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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TRANSPORT

– Standard of living
– Economic growth
– Development
– Communication
– Mobility
% 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)]
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
### Countries' Road Investments and Road Maintenance 2013

<table>
<thead>
<tr>
<th>Country</th>
<th>Road investments</th>
<th>Road maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>13,086,085,940</td>
<td>3,942,560,656</td>
</tr>
<tr>
<td>France</td>
<td>10,297,735,752</td>
<td>2,904,000,000</td>
</tr>
<tr>
<td>Germany</td>
<td>11,730,000,000</td>
<td>—</td>
</tr>
<tr>
<td>Italy</td>
<td>2,841,000,000</td>
<td>9,134,000,000</td>
</tr>
<tr>
<td>Japan</td>
<td>33,129,221,998</td>
<td>16,256,879,830</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>6,030,381,536</td>
<td>3,145,313,236</td>
</tr>
<tr>
<td>United States</td>
<td>62,415,298,901</td>
<td>36,146,664,659</td>
</tr>
</tbody>
</table>

Euros spent in road investments and road maintenance by G7 countries in 2013  
**Source** [OECD Transport Statistics](http://www.oecd.org)  
[Organization for Economic Co-operation and Development (OECD)]
Introduction (VI)

Trends in freight traffic and GDP (EU)

Source ODYSEE-MURE
Passenger traffic and GDP at EU level

Source: ODYSEE-MURE
**ECONOMIC CRISIS**

- **Investment in road infrastructures(***):**
  
  \[85.8 \text{ billion EUR} \rightarrow 63.3 \text{ billion EUR}\]
  
  
  Reduction \approx 26% 

- **Investment in road infrastructure maintenance(***):**
  
  \[30.2 \text{ billion EUR} \rightarrow 23.4 \text{ billion EUR}\]
  
  
  Reduction \approx 23%

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

“Double the skid resistance and halve the accidents”
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)

Good

Bad

TIME

Good

Bad
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  ⇒  MINER’s RULE
Deterioration (VI)

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

Source Previous GMNI work
<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>304,349,924</td>
<td>308,332,988</td>
<td>317,497,306</td>
<td>323,584,629</td>
</tr>
<tr>
<td>Light commercial vehicles</td>
<td>38,901,972</td>
<td>39,296,021</td>
<td>39,817,663</td>
<td>40,727,091</td>
</tr>
<tr>
<td>Medium and heavy commercial vehicles</td>
<td>13,158,496</td>
<td>13,063,573</td>
<td>13,091,936</td>
<td>13,048,717</td>
</tr>
<tr>
<td>Buses</td>
<td>970,182</td>
<td>954,871</td>
<td>943,192</td>
<td>957,597</td>
</tr>
</tbody>
</table>

Vehicles in use in Europe.
Source European Automobile Manufacturers Association
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
Deterioration Effects (II)

Safety (Direct)

- Microtexture

↑ Microtexture  ⇒  ↑ Safety

Relationship between Wet-Accident and Surface Texture Depth

Source Gothie 1991
Deterioration Effects (III)

Safety (Direct)

- Macrotexture

↑ Macrotexture ⇒ ↓ Less Friction surface ⇒ ↓ Safety
Deterioration Effects (IV)

Safety (Direct)

▶ Megatexture

↑ Megatexture  ⇒  ↓↓ Safety
Deterioration Effects (V)

Damage (Direct)

- Megatexture

↑ Roughness (IRI)  ⇒  ↑ Structural Damage
Deterioration Effects (VI)

Fuel Consumption (Indirect)

- Roughness (Megatexture)
- Macrotexture
- Structural Responsiveness

$CO_2$
### Fuel Consumption (Indirect)

<table>
<thead>
<tr>
<th>Transport type</th>
<th>Mt$CO_2$</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>852</td>
<td>95,2</td>
</tr>
<tr>
<td>Domestic air</td>
<td>16,2</td>
<td>1,8</td>
</tr>
<tr>
<td>Rail</td>
<td>14,9</td>
<td>1,7</td>
</tr>
<tr>
<td>Inland waterways</td>
<td>6,12</td>
<td>0,7</td>
</tr>
<tr>
<td>Other transportation</td>
<td>5,79</td>
<td>0,6</td>
</tr>
</tbody>
</table>

Emissions from transport in 2015 (EU)

Source [European Environment Agency](http://www.eea.europa.eu)
Deterioration Effects (VIII)

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

**OUTPUTS**

**MATHEMATICAL MODEL**
Impact of Preventive Maintenance on Flexible Pavement Service Life

Report No.1
State of Knowledge

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A Coruña, February the 28th, 2017
Impact of Preventive Maintenance on Flexible Pavement Service Life

Report No.2
Mathematical Model and Sample Results

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Universidad de A Coruña — Fundación de la Ingeniería Civil de Galicia

A Coruña, October the 15th, 2017
Impact of Preventive Maintenance on Flexible Pavement Service Life

Dynamic & Maintenance Simulation App: User's guide

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Universidad de A Coruña — Fundación de la Ingeniería Civil de Galicia

A Coruña, December the 23rd, 2017
Project Results (IV)

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

DYNAMIC & MAINTENANCE SIMULATION APP

DMSA

RUN

European Investment Bank • Institute

Fundación Ingeniería Civil de Galicia

About  Save  Load
DMSA (II)

Sample result obtained with DMSA
Sample maintenance strategy simulated with DMSA
Project Results (IV)

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.