Toolbox, selection of maintenance candidates based on new triggers

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Abstract

Maintenance of paved roads is carried out to preserve and improve the pavement and reduce the deterioration process. An adapted treatment will make the pavement last for a certain time interval before next treatment is necessary. Pavement managers deal with complex decisions when identifying lengths of their networks in need of maintenance and selection of the appropriate maintenance treatments. Decades of road network monitoring and follow up projects have generated a huge volume of empirical data on pavement condition. To complement this information, several decades of research and development has accumulated a substantial volume of knowledge, models and tools that can use the information to assist in maintenance decisions. Even so, these support tools are not yet implemented to their full potential, and most tools do not address user expectations and new environmental impacts such as fuel consumption and emissions. This paper will demonstrate a tool to assist road authorities in optimising the maintenance of their road networks.

Keywords: Maintenance; triggers; road users; environmental impact;

Résumé

L'entretien des routes a pour but de préserver les caractéristiques de la chaussée et de réduire le processus de dégradation. Un entretien adapté lui permettra de durer un certain intervalle de temps avant que l'entretien suivant ne soit nécessaire. Les gestionnaires doivent faire face à des décisions complexes lors de l'identification des longueurs de leurs réseaux ayant besoin d'entretien et lors du choix de la technique d'entretien appropriée. Des décennies de surveillance du réseau routier et le suivi de projets ont généré un volume énorme de données empiriques concernant l'état des chaussées. Pour compléter cette information, plusieurs décennies de recherche et de développement ont permis d'accumuler une quantité importante de connaissances, de modèles et d'outils que peuvent utiliser les informations recueillies afin d'aider aux choix en matière d'entretien routier. Malgré cela, ces outils d'aide à la décision ne sont pas encore pleinement mis en œuvre, et la plupart d’entre eux ne répondent pas aux attentes des utilisateurs et aux nouveaux enjeux environnementaux concernant la consommation de carburant et les émissions. Cet article propose un outil permettant d’aider les administrations routières à optimiser l’entretien de leurs réseaux routiers.

Mots-clé: Entretien ; critères ; usagers de la route ; impact sur l'environnement ;

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1. Introduction

Maintenance of paved roads is carried out to preserve and improve the pavement and reduce the deterioration process. A treatment will make the pavement last for a certain time interval before next treatment is necessary. The time for which a treatment lasts can be related to many factors such as condition before treatment, selected treatment method, maintenance strategies (and changes in the strategy), technical quality, changes in traffic flow and budget levels.

Pavement managers deal with complex decisions when identifying lengths of their networks in need of maintenance and selection of the appropriate maintenance treatments. Currently, they are heavily dependent on experience, even though many support systems exist. Decades of road network monitoring and follow up projects have generated a huge volume of empirical data on pavement condition. To complement this information, several decades of research and development has accumulated a substantial volume of knowledge, models and tools that can use the information to assist in maintenance decisions, with an aim to assist in applying a strategy that delivers a sound road network with minimum cost. Even so, these support tools are not yet implemented to their full potential, and most tools do not address user expectations and new environmental impacts such as fuel consumption and emissions.

This paper will demonstrate a work that aims to advance the development and implementation of practical strategies and tools to assist road authorities in optimising the maintenance of their road networks, whilst addressing the key interests and expectations of road users.

2. The project Toolbox

The aim of the Toolbox project has been to advance the development and implementation of practical strategies and tools to assist road authorities in optimising the maintenance of their road networks, whilst still addressing the key interests and expectations of road users.

Within Toolbox a “concept for proper maintenance planning” to ensure the selection of adequate maintenance works (“schemes” or “projects”) to make effective use of the maintenance budget, based on available road condition data, and giving minimal negative effects on road users and safety for road workers has been developed.

The Toolbox concept is applicable in the selection of lengths for maintenance (candidates), linked to comfort, safety, durability and the environment, including how the data is used, combined and weighted within current decision tools and models. Toolbox has not developed new models, for the technical parameters that are not currently measured (e.g. fuel consumption) but identified and extracted key tools from existing models used in Europe. The work has considered and developed an understanding of how existing knowledge (data) should be used to account for road user expectations in the selection of object lengths for maintenance. These existing and new concepts have been used to establish a set of functional triggers for selecting lengths (candidates) for maintenance on the network that include road user expectations and combine them to make recommended prioritised treatment objects.

Toolbox demonstrates the application of the concepts developed within the project via a prototype tool applied to a sample test network, to compare and contrast the approach proposed by the Toolbox tool with the approach proposed by current systems.

