Maintenance Planning for Road Pavements and Structures – Commonality of Principles and Procedures

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Abstract

Pavements and bridges are the main components of a road infrastructure system. Both essentially perform a structural function in that they transfer the traffic loads to the foundation level or sub-grade below. In order to achieve a common rational approach for determining and funding their maintenance expenditure, it is necessary to understand the overall engineering processes involved in predicting and planning maintenance work in the two areas, their differences and similarities. Clearly, some of the differences will be fundamental, while others are nothing more than the same processes in a different guise. This paper is intended to provide an overview of the similarities and differences in the maintenance procedures used for road pavement and structures.

Introduction

Pavements and bridges are the main components of a road infrastructure system. Both essentially perform a structural function in that they transfer the traffic loads to the foundation level or sub-grade below.
The organisational arrangements for bidding for and allocating maintenance funding for pavements and structures are usually the same. Yet the methods for determining maintenance needs and preparing bids have evolved through time to be formulated in very different formats by separate groups of specialist engineers. Their paths seldom cross, technically speaking, except on occasions such as when bridge headroom or superimposed-load might be affected by overlaying, or when collecting traffic load data in a combined exercise.
As the main construction phase of the road network in the UK has more or less come to an end, the maintenance of the existing assets has become increasingly important for the authorities. In recent years, the maintenance bidding process including the prioritisation of the bids and consideration of risks and options, both for pavements and structures, has become the subject of considerable investigation and discussion. The Highways Agency, for instance, is currently developing a new pavement management system and a new structures management procedure accompanied by bidding and information systems.
The input for the above systems will mainly come from the same source, i.e the maintaining agents, and the 'high level' use of the systems will also be made by the

same people at the Agency headquarters. It is therefore essential that these systems have the same 'look and feel' and also the procedures should be very similar, if not the same, for both structures and pavements.

In order to achieve this objective, it is necessary to understand the overall engineering processes involved in predicting and planning maintenance work in the two areas, their differences and similarities. Clearly, some of the differences will be fundamental, while for others, it is nothing more than the same process in a different guise. This paper is intended to provide an overview of the similarities and differences in the maintenance procedures used for road pavement and structures.

The bridge management methodology described in the paper has been developed in recent years in the Highways Agency and has been explained in detail in a number of earlier papers [1,2,3]. The section on whole life performance of pavements reflect the requirements of the DMRB standards relevant to pavement condition survey and assessment. The section on strategic plan for pavements is based on a method of forecasting future maintenance needs of civil infrastructure systems currently being developed at the Infrastructure Reliability and Management Centre (IRMAC) of the University of Surrey.

Maintenance Objectives

Bridges and road pavements, in common with any other element of the built environment, deteriorate with time. The deterioration in their case is caused usually by a combination of the following :-

(1) Traffic related effects, e.g. surface/joint damage, fatigue effects, deformation.

(2) Environmental factors both natural and man made, e.g. de-icing salts, freeze thaw cycles

(3) Material degradation, e.g. embrittlement, corrosion, cracking.

Progressive deterioration can ultimately reach unacceptable levels, beyond which further course of deterioration or structural behaviour may become unpredictable, user and public safety may be compromised, or at the very least, may cause public alarm. When deterioration reaches this stage, some remedial action becomes essential.

In addition, bridges and other structures may sometimes be considered to be at risk, irrespective of their inspected condition, from factors such inadequate original specification of materials and methods, increased traffic loading or inadequate original design requirements. When groups of structures become suspect for any of these reasons, they are put into a programme of assessment for checking their structural adequacy. Some of these structures may be found to be at an unacceptable level of risk i.e. are deemed to be sub-standard. Structures assessed to be sub-standard require some form of urgent remedial action, even if they do not have any signs of deterioration.

Fig.1 shows the distribution of the bridges on the Highways Agency's trunk road network in terms of their load carrying capacity. The bridges to the left of the assessment load level are considered to be 'sub-standard' and are being strengthened in the current bridge rehabilitation programme. Similarly, the distribution of the pavements in terms of their currently measured 'rut depth' is shown in Fig.2. The rut depth of 10mm is one of the indicators at which some investigation subsequent to remedial action is considered necessary.

Using a typical statistical distribution of existing condition as in Fig.1 and Fig.2, let us assume that that a particular performance indicator for the whole population of elements of a given type in an infrastructure system is expressed as shown in Fig.3 for the Year 0 distribution. The better elements are likely to be towards the right of this distribution and some 'unacceptable' elements such as those with severe deterioration are likely to be located towards the left.

