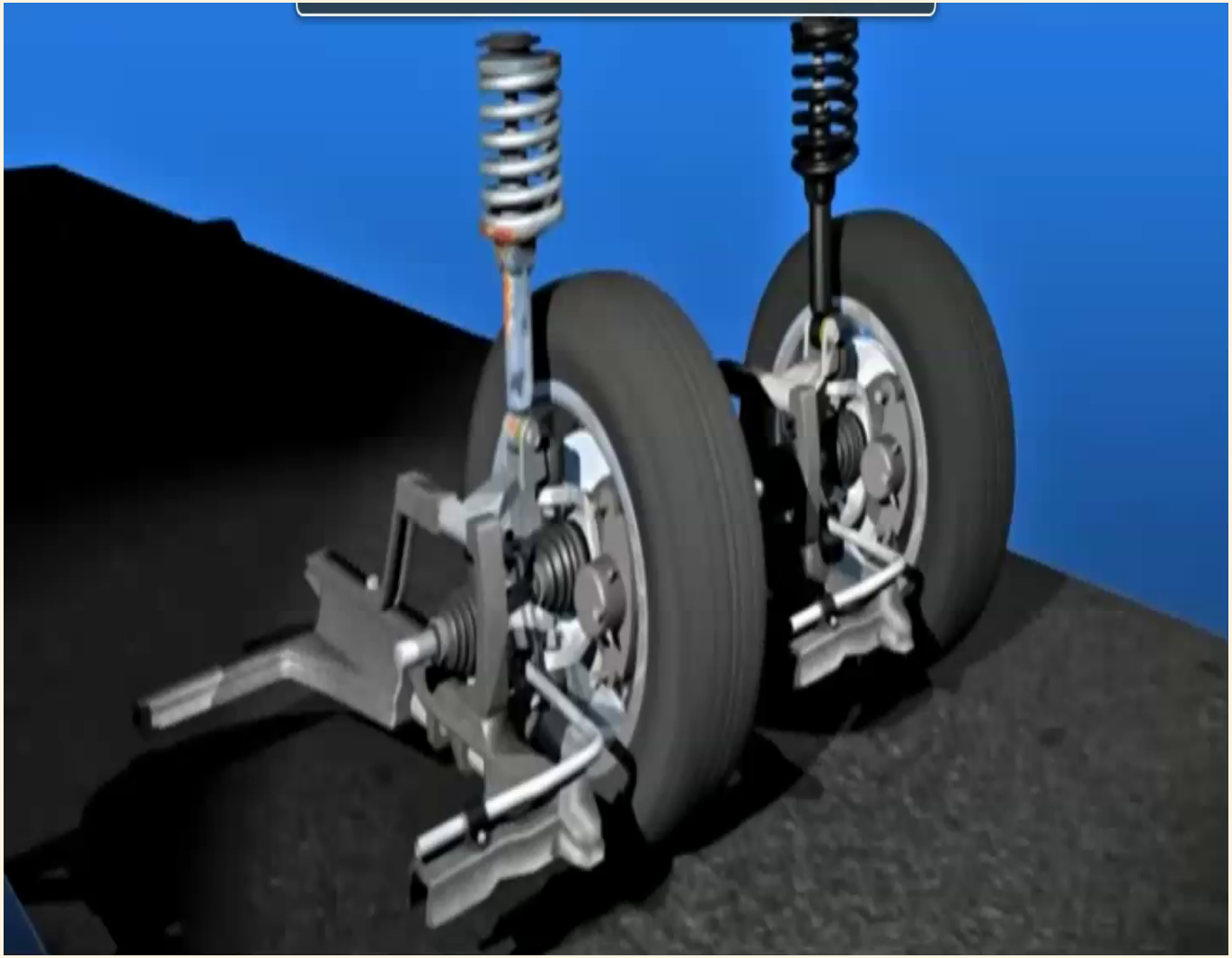
# Dynamic Axle Loads (VI)

Three of the key factors in the dynamic loading behaviour are:

- Pavement condition $\longrightarrow$ Roughness $\Rightarrow$ IRI(*)
- Suspension System
- Axle distribution of heavy vehicles