2.1. Project organisation

Toolbox has delivered its objectives via five work packages. The core activities are summarised in the following paragraph to show how they link together within the project. Although the work packages are led by a leader from one of the partners, the work has been done in a cooperative manner with close contact between partners. The first Work Package (WP) has reviewed and specified the current situation regarding the frameworks, tools and models used in current Pavement Management Systems (PMS). The second WP adapted selected models to fit the Toolbox principle. This meant specifying the necessary data and finding a common base for (at least) all partner countries. Since the focus is to develop a working framework, the third WP commenced with the integration of weighting factors and functional triggers, and the selection of prioritisation models. Considerations of maintenance strategies and treatment methods take place in this WP and a life cycle perspective is included in the final results.
The main goal of Toolbox has been to make a working framework (in Excel) that can select maintenance candidates by using higher level indicators (functional triggers) as input, such as safety, durability, comfort etc. instead of only using technical parameters such as rut depth and IRI, as is the common approach currently. An overview of this process is shown in Figure 1.

Fig 1
Overview of process to enable selection of maintenance candidates (*the weight given to each functional trigger are determined by individual road owners’ policies)

3. Functional triggers

In an objective system, the choice of maintenance candidates must rely on the availability of quantitative condition information, which is typically provided in the form of condition data expressed as technical parameters. Within WP2 of the Toolbox project, the aim was to establish a set of functional triggers for selecting lengths for maintenance on the network and there was therefore a need to convert technical parameters into a single value for each of the triggers considered for Toolbox: Safety, Durability, Environment and Comfort. The Toolbox project has only used existing data, and did not aim to develop new data. It has also been assumed that the condition data provided is of good quality (even if it is known that it is not).

The minimum section length to be used is 100m and all triggers (whether based on existing models or developed in WP2) will have values of between 0 and 100 inclusive, where 0 means that the road is in good condition and 100 means that maintenance is needed. In the future, new models could be added or the selected models could be improved.

3.1. Comfort trigger

No model, that utilized all parameters influencing comfort, was identified during the review and therefore a model was suggested (Benbow & Sjögren, 2013). This takes the form:

\[ a_1 * G_C(\text{IRI}_{\text{NS}}) + a_2 * G_C(\text{IRI}_{\text{OS}}) + a_3 * G_C(\text{LR}_{\text{NS}}) + a_4 * G_C(\text{LR}_{\text{OS}}) + a_5 * G_C(\text{Rut}_{\text{NS}}) + a_6 * G_C(\text{Rut}_{\text{OS}}) + a_7 * G_C(\text{Edge}) \]

This trigger will have a value between 0 and 100 (inclusive), and IRI_{NS} is the IRI measured in the nearside wheelpath (closest to the edge of the road), IRI_{OS} is the IRI measured in the offside wheelpath (closest to the middle of the road); LR_{NS} and LR_{OS} are the Localised Roughness parameters calculated in the nearside and offside wheelpaths, respectively; Rut_{NS} and Rut_{OS} are the rut depths calculated in the nearside and offside wheelpaths, respectively and Edge is the edge roughness parameter. The $G_C$ are indices based on each parameter, whilst $a_1, \ldots, a_7$ are the weights given to the indices.
\[ G_c(\text{IRI}) = \begin{cases} 0 & \text{if IRI} \leq \text{TL}\text{IRI} \text{mm/m} \\ f_{\text{IRI}}(\text{IRI}) & \text{if TL}\text{IRI} \text{mm/m} < \text{IRI} < \text{TU}\text{IRI} \text{mm/m} \\ 100 & \text{if IRI} \geq \text{TU}\text{IRI} \text{mm/m} \end{cases} \]

\[ G_c(\text{LR}) = \begin{cases} 0 & \text{if there is no localised roughness in the 100m length} \\ f_{\text{LR}}(\text{localised roughness}) & \text{if there is moderate localised roughness} \\ 100 & \text{if there is a lot of localised roughness present} \end{cases} \]

\[ G_c(\text{Rut}) = \begin{cases} 0 & \text{if Rut depth} \leq \text{TL}\text{Rut} \text{mm} \\ f_{\text{Rut}}(\text{Rut depth}) & \text{if TL}\text{Rut} \text{mm} < \text{Rut depth} < \text{TU}\text{Rut} \text{mm} \\ 100 & \text{if Rut depth} \geq \text{TU}\text{Rut} \text{mm} \end{cases} \]

\[ G_c(\text{Edge}) = \begin{cases} 0 & \text{if the edge of the road is smooth} \\ f_{\text{Edge}}(\text{edge roughness}) & \text{if the edge is moderately rough} \\ 100 & \text{if the edge is very rough} \end{cases} \]

The weighting factors to be used for the comfort trigger for the demonstration network are as follows:

\[ \text{Comfort trigger} = 0.2*G_c(\text{IRI}_{\text{NS}}) + 0.2*G_c(\text{IRI}_{\text{OS}}) + 0.1*G_c(\text{LR}_{\text{NS}}) + 0.1*G_c(\text{LR}_{\text{OS}}) + 0.1*G_c(\text{Rut}_{\text{NS}}) + 0.1*G_c(\text{Rut}_{\text{OS}}) + 0.1*G_c(\text{Edge}) \]

Most weight is given to general ride quality, with all other parameters contributing equally to the trigger. Table 1 shows the thresholds and functions that may be used for the indices, GC that will be applied to the data in the Demonstration.

