

FEHRL



FEHRL REPORT 2004/01

ELLPAG PHASE 1

A Guide to the Use of Long-Life
Fully-Flexible Pavements



FEHRL OVERVIEW

FEHRL is a registered International Association with a permanent Secretariat based in Brussels. Formed in 1989 as the Forum of European National Highway Research Laboratories, FEHRL is governed by the Directors of each of the national institutes. At present, FEHRL comprises twenty-five national laboratories from the member states in the European Union, the EFTA countries and the rest of Europe.

Under the day-to-day management of the Executive Committee, FEHRL is engaged in research topics including road safety, materials, environmental issues, telematics and economic evaluation.

Research capacity is provided by the national institutes and makes use of the wide range of test facilities available.

AIMS AND OBJECTIVES

The mission of FEHRL is to promote and facilitate collaboration between its institutes and provide high quality information and advice to governments, the European Commission, the road industry and road users on technologies and policies related to roads.

The objectives of collaborative research are:

- to provide input to EU and national government policy on highway infrastructure
- to create and maintain an efficient and safe road network in Europe
- to increase the competitiveness of European road construction and road-using industries
- to improve the energy efficiency of highway construction and maintenance
- to protect the environment and improve quality of life

FEHRL Report 2004/01

ELLPAG Phase 1 Report

A Guide to the Use
of Long-Life Fully-Flexible
Pavements

FEHRL Report 2004/1

Title: ELLPAG Phase 1 Report

Keywords: long-life pavements, economic benefits, deterioration mechanisms, design, maintenance

Although FEHRL has done its best to ensure that any information given is accurate, no liability or responsibility of any kind (including liability of negligence) is accepted in this respect by FEHRL, its members or its agents.

© FEHRL 2004

ISSN 1362-6019

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of FEHRL.

FEHRL Secretariat: S. Phillips
Boulevard de la Woluwe, 42 – 1200 Brussels, Belgium
Tel +32 2 775 82 38
Fax +32 2 775 82 54
e-mail: info@fehrl.org
Web site: <http://www.fehrl.org>

Preface

FEHRL is a registered International Association with a permanent Secretariat based in Brussels. Formed in 1989 as the Forum of European National Highway Research Laboratories, FEHRL is governed by the Directors of each of the national institutes. At present, FEHRL comprises twenty-seven national laboratories from the member states in the European Union, the EFTA countries and the rest of Europe.

The mission of FEHRL is to promote and facilitate collaboration between its institutes and provide high quality information and advice to governments, the European Commission, the road industry and road users on technologies and policies related to roads.

The objectives of collaborative research are:

- to provide input to EU and national government policy on highway infrastructure
- to create and maintain an efficient and safe road network in Europe
- to increase the competitiveness of European road construction and road-using industries
- to improve the energy efficiency of highway construction and maintenance
- to protect the environment and improve quality of life

FEHRL produces four different document types:

- Reports
- Technical Notes
- Management Notes
- Newsletter and other literature

During 1998/99, the Western European Road Directors (WERD), now called the Conference of European Directors of Roads (CEDR), asked its members for topics of interest affecting the European road network, with the aims of identifying any knowledge gaps and initiating research. Long-life pavements (LLPs) was one of the topics suggested by the UK Highways Agency and was later endorsed by WERD as an appropriate area for a co-operative approach.

The European Long-Life Pavement Group (ELLPAG) was subsequently established as a FEHRL Working Group to act as the focal point for determining the way forward. Members of the Group comprise representatives of research institutes (FEHRL members) and the UK Highways Agency, representing CEDR.

The objective of this report is to provide a state-of-the-art Review of current European knowledge on the design and maintenance of long-life fully-flexible pavements.

TABLE OF CONTENTS

Preface	iii
Table of Contents.....	v
Executive Summary	1
1. Introduction.....	5
2. Definition	9
2.1 Objectives	9
2.2 Contributions from national definitions	9
2.3 Contributing elements to the definition from Group discussions.....	10
2.4 Definition of long-life pavement concepts	11
3. Design and Construction of New Long-Life Pavements	13
3.1 Review of COST Action 333	13
3.2 Review of Existing European Design Methods for Long-life.....	17
3.3 Example Pavement Designs.....	23
3.4 The Preferred Way Forward	26
3.5 Conclusions.....	27
3.6 Best Practice	28
4. Assessment and Upgrading of Existing Pavements to Long-Life	31
4.1 Assessment.....	31
4.2 Upgrading.....	33
4.3 Conclusions.....	34
4.4 Best practice	34
5. Maintenance of Long-Life Pavements.....	37
5.1 Functional pavement surface characteristics	37
5.2 Pavement condition evaluation (assessment).....	38
5.3 Maintenance management procedure for long-life pavements.....	39
5.4 Maintenance Treatments for Long-Life Pavements	40
5.5 Treatment Selection	40
5.6 Conclusions.....	41
5.7 Best practice	42
6. Economic Analysis	45
6.1 Cost/Benefit Analysis (CBA)	45
6.2 Enquiry	48
6.3 Summary of the answers to the questionnaire	49
6.4 Summary	54
6.5 Conclusions.....	57
7. Research Needs.....	59
7.1 Discussion	59
7.2 Summary of identified research needs	64
8. Recommendations.....	67
9. References	71
Appendix A: ELLPAG Membership	73
Appendix B: New Pavements.....	74
Appendix C: Assessment and Upgrading.....	75
Appendix D: Maintenance of Long-Life Fully-Flexible Pavements	93
Appendix E: Economics	107
Appendix F: Research Needs.....	116

Executive Summary

During 1998/99, the Western European Road Directors (WERD), now called the Conference of European Directors of Roads (CEDR), asked its members for topics of interest affecting the European road network, with the aims of identifying any knowledge gaps and initiating research. Long-life pavements (LLPs) was one of the topics suggested by the UK Highways Agency and was later endorsed by WERD as an appropriate area for a co-operative approach.

The European Long-Life Pavement Group (ELLPAG) was subsequently established as a FEHRL Working Group to act as the focal point for determining the way forward. Members of the Group comprise representatives of research institutes (FEHRL members) and the UK Highways Agency, representing CEDR.

The original objectives of ELLPAG can be stated chronologically as short-term, medium term and long-term objectives.

- The short-term objective of the Group is to produce within 12 months of starting the formal project a State-of-the-art Review of current European knowledge on the design and maintenance of long-life fully-flexible pavements.
- The medium-term objectives are to produce similar state-of-the-art reviews for the other common pavement types.
- The long-term objective is to produce a user-friendly comprehensive Best Practice Guidance note on long-life pavement design and maintenance for all the common types of pavement construction used in Europe.

In 2002, a proposal for a first phase of work undertaken by ELLPAG was approved by FEHRL and CEDR. Funding was secured from each of the core member's national road administrations to participate in this work and the main work for Phase 1 was carried out between September 2002 and August 2003. This document is the final report of Phase 1 that covers only long-life fully-flexible pavements. Other major pavement types are planned to be covered in subsequent phases of work. Work on Phases 2 and 3 has also now been approved and Phase 2, covering semi-rigid pavements, has commenced.

The work in this report has been sub-divided into six main areas which correspond to the main chapters of this Report: Definition, New Pavements, Assessment and Upgrading, Maintenance, Economic Analysis and Research Needs. The methodology combined reviews of existing documentation and contributions for each area by the core member participants.

Definition

The main aim of this task was to produce a consensus definition of long-life pavements; this task had to ensure that there is a consistency of approach within the work of the other tasks. In order to produce a definition, contributions were sought from national organisations, most notably the UK and USA, where long-life or 'perpetual' pavement methodologies are already in place. A functional type definition whereby the definition is

based upon the expected performance characteristics rather than some specification of the design detail was favoured by the ELLPAG group. Such work was distilled into a short definition of a long-life pavement:

A long-life pavement is a type of pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out.

New Pavements

This work considered the latest information from many national design standards as well as capitalising on recent work undertaken in COST Action 333, 'Development of a new bituminous pavement design method'. In addition, information was collected from ELLPAG members regarding their country's current design and construction practices.

On reviewing the information contained within COST Action 333, it was observed that non-structural deterioration modes were the most significant forms of deterioration on thick, fully-flexible pavements used in heavily trafficked situations. It was therefore concluded that long-life fully-flexible pavements are already likely to be in-service in many countries in Europe.

For those countries that do not currently have a long-life pavement design methodology in place, the members were asked to select a preferred route for the development of a methodology. The over whelming preference of the ELLPAG members was to achieve a long-life design methodology using improved materials and/or design. Such a route is already being under taken in a number of countries, for example, using high modulus asphalt with polymer modified binder to improve stiffness and fatigue resistance.

Best practice guidance has also been provided in the form of a generalised model for developing the design and construction of long-life pavements. Long-life design procedures from the UK and the USA are presented as examples of best practice.

Assessment and Upgrading

In addition to the construction of new long-life pavements, long-life pavements can also be found within the existing road network. This chapter is a review of the techniques for the assessment of in-service pavements that are potentially long-life pavements and also the methods that could be used to upgrade pavements in order that they can be considered to be a long-life pavement.

The majority of contributors noted that structural maintenance is no longer significant on the primary road network. Most contributors stated that their method of assessment gives a residual life, however, for the primary road network, the assessment methods appear to under-estimate the residual life of the pavement. It is suspected that the under-estimation of residual life has been caused by the extrapolation of assessment criteria from many years ago when traffic levels were much lighter than seen today.

While the UK is the only country that has an explicit method of upgrading a pavement to a long-life pavement, other countries also upgrade their pavements to extend their life, usually by 15 to 20 years, in order to prevent the need for reconstruction. Indeed it was stated that no country allows its pavements to reach a state requiring reconstruction. No consensus view was found on the most appropriate manner with which to deal with full-depth structural cracking and no special materials or construction practices were detected.

Some best practice guidance on upgrading and assessment has been provided. This guidance advises that for thick pavements with good surface condition and layer moduli a very critical view should be taken of any recommendation for further strengthening treatment.

Maintenance

The maintenance of long-life pavements naturally concentrates on the surfacing layers with a view to maintaining the functional characteristics of the pavement such as evenness and skid resistance. Thus, the scope of this chapter is only the maintenance of asphalt surfacing layers on a long-life pavement structure; however, it is accepted that there is a small risk that pavements that are considered to be potentially long-life pavements will require some form of structural maintenance in the future.