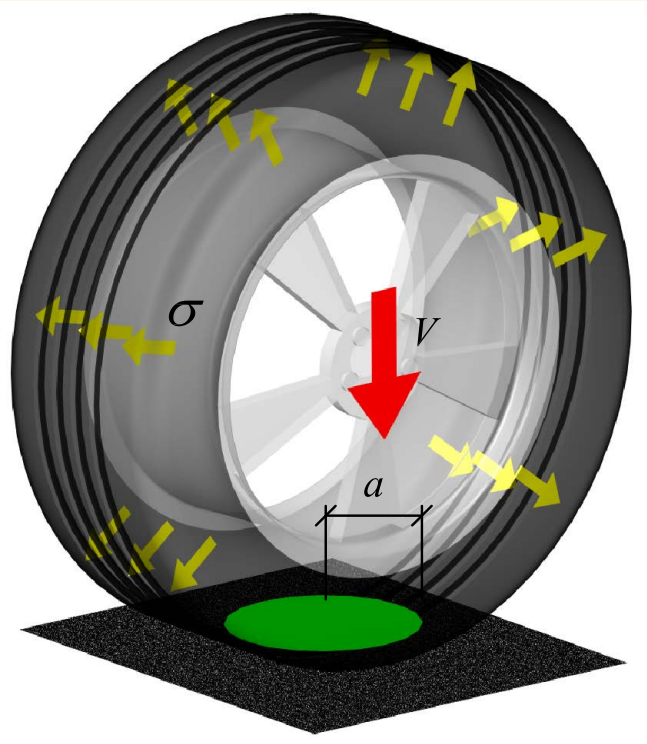
(*)International Roughness Index

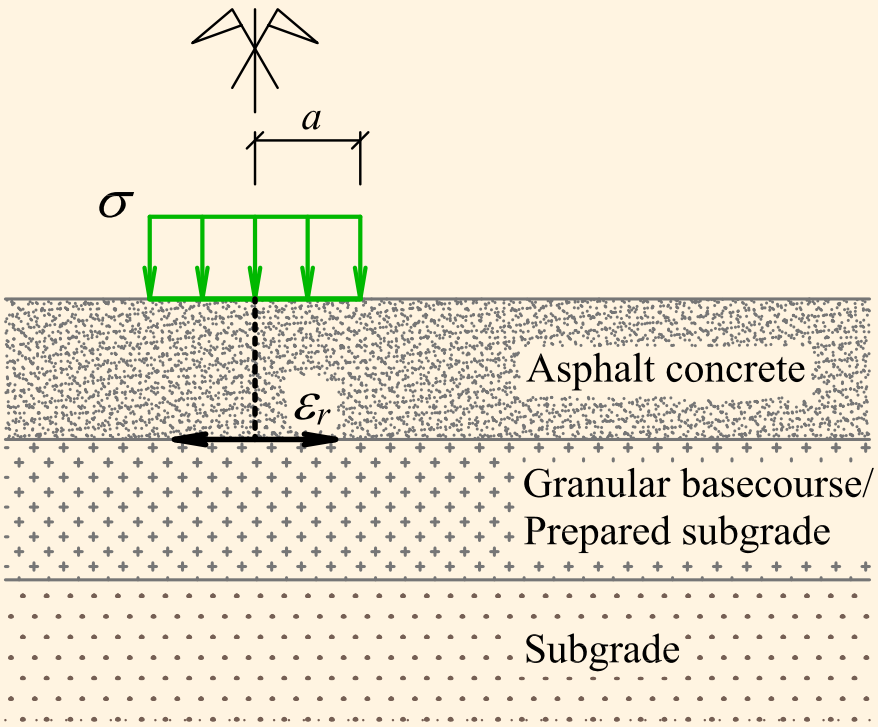
# Suspension System



Suspension behaviour.Old vs New.
Source **KYB**

# Axle distribution of heavy vehicles (I)




Transmission of load to the pavement and reference strain for the fatigue model.