### Table 1: Example thresholds and functions that may be used in Demonstration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TL</th>
<th>TU</th>
<th>( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRI</td>
<td>3 mm/m</td>
<td>4.5 mm/m</td>
<td>( f_{\text{IRI}}(\text{IRI}) = 100*(\text{IRI}-3)/1.5 )</td>
</tr>
<tr>
<td>Localised Roughness</td>
<td>0</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>Rutting</td>
<td>10 mm</td>
<td>20 mm</td>
<td>( f_{\text{Rut}}(\text{Rut depth}) = 10*(\text{Rut depth} -10) )</td>
</tr>
<tr>
<td>Edge roughness</td>
<td>SWE</td>
<td>20 mm</td>
<td>40 mm</td>
</tr>
<tr>
<td></td>
<td>UK</td>
<td>0.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

\[ b_1*I_{SI} + b_2*I_{Def} + b_3*I_{RQ} + b_4*I_{surf} \] (2)

Where
- \( I_{SI} \) is an index for structural strength
- \( I_{Def} \) is an index for pavement deformation
- \( I_{RQ} \) is an index for ride quality
- \( I_{surf} \) is an index for the visual condition of the surface
- \( b_1, \ldots, b_4 \) are the weights given to each index.
3.3. Safety trigger

The Toolbox safety trigger is based on ALERTINFRA (Cerezo V. and al., 2011), which is a software tool that automatically detects dangerous areas of infrastructure. The tool was developed by the Technical Centre of French Ministry of transports (CETE) and IFSTTAR (ex. LCPC) and provides up to 15 warnings on curves and 4 warnings on straight roads (19 warnings among which one warning in crossroads and four warnings in straight lines). The warnings are based on geometrical characteristics (radius of curvature, slope, crossfall) and surface characteristics (skid resistance, MPD, unevenness on short wavelengths).

Safety trigger = \( \Sigma (W \cdot I_{\text{warning}}) \cdot \Sigma W \)  

With \( W \): weight of the various warnings defined by statistical analyses (i.e. coefficients ranging between 0 and 1 – the weights are assumed not to be equal one to each other and their values depend on the importance of the warnings)

\( \Sigma W = 4.34 \) (sum of the weights of all the warnings)

\( I_{\text{warning}} \): index taking the value 0, 1 or 2 (0: warning not detected on the area; 1: warning detected on the area, 2: warning detected and connected to another warning).

Thus, the global safety index is a linear combination of the various risk observed on the infrastructure. Its final value ranges from 0 to 100, this last value representing the highest risk met on the road.

3.4. Environmental trigger

The external noise, particulates and fuel consumption are included in the environment trigger:

Environment trigger = \( a_1 \cdot I_{\text{Noise}} + a_2 \cdot I_{\text{Fuel}} + a_3 \cdot I_{\text{Part}} \)

Where \( I_{\text{Noise}} \) is an index for external noise
\( I_{\text{Fuel}} \) is an index for fuel consumption
\( I_{\text{Part}} \) is an index for particulates and other emissions.

An NRA has no (or very little) control over the number and types of vehicles travelling on its road network, and therefore would be limited to making changes to the road alignment and rolling resistance. Road alignment (i.e. gradient, crossfall, curvature) is generally set when the road is constructed and is very costly to change. Thus, of the contributions to fuel consumption, the aspect over which an NRA has most control, and the greatest chance of changing, is the rolling resistance of the pavement. Thus, we will use a model for rolling resistance as a proxy for fuel consumption within Toolbox.

The following model is a simplified model based on the developments in a MIRIAM related project (Hammarström et al., 2012) and will be used for estimating the fuel consumption that can be considered generated by the road surface:

\[ FC = 2.75 + 0.0682 \times IRI + 0.198 \times MPD \]

Where IRI is the maximum IRI value and MPD the maximum mean profile depth measured in either wheelpath. This function represents the amount of fuel consumed by a truck and trailer, travelling at a constant speed of 22.2 m/s (80 km/h) on a flat and straight road, with no prevailing wind. Thus, it will be a much larger value than that expected for an average vehicle travelling on the road and cannot be used to estimate the consumption of a normal vehicle fleet (i.e. a combination of HGV, cars etc.).