It is evident that efficient (proper and timely) maintenance of road surfacings can have a significant role in ensuring the long-life of pavements. One of the preconditions of the effective maintenance is the reliable knowledge about every relevant pavement condition parameter (unevenness, surface distress, pavement texture and friction). On the basis of measurements obtained using, preferably, high-speed and multi-functional measuring techniques, as well as applying well-established pavement performance models and intervention criteria, short-term and medium-term intervention needs can be determined.

The selection of an appropriate maintenance treatment for a long-life pavement should take into consideration the performance, longevity and efficiency of the treatment as well as user delay costs of performing the maintenance operation. A strategy for the initial selection of maintenance treatments is required, however local conditions will have a significant effect on the final choice of treatment.

Economics

The objective of this task was to provide a Europe-wide cost benefit analysis for the adoption of long-life pavements. The methodology that is proposed is to compare the results of the cost benefit assessment of determinate life pavements with that of long-life pavements. This approach is relevant but nevertheless raises certain issues such as the determination of residual life.

Three models have been identified, which seem to be adapted for the economic assessment of long-life pavements. They are:

- The model developed and currently used by the UK for assessing the cost/benefits of Long Life Pavements (LLP).
- A model under development by OECD and called PASI (Project Analysis System International). This model is adapted from the UK SAS model.
- The model that is being developed in the FORMAT project.

However, those models do not take into account all of the significant parameters for the economic appreciation of long-life pavements, for example dedicated environmental costs. Other parameters may be difficult to assess with sufficient accuracy due to the specific behaviour of long-life pavements such as the residual value of the structure and more specifically of the layers, which are not expected to show any distress.

At this stage, it does not seem possible to carry out a totally comprehensive Europe-wide cost benefit analysis on long-life pavements. It is therefore considered that the

development of a specific model for the economical assessment of long-life pavements that is adapted to the specific needs of these pavements is required.

However, a cost benefit analysis has been carried out to estimate the comparative costs of improving and maintaining a core heavily trafficked road network of around 10,000km in length over a ten year period using long-life pavement designs as against more conventional determinate life designs; this analysis is based on work carried out in the UK. The savings in construction and maintenance costs for the new pavements amounted to around €120M and €220M for the maintenance of the existing network, a combined saving of just under €350M or around 10% of the total construction and maintenance budget over the same period. This illustrates the large potential benefits to be obtained from the adoption of the long-life pavement design principles on a heavily trafficked road network even before considering the potential environmental benefits of such an approach.

Research Needs and Recommendations

The ultimate objective of this work was to define guidelines for a possible research programme arising from the first phase of the ELLPAG project with regard to the design, construction and maintenance of long-life fully-flexible pavements. A number of research needs were highlighted which has lead to recommending European collaborative research in the following areas:

- To investigate the deterioration mechanisms of long-life fully-flexible pavements.
- To develop improved techniques for estimating the residual life of both determinate and long-life flexible pavements.
- To trial the UK upgrading methodology on a Europe-wide basis.
- To develop an optimum strategy for managing surface distress.
- To develop a standardised and comprehensive cost benefit model for long-life flexible pavements.

1. Introduction

During 1998/99, the Western European Road Directors (WERD), now called the Conference of European Directors of Roads (CEDR), asked its members for topics of interest affecting the European road network, with the aims of identifying any knowledge gaps and initiating research. Long-life pavements (LLPs) was one of the topics suggested by the UK Highways Agency and was later endorsed by WERD as an appropriate area for a co-operative approach.

The European Long-Life Pavement Group (ELLPAG) was subsequently established as a FEHRL Working Group to act as the focal point for determining the way forward. Members of the Group comprise representatives of research institutes (FEHRL members) and the UK Highways Agency, representing CEDR.

Two levels of membership of the Group have been created. Core members are directly involved in the work of the Group and their representatives attend regular meetings as required. All core members are from either the FEHRL or CEDR organisations. Associate or affiliate members are kept informed of the work of the Group and contribute through supplying information as requested and commenting on draft outputs; these members do not need to be part of FEHRL or CEDR.

The original objectives of ELLPAG can be stated chronologically as short-term, medium term and long-term objectives.

- The short-term objective of the Group is to produce within 12 months of starting the formal project a State-of-the-art Review of current European knowledge on the design and maintenance of long-life fully-flexible pavements.
- The medium-term objectives are to produce similar state-of-the-art reviews for the other common pavement types.
- The long-term objective is to produce a user-friendly comprehensive Best Practice Guidance note on long-life pavement design and maintenance for all the common types of pavement construction used in Europe.

Since then, the Group has responded to a request from CEDR to produce interim best practice guidance within the Phase 1 Report.

In 2002, a proposal for a first phase of work undertaken by ELLPAG was approved by FEHRL and CEDR. Funding was secured from each of the core member's national road administrations to participate in this work and the main work for Phase 1 was carried out between September 2002 and August 2003. This document is the final report of Phase 1 that covers only long-life fully-flexible pavements. Other major pavement types are planned to be covered in subsequent phases of work as shown in Figure 1.1. Work on Phases 2 and 3 has also now been approved and Phase 2 has commenced.

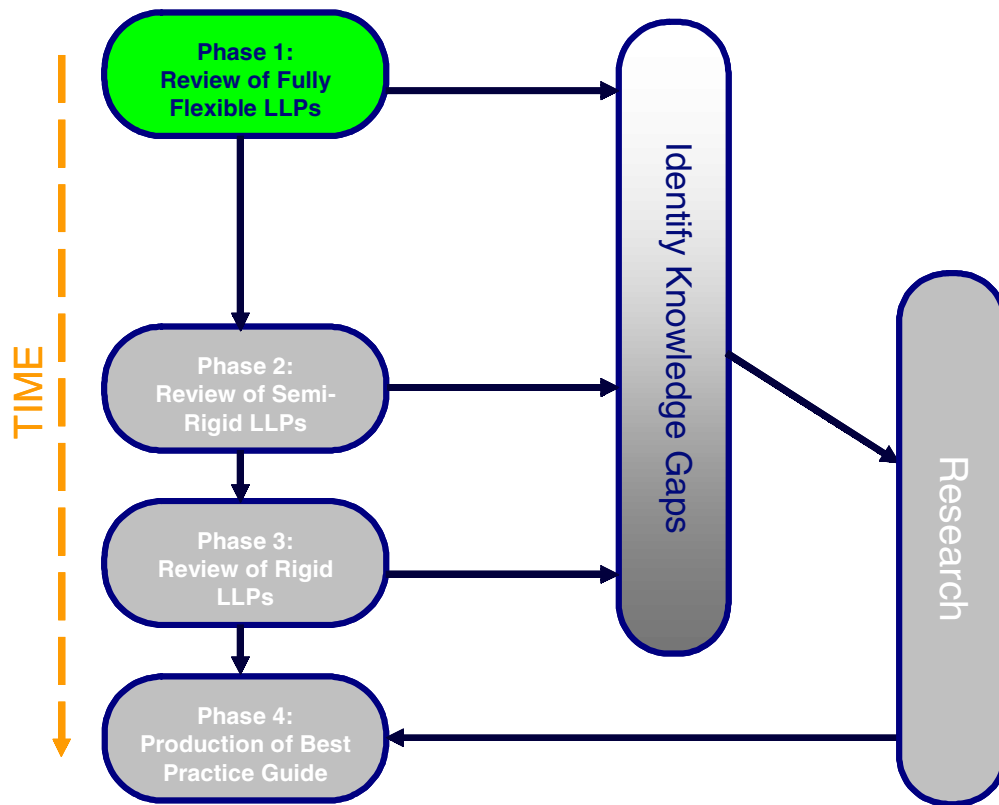


Figure 1.1. Plan for the flow of the work of ELLPAG

The work in this report has been sub-divided into six main areas which correspond to the main chapters of this Report: Definition, New Pavements, Assessment and Upgrading, Maintenance, Economic Analysis and Research Needs. The methodology combined reviews of existing documentation and contributions for each area by the core member participants. The tasks carried out to produce this report are listed in Table 1.1 together with the lead partner responsible for that task. A fuller list of the organizations is given in Appendix A. The following chapters and Appendices describe the outcome of these tasks.

Table 1.1 Phase 1 tasks and lead partners

Task Title	Lead Partner	Organization	Country
Technical Management	Brian Ferne	TRL	UK
Definition of Long-life Pavements	Michel Gorski	BRRC	Belgium
Design and construction of new Long-life pavements	Darren Merrill and Mike Nunn	TRL	UK
Assessment and upgrading of existing pavements to long-life	Arthur van Dommelen	DWW	The Netherlands
Maintenance of Long-life Pavements	Laszlo Gaspar	KTI	Hungary
Economic analysis	Jean-Claude Turtshy	LAVOC	Switzerland
Knowledge gaps and research needs	Hans Ertman Larsen	DRI	Denmark
Reporting	Brian Ferne	TRL	UK

2. Definition

2.1 Objectives

In creating Terms of Reference, the Group has to consider the scope of the meaning of long-life pavements. It is suggested that this should not be 'life' related but based on the concept that a long-life pavement is one that is heavily trafficked, and is designed and maintained such that no structural deterioration occurs in the main supporting layers of the pavement, whatever the traffic loading conditions given the current legal maximum axle load in each country. The only deterioration that occurs should be in the upper or surface layers of the pavement.

The main aim of this task is to produce a consensus definition of long-life pavements. This task is critical to the project and was performed at an early stage in the project prior to commencement of the other tasks. This task had to ensure that there is a consistency of approach within the working groups.

The task involved obtaining national definition of long-life pavements from each of the participating member's countries. From these definitions, and discussions, a consensus definition of a long-life pavement has been brought together and made available as a reference to all the members of ELLPAG. The definition of long-life pavements has been refined during the course of this project. This has led to a short statement of the definition of long-life pavements at the end of this chapter.

2.2 Contributions from national definitions

Two sources can be quoted which provide an insight and attempt definitions on LLP.

From the United Kingdom:

"Well constructed roads that are designed above a threshold strength will have a life in excess of 40 years. These roads are referred to as long-life roads." (Nunn *et al.*, 1997)

References for the pavement design charts (for new long-life pavements) are contained in the UK Design Manual for Roads and Bridges (DMRB 7.2.3)

Another quote from the UK addresses the Long-life fully-flexible pavements:

"Recent studies have shown that some thick well constructed fully-flexible pavements on strong foundations are not subject to road base fatigue cracking or structural deformation. Environmental mechanisms can cause cracking to develop from the surface which may not progress downwards into the road base layers. Furthermore deformation in these pavements also tends to be limited to the surfacing layers (i.e. is non-structural). By the timely removal of any cracked or severely rutted material and its replacement by new material, very long lives can be achieved.

