ACCEPTABILITY OF MULTICRITERIA ANALYSIS AS A TOOL FOR DEVELOPING PAVEMENT MAINTENANCE STANDARDS IN LOCAL AUTHORITIES

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ABSTRACT

Pavement maintenance standards define the level of condition at which pavements should be kept, and therefore have an important impact in the definition of budgets for road maintenance. Standards, defining when and how pavements should be maintained, have been developed in the past based on local engineering experience, research and more recently the use of economic models such as HDM-4. It has been argued that in some instances it would be beneficial to include other parameters when defining maintenance standards for pavements, such as the effects of their introduction on the natural environment, the society served by the road, as well as the economic implications of their adoption. A tool available for encompassing all the relevant criteria when developing maintenance standards for pavements is Multicriteria Analysis (MCA). Theoretical studies have been carried out in the past, which demonstrate that MCA is potentially a very useful tool when defining maintenance standards for pavements. MCA allows to take into account, several impacts (such as economical, environmental, social) of a number of alternative and competing maintenance standards and to select the one that satisfies the overall long-term goal. This study was aimed at introducing MCA to those responsible for the maintenance and management of Local Authority's pavements, in order to gauge their acceptability from several viewpoints: relevance to their modus operandi, ease of gathering all the required data and the ease of implementation. The concepts behind the logic of MCA and its applicability in the definition of pavement maintenance standards were explained to those responsible for the maintenance of pavements in a Local Authority in the United Kingdom. By means of a panel discussion, the following topics were followed: firstly, the definition of objectives to be achieved; secondly, the definition of attributes to measure the performance of a number of competing maintenance standards in achieving the pre-established objectives; and thirdly, discussions related to the ease with which data on the various attributes would be collected. The responses in the methodology were varied, but the Authority found the approach worthwhile. A number of rules for a pilot implementation were defined, together with a methodology that will allow Local Authorities to use this tool in the future.

KEY WORDS

MAINTENANCE STANDARDS / PAVEMENT / MULTICRITERIA ANALYSIS / LOCAL AUTHORITY

1. INTRODUCTION

Maintenance standards, indicating the condition level at which pavements should be kept, have been developed in the past from local engineering experience, research and more recently the use of economic models. These maintenance standards are aimed at achieving consistency throughout road networks while providing a safe and sustainable level of service. They are commonly defined as intervention levels in Pavement Management Systems (PMS), indicating condition levels at which maintenance is required, together with the generic maintenance treatment to be applied.

Most Local Authorities use a PMS to assist in pavement maintenance and rehabilitation decision-making. The intervention levels used in such systems may be those defined nationally but adapted to local circumstances, ensuring variations are applied consistently.

Previous research has indicated that there are instances when social, political and environmental factors should be taken into account when defining maintenance standards for highways (Ortiz-García, 2000; Costello and Snaith, 2000). Such research has identified Multicriteria Analysis (MCA) as a suitable tool to take into account a variety of often conflicting criteria when setting intervention levels for pavement maintenance. MCA has found other applications in infrastructure management, for instance in HDM-4 (Kerali et al, 1999) as a tool for prioritising maintenance schemes from a number of criteria (Cafiso et al, 2002).

This paper provides an overview of MCA, indicating the principal components and requirements of the methodology, outlines the Local Authorities' approach to pavement maintenance management, in particular in the United Kingdom, and then moves on to describing the applicability of MCA when defining maintenance standards for Local Authorities' roads.

2. MCA OVERVIEW

In its broadest sense, MCA seeks to investigate a number of choices or alternatives, in the light of conflicting priorities (Voogd, 1983). When a problem is structured in this way, the alternatives may be ranked according to pre-established preferences in order to achieve pre-established objectives. At the heart of the analysis is a two- (or more) dimensional matrix, where one dimension expresses the various alternatives and the other dimension the criteria by which the alternatives should be evaluated.

Hence, MCA requires the clear definition of possible alternatives, together with the identification of the criteria under which the relative performance of the alternatives in achieving pre-established objectives is to be measured. In general, each criterion may be represented by a surrogate measure of performance, or attribute, of the consequences arising from implementation of any particular alternative. Thereafter, MCA requires the assignment of preferences (i.e. a measure of relative importance, or weighting) to each of the criteria.