3.5. Combined condition index

The Comfort, Durability, Safety and Environment triggers will be combined, to produce the Combined Condition Indicator (OCI) as follows:

\[ CCI = w_C \times \text{Comfort Trigger} + w_D \times \text{Durability Trigger} + w_S \times \text{Safety Trigger} + w_E \times \text{Environment Trigger} \]

Where \( w_C + w_D + w_S + w_E = 1 \) and are values chosen by the Toolbox user, depending on individual road owners’ policies.
A spreadsheet tool has been developed in Excel that combines technical parameters into functional triggers and then combines these in turn, with user-defined weightings, to form a Combined Condition Index. This Combined Condition Index is then used by the spreadsheet to identify potential maintenance candidates.

4. The Toolbox spreadsheet tool

The maintenance candidate selection tool consists of 5 sheets within an Excel workbook (see Figure 2) and utilises Excel macros (the user will need to enable these when opening the workbook). The majority of the tool is implemented in the data sheet. This sheet contains a table where input data can be inserted, from which the functional triggers, Combined Condition Index and treatment options are automatically calculated. The results of these calculations are dependent on the parameters that can be found (and, if necessary, altered by the user) on the ‘Trigger Weighting Parameters’, ‘Trigger Thresholds’ and ‘Treatment Thresholds’ sheets.

![Figure 2](image1)

In the tab Data the input data, measured condition parameters are entered. As described above those are the input parameters used to calculate the Safety, Comfort, Durability and Environmental that can be seen in column AJ to CC in figure 3.

![Figure 3](image2)
4.1. How the tool select maintenance candidates.

Once the Combined Condition Index has been calculated the lengths can then be grouped into maintenance candidates (schemes). The aim of this process is to group contiguous lengths of similar condition (in terms of their need of maintenance work), which in Toolbox is defined by the Combined Condition Index.

In order to estimate costs for a maintenance candidate, one needs to know what treatment might be suitable for that candidate and also how such treatment may be best carried out. Choosing a treatment for a specific maintenance candidate, or scheme, requires knowledge of, not only the condition of the road, but also the road’s age, construction, its use, the traffic volume and composition and also details of any historical maintenance. In Toolbox the choice of treatment has been carried out using a simplified method (based on SWEEP.S, software used by the UK Highways Agency (SWEEP, 2008)) and we have assumed that all pavements have flexible construction. This could be improved on, or changed, in future versions of the tool.

The tool divides the whole route, provided by the user, into potential maintenance candidates (or schemes), ready for the user to select which candidates to carry out cost-benefit analysis on. To aid this selection process, the tool summarises the schemes created, including the number of lengths included in the scheme and the number of lengths with a minimum suggested treatment of each of the treatment options. The summary also orders the schemes by the number of lengths with each of the minimum suggested treatment from most severe (redesign) to the least severe (thin surface).

5. LCCA and its application to Toolbox

Often the term cost-benefit analysis (CBA or BCA) is used synonymously for the methodology to evaluate different alternative WLC (Whole Life Cost). While WLC considers both costs and benefits, the life cycle cost (LCC) can be considered to be a subset of WLC for which only the asset’s costs are included. CBA is normally used in planning stages which emphasise societal benefits and costs, as opposed to WLC and LCC which focus on decisions in the later stages with more emphasis on road manager costs. The components of WLC suggested to be included to describe consequences of maintenance schemes in Toolbox are:

- Road owner costs
  - Investment cost
  - Maintenance costs
  - Road user costs

- Delay costs
  - Reroute time
  - Queue time and reduced speed

- Vehicle operation costs
  - External costs
  - Emissions

- Road workers
  - Safety.

The objective of Toolbox is to be able to support prioritization between different maintenance schemes. This means that some schemes will be selected for treatment during the coming season and others will be programmed in the years to come or not considered for treatment. The outcome of the Toolbox scheme selection phase is a number of road sections grouped into schemes with similar road properties and ordered by for example a number quantifying the urgency for maintenance. For each section a treatment is automatically suggested. The purpose of the LCCA phase is then to optimise maintenance schemes trying to meet different objectives such as budget, LCC, safety, environment and comfort. This is done by adjusting suggested maintenance treatments and checking the resulting output in LCC and WLC terms. Thus the overall concept is to identify how the capability of current approaches could be expanded by developing a framework to create maintenance candidates that will both optimise benefits to road users and the environment and deliver adequate road owner life cycle costs.

Acknowledgements

Toolbox would like to acknowledge The ERANET Road program that have made this project possible. All partners in the project should also be mentioned and acknowledged for their valuable contribution to the work; TRL United Kingdom, VTI and WSP Sweden, CETE of Lyon and IFSTTAR France and AIT, Austria.
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