Identification of potential highways maintenance schemes using MCA

Abstract

This paper presents a methodology for identifying potential pavement maintenance schemes based upon machine survey data. Highways authorities make maintenance decisions based on a number of factors; condition data is a common starting point. However there are currently no universally accepted techniques for ranking sub-sections by condition, based on the comparison of data from multiple condition assessment surveys. The methodology presented in this paper utilises condition data that has been captured from standard machine-based condition assessment surveys – specifically the TRACs survey, Deflectograph and the SCRIM survey. The resultant data is analysed using a Multi-Criteria Analysis (MCA) technique known as TOPSIS (the Technique for Order Preference by Similarity to the Ideal Solution). This technique is capable of investigating a number of alternative solutions. The data set is prioritised in terms of relative condition. The road sub-sections exhibiting the worst condition can then be highlighted, and potential schemes can be identified.

1. Introduction

Highway authorities develop short and long term road maintenance programmes based on various sets of pavement condition and performance data. Authorities must periodically highlight any condition hotspots and potential future maintenance schemes. This paper presents a methodology for assessing available condition data collected by machine surveys, to identify hotspots on a road network.

2. Condition assessment surveys and HAPMS

The measurement of road condition can involve either simple techniques, such as a visual survey of the road surface (Bandara, 2001), or more complex techniques, such as the analysis of laboratory samples. The condition of a road structure changes continuously over time, and therefore its condition data needs to be reviewed on a regular basis.

It is widely accepted that high-speed vehicle mounted apparatus provides the safest method of collecting condition data, when compared to inspectors performing walked-surveys in close proximity to live traffic. The Highways Agency actively promotes the development of machine-based survey systems for this very reason. Machine-based surveys also offer a quick and economical means of assessing the condition of a road network. These apparatus are capable of measuring a number of different pavement condition attributes.

There are a number of different defects that affect the condition of the road (Robinson, 1998). These include longitudinal-profile, transverse-profile, bearing capacity, surface friction, cracking, etc. Different condition survey machines capture different condition attributes and a consideration must be made as to which attributes are suitable to the identification of potential maintenance schemes.
In the UK, inventory data and condition data for the trunk road network is stored on a central database known as HAPMS (the Highways Agency Pavement Management System). HAPMS stores condition data collected by three machine-based condition surveys namely, Deflectograph, TRACS and SCRIM.

The Deflectograph survey measures the deflection values of a road pavement when subjected to a standard load by loading dual wheels on the rear axle of a suitable vehicle (HA, 2001). The Traffic-Speed Road Assessment Condition Survey (TRACS) records data that includes cracking and rutting (HA, 2005). Finally the Sideways Force Coefficient Routine Investigation Machine (SCRIM) measures low-speed skid resistance and assesses the condition of the microtexture of the surfacing (HA, 2004). The condition surveys mentioned here record a large number of attributes for each location along the survey route.

3. Pre-analysis

Appropriate condition parameters

The three condition assessment techniques described previously result in over 200 different attributes. After reviewing various HAPMS documents and following consultation with experienced pavement engineers, the following parameters were judged to be the most relevant, robust indicators of pavement condition:

**Deflectograph**
- Deflection 85th percentile
- Residual Life 15th percentile
- Required Overlay 85th percentile

**TRACS**
- Maximum Rut Category
- Texture Category
- Ride Quality (in terms of LPV 3m Category, LPV 10m Category and LPV 30m Category)

**SCRIM**
- SCRIM deficiency

These parameters were therefore used in the methodology outlined in this paper.

Sectioning

The three survey techniques employ two different sectioning techniques. The Deflectograph and TRACS surveys consider sections in 100m lengths whereas the SCRIM survey is based on varying lengths due to the assignment of risk values that relate to the road location and geometry.