These potentially long-life pavements are identified with deflection and thickness criteria. The structural condition of other flexible and flexible composite pavements is assessed in terms of residual life using a long established design method based on deflection and traffic loading”.

Further details on existing pavements that are likely to be long-life are contained in the UK Design Manual for Roads and Bridges (DMRB 7.3.2 and DMRB 7.3.3)

From the USA:

A tentative definition was given in a workshop on Perpetual Asphalt Pavements (TRB, 2002):

“These pavements have thick asphalt layers overlying sound foundations comprised of granular base and sub base materials or placed directly on a prepared sub grade. A conscientious process of design and construction formulated to preclude structural rutting and bottom-up fatigue cracking will result in a pavement system where the distresses are confined to the surface and easily maintained or corrected.”

2.3 Contributing elements to the definition from Group discussions.

The ELLPAG working group held discussions to identify elements which could be taken into account in an attempt to define the concept of long-life pavements so that these pavements could either be designed or identified on the existing road network.

It was noted that a definition could be approached from two points of view:

- A functional definition: Based on performance and economics (such as life cycle cost analysis).
- An operational definition (standard and prescription based): Relying on design, construction (materials) and maintenance.

Functional Definitions

Any definition should bear the possibility of being directly or indirectly observable: in other words, if the definition involves a causal relationship then either the cause (direct) or the effect (indirect) or both should be measurable (or identifiable). Observations should be reached by using any or all of visual assessment, surface measurements, structural performance evaluation, detailed field investigation, and/or laboratory testing. The conditions of measurement should enable one to discriminate surface only effects from structural effects bearing in mind that effects at surface level can be induced by structural inadequacies or limitations.

Identification also requires that a reasonable level of historical data is available, including pavement age, composition and periodic condition monitoring reports. It is also imperative that the traffic that has been carried by these pavements since construction be known to a reasonable degree of accuracy in order that the life predicted using current design

recommendations could be compared with the observed life. These conditions can also be used as criteria for site selection.

Operational Definitions

In the case of an operational definition, it is imperative that the critical calibration factors between measured performance, current pavement design procedures and material specifications are known. For example, the links between characterisation of fundamental properties of asphalt mixes and the in-service performance of flexible pavements should be established (design / performance).

If the definition should be based on a mechanistic design, the design would consist of providing enough stiffness in the upper pavement layers to preclude rutting and enough total pavement thickness and flexibility in the lower layer to avoid fatigue cracking from the bottom of the pavement structure. This is probably the way forward from the point of view of providing a solution to: new constructions / replacement construction / reinforcements.

An operational definition based on a threshold strength approach (Nunn *et al.*, 1997) should imply that well-constructed flexible pavement built above a threshold strength is expected to exhibit in the structural layer:

- fatigue,
- deformation.

provided that a defined maximum axle load is not exceeded.

In terms of economics, candidate long-life pavements can be compared to classical solutions in terms of life cycle costing taking care that the analysis period be appropriately related to the design life of the classical structure.

The definition should also consider which of the following alternative descriptions is most appropriate: Long-life / Long lasting / Perpetual / Heavy duty / Maintenance free.

2.4 Definition of long-life pavement concepts

ELLPAG favours the functional approach to the definition of long-life pavements. It has therefore defined long-life pavements on the basis of performance rather than on the basis of design with threshold criteria; moreover, it avoids any reference to life or total bearing capacity.

This definition is objective oriented; the objective being the persistence of the structure apart from the maintenance of the surfacing. In so doing it avoids the multiplicity of definitions based on different designs and their performance threshold criteria meeting the objectives.

The definition stated is not restricted to fully-flexible pavements but is expressed in such a way that it may also cover the composite (semi-rigid) and rigid structures.

Definition:

A long-life pavement is a type of pavement where no significant deterioration will develop in the foundations or the road base layers provided that correct surface maintenance is carried out.

This concise definition can be elaborated with the following clarification.

Deterioration: This includes whatever the network manager considers important e.g. significant cracking or (progressive) deformation in the structural layers of a fully-flexible pavement; for other types of pavement 'deterioration' could be quite different.

3. Design and Construction of New Long-Life Pavements

There are two methods of creating long-life fully-flexible pavements: construction of an entirely new structure from the formation level upwards or upgrading of an existing structure so that it has the characteristics of a long-life pavement. This section comprises a review of information regarding the design and construction of entirely new long-life fully-flexible pavement starting at the subgrade layer. The purpose of the review was to determine how long-life pavements are designed and to obtain knowledge of other design and construction practices which may assist in the production of long-life fully-flexible pavements.

COST Action 333 was entitled 'Development of a new bituminous pavement design method'. A detailed review of European bituminous pavement design was carried out for this action (Nunn and Merrill, 1997). The data contained in the review were revisited in order to extract information that would support the work of ELLPAG.

A focussed view of the state-of-the-art in long-life pavement design was obtained from ELLPAG members and also a selection of European pavement design standards. In particular, the range of design periods and design traffic used throughout Europe was assessed. Special treatments of specific layers were identified for design periods that are longer than 20 years and for conditions of heavy traffic; special construction practices and novel design details were also collected.

ELLPAG members were asked to submit pavement designs for the most heavily trafficked conditions in their native country; in some cases these designs could be considered to be long-life pavements. As well as assessing the range of asphalt design thickness for heaviest traffic conditions, the stated thickness appeared to follow a general trend enabling some inferences on this trend to be drawn.

3.1 Review of COST Action 333

COST Action 333 contained a detailed survey of flexible and flexible-composite design methods in 22 European countries (COST, 1999). This review has been revisited as part of the work of ELLPAG to determine which countries, if any, have designed fully-flexible pavements that could be considered to be long-life pavements at the time of the survey and what features of the design method are applicable to long-life characteristics.

The survey was based on a detailed questionnaire supplemented with information provided by the participants in the Action. The respondents were asked to state the nominal design period for the heaviest traffic levels in their country. Figure 3.1 shows that the majority of the responses to this question were 20 years. Only Romania and France stated alternative design periods of 15 and 30 years respectively.

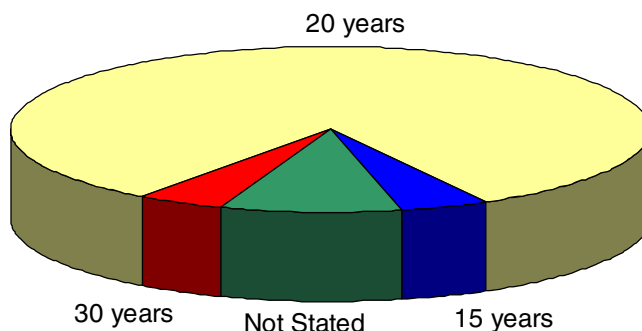


Figure 3.1. Stated Nominal Design Periods in European Countries

Further to the information supplied with the questionnaire, a more elaborate description of each country's design method was provided. Within these descriptions, the authors supplied more information on the design period that is used in the method. Some authors did not state a design period. Only the UK explicitly stated that their pavements are designed for 40 years where it is economically viable to do so. Portugal nominally uses a 20 year design period although the design guide encourages a 40 year economic analysis period to determine the most appropriate design life.

Nine out of the twenty-two European design methods that were reviewed have design periods which depend on either the materials or the type of road being considered. Furthermore, the majority of countries base their design periods on economic considerations.

Typical fully-flexible pavement designs were provided for 1, 10 and 100msa₈₀. For the purpose of the work of ELLPAG, the designs of most interest are likely to be those provided for the most heavily trafficked roads (100msa₈₀). For this level of traffic only fourteen of the twenty-two countries involved in the survey provided designs; some countries do not design for a level of traffic at 100msa₈₀ simply because such levels of traffic are not experienced in their country. This suggests that long-life pavements may not be appropriate in all countries.

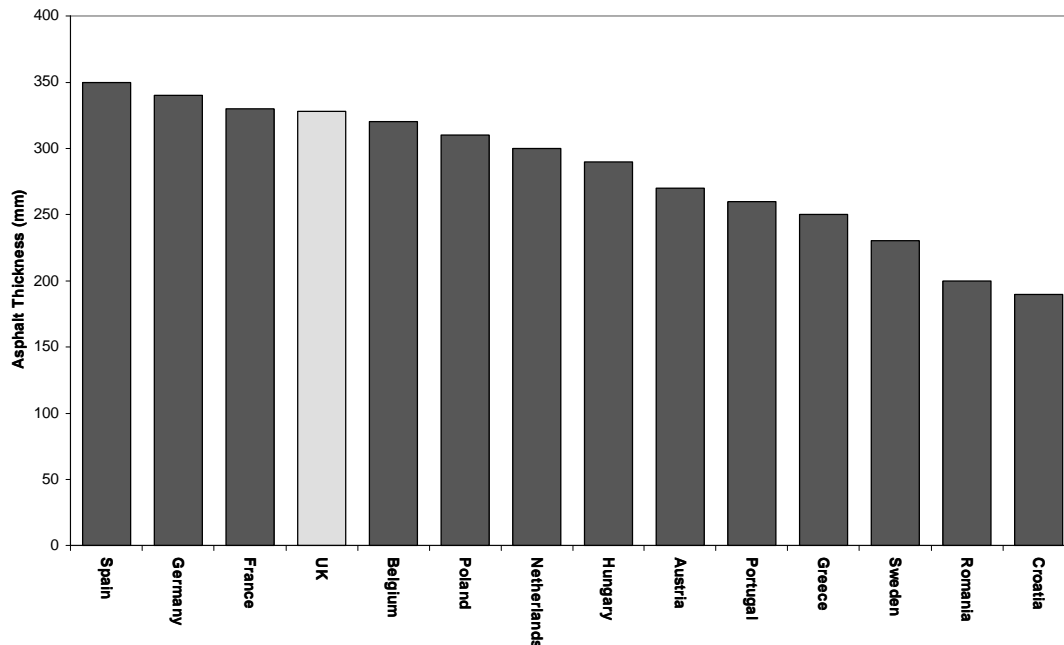


Figure 3.2. Asphalt design thicknesses for 100msa₈₀ design traffic

The 100msa₈₀ designs provided had an average asphalt layer thickness of 295mm and ranged from a minimum of 195mm to a maximum of 350mm. Figure 3.2 gives the design for each country ranked in order of asphalt thickness; however it does not fully explain the differences in traffic loading and materials used in each country. It is clear that many countries design thick asphalt pavements, many above 300mm. The UK design (330mm) is highlighted because it is the only design in this group that is explicitly a long-life pavement design. Germany is widely known to construct fully-flexible pavements with an indeterminate life and the asphalt layers stated in the survey are 340mm thick. Other countries have provided asphalt designs which are of similar thickness to, or even exceed, those provided by both the UK and Germany.