# Axle distribution of heavy vehicles (II)

| CODE | DESCRIPTION | LOAD DISTRIBUTION |
|---|---|---|
| 12-2 | TRUCK SEMI TRAILER (5 AXLE) | 0.112W 0.222W 0.222W 0.222W 0.222W |
| 11-3 | TRUCK SEMI-TRAILER (5 AXLE) | 0.155W 0.197W 0.216W 0.216W 0.216W |
| 11-11 | TRUCK TRAILER ( 4 AXLE) | 0.169W 0.298W 0.254W 0.279W |
| 12-12 | TRUCK TRAILER (6 AXLE) | 0.109W 0.177W 0.188W 0.263W 0.131W 0.132W |
| 12-3 | TRUCK SEMI - TRAILER ( 6 AXLE) | 0.0755W 0.196W 0.196W 0.1875W 0.1875W 0.1575W |

| CODE | DESCRIPTION | LOAD DISTRIBUTION |
|---|---|---|
| 1-1 | TRUCK (2 AXLE) | 0.2W 0.80W |
| 1-2 | TRUCK w/ TANDEM AXLE (3 AXLE) | 0.2W 0.4W 0.4W |
| 1-3 | TRUCK W/ TRIDEM AXLE ( 4 AXLE) | 0.208W 0.264W 0.264W 0.264W |
| 11-1 | TRUCK SEMI TRAILER (3 AXLE) | 0.112W 0.444W 0.444W |
| 11-2 | TRUCK SEMI - TRAILER ( 4 AXLE) | 0.1688W 0.2981W 0.2793W 0.2538W |
| 12-1 | TRUCK SEMI TRAILER (4 AXLE) | 0.1688W 0.2538W 0.2793W 0.2981W |

Some axle load distribution factors.
Source **AASHTO**
[American Association of State Highway and Transport Officials (AASHTO)]

# 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

# Objectives

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# Objectives (I)

ANALYZE

UNDERSTAND

IMPROVE

# Objectives (II)

**INPUTS**

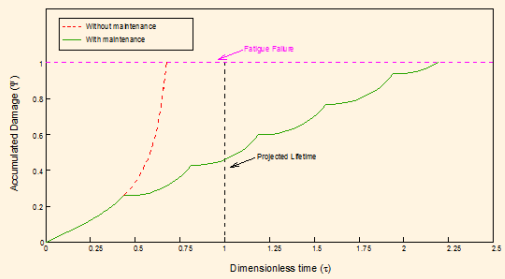
-Pavement Characteristics:
 -Materials
 -Number of layers
 -Pavement Condition Index (PCI)
 -Projected Service Lifetime
 -Current IRI

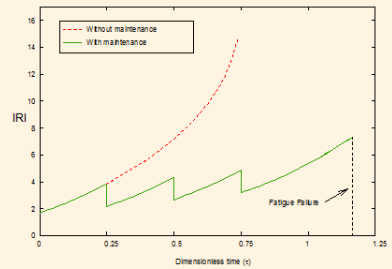
-Average daily traffic of heavy vehicles ($ADT_h$)