It is reasonable to expect that, without any maintenance activity, the overall distribution of the stock will tend to move leftwards, i.e. many elements will become progressively worse with time in terms of the performance indicator concerned. Some will of course deteriorate more slowly than others or stay in the same condition for indefinite periods.

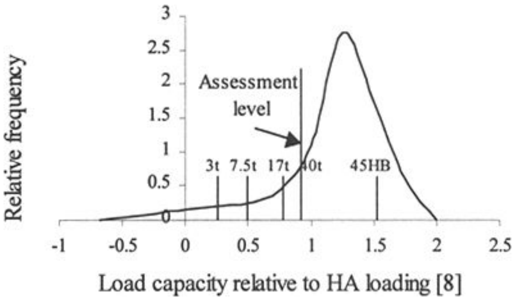

Figure 1. Distribution of load carrying capacity

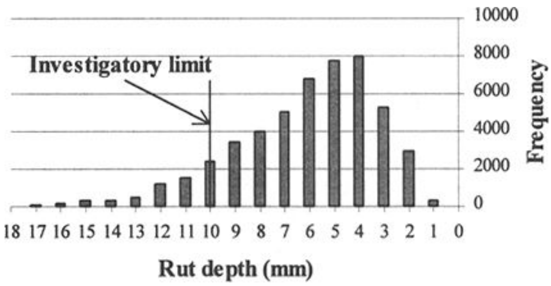

Figure 2. Distribution of pavements with different rut depths.

The nature of the distribution is such that, if the 'unacceptable' elements are the only ones repaired or replaced at year 0, after a period of time, say at year N, the number of elements to be repaired or strengthened will be much greater, as shown by the Year N distribution. After another similar period the numbers to be strengthened could reach unmanageable proportions (Year 2N distribution). For this reason, it is not sufficient to repair, strengthen or replace only those elements which are found to be inadequate at any point of time, but others may also require preventative maintenance to avoid future logistical and funding problems resulting from backlogs. The overall purpose of maintenance is, therefore, to undertake the essential remedial actions regarding the 'unacceptable' elements and to keep maintenance at a steady level as far as possible and prevent unmanageable backlogs of work from developing.

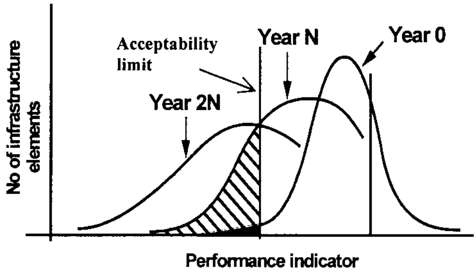

Figure 3. Infrastructure deterioration

Maintenance Planning and Bidding

The maintenance planning procedure for any civil infrastructure system typically comprises the activities shown in Fig.4. For the Highways Agency's bridges and pavements, there are established procedures including a number of standards and advice notes in most of these areas, particularly for inspections, condition survey and assessment. Guidance and software systems for bidding, bid prioritisation and strategic planning are currently being developed. The broad purposes behind the component activities shown in Fig.4, apart from those for inspection and condition survey which are obvious, are as follows:-

Group maintenance strategies. Maintenance needs and procedures are generally related to specific structure and pavement types. For instance, steel bridges need regular painting while masonry bridges may only occasionally need maintenance. Similarly, the maintenance needs of flexible and rigid pavements are different. Even condition monitoring and inspection requirements can be different for different types. The first step of infrastructure management is therefore to separate the elements into groups of similar characteristics, for example by construction type.
For each group, it necessary to establish an optimum maintenance regime, which will cover condition survey and inspection and assessment. It may also include specific programmes to deal with particular groups, especially if there are existing backlogs of work. The optimum maintenance regime will be based, implicitly or explicitly, on whole life cost considerations for the group. The regime may be established through experience, for example it has been found that 'long life' pavements require only periodic resurfacing as their maintenance need. Sometimes, however, the optimum maintenance requirements have to be determined by comparing the whole life costs of different options. For instance, the need to impregnate bridge surfaces with silane, or to apply cathodic protection to certain types of bridges need to examined in terms of whole life costs.

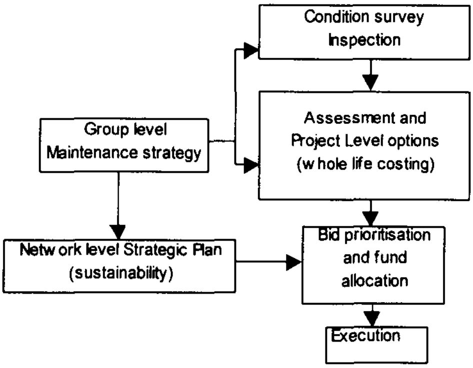

Figure 4. Maintenance planning procedure

Strategic plan. Once the group optimum maintenance strategies are established, the planning and programming is approached from two directions - the infrastructure or network level strategy (the 'strategic plan') and the project level plan (project or scheme maintenance options).