Figure 3.3 gives a Europe-wide impression of the significant forms of deterioration in fully-flexible pavements; the respondents were asked to individually rank the significance of a number of modes of deterioration. Surface related deterioration including non-structural rutting, loss of skidding resistance and surface cracking predominated whilst modes of structural deterioration such as cracking initiated at the bottom of the base and rutting in the subgrade were rated as less significant.

Long-life pavements are expected to experience deterioration in the surfacing rather than structural deterioration deeper in the pavement. The fact that surface related problems predominated in this review strongly suggests that pavements with these characteristics were in operation at the time of the survey.

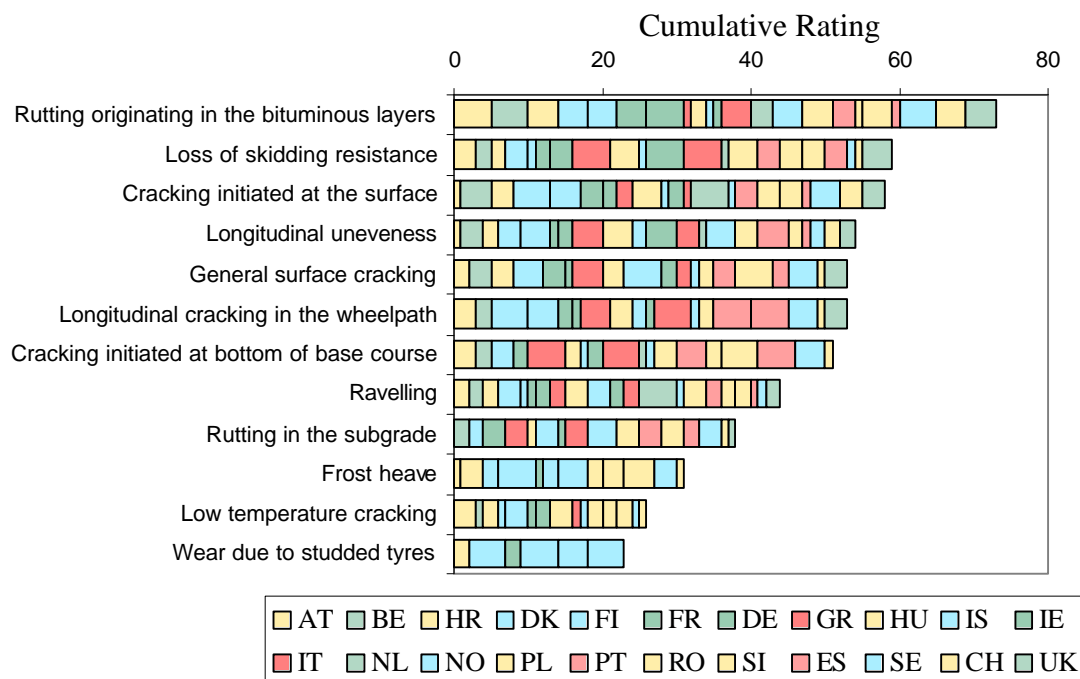


Figure 3.3. Rating of observed deterioration in flexible pavements

In Figure 3.3 each country used a scale from 0 to 5 where a rating of 0 meant that the deterioration was "Irrelevant", 1 meant - "Occasionally occurs" and 5 meant - "Major determinant of maintenance". Of the forms of deterioration listed in Figure 3.3, rutting in the subgrade and cracking initiated at the bottom of base are not expected in long-life pavements. The following countries gave ratings of 1 or less for both these forms of deterioration: Croatia, Denmark, Germany, The Netherlands, Switzerland and United Kingdom. Of these six countries, two countries did not declare designs for 100msa₈₀ design traffic and three countries declared a design thickness of at least 300mm as shown in Figure 3.2.

Based on this analysis, at least these six countries in Europe rated the forms of deterioration associated with determinate life pavements as insignificant. It is therefore likely that long-life pavements already exist in these countries.

3.1.1 Summary of European Experience of Long-Life Pavements after Cost Action 333

The COST review found that most flexible pavements in Europe are designed for a nominal period of 20 years. However, the design period can be subject to change for economic reasons. France constructs its pavements for a 30 year life. Both Portugal and the UK acknowledge that a 40 year design life can be justified for economic reasons in some circumstances. Germany does not state that it uses a design period nor does it state any terminal condition for its pavements.

Non-structural forms of deterioration, that are a characteristic of long-life fully-flexible pavements, were rated as much more significant than those forms of deterioration associated with traditional pavements.

Given that the review recorded that pavement designs were available for heavily trafficked situations and that non-structural modes of deterioration are the most significant forms of deterioration in existing pavements, it is likely that the design of long-life fully-flexible pavements may be easily achievable in many countries, indeed long-life pavements may already be in-service in some countries.

3.2 Review of Existing European Design Methods for Long-life

The ELLPAG members were consulted on their view on the design and construction of long-life fully-flexible pavements and/or fully-flexible pavements designed for the heavy traffic situations.

To supplement these questions, a small number of countries were identified as having specific pavement design factors that are likely to result in long-life pavements. The official design documents for these countries were reviewed and the design aspects that may be connected to long-life pavements highlighted. Three design documents were reviewed: The French Design Manual for Pavement Structures (Setra-LCPC, 1997); The German Guidelines for the Standardisation of the Upper Structure of Traffic Bearing Surfaces (RStO, 1986) and the UK Design Manual for Roads and Bridges (The Stationery Office, 2004).

The information collected in this review has been organised into the different facets of the design and construction of new pavements: design period, design traffic, the design of the pavement layers, climatic factors, construction practices and other considerations.

3.2.1 Design Period

The majority of European fully-flexible pavement design methods use a maximum design period of 20 years. Some countries are adopting longer design periods and acknowledging that pavements can last for longer than 20 years without structural maintenance as shown in Figure 3.4.

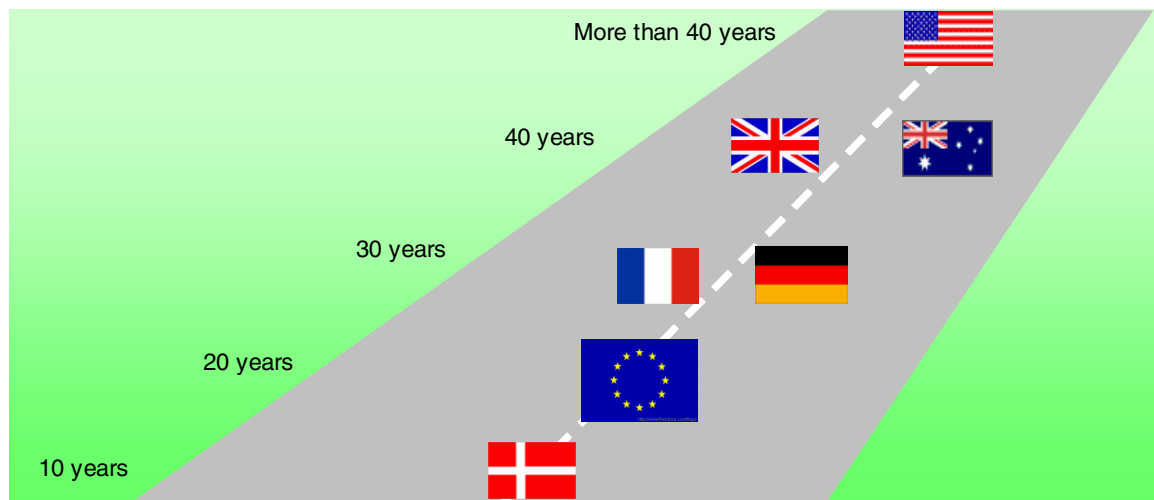


Figure 3.4. Design periods in use (European Union Flag illustrates typical European Standard Design Period)

The nominal design life in France is 30 years; however, other lengths of design period can be accommodated within an analytical design procedure. The life of the pavement construction is decided according to an economic strategy. Economic analysis is usually carried out over 30 years (this period is often 40 years on privately run motorways). These periods are typical although the design manual advises that economic analysis can be performed for periods of up to 50 years. The design period is referred to in the French design manual as the 'Initial Duration' and during this period there should be "no structural maintenance in the intervening period, that the deterioration in the pavement would be such as to require strengthening work tantamount to a full-scale reconstruction of the pavement" (SETRA-LCPC, 1997).

In the Netherlands, fully-flexible pavements are designed for an initial 20 year period. National experts anticipate that these pavements will have a low incidence of fatigue even when the age of the pavement is greater than 20 years. These pavements can be overlaid so that in practice they never reach a structural failure condition.

The design period of flexible pavements in the UK is either 20 or 40 years. Provided that these pavements are well constructed, fully-flexible pavements designed for 40 years and for traffic in excess of 80msa_{80} , should be considered to be long-life pavements as defined by Nunn *et al.* (1997). The design traffic for 40 years is determined in a similar manner to that of a 20 year life with enlarged traffic multipliers to account for the greater growth in traffic over the extended period.

Historically, the AASHTO design periods ranged up to 40 years (AASHTO, 1993); however within the Perpetual Pavement concept (TRB, 2001) the notion of design period is less significant.

A design period is not defined for flexible pavements in the German pavement design method; instead there is a "useful life" of 20 years. Pavements are designed according to the number of daily weighted-average passages of commercial vehicles in a single traffic lane mid-way through the useful life. The useful life simply sets the date to which the daily traffic is projected. Useful life does not determine the cumulative number of loads that will

be applied to the structure. The level of traffic loading determines one of seven pavement construction classes (labelled SV, I to VI).

3.2.2 Design Traffic

Table 3.1 shows the maximum level of design traffic for each national design method declared in the ELLPAG questionnaire responses; these are also expressed in terms of equivalent 100kN standard axles. Initially there appears to be a wide variation in maximum design traffic in each country whereas designs that have been offered from each country for these loadings are often similar. However, much of the variation originates from differences in the reference standard axle, the exponent of the load equivalence relationship and the legal maximum axle load in each country.