It is therefore not possible to directly compare all SCRIM survey data with TRACS data. It was decided to consider the road data as homogenous sub-sections. This would divide the analysis into two parts and result in two outputs:

- A list of 100m road sub-sections prioritised in terms of condition with respect to Deflectograph and TRACS, and
- A list of road sub-sections of varying lengths prioritised in terms of condition with respect to SCRIM deficiency.
Inconsistent data

Due to the different scheduling intervals employed for the various surveys, network coverage is not complete. Although all sections should have TRACS and SCRAM data for Lane 1 and 2, the coverage is not total. An approach was developed to aid the analysis of non-existent data for those cases where surveys had not been conducted. This approach involved the rationalisation of the missing data.

The approach assumes that where data is missing, the missing survey data would have yielded average results. In other words, the average results for each criterion are calculated across the entire network and assigned to sections with missing survey data.

By rationalising the condition data, the data is in a form suitable to use as part of a methodology for identifying maintenance schemes.

4. Methodology

The methodology described in this section has been developed to utilise the data obtained from the steps described above.

The methodology employs a decision-making tool known as Multi-Criteria Analysis (MCA). There are a number of different MCA techniques. The Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) is one such methodology that was developed by Hwang and Yoon (Yoon, 1995). An MCA problem with m attributes and n alternatives can be visualised in terms of a geometric system with m points in n-dimensional space. The TOPSIS method is based upon the concept that the optimal solution is the solution that is closest to the positive-ideal whilst simultaneously being furthest away from the negative-ideal. Where no such solution exists, a trade-off between the two distances is calculated for each alternative.

The TOPSIS method is based upon the ranking of alternatives according to their score (C_i^*). The alternative with the highest score is denoted as the optimal solution. The overall process is formulated by the following equation:

$$C_i^* = \sqrt{\sum_{j=1}^{n} \left( \frac{w_j (x_{ij} - \min_{i} x_{ij})}{\sum_{i=1}^{m} x_{ij}} \right)^2 + \sum_{j=1}^{n} \left( \frac{w_j (x_{ij} - \max_{i} x_{ij})}{\sum_{i=1}^{m} x_{ij}} \right)^2}$$

EQUATION 1
OVERALL TOPSIS METHOD

Where:

- $x_{ij}$ is the score x for the alternative i under the attribute j
- $(i = 1,2,...,m), (j = 1,2,...,n)$
- $w_j$ is the weight of attribute j

In MCA, the attribute weights (which represent the relative importance or value trade-offs of the attributes), are normally determined in accordance with the subjective preference of the decision makers or stakeholders. There are a number of different methods for determining weightings. However no method can guarantee a more accurate result than any other method, and the same decision maker may obtain different weightings using different methods.

With the diversity of attributes in the condition analysis problem, in conjunction with the multiplicity of stakeholders involved in road maintenance management decision making, it is difficult for an agreement to be reached on the relative importance via a subjective weighting process.
By recognising that no reliable subjective weightings can be obtained for the problem, the condition attributes are constructed in such a way that equal weightings can be applied; that is, there is no need for assigning attribute weights. The use of equal attribute weightings is in line with the principle of insufficient reason (Starr, 1977), which states that the use of equal weightings should be considered if the decision maker has no reason to prefer one attribute to another or when reliable subjective weightings are not obtainable.

In the methodology described in this paper, the TOPSIS model will consider each road sub-section and rank it in terms of its relative condition. The output will be a list of sections, ranked in terms of condition.

As the SCRIM data is expressed in terms of a single attribute, it is unnecessary to perform a MCA analysis; the list can simply be ranked in terms of SCRIM deficiency.

5. Analysis of Highway Agency Area 10 trunk road network

The methodology was applied to a road network within the UK. The UK’s Highways Agency Area 10 road network covers the trunk roads in Cheshire, Merseyside, Greater Manchester and South Lancashire. In total the carriageway length of Area 10 is 1,500km. Area 10 condition data was extracted from HAPMS, the pre-analysis described above was applied, and the data subjected to the TOPSIS model.
Results of the Deflectograph and TRACS analysis

The analysis ranked 28,961 road sub-sections using Deflectograph and TRACS data. The sub-sections included 25,728 sections of exactly 100m in length and 3,233 sections of length less than 100m, i.e. residual lengths at the end of sections.