A number of MCA methodologies have been developed over time to help decision-makers discover the most desirable solution to a multi-objective problem. The various types of methodology differ in the way the preferences on the various criteria are specified and the way in which the alternatives are ranked. Previous research (Di Graziano, 2000; Ortiz-García, 2000) has highlighted the flexibility of the Analytical Hierarchy Process (AHP) method (Saaty, 1990), an MCA approach, for application in road infrastructure management. In particular, the approach does not require an explicit definition of trade-offs between the possible values of each attribute and it is easier for users to understand the way in which outcomes are reached and how the weightings influence the outcomes. Hence, the approach is useful when the decision maker needs to decide whether one option is better than another on the basis of all the criteria and to easily determine the relative importance of these criteria.

3. PAVEMENT MAINTENANCE MANAGEMENT IN LOCAL AUTHORITIES

3.1 Background

The relatively large Local Authority road networks commonly comprise roads of various functional characteristics (i.e. from local to principal roads) and a variety of construction types. Such complex road networks require maintenance solutions tailored to the needs of the Local Authority. Against this background, pavement management is founded on the experience of local engineers and is commonly constrained by low budgets and a variety of local external requirements.

Since detailed information is not available for most of the roads being managed, Local Authorities commonly use “pavement families” as surrogate units to manage their network. A “pavement family” typically contains segments of roads that have similar construction history, traffic and functional classification. Pavements within a family are assumed to deteriorate in the same manner and require the same type of maintenance treatment when falling below standard. The condition of pavements in a family is generally defined by combining a number of defects into a single condition index, from which the prioritisation of maintenance interventions is carried out (Andres and Collura, 1994). The allocation of resources then takes place through either empirical performance models (de Melo e Silva, 2000) or intervention levels (Dewan, 2003). The present work was focused on the definition of such intervention levels for United Kingdom Local Authorities.

3.2 Local Authorities in the United Kingdom

In the United Kingdom, the Department of the Environment, Transport and the Regions (DETR) in partnership with the Local Government Associations sponsored the production of a Code of Practice for Maintenance Management (DETR, 2001). The Code recognises the importance of highway maintenance and the high value placed on this by users and the wider community. Local Authorities are recommended to adopt the principles of the Code, adapting them as necessary taking into account local circumstances but ensuring variations are applied consistently. Where authorities decide in the light of local circumstances to adopt standards differing from those suggested by the Code, it is essential for these to be identified together with the reasoning for such differences.

The Code defines core objectives for highway maintenance grouped under the following headings: network safety, network serviceability and network sustainability. The recommendation on condition standards takes into account these objectives, but it is left to the authorities to define standards for the condition of each element of the network.

Standards in the Code are understood as the investigatory level at which the element of the network has to be maintained before it deteriorates further. Such investigatory levels are not compulsory, but only a guideline to provide consistency throughout the Local Authority networks in the United Kingdom. However, the Code also recommends the use of the United Kingdom Pavement Management System (UKPMS), which at present may be used as a treatment selection and prioritisation tool. UKPMS is a system that allows the authority to store a definition of their network together with condition information that may be collected at pre-set intervals. In UKPMS raw observations from condition surveys, both visual and machine based, are converted into rating values on a scale that ranges from 0 (so good that to be any better would not be significant) to 100 (so poor that to be any worse would not be significant). Each defect is rated individually using either step functions, or continuous rating scales (Figure 1).