The infrastructure strategic plan is the summation of the recommended strategies for all the groups together, and is essentially an expenditure profile for the whole stock covering a number of years into the future. The strategic plan gives a broad overview of future maintenance needs for each group as well as of the total. It can be used to develop forward plans for future funding needs.

The strategic plan provides an opportunity to examine if the total maintenance expenditure levels (i.e. the projected work-loads) are sustainable into the future. As the group strategies are largely based on whole life costing, and cost discounting can result in postponing more costly work to the future, the totals from the group strategies may be loaded more in the future years. If this is noticed, adjustments need to be made in the strategic plan, perhaps by bringing forward work, thus sometimes overriding the whole life costing results for the sake of long-term sustainability.

Assessment. At the project level, normally each year, the findings from condition measurements are used to carry out assessments, accompanied by further investigations as necessary, of individual structures and pavement lengths. The assessments not only determine if any essential work is needed at present but also develop future plans for maintenance works. Ideally the assessments should produce a number of alternative strategies and their cost and other implications. In many situations, however, the project level choice is limited by various extraneous obligations such as operational needs. The options derived in the assessments form the basis for any bids for funding.

Bid prioritisation. Once the project level maintenance options are available, those with the lowest present value (PV) will normally be chosen, unless there are operational or other unavoidable reasons. However, as mentioned earlier, cost discounting to present value may favour options which postpone major works into the future, resulting in uneven workloads through the years. For long term sustainability of resources and investment, therefore, it is necessary to compare the total works (i.e. costs) planned for each groups and each type of activities arising from the project level bids with the corresponding levels in the strategic plan. If necessary, the project level programmes are adjusted to reflect the strategic plan and then prioritised for allocation of funding. The prioritisation should ideally show the consequences of not funding (or not carrying out) part of the bids. One consequence that is particularly relevant is the PV of the road user delay cost when a project is not funded or undertaken.

Although the bidding and prioritisation processes for both structures and pavements are currently under development, the other procedures are largely established at present. The following is an account of the general procedures and how these are related to the maintenance of pavements and structures respectively.

Assessment

Whole Life Performance (WLP)

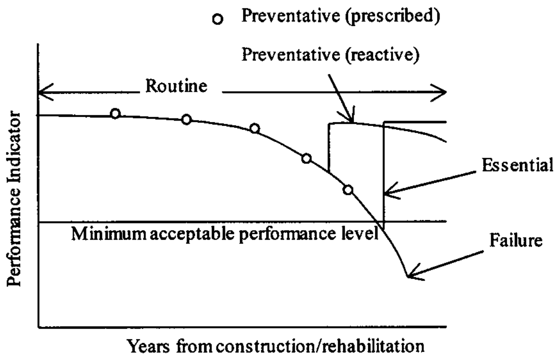

Figure 5. Whole life performance profile.

In general, a typical element of a civil infrastructure system is likely to have a time related performance profile such as that shown in Fig.5. In order to describe performance at any point in time, an appropriate performance indicator is required. The performance indicator is used in particular to specify when any work or investigation is deemed necessary.

The whole life performance profile is intended to show the performance of an element from the time of its construction, installation, rehabilitation or replacement to the end of its functional life. As most elements are required to remain functional without requiring any major repairs for a long period, the initial (as constructed) performance level is usually much higher than the critical level beyond which the behaviour of the element becomes unreliable. The element, even without being repaired, will however continue to perform, sometimes quite adequately, until the failure condition occurs.

During its functional life, an infrastructure receives some regular maintenance in the form of service maintenance and minor repairs, which is referred to as routine maintenance. Apart from routine maintenance, most elements will require, from time to time, some major repairs. The purpose of such repairs, which in some cases may be full rehabilitation or even reconstruction, is to improve the performance level to a desired level, normally to the almost as new condition if possible. At or beyond the point when the performance is deemed to be critical, structural strengthening becomes

essential in order to restore reliability, and can be referred to as 'essential maintenance'. When repair work etc. are carried out before the critical level is reached, they in effect postpone the onset of the critical condition, and are therefore referred to as 'preventative maintenance'.
Preventative maintenance can be of two types. Sometimes certain work is recommended to be carried out periodically from the as new state even in the absence of any sign of deterioration. Such treatments can be referred to as 'preventative (prescribed) maintenance', for instance repainting of steelwork periodically, or replacement of waterproofing of bridge decks when pavement resurfacing is carried out. Other preventative measures are only undertaken when significant loss of performance is found through either condition monitoring and/or assessment. Such measures can be termed as 'preventative (reactive) maintenance'.