For illustrative purposes, the worst 100 sub-sections (0.3% of the network) were plotted on a map of Area 10. Of particular note are sections within a close proximity which are also on the worst 100 list. In the case where a section exhibits two or more 100m lengths in the worst 100 sub-sections, it is recommended that these should be considered for further investigation as possible maintenance schemes.

Results of the SCRIM ranking

The analysis of SCRIM data resulted in the prioritisation of 13,582 road sub-sections. The lengths of these sub-sections varied, with an average of 91m. For illustrative purposes, the worst 100 sub-sections, in terms of SCRIM difference, have been plotted geographically on a map of Area 10, as can be seen below.

Again, of particular note are sections in Area 10 that appear twice or more in the worst 100 sections.
6. Verification

In order to verify the analysis technique, the results were compared to schemes that have been carried out by Area 10 since 2001. If those parts of the network subject to schemes since 2001 are designated as being in poor condition in the ranked list, then some indication of the credence of the model can be established.

691 sub-sections maintained by Area 10 since 2001 were determined to be present in the Deflectograph and TRACS condition ranking.

Figure 3 shows the distribution of these schemes within the overall condition ranking (all 28,000 sub-sections subjected to analysis).

It is interesting to note that a significant majority of the schemes undertaken by Area 10 since 2001 include sub-sections indicated as falling within the worst 60-100% of the ranked sub-sections.

483 sub-sections maintained by Area 10 were present in the SCRIM condition ranking. Figure 4 shows the distribution of these schemes within the condition ranking.

The majority of the schemes undertaken in recent years appeared in the worst 60-80% of the ranked Deflectograph-TRACS list.

Few schemes were undertaken on the worst 50% of road sub-sections when ranked by SCRIM difference. By analysing the SCRIM rankings, it can be seen that the relative condition of sub-sections based on SCRIM data does not correlate with sub-sections where a maintenance treatment has been carried out. This is not surprising as the decision to treat a SCRIM deficient sub-section is rarely based solely on the SCRIM data. Other non-condition related factors are also taken into consideration, such as intervention level, accident rate etc.
7. Conclusions

This paper has presented a model for ranking a list of sub-sections within a road network in order to identify possible candidates for future works programmes. The sub-sections were ranked in terms of condition using an MCA methodology known as TOPSIS.

The final ranking is only as accurate as the data it is based upon. Therefore the robustness of the methodology is dependent on the accuracy of the data from the surveys, and the completeness and currency of the data in the HAPMS database.

To maximise the area of the network included in the analysis, assumptions were made to cater for missing data. These assumptions resulted in the adjustment of the data that could reduce the accuracy of the final ranked list.

The resultant ranked list of sub-sections is not intended to be used solely as a works programme. However the validation of the model showed that the Area 10 have already considered maintenance on a majority of the road sub-sections that were found to be in the worst 40% of condition of the condition ranking.

The model can therefore be used as a basis for a Highway Authority to identify potential schemes. By grouping clusters of road sub-sections (with low rankings) that are in close proximity to each other, a Highway Authority can identify candidate schemes and subsequently commission detailed pavement investigation to investigate the hotspots further. The methodology provides a systematic, flexible framework that can allow for any number of condition attributes to be considered by the decision maker.

8. Ongoing work

Further validation of the methodology presented is underway. This work is specifically assessing the influence of Deflection data on the model.

The spreadsheet tools used for this study are being developed to allow the methodology to be an efficient process that can be used on an annual basis to update the outputs.

The viability of including other condition attributes, such as cracking and fretting, is currently being assessed.

The applicability of this MCA technique to identifying potential schemes for non-pavement assets, such as vehicle restrain systems is being studied. This work is developing bespoke machine-based survey techniques and appropriate data assessment software.
References