Table 3.1 Stated Maximum Design Traffic in each country

	Reference Standard Axle (kN)	Maximum Design Traffic (msa)	Highest Traffic Category (msa ₁₀₀)	Design Period (years)
Austria	100	25	25	20
Belgium	100	128	128	20
Denmark	100	5.5	5.5	10
Finland	100	10	10	20
France	130	75	215	30
Germany	100	>32	>32	30
Greece	130	44	126	20
Hungary	100	22	22	20
Italy	80	68	28	20
Norway	100	10	10	20
Poland	100	15	15	20
Sweden	100	19	19	20
Switzerland	80	73	30	20
USA	80	200	82	40
UK	80	500*	205	40
Netherlands	100	-	-	20

* The design curve is truncated at 80msa₈₀ but extends up to 500msa₈₀.

Expressing the maximum design traffic in each country in terms of equivalent 100kN standard axles produces a very wide range of values. However, a crude analysis of the actual traffic flows in Belgium, France and the UK can show that the picture is in reality rather different and characteristic flows vary much less.

The crude analysis defined characteristic vehicles that represent the national traffic conditions; these characteristic vehicles were 5 axle articulated heavy goods vehicles, loaded to an axle load at 85% of the national maximum legal axle load. The highest traffic level in France is 75 msa₁₃₀, over a 30 year period this equates to a flow of 10,000 characteristic vehicles per day. In Belgium, the maximum design traffic is 128msa₁₀₀ over 20 years, which equates to a flow of 8,000 characteristic vehicles per day. In the UK, the design curves extend up to 500msa₈₀ (although the thickness is truncated at 80msa₈₀), 500msa₈₀ over a 40 year design period also equates to a flow of 8,000 characteristic vehicles per day.

The wide range of maximum design traffic in Table 3.1 appears to correspond to a much smaller range of actual flows. The subsequent pavement designs shown in Figure 3.5 for Belgium, France and the UK are similar at the maximum traffic levels. The suitability of the load equivalence concept for thick, heavily trafficked flexible pavements is therefore questionable; this fundamental point is worthy of further investigation (See Section 8).

The French pavement design method contains both traffic classes and a method of computing design traffic from heavy vehicle flows. The traffic classes are a simple method for assigning the suitability of certain constructions and materials, while detailed traffic calculations are required to set the pavement design thickness. Detailed traffic calculations are made using the flow of heavy goods vehicles over the initial design period (with a growth factor) and a co-efficient of aggressiveness (average vehicle wear factor).

In Germany, the design traffic relates to a daily flow mid way through the useful life and so cumulative design traffic levels are not required (see Section 3.2.1).

In the UK, pavement thicknesses are capped at a design traffic level of 80msa₈₀ (33msa₁₀₀) for standard designs above this level, pavements are said to be designed as long-life pavements. While the design traffic is determined from the flow of commercial vehicles, expressed as commercial vehicles per day, there are notable shifts in the curve that add safety factors depending on the proportion of very heavy goods vehicles in the traffic flow.

For the perpetual pavement concept from the USA (TRB, 2001), the design traffic will be specified in terms of traffic counts (or flows) rather than cumulative traffic. However, the equivalent design traffic over 40 years is said to be approximately 200msa₈₀ (82msa₁₀₀).

3.2.3 Design of Pavement Layers

Each of the layers of a long-life pavement contributes to the overall performance of a long-life fully-flexible pavement. The following section reviews the requirements for each of the main pavement layers; it highlights the requirements for long-life pavements and also where other additional requirements are made to specifically improve the performance of the pavement as a whole.

3.2.3.1 Subgrade and formation

The subgrade and formation provides the underlying support to a long-life pavement. It is therefore essential that the performance of these layers is sufficient in order that the overlying pavement layers can fulfil their role. The performance of the subgrade and formation can be controlled by setting requirements for minimum stiffness, minimum strength or increased thickness of capping. Special considerations can be undertaken by the use of classes.

Austria requires that the modulus of the subgrade should be at least 35 MPa, when measured by a static plate loading test. Germany also requires that the formation at all sites should have a minimum modulus of deformation, in this case greater than 45 MPa; however there are no special long-term or traffic related requirements on the subgrade. In Hungary, there are minimum criteria for the bearing capacity of the subgrade and formation layers; for the heaviest trafficked pavements a stiffness of 80 MPa is required.

The design of the formation in the French method is based on determining a pavement formation class (PFI). The PF class is obtained based on the type of subgrade or "arize"

type (AR class). A PF3 formation, which should have a modulus of deformation in excess of 120 MPa, is required for heavy traffic conditions in excess of 14 million heavy goods vehicles. Such a requirement is rarely satisfied using granular materials and some form of stabilisation of the subgrade is usually required. The formation in the French pavement design method can also be considered to be the foundation as defined in Appendix B.

In Greece, the heaviest trafficked pavements must include a capping layer in excess of 7% CBR.

For heavily trafficked routes, the Dutch design guide recommends at least a one metre sand-capping layer. This is not a formal requirement and often thinner capping layers or other materials are used.

In the UK, the concept of an equivalent foundation plays an important role in the design of the formation for all pavements. Therefore there are no special long-term or traffic level requirements on the subgrade for long-life pavements.

3.2.3.2 Pavement Layers

The pavement layers can be engineered for long-life characteristics. Among the approaches encountered are the restriction of the use of certain materials for high levels of traffic, improved foundation support, the deduction of a limit strain whereby structural deterioration does not occur and special bituminous mixes that are designed to reduce structural deterioration.

The French design method restricts the types of materials that are used in the subbase layer for certain classes of traffic. Generally, as traffic level increases, the quality required of the subbase increases. Unbound granular materials are only permitted for subbases to traffic class T3 (up to 150 heavy commercial vehicles per day); hydraulically bound subbases and bases are quite extensively used in France. For granular materials, the method makes little distinction between subbase and base with similar methods and requirements made for each. For traffic greater than Class T3, a higher quality gradation is required in the asphalt layer and must it attain a superior, long-term mechanical performance class. Moreover, for the heaviest traffic class a minimum asphalt quality is allowed, although asphalt with increased binder is advised.

The German pavement design method requires the modulus of deformation of the subbase layer to be a minimum of 150 MPa for construction class IV and superior classes, whereas for Classes V and VI the minimum requirement is lower at 120 MPa. The bituminous base thickness can be reduced by 20mm provided that the modulus of deformation of the subbase layer increases from 150 MPa to 180 MPa and from 120 MPa to 159 MPa respectively. A modulus of deformation requirement of 120 MPa also exists for the heaviest vehicle category in Poland.

For the heaviest traffic categories (SV, I, II) in the German design method, the thickness of the surface course must be increased from nominally 35mm to 50mm; this enables a corresponding reduction in the binder course from 80mm to 70mm. In special circumstances, a surface course thickness of 40mm may be used provided that lower layers are adjusted so that the total thickness of the bituminous layer is maintained.

In the UK, the thickness of the subbase layer is determined from the strength of the material at formation. The foundation of a long-life pavement must provide good support throughout its service life; therefore the foundation should include good drainage in its design. The design of the asphalt layers is currently based on four standard asphalt types

and the thickness of the asphalt layer is chosen so that both fatigue and subgrade strain criteria are satisfied in an analytical design method. For these standard pavement types, a threshold thickness has been determined where structural deterioration is unlikely to occur; this thickness has been determined for the 80msa₈₀ level. Only the standard designs included in Nunn *et al.* (1997) and the UK Design Manual for Roads and Bridges (DMRB 7.2.3) can be officially referred to as "long-life pavements"; however other more novel designs are permitted within the long-life design concept provided that they can be demonstrated to be comparable to the standard designs.

The perpetual pavement concept (TRB,2001), that was developed in the USA, utilises a more fatigue resistant asphalt layer at the bottom of the bound layers together with a polymer modified asphalt layer placed immediately underneath the surface course to prevent deformation. Additional fatigue resistance is achieved by the addition of 0.5% of asphalt binder in the mixture. The use of polymer modified binders is also specified for heavy traffic conditions in Belgium.

3.2.4 Construction Practices

The design and construction of long-life fully-flexible pavements could be influenced by special construction practices that ensure a better or more consistent product. The construction of all pavements is subject to the clients' specifications. However this review has uncovered some situations where changes have been made to the specification specifically to improve construction practice.

For heavily trafficked routes, the production of asphalt in France is particularly closely controlled; however there is no specific construction provision for these routes.

There is an increasing emphasis on the degree of asphalt compaction in Australia and a target level of air voids of less than 7% is now commonly specified.

In the UK, there is a drive towards end-product performance specification for the pavement layers and the foundations. Two such specifications (MCHW series 900) are already in common use; one for bituminous surfacings and the other for bituminous bases. Further specifications for the foundation layers are under development.

3.2.5 Other Considerations for Long-Life Pavements

The most common climatic factor accounted for in the design of heavily trafficked pavements is frost. This is accounted for in the pavement design methods of Austria, Belgium, France, Hungary, The Netherlands, Poland and the UK. These requirements generally apply to all types of pavements.

A number of countries reported that many of their fully-flexible pavements do not appear to suffer from structural deterioration. Meanwhile, non-structural deterioration in form of deformation within the asphalt layer and cracking may call for periodic replacement of the surfacing. In Norway, the dominant form of deterioration is wear due to the use of studded tyres. Recent reductions in the wear of the surfacing layers have been achieved through restrictions on the use of these tyres.

Work is being carried out in the Netherlands to enable the use of materials with a high fatigue resistance such as EME (Enrobés à Module Élevé) and to optimise the benefits of

using such materials for the whole pavement construction. Current policy is to allow a maximum reduction of 50mm asphalt thickness when EME is laid in the heaviest trafficked lane. This reduced thickness is then maintained across other less heavily trafficked lanes that are constructed with standard asphalt materials.

In the Netherlands, the placement of longitudinal joints outside of the heaviest traffic lane is viewed as a method of maximising the structural life of pavements. However, it is acknowledged that future maintenance such as pavement widening and realignment could affect the placement of these longitudinal joints.

3.2.6 Summary of the ELLPAG Design Review

Many countries permit the design of fully-flexible pavements for periods in excess of 20 years including France, Germany, The Netherlands, Hungary, USA and the UK.

For heavily trafficked pavements, design traffic can be expressed in a number of ways: traffic classes, cumulative traffic (with or without a capped level) and traffic flows derived at a certain time in the life of the pavement.

In general, no special provision has been found for the treatment of the subgrade or formation for long-life pavements. Some countries require a minimum bearing capacity from the formation while others require a specific strength of formation. Other methods of defining the formation include using classes of support and the specification of minimum capping thickness.