Whole Life Performance of Pavements

General

Road pavements broadly fall into three categories, flexible - determinate life, flexible - long life and rigid. The deterioration processes of the three types are distinctly different from each other and their maintenance considerations and procedures are also very different. In the Highways Agency's network, rigid (concrete) pavements constitute only 5% of the motorway lengths and 15% of the all purpose trunk roads (APTRs). Hence, for the purposes of this paper, only flexible pavements will be considered in some detail.

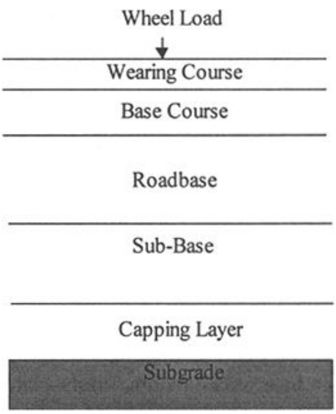

Figure 6. Typical cross section of flexible pavement

A flexible pavement typically consists of a number of layers, as shown in Fig.6. The individual layers essentially perform the task of transferring the traffic loads to the next layer below without exceeding the capacity of the latter. In general, each succeeding upper layer, therefore, is structurally stronger than the layer below. The sub-grade, the capping layer and the sub-base constitute the foundation of the road, the road base is the main load bearing layer, and the base course and the wearing course together form the surfacing.

Long life pavements are more recent and better constructed with thicker layers. It has been found that they remain in sound structural condition indefinitely and only require resurfacing as the main maintenance activity. It is estimated that about 60 % of the Highways Agency's pavements are of this type. Determinate life pavements undergo structural deformation with time and traffic use, and in due course require strengthening by overlaying or even reconstruction.
The maintenance needs for pavements are determined primarily by measuring deflections and rut depths (structural and surfacing characteristics) accompanied by visual surveys, as well as by measuring skidding resistance (safety characteristics) and longitudinal evenness. Full details of the standard measurement methods and the tools are given in HD 28 [4] and 29 [5]. The process of determining if and when the various maintenance activities should be considered is a complex process of assessment, described in detail in HD 30 [6]. All these decisions are based upon monitored data and additional investigation which is essential for designing individual schemes.

Performance indicators

The data on which maintenance needs are based, mainly consist of safety related characteristics (sideways-friction coefficient, SFC), depth of rutting and 'standard deflection'. Deflection is measured as the deflection of the pavement under a specified wheel as the wheel passes over. This is a very important parameter which is used to predict the remaining service life of individual determinate life pavements, that is the predicted time left until the critical state is reached.
For determinate life pavements, the 'critical' condition is defined as the stage in its life beyond which the rate or mode of its further deterioration becomes unpredictable. The residual life is defined as the time from the present (time of assessment) until that point is reached. In physical terms nothing specific occurs at that point to prevent adequate use for some time to come. Indeed for some pavements the second period can be almost as long as the first. The residual life of pavements with different traffic loading history and different measured deflection has been established by TRL [7] who have conducted a large number of full scale road experiments since the 1950's for this purpose. The performance indicators therefore are as follows :-

Long life pavements - SFC and Rut Depth
Determinate life pavements - SFC, Rut Depth and Residual Life

Minimum acceptable performance levels. Limits of pavement performance are used primarily as 'investigatory levels' i.e. when these limits are reached, further investigation or assessment becomes necessary. Pavements as such do not have any minimum acceptable performance levels since a pavement can remain serviceable beyond the investigatory levels. In broad terms, further investigation becomes necessary if the following limits are reached :-

Remaining service life = 0
Rut depth = 10mm
SFC = Investigatory levels (HD 28)

Maintenance Activities. Broadly speaking, apart from routine maintenance such as clearing drains, three types of maintenance work are carried out on flexible pavements [8]. These are described below:-

(1) Surface dressing. This is initiated by the SFC level and, subject to investigations, this would normally be necessary at about 7 yearly interval, except that often in reality, resurfacing obviates the need for surface dressing by itself.
(2) Resurfacing. This is carried out when the rut depth is greater than 10mm or the skid resistance falls below a certain level. Again, subject to investigations, such maintenance generally occurs at between 7 to 15 years, on average at around 12 years' interval.
(3) Strengthening. Strengthening is only applied to determinate life pavements, and is carried out at or some time after the 'critical' state is reached i.e. when the residual life is less than 0 years. Strengthening involves overlaying, where this is feasible (bridge headroom and drainage requirements may sometimes prevent this), or reconstruction to the required level. The longer the delay before strengthening is carried out after the end of the remaining service life is reached, the more extensive the remedial work becomes.
The function of an overlay is to reduce deflection and increase the strength of a flexible pavement. The results depend on the thickness of the overlay, its elastic properties and the deflection of the existing pavement [7].