-Maintenance Strategy

**MATHEMATICAL MODEL**

**OUTPUTS**



# Preliminary results

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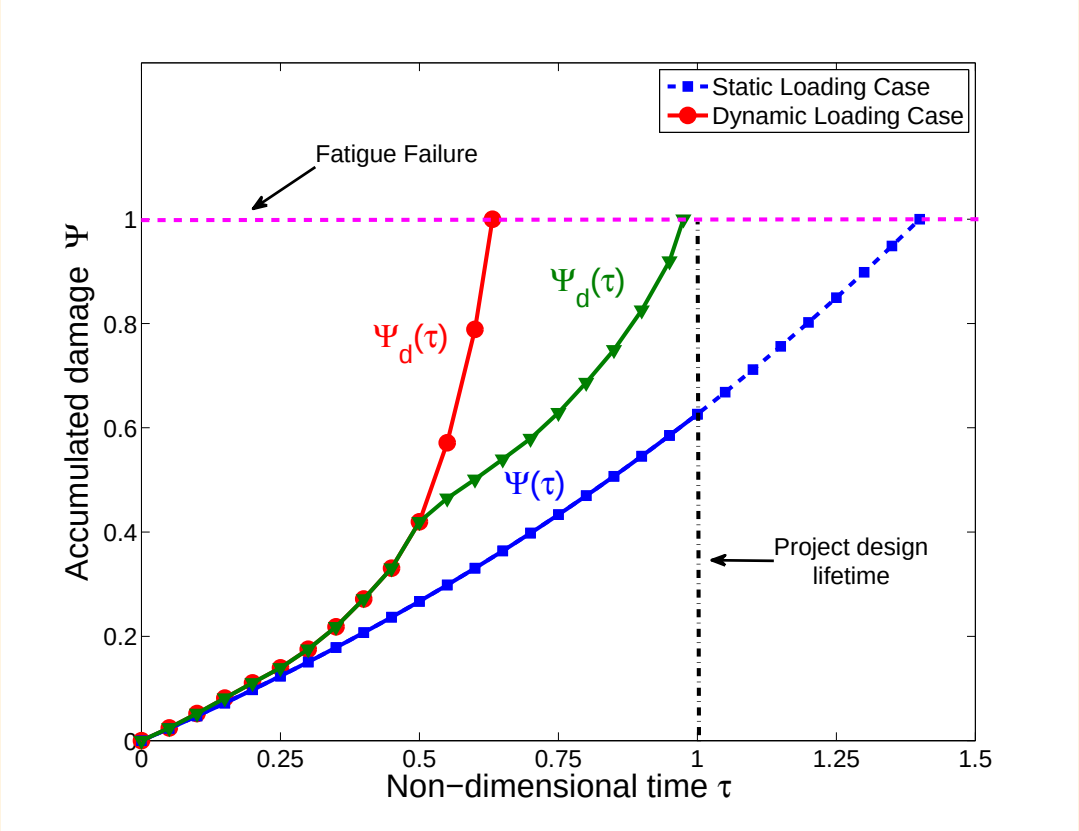
# Preliminary results (I)

- Application of Conservation strategies to a secondary road.
- Input:
  - Section T3121 of the Spanish Standard 6.1-IC (*)
  - $IRI_0 = 1.5mm/m$.
- Two strategies:
  - Strategy 1: Single superficial renew of the upper layer at $\Delta\tau = 1/2$.
  - Strategy 2: Two superficial renews of the upper layer each $\Delta\tau = 1/3$.

(*) C. Kraemer and R. Albelda., *Evaluación técnico-económica de las secciones de firme de la Norma 6.1-IC*, *VI Congreso Nacional de Firmes: Normalización e Innovación*, Asociación Española de la Carretera, Madrid, 2004.

# Preliminary results (II)

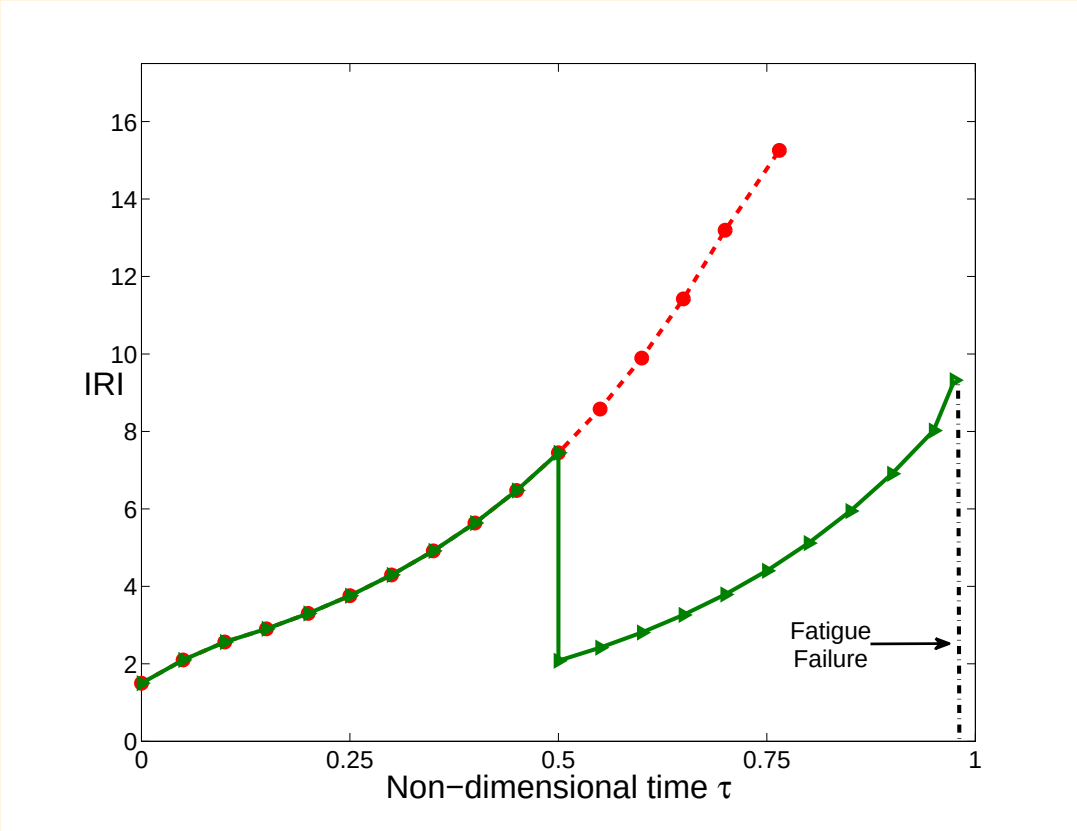
- Application of Conservation Strategy 1 to a secondary road.