One national design method requires a superior modulus of deformation for the foundation or subbase layers for the higher traffic levels and also allows for the thickness of the asphalt layer to be reduced by up to 20mm for superior quality foundations. Another method requires the quality of the subbase layers to increase with increasing traffic level.

Some countries apply special instructions for the design of asphalt layers for the heaviest traffic categories; these instructions can affect all layers including special surfacings and fatigue resistant lower layers. One country applies a maximum thickness that has been defined based on a notional threshold strain below which structural deterioration is unlikely to occur. Traffic classes can be used to apply particular specifications and asphalt material types for different traffic levels.

In general, frost is the main climatic factor which is accounted for although there are no special considerations of climatic factors for long-life pavements.

Some countries require improved quality or quality control for their heaviest trafficked pavements. Recent developments noted were additional requirements on asphalt compaction and the introduction of end-product performance specifications.

3.3 Example Pavement Designs

The members of ELLPAG were asked to submit suitable fully-flexible pavement designs for the most heavily trafficked conditions covered in their country's design method. The designs for maximum traffic as well as a heavy traffic threshold were requested so that

pavements could also be compared that were not explicitly labelled as long-life type pavements, but the behaviour maybe consistent with the definition of long-life pavements given in Section 2.

The designs in Figure 3.6 that are considered to be consistent with the definition of long-life (labelled 'designs for a heavy traffic threshold') have a total thickness of between 310 mm and 340 mm; the average thickness for these three designs is 325mm. For the design from the USA, the lowest 75mm of asphalt is a fatigue resistant layer.

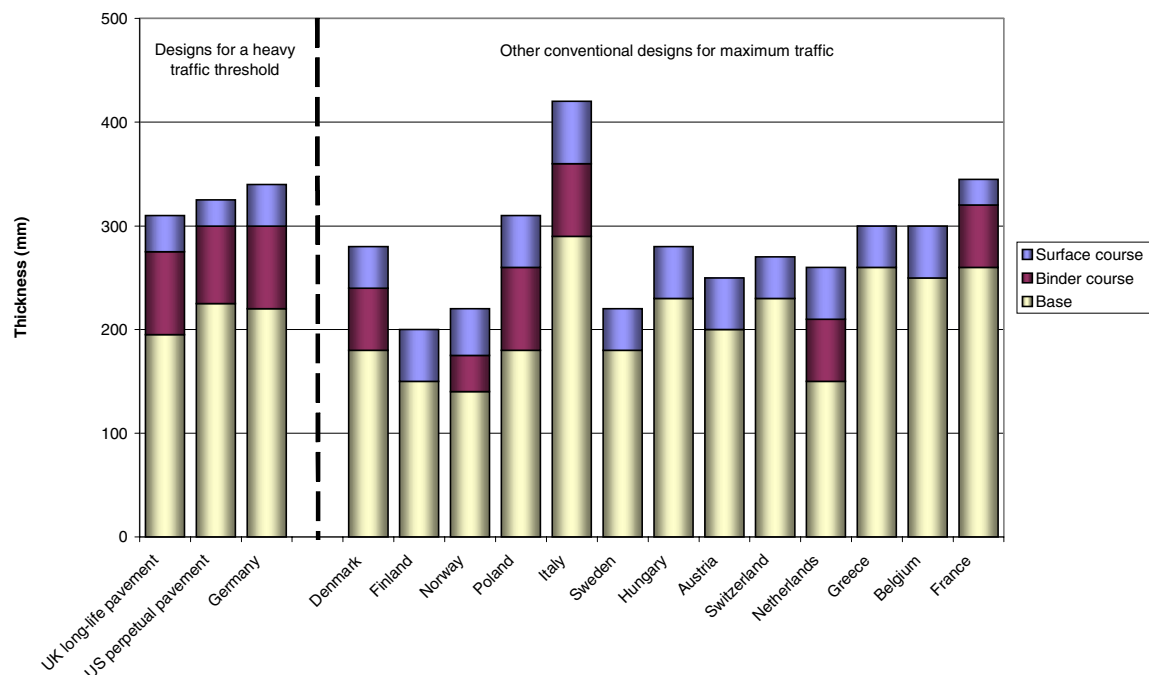


Figure 3.5. Pavement designs for national maximum design traffic levels

The total thickness of the designs in Figure 3.5 ranges from 185mm to 420mm, whereas the designs for a heavy traffic threshold ranged from 310mm to 340mm. In Figure 3.5, the lack of a defined binder course in a pavement design does not imply that such a layer is not used.

Figure 3.5 shows that some countries have the potential to produce pavements that are similar to, or even exceed, the thickness of the designs labelled long-life designs. For some countries, thick designs are required to account for particular national traffic conditions whereas for others the construction of long-life pavements may be possible with only a small change to the current design and construction standards.

The designs in Figure 3.5 for the maximum traffic conditions have been ordered from left to right in terms of increasing design traffic (equivalent 100kN standard axles). The design traffic declared for these designs ranged from 5.5 msa₁₀₀ to 215 msa₁₀₀. As expected the thickness increases with design traffic, as shown in Figure 3.6.

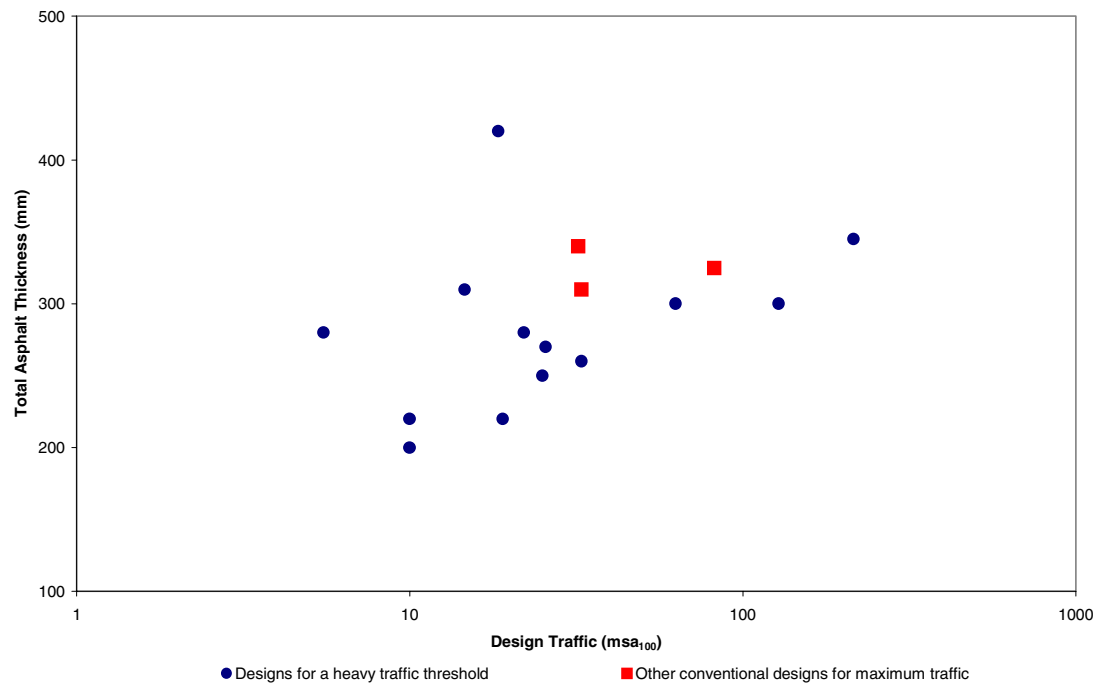


Figure 3.6. Relationship between design traffic and total asphalt thickness

Figure 3.6 shows that there is a relationship between asphalt thickness and design traffic across Europe. Pavement designs for a heavy traffic threshold are shown as red squares in Figure 3.6; these are slightly higher in general than the other design thickness but do not appear to be strongly correlated with the design traffic.

3.4 The Preferred Way Forward

The contributors to the review of the design of new long-life fully-flexible pavements were asked to express a preference for a basis for developing long-life fully-flexible pavement design methods. The choices offered were:

- The extrapolation of current design curves (thicker pavements using conventional materials),
- The recognition that above a certain strength (threshold strength), pavement wear does not accumulate,
- The use of improved materials and/or design to prevent the expected modes of deterioration occurring (e.g. use of an anti-fatigue layer as the lower base layer).

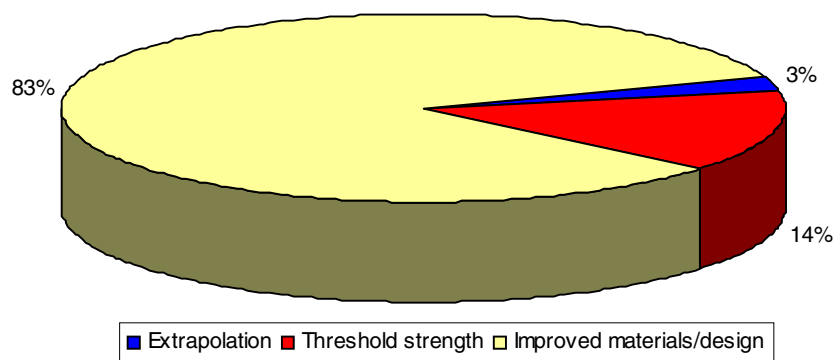


Figure 3.7. The preferred way approach to developing a long-life design method

As Figure 3.7 shows, there is a strong preference for the development of a long-life fully-flexible pavement design method using improved materials and/or preventing expected modes of deterioration occurring.

This preference concurs with methods of extending the life of a pavement structure which are currently under development in many countries. A common approach is to employ high modulus asphalt with polymer modified binders for such purposes with a view to improving pavement stiffness and fatigue life. However, one respondent advised the need to acknowledge the function of different layers under different conditions; for heavily trafficked routes, stiff lower layers are attractive and stone skeleton surfacing material would be preferred using a polymer modified binder whereas for lower volume roads, a high binder content/low void material could provide durability. Such material or improvements in design could indeed result in future pavements exceeding some threshold strength.

3.5 Conclusions

There is a large variation in what is considered to be the maximum traffic level in each country. This is due, in part, to the term maximum design traffic. For some countries a maximum design traffic reflects the actual maximum traffic on the network; for others, it is simply the maximum traffic that has been defined for standard design charts. However, amongst countries with design traffic greater than 100msa₁₀₀, the representative daily flows of commercial vehicles are similar as were the pavement designs that were supplied for the maximum traffic level despite the design traffic, in terms of standard axles, varying by a factor of two. This comparison questions the suitability of the load equivalence concept for thick, heavily trafficked pavements; this fundamental point is worthy of further investigation (see Section 8).