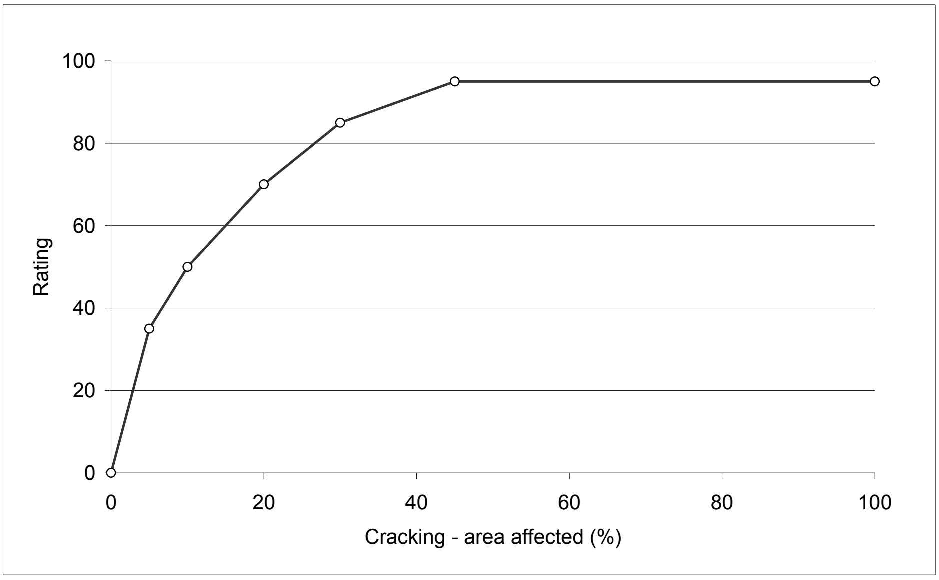

Figure 1 – Rating scale for cracking (adapted from HA, 1994)

These ratings are aimed at bringing all the defects values to a single common numerical scale that indicates the general defectiveness of a length of road. Numerical ratings from related defects are then combined into condition indices (CI), which represent the degree of defectiveness of the pavement. Condition indices for bituminous pavements include Surface CI, Structural CI, Edge CI and Overall CI. An example of the definition of such indices is presented in Table 1.

Table 1 – Example of Condition Index algorithms (adapted from HA, 1994)

Condition Index	Algorithm
Structural	Highest rating of: – 1.0 x Wheel track cracking + 0.5 Wheel track rutting; or – 1.0 Wheel track rutting + 0.5 Wheel track cracking
Surface	Highest rating of: – Whole carriageway fretting; or – 1.0 x Pot-holing + 0.5 Whole carriageway fretting; or – Whole carriageway fatting; or – 1.0 x Pot-holing + 0.7 Whole carriageway cracking
Edge	Highest rating of recorded severities
Overall	Highest of: – Individual CIs; or – 0.55 x Structural CI + 0.55 x Surface CI; or – (highest of Structural CI or Surface CI) + (0.1 x Edge CI)

Condition indices calculated in this way for a particular road length are then compared against intervention levels (Table 2), which reflect the condition of the pavement at which maintenance is required, in addition to the maintenance treatment as would be defined by an experienced maintenance engineer.

Table 2 – Treatment selection for bituminous carriageways (adapted from HA, 1994)

Overall CI	Treatment
≥ IL4	Reconstruction
≥ IL3	Partial reconstruction
≥ IL2	Overlay
≥ IL1	Inlay

These intervention levels are defined by individual Local Authorities for various road categories, according to particular needs (Table 3).

Table 3 – Example of Intervention Levels in terms of CI values (adapted from HA, 1994)

Intervention Level	Primary Road	Secondary Road	Tertiary Road
IL4	80	90	95
IL3	75	80	80
IL2	70	70	60
IL1	65	60	50

As a systematic method has not been employed to define these standards, it was envisaged that MCA could be a potentially useful tool to aid such definition.

4. APPLICABILITY OF MCA IN SETTING PAVEMENT MAINTENANCE STANDARDS

The theory behind MCA, together with the particularities of the AHP, was introduced to those responsible for managing pavement maintenance in Northamptonshire County Council (United Kingdom). Through a panel meeting, the acceptability of the AHP as a tool for developing pavement maintenance standards was evaluated. The discussion aimed also at identifying the data requirements for a pilot implementation. Details of the computational procedure in the AHP may be found in a paper by Cafiso et al (2002).

4.1 Northamptonshire County Council

Northamptonshire's 4,000km of roads are managed and maintained by Northamptonshire County Council and Atkins. Their management process caters for the maintenance of network inventory, the collection of pavement condition information and the decision-making process regarding pavement maintenance. Condition information collected throughout the network includes Coarse Visual Inspections (CVI), Detailed Visual Inspections (DVI), Deflectograph, SCRIM and TRACS surveys; machine data collection is carried out mainly on the principal road network.

The Council, like many other Local Authorities in the United Kingdom, have implemented UKPMS with the initial aim to calculate Best Value Performance Indicators (BVPI), which are used by Central Government to allocate funds. These BVPI are based on condition information collected throughout the network and indicate the proportion of it above certain condition thresholds (UKPMS, 2002a and b).

Having populated the UKPMS database with condition information, the County is considering the possibility of using the treatment selection and prioritisation elements of UKPMS to aid the pavement maintenance decision-making process. To achieve this it will be necessary to define appropriate intervention levels that reflect local needs and the County's policy. It was therefore suggested that MCA could be used to define such intervention levels. Through a panel meeting the derivation of alternatives, objectives, criteria, attributes and preferences for the implementation of the MCA were discussed.