Evolution of accumulated fatigue damage indicator $\Psi(\tau)$.

# Preliminary results (III)

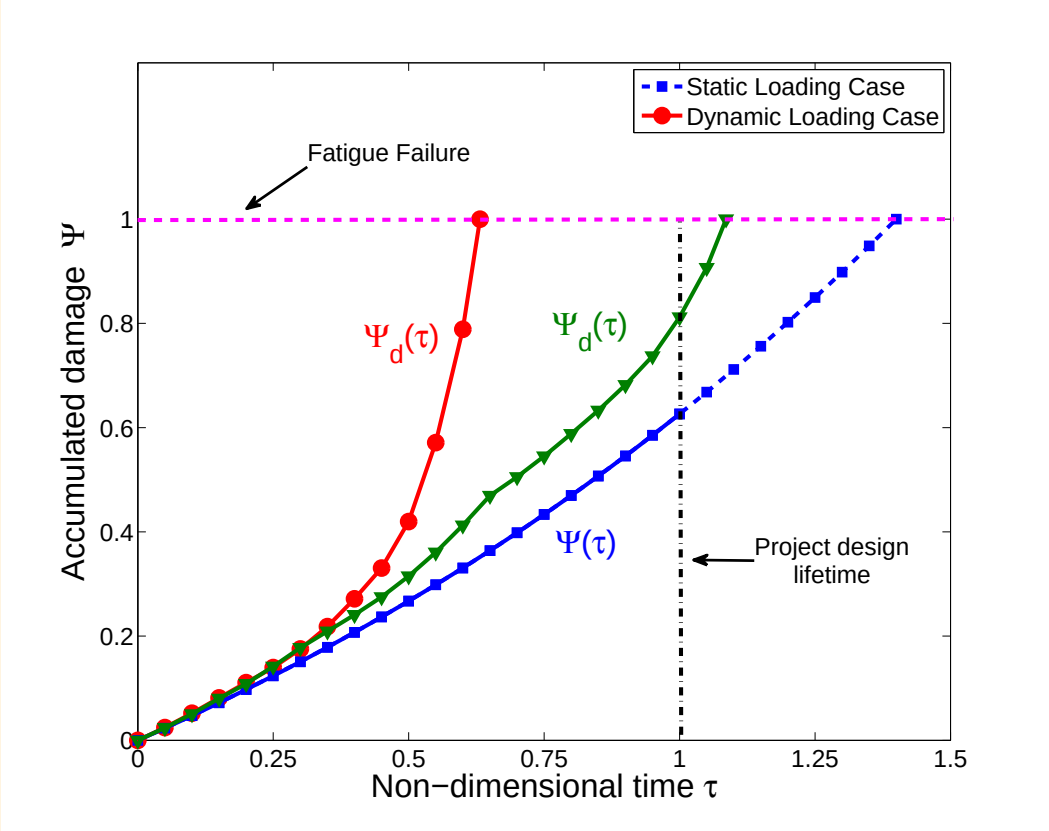
- Application of Conservation Strategy 1 to a secondary road.