In terms of deterioration, a large number of countries reported forms of deterioration in thick, fully-flexible pavements that are consistent with the forms of deterioration expected in long-life fully-flexible pavements. The information extracted from the COST333 review of pavement design suggested that at the time, fully-flexible pavement that behaved like a long-life pavement were likely to be in-service in many European countries.

By examination of the construction of pavements and the deterioration that is occurring in particular countries, lessons can be learnt in order to produce explicit long-life pavement design methods that are consistent with a particular country's construction standards.

More recently, the concept of constructing long-life pavements has been explicitly addressed in a number of countries, most notably in the UK and the USA. Other countries are also designing pavements for long periods without structural maintenance.

The classical terminology surrounding pavement design such as design life, terminal condition and design period is being challenged by the concept of long-life pavements. Some methods have rejected some or all of these terms, concentrating instead on traffic intensity and the future maintenance needs of the pavement so that structural deterioration does not occur.

Many examples exist of particular treatments to different pavement layers for long-life or heavily trafficked situations. Overall there is an understanding that measures may be required for these situations that are not simply an additional thickness of asphalt and that a long-life pavement may not be easily by simply extending the design period. Along with special treatment of the pavement layers, some methods now require that designs for heavily trafficked pavements are also constructed with improved quality control.

Owing to the small number of methodologies that use a threshold level of heavy traffic for design, an overall view on how the design of 'long-life' fully-flexible pavements could be achieved, was not deduced except for the idea that the asphalt layer should have a thickness in excess of 300mm. However, there are some elements of 'long-life' design that can differentiate it from conventional pavement design:

- The discrimination of conditions where pavements that do not structurally deteriorate are economically attractive, usually described by some threshold level of traffic.
- The design can be independent of a design period and a level of design traffic.
- Once constructed, structural deterioration is not expected to occur.

- The foundation is designed to provide good support throughout the service life of the pavement.
- Special treatments of the pavement layers can be employed to reduce the risk of structural deterioration.
- A long-life pavement should be a well constructed, high quality pavement; therefore, good construction practice should be carried out.

Some countries are already employing long-life designs that are not expected to structurally deteriorate whereas other countries are building similar designs but anticipated that structural maintenance will be required after the design period. In some cases this difference in expected performance may be due to differences in traffic loading or environment but in others a clearer understanding of why some pavements do not require structural maintenance (in other words long-life pavements) would lead to much more efficient pavement design.

3.6 Best Practice

This best practice guidance does not set out to prescribe how to build new long-life pavements; more simply it suggests a route to the production of long-life design methodologies and construction standards. There are five steps to this best practice guidance for new long-life fully-flexible pavements:

1. Determine how existing fully-flexible pavements perform.
2. Diagnose the cause of good or bad performance.
3. Update the design method or construction standards as required.
4. Adopt these revised methods and standards.
5. Monitor the benefits from these changes.

One of the fundamental elements of the route is to be aware of how the fully-flexible pavements are performing. A range of existing fully-flexible pavements should be identified and their performance assessed. It is important to assess whether these pavements are achieving their design lives and if so, by how much have they outlasted their expected life. These assessments should also record any observed deterioration. Such a process could observe the following aspects:

- The quality of the pavement surface and user characteristics such as ride quality.
- The level of traffic incurred by the pavement.
- The climate within which the pavement has served.

The key difference between conventional and long-life pavements is in the manner in which they are expected to deteriorate. It is therefore important to understand how in-service pavements are deteriorating. It is necessary to determine which types of fully-flexible pavement have a low risk of structural deterioration and which types have a higher risk. In addition, a detailed examination of the deterioration that is actually occurring can explain the aspects of the design method or construction standards that are connected to long-life pavement characteristics. Structural deterioration can be indicated by such observations as:

- Cracking that is evident on the surface of the pavement penetrating more than 100mm deep.
- Significant rutting that is not confined to the surfacing layers.
- Other deterioration in the base layers or foundation layers.

The potential economic benefits of the adoption of new long-life pavements should be assessed prior to the adoption of long-life pavement design methodologies. If there are potential benefits, it will be necessary to make changes to the design and construction standards. These documents should be reviewed, taking into account aspects of the design methods connected to long-life pavement characteristics. Changes can then be proposed to these documents which will make a perceivable impact by enhancing the performance of pavements and harnessing the full economic advantages of long-life pavements.

It may be a considerable period of time after the production of a long-life pavement construction methodology for a full review to be conducted of the actual impact of the changes made to design methods and construction standards. However, the review stage is an important part of the best practice process. Such a review could be a long-term continuous monitoring programme or an agreed monitoring stage at some time in the future.

A key benefit of long-life pavements is that, for some situations, they offer better value for money in terms of whole-life costs. The relative economic benefits of long-life pavements vary in time and are dependent on changes in construction costs and other external economic constraints. Therefore the monitoring step should be an on-going process that should include an assessment of the financial benefits of the changes in order to maximise the benefits that long-life pavements can offer.

3.6.1 Examples of Best Practice

In the UK, a series of studies on the performance and deterioration mechanisms occurring in heavily trafficked fully-flexible pavements were undertaken. The results of these studies indicate that many flexible pavements outlasted their nominal design life of 20 years and the deterioration of these pavements was generally confined to the surfacing layers (Nunn *et al.*, 1997). This led to the idea of threshold strength for flexible pavements, above which only non-structural deterioration was expected. A revised set of design curves were proposed and the economic benefits of this methodology were assessed. This work showed that there were significant economic advantages to adopting a 'long-life' approach to design.

Similarly, the USA has acknowledged that generally, 'bottom-up' fatigue cracking is unlikely in thick asphalt pavements following state surveys and the Long Term Performance Programme (LTPP). The principle of 'Perpetual Pavements' is to harvest the economic benefits of long-life pavements by specifically managing the risk of structural deterioration. The risk of 'bottom-up' fatigue cracking is controlled through special fatigue resistant bituminous mixes. The risk of rutting is controlled by the use of special binder course layers. Currently several US states are developing design methods based on the 'Perpetual Pavement' principle; a more general national method is also under development.

4. Assessment and Upgrading of Existing Pavements to Long-Life

In addition to the creation and construction of new long-life pavements, long-life pavements can be found within the existing road network. This chapter is a review of the techniques for the assessment of in-service pavements that are potentially long-life pavements and also the methods that could be used to upgrade pavements in order that they can be considered to be long-life pavements. The information on which this review is based was provided by the members of ELLPAG. Some conclusions on these different practices have been drawn and preliminary guidelines of best practice have also been suggested, based upon the opinion of the author and discussion within the ELLPAG group.

In general, “assessment” of pavements means determining their properties. In this review, assessment relates to the determination of the structural properties which are usually translated into a residual life or a need for strengthening. A special case of assessment is to determine whether a pavement is expected to be free of structural deterioration in the future i.e. having long-life characteristics.

Although “upgrading” of pavements generally means improving the properties of the pavement, in this context it relates to the improvement of the structural properties so that further structural deterioration is not expected which usually means repairing and/or strengthening the pavement¹.

4.1 Assessment

Further details of the assessment methods covered in this review can be found in Appendix C.

4.1.1 Assessment levels

The assessment of pavements is carried out on two levels: network and project level. The network level assessment is intended to assess global national or regional budgets for maintenance, to allocate these budgets, to select maintenance sections and to prioritise the maintenance order of these sections. The project level assessment, which usually comprises more detailed analysis of the pavements which were selected for maintenance according to the network planning, is intended for diagnosis of the problem and selection of the appropriate maintenance treatment.

In the majority of cases the assessment methods provided by the members of ELLPAG are project level methods. Only Denmark uses the same method for both project and

¹ It can be disputed whether restoring the bearing capacity to its original level is upgrading, or whether upgrading means bringing the bearing capacity in a higher category. In the following paragraphs both are considered as upgrading.

network level; this is possible because the method is applied on the full network periodically, allowing a synthesis of the results to network level.

4.1.2 Assessment methods

Many methods exist to evaluate the structural condition of pavements. These methods can be categorised as follows:

- methods based upon deflections
 - comparing with threshold values / deflection classes
 - entering in (often empirical) deterioration models
 - using empirical relations between service life and deflections
 - translating deflections into Structural Number
- methods based upon stresses and strains
 - using asphalt strain criteria
 - using subbase strain criteria
 - using subgrade strain criteria
- methods based on judging back-calculated moduli
 - comparing back-calculated moduli against reference values
- methods based upon visual condition and structural information
 - assigning a structural value to each layer depending on layer type and thickness, correcting for visual condition of layer and, and combining layer values to give the Structural Number of the pavement

The review determined that methods from all these categories of methods are used in Europe. Some countries use methods from more than one of these categories and the methods are not always the official national approved methods, but are considered as best practice.

4.1.3 Summary of Structural Assessment Methods

Most structural assessment methods require deflections to be measured in the wheel path, knowledge of layer types and thicknesses, and visual condition data. Some methods require deflections in both wheel tracks and/or knowledge of past traffic carried by the pavement.

For the analytical methods, the criterion that is most commonly checked is the asphalt fatigue criterion; many methods also check the subgrade compression criterion. The subbase compression criterion is used in only one method. The methods using deflections or Structural Number obviously check these parameters directly.

The methods based on calculating stresses and strains in the pavement all aim to estimate values of residual life. In contrast, the methods based upon either deflections or some structural number are likely to be used to assess whether the pavement is adequate or otherwise and to directly calculate the required overlay. While the deflection-based methods usually use graphs that relate allowable deflection levels as a function of traffic load, these methods can also be used to give an indication of residual life.

Where residual life is calculated, the life usually refers to the remaining period until an overlay is necessary; however, in one European method the residual life means the residual time up to repairs plus overlays. Residual life does not refer to the remaining period until reconstruction is necessary in any method.

While most countries conduct assessments so that structural failures are avoided, only the UK has effectively adopted a long-life concept in the structural assessment of pavements; a method and criteria for identifying potential long-life pavements has been developed. Generally, structural maintenance is no longer considered the most significant operation on the primary road network in Europe.

In spite of the big differences in assessment methodologies, the assessment methods generally seem to underestimate the residual life of the pavement. It should be remembered that some methods do not compare the calculated residual life and observed pavement condition; therefore, in such cases this kind of statement could not be made.

At least for the methods that are based on stresses and strains, it should be remembered that these were often formulated more than 30 or 40 years ago. At the time of formulation, the traffic loading were considerably lower than today and consequently the pavement thickness was much thinner. These methods have been extrapolated to be applied on significantly thicker pavements; the experience collected in this review indicates that this extrapolation has lead to a mismatch between the results of the assessment methods and practice.