4.2 Alternative maintenance standards

Maintenance standards to be defined through MCA correspond in this particular application to the system intervention levels in UKPMS. Consequently, the alternative options need to be defined in a form similar to that in Table 3. In effect, the Council is interested in finding the combination of intervention levels IL1 to IL4 that will yield the achievement of the overall objective defined in section 4.3.

These alternative maintenance standards may be developed from existing standards, for instance modifying the intervention levels specified in the national set of UKPMS rules and parameters. The various alternatives may be as shown in Table 4, for a particular sub-network. It may be appreciated that the definition of these alternatives requires a full understanding of UKPMS condition indices and the processes leading to treatment selection.

Table 4 – Alternative maintenance standards for a sub-network

Intervention Level	Alternative A	Alternative B	Alternative C	Alternative D
IL4	85	90	90	95
IL3	75	80	80	80
IL2	65	70	70	65
IL1	45	50	40	40

4.3 Objectives and criteria

Arguably the most important component of the MCA process is the identification of the objectives relevant to the problem of defining maintenance standards, together with their associated criteria. The general objective to be achieved with this particular application of MCA is to produce an appropriate set of maintenance standards to ensure the long-term integrity of the highway asset. This general objective embrace a number of specific objectives, such as complying with statutory obligations, meeting users' needs, ensuring availability, achieving integrity, maintaining reliability, enhancing quality, minimising cost over time, maximising value to the community and maximising environmental contribution (DETR, 2001).

The criteria, under which the relative performance of the alternatives in achieving these objectives is measured, may be as indicated in Table 5.

Table 5 – Performance criteria

Network Sustainability – Economics
Network Sustainability – Environment
Network Serviceability
Network Safety

4.4 Attributes

Each criterion should be represented by a measure of performance, or attribute, of the consequences arising from the implementation of any alternative. The modality with which the performance of the various alternatives would be estimated was discussed with the panel. The discussion centred on the collection of the necessary data on the various attributes, which guaranteed a consistent procedure even if not exhaustive models were used. The following attributes were identified as potential measures for the criteria in Table 5.

The attribute to measure the performance of the alternatives under the Network Sustainability – Economics criterion is the Net Present Value (NPV) of the cost resulting from the implementation of such intervention levels. The calculation of NPV will require the use of Economic models, such as HDM-4, to quantify for the analysis period the impact of the standard on maintenance frequencies, user delay and traffic management costs. The performance of the alternative on the economic criteria will be inversely related to the NPV.

The performance of the alternatives on the Network Sustainability – Environment criterion will be based on environmental models that yield, for the analysis period, totals of emissions as a function of pavement surface conditions. The performance will be inversely related to the amount of such emissions.

The performance of the alternatives on Network Serviceability will be directly related to the level of service at which the road is maintained (i.e. the performance will correspond to the intervention level being tested). In other words, the higher the standard, the higher the performance of that alternative.

The performance of the alternatives on Network Safety will be linked to the accident rate associated with the condition of roads. In Local Authorities that collect skid resistance data, the performance of the alternatives will be based on accident models that yield, for the analysis period, number of accidents as a function of friction (Cafiso and Di Graziano, 2000). The performance will be inversely related to the amount of such accidents.

Performance measures obtained from the models above may be entered, for each of the criteria, into an AHP working model. In such a model, a matrix may be established by comparing each alternative to all other alternatives, in order to obtain a vector (W) containing the relative importance of each alternative under the specific criterion (Figure 2). In such a model, the higher the value of the attribute the better the performance of the alternative in achieving the overall objective. The values in Figure 2 are for illustration only and do not correspond to results from an economic analysis.

SUSTAINABILITY: ECONOMICS

	Alternative A	Alternative B	Alternative C	Alternative D
Performance	2.00	2.00	4.00	5.00

	Alternative A	Alternative B	Alternative C	Alternative D	W
Alternative A	1.00	1.00	0.50	0.40	0.15
Alternative B	1.00	1.00	0.50	0.40	0.15
Alternative C	2.00	2.00	1.00	0.80	0.31
Alternative D	2.50	2.50	1.25	1.00	0.38
Σ C	6.50	6.50	3.25	2.60	

Consistency
0.00

Figure 2 – Alternatives comparisons under Network Sustainability – Economics criterion

4.5 Definition of preferences

A criteria hierarchy matrix may be established by carrying out a number of pair-wise comparisons, in which each criterion is compared to all the other criteria, according to their performance in achieving the pre-established objective. This involves assignment of weights between 1 and 9 to represent the importance of one criterion relative to the other. A value of 1 if both criteria are equally important and a value of 9 if the criterion being compared is clearly more important than the other. Intermediate values are assigned according to their relative importance.