Evolution of International Roughness Index $IRI$.

# Preliminary results (IV)

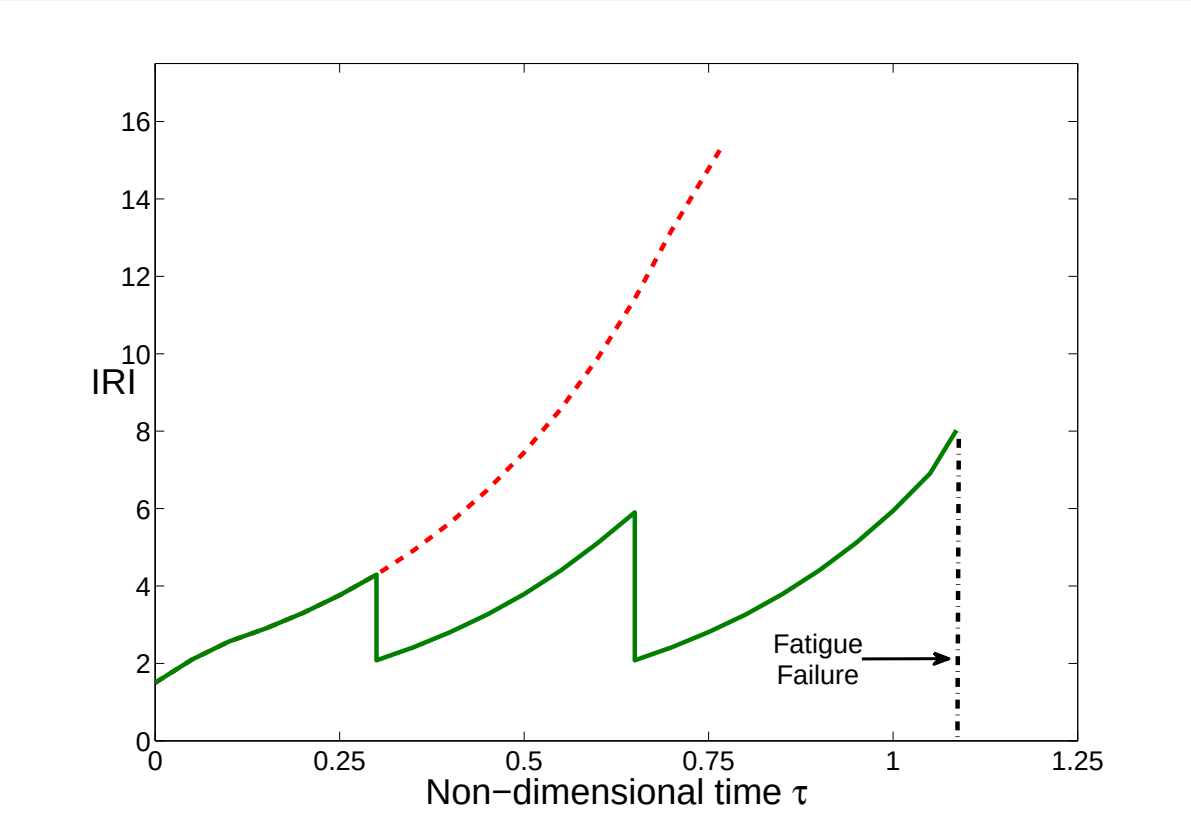
- Application of Conservation Strategy 2 to a secondary road.




Evolution of accumulated fatigue damage indicator $\Psi(\tau)$.

# Preliminary results (V)

- Application of Conservation Strategy 2 to a secondary road.




Evolution of International Roughness Index $IRI$.

# Expected Outcome

- Introduction
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# Expected Outcome (I)

- **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.

# IMPACT OF PREVENTIVE MAINTENANCE ON FLEXIBLE PAVEMENT SERVICE LIFE

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Thank you

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