4.2 Upgrading

A number of upgrading techniques covered in this review are national guidelines but some other methods considered can be viewed as best practice. Some countries use more than one type of method for upgrading.

Those countries that use an assessment method based upon calculating stresses and strains usually use a similar method to derive an overlay thickness by iteratively calculating the stresses and strains so that some design criteria are met. The methods based on deflection usually give an overlay thickness direct from empirically derived charts; the method based upon structural number uses a similar method to determine the overlay requirements. Most methods provide an overlay thickness for a design period of between 15 and 20 years.

In some countries there is no correction of the calculated overlay thickness taking into account structural cracks. There reasons for this are:

- cracking already gives lower effective (back-calculated) moduli for the existing layers and will therefore automatically lead to a conservative overlay thickness.
- cracking is supposed to be repaired first prior to treatment by overlay.

Whilst some countries provide a correction of overlay requirements due to the presence of cracking, crack propagation analysis is not used for the determination of overlay thickness.

Badly cracked structures are either considered as unbound road bases or are fully reconstructed. These decisions are obviously related to the severity of cracking; however, the review did not determine objective criteria for such decisions. It is suggested that these decisions are largely based on the judgement of the engineer.

Only the UK effectively uses the concept of long-life pavements and has guidelines on how to upgrade a pavement to this condition (Appendix C contains a description of these guidelines). All other countries strengthen pavements that have insufficient residual life to survive for a finite number of additional years.

4.3 Conclusions

A set of assessment criteria has been developed by one European country to identify those in-service pavements that are potentially long-life based on deflection and thickness. Classical structural assessment techniques that estimate residual life based on deflection measurements are more widely used but often under-estimate the lives observed. Such a widespread disparity suggests that the classical techniques need to be reviewed. It could be that adopting the 'long-life' approach to the interpretation of the measurements could resolve some of these anomalies.

There may be a limit to the pavement strength that is required. Pavements that are strengthened could be considered as long-life pavements and may need no further strengthening. This possible existence of a threshold strength level can therefore be considered the main question, irrespectively of whether one follows a long-life strategy or a strategy of repeated strengthening.

Only one European country has fully adopted a "long-life" concept for assessment and upgrading of pavements which implies strengthening to a level where structural deterioration is no longer expected to occur. All other countries also aim to prevent the need for reconstruction, but repeated strengthening operations are used to achieve this. No country operates a deliberate strategy so that a pavement reaches a condition whereby reconstruction is necessary. Whilst most countries upgrade pavements using an overlay only, some countries allow for some repairs to the existing structure to be taken into account.

4.4 Best practice

The following advice for best practice in the assessment and upgrading of heavily trafficked pavements can be given:

- Always compare the calculated residual life and required overlay with the observed condition of the pavement.
- For thick pavements and good layer moduli, be prudent with strengthening treatments if the pavement condition appears to be considerably better than would

be expected from the assessment method. The pavement may be exhibiting long-life characteristics.

- If long-life characteristics are evident, further strengthening may be unnecessary. It may be preferable to plan another assessment to verify if the structural condition is stable rather than to overlay the pavement immediately.
- At a network level, if the pavement meets the assessment criteria for long-life as used in the UK, the pavement is likely to be free from structural deterioration and less frequent future structural assessments will be required.
- A method for upgrading a pavement to long-life based on deflection and thickness is employed in the UK. A pavement that is free from structural deterioration and has low deflections can be upgraded by means of a modest overlay that would enable the pavement to meet the associated long-life assessment criteria

5. Maintenance of Long-Life Pavements

It is known that pavement maintenance activities are carried out to restore the original condition and/or to delay the need for structural maintenance. Therefore, proper and effective pavement maintenance techniques are necessary to ensure that a pavement can have a long life.

Recent studies have shown that some thick, well-constructed fully-flexible pavements on strong foundations are not subject to base fatigue cracking or structural deformation. However, environmental mechanisms can cause cracking to develop from the surface which may not progress downwards into the base layers. Furthermore deformation in these pavements also tends to be limited to the surfacing layers (that is, it is non-structural deformation). By the timely replacement of any cracked or severely rutted material, very long pavement lives can be achieved. Therefore, the deterioration of the surfacing layer should be controlled by proper maintenance so that the structural capacity of the pavement is not jeopardised.

Thus, the scope of this chapter is only the maintenance of asphalt surfacing layers on a long-life pavement structure. However, it is accepted that there is a small risk that pavements that are considered to be potentially long-life pavements will require some form of structural maintenance in the future. Subsequently, the required pavement surface characteristics will be discussed, then the condition evaluation techniques generally performed and some problems of maintenance management are to be summarised followed by the optimisation procedure of maintenance treatment selection. Finally the summary of some case studies is given as examples of best practice.

5.1 Functional pavement surface characteristics

The asphalt surface course of a new long-life fully-flexible pavement structure should have excellent functional surface characteristics such as good evenness, high surface friction (skid resistance), no surface defects, lack of ruts, favourable pavement surface light reflectivity, low pavement induced traffic noise. Naturally, these characteristics will gradually deteriorate as a consequence of traffic loading and environmental effects. If any of the functional characteristics deteriorate beyond an agreed limit (often referred to as an intervention level), an appropriate maintenance treatment should be carried out.

5.2 Pavement condition evaluation (assessment)

In order to select the most appropriate maintenance treatment, the current condition of the pavement will need to be known. Therefore, a systematic method for acquiring the necessary condition data is necessary.

Maintenance assessment procedures generally have two levels: a network level and a project level. Condition data may be collected in different ways for each level. The network level assessment is intended to assess global national or regional budgets for maintenance, to allocate these budgets, to select maintenance sections and to prioritise the maintenance order of these sections. The project level assessment, which usually comprises more detailed analysis of the pavements which were selected for maintenance according to the network planning, is intended for diagnosis of the problem and selection of the appropriate maintenance treatment. Appendix D1 gives a more detailed overview of typical pavement condition evaluation methods.

a.) Network level assessment

Information is collected about the current condition of the network and compared to historical data in order to assess changes; these changes can be rapid. The comparison of measured road condition with pre-defined standards or intervention levels provides a basic statement of the shortfall in serviceability which can be translated into maintenance need.

Whilst structural condition information is collected at a network level, this chapter concentrates on the information collected about the condition of the surface layers.

The network-level condition assessment of the surface layers is usually carried out by high-speed multi-function measuring equipment and visual inspection. The widespread techniques applied for the relevant condition parameter are as follows. (Haas *et al.*, 1994).

I. Unevenness (termed 'roughness' in North America)

Profile measuring devices and surface-response devices are widely used for measuring this condition parameter.

II. Surface distress (including rut depth)

The automatic measurement of rut depth can be performed using ultrasonics or laser technology.

Information on surface cracks can be automatically collected under artificial lighting conditions; it is achieved using various photographic and video devices.

III. Pavement texture and friction

High-speed machines are available that can record texture depth using a laser measurement technique. A mechanised skidding resistance measurement can be performed by the determination of either a sideways force or a braking force.

b.) Project level assessment

If the network level assessment identifies some pavement sections as candidates for maintenance treatment, a more detailed and/or more localised condition evaluation is usually performed. For a project level assessment some manual methods for collecting condition information can be used.

I. Unevenness

Manual methods are not practical for the measurement of evenness, although a visual assessment of unevenness can be used in the absence of any other means being available.

II. Surface distress (including rut depth)

Machine based devices are still unable to measure certain types of surface defects; in order to collect information on such defects, visual methods are used.

III. Pavement texture and skidding

The macro-texture depth and the skidding resistance can also be determined by manual techniques at isolated points.

5.3 Maintenance management procedure for long-life pavements

The management of pavement maintenance in general is a critical part of achieving the long-life approach. The management procedure covers a wide range of tasks. It is important to account for long-life pavements within the management procedure in order to harness adequately the full economic advantages that are offered by the pavements. The procedure should:

- Adopt the most efficient condition assessment methods. For the sections of the network that are potentially long-life pavements, the condition assessment could be restricted only to the surface condition.
- Establish criteria for maintenance (intervention levels) that reflect both traditional types of pavement and long-life pavements. For example, surface cracking on a thin traditional pavement may require immediate treatment to prevent structural failure, whereas the urgency for maintenance of such distress could be less for a long-life structure. Prediction models can assist with the planning of maintenance.
- Establish the most efficient methods of managing cyclic and reactive works for long-life pavements. These works should be managed so the structure of the long-life pavement is never compromised.
- Establish rules for treatment selection

5.4 Maintenance Treatments for Long-Life Pavements

Long-life pavements are not expected to require structural maintenance, therefore the maintenance treatments that are applicable to long-life pavements are any treatments that are permitted by the road manager where the primary purpose is to restore the functional characteristics rather than improve the structure of the pavement.

A wide range of treatments are available to restore functional characteristics of pavements. These treatments are either applied to the existing surface of the pavement, such as a surface dressing treatment, or require the replacement of part, or all, of the surfacing layer.

The following list of treatments that can be used for long-life pavements is suggested; this is not a comprehensive list:

- Inlay
- Resurfacing
- Surface patch
- Surface dressing
- Rejuvenation of the surface

5.5 Treatment Selection

Maintenance of long-life pavements in the most efficient manner requires that appropriate maintenance treatments are performed at the optimum time. Such an aim requires that some form of treatment strategy is required based upon national experience of the treatments to remedy different types of distress.

The extent and type of distress will have a major influence of the selection on the most appropriate treatment. The treatment selection strategy should include criteria for the selection of treatments and ways to rationalise the most appropriate maintenance operations for a length of pavement that is showing different types and levels of distress; these criteria should be produced considering the whole life cost implications of the operations.

Table 5.1. Example of appropriate maintenance treatment selection from the Netherlands

Dominant damage type	Type of maintenance treatment							
	Non-porous surface course							Porous surface course
	Surface course Conservation	Surface course regeneration course	Surface course replacement	Overlay	Rut filling	Longitudinal reprofiling	Cross-fall correction	Porous surface course replacement
Structural damage				■				■
Surface and transversal cracking	■	●	■	■				■
Ravelling	■	■	●	●				■
Longitudinal unevenness				●		■		■
Transversal unevenness		●	●	●	■			■
Loss of skid resistance	■	■	●	●				■
Insufficient cross-fall				●		●	■	■

●: possible treatments

■: most effective treatments

If several maintenance treatments are possible, the