In terms of the general terminology, all maintenance activities on pavements, other than routine, are applied after the appropriate investigatory levels. Hence surface dressing, resurfacing and strengthening including overlaying and reconstruction can be considered as essential work.

Failure State. The state of failure is reached when the pavement breaks up or deforms to an extent when it becomes unsafe or otherwise difficult to use. Pavements in the UK are rarely allowed to reach this state. In terms of visible surface condition, TRL LR 833 defines the evidence of pavement failure as multiple cracking or depth of rutting of 20mm or greater.

Whole Life Performance of Highway Structures

General. Any significant maintenance work for structures arises mainly for two reasons - evidence of deterioration or inadequate structural capacity (to safely carry the required loads) identified through assessments.

Bridges and other highway structures are inspected regularly using different levels of inspection [6]. Most bridges, although suffering from general weathering, do not show any significant deterioration even after a long service life. In the case of those that do show deterioration, only certain parts, such as areas near road joints or deck areas under the surfacing are mainly affected, specifically due to chloride attack (from de-icing salts). The inspection procedure requires the inspector to give a condition rating to any deterioration noticed, and denote if maintenance work should be considered soon. In most situations involving significant deterioration, the next stage is to carry out more detailed investigations, using tests and material sampling as appropriate. Based on the results, the remedial works are then designed.

The assessments also make use of inspection reports, tests and sampling etc. The assessments are carried out according to the assessment standard BD 21 [11], which stipulates that, those that fail assessment, require strengthening or replacement as soon as practicable. Until the work is carried out, a substandard structure requires to be adequately safeguarded through recommended interim measures [12]. Sometimes preventative work is carried out on 'above standard' structures in order to delay the time when they are likely to become sub-standard.

Bridges essentially consist of three structural components - end supports, decks and, in the case of multi-span bridges, intermediate supports. Each of these components can be of a variety of construction forms and materials. Since both deterioration and structural inadequacy are localised, the maintenance needs are structure specific, and hence, generalised prediction of behaviour or maintenance needs for structures is likely to be very approximate. The basic principles behind the procedures used for structural maintenance are discussed in detail elsewhere [13].

If adequate preventative work is not carried out on structures, the effects will take a very long time, perhaps decades, to become apparent. Since whole life costing using a test discount rate of 6% brings the effective time frame to under 40 years or so, it is essential to have a long term strategy for maintenance work in parallel with the assessment of annual bids on the basis of whole life cost. This is also important because the use of whole life costing may give the best strategies for individual structures, nevertheless these in total may not represent the best strategy for the network.

Performance Indicators. The two principal factors that necessitate any maintenance activities on structures are, the need to be safe and the need to stop deterioration reaching a critical level. The level of safety is denoted by the load carrying capacity (K factor in BD 21[11]) and the level of deterioration is indicated by the 'severity rating' given at an inspection. Hence the performance indicators I in Fig.7a and b are each of these two parameters depending on whether the subject of consideration is safety or condition.

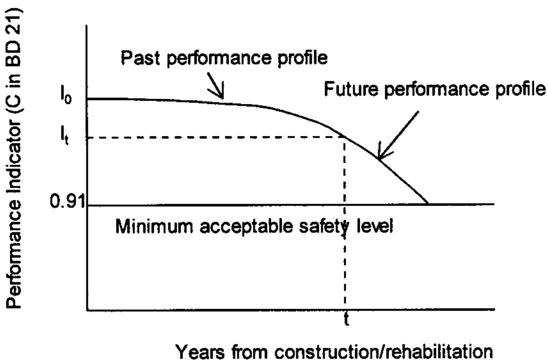

Figure 7a.Whole life safety performance

Critical Performance Levels. The critical performance level indicator in respect of safety is the minimum acceptable load capacity level for a particular element. In the case of bridge decks and other load carrying elements, for instance, this will be the assessment load requirement level stipulated in BD 21. It is individually defined for components such as bearings and expansion joints, or for elements where traffic loading is not significant, in Draft Advice Note BA 81 [14]. The critical performance level in respect of condition is Severity Level 4 as defined in the current bridge inspection requirements [9].