For the criteria defined in Table 5 the hierarchy matrix in Figure 3 may be defined in co-operation with the Local Authority (values in red are inputs).

Hierarchy Matrix

	Economics	Enviroment	Serviceability	Safety	Priorities Vector PV
Sustainability: Economics	1.00	4.00	3.00	0.25	0.23
Sustainability: Enviroment	0.25	1.00	1.00	0.17	0.08
Serviceability	0.33	1.00	1.00	0.14	0.08
Safety	4.00	6.00	7.00	1.00	0.61
Σ C	5.58	12.00	12.00	1.56	

Consistency
0.03

Figure 3 – Hierarchy Matrix of Criteria

The Priorities Vector (PV), obtained from the hierarchy matrix through AHP, indicates the relative importance of the criteria.

4.6 Ranking Priorities

For the pavement family under analysis a ranking vector (RV) of the selected alternatives may be obtained through the application of the AHP (Figure 4), showing the relative preference of each alternative.

RANKING

Matrix of Comparisons MC

	Economics	Enviroment	Serviceability	Safety
Alternative A	0.15	0.27	0.15	0.38
Alternative B	0.15	0.25	0.21	0.31
Alternative C	0.31	0.24	0.32	0.16
Alternative D	0.38	0.24	0.32	0.16

Priorities Vector PV

w Hierarchy Matrix
0.23
0.08
0.08
0.61

Ranking Vector RV = MC x PV

Alternative A	0.298
Alternative B	0.262
Alternative C	0.211
Alternative D	0.229

Figure 4 – Ranking Vector

In this example alternative A obtains the highest score and would be, if implemented, the alternative that better satisfies the overall objective for the pavement family during the specified analysis period.

5. CONCLUSIONS

Local Authorities are introducing PMSs to help the maintenance engineer in the decision-making processes regarding pavement maintenance. Such systems require appropriate intervention levels to be used in the identification of portions of the network in need of maintenance. These intervention levels, in turn, need to be defined taking into account national policies and any local requirements.

The presence of evaluation criteria that do not use monetary values (e.g. the environment, road safety, comfort) when defining intervention levels suggests the need for MCA models. MCA allows to take into account several impacts of a number of alternative and competing maintenance standards and to select the one that satisfies the overall long-term goal. Consequently, MCA was introduced to a Local Authority in the United Kingdom as a tool to obtain intervention levels for their PMS. Through a panel meeting with those responsible for pavement maintenance management in the Local Authority, the derivation of alternatives, objectives, criteria, attributes and preferences for the implementation of the MCA were discussed, as follows:

- Alternative maintenance standards to be defined by the maintenance engineer, taking into account the logic in the PMS.

- Objectives and criteria to be used in MCA are to be defined by a panel comprising representatives from the Local Authority in the first instance; members from the public and other stakeholders may take place at a later stage.

- The value of attributes, measuring the performance of the various alternatives, is to be calculated using appropriately calibrated models. It is apparent that this is the most difficult part of the approach, as it involves running a variety of models for which the necessary information may not be available. It is necessary to find a compromise between the ease with which data on the various attributes would be collected and the consistency of the models used. It may be useful to work with models that allow different levels of information to be used, such as HDM-4.

- Preferences between the criteria are to be defined by policy-makers within the Local Authority.

The MCA application in this work was carried out using the AHP method, which presents flexibility for application in road infrastructure management. The AHP is simple to use, requires realistic amounts of data, expertise, and time. The technical aspects may involve only the maintenance engineer, while the policy-makers may be involved in the formulation of evaluation criteria and preferences.

It is important to note that the type and the logic of proposed criteria and alternatives could be changed without changing the working logic of the MCA model. The number of criteria and alternatives may be increased but in any case they should not be more than eight.

The work carried out in collaboration with Northamptonshire County Council has set out the basis for the definition of intervention levels in a road network, demonstrating the approach to be worthwhile. The panel agreed that a pilot implementation would be applicable to secondary roads, for which most of the required condition data is available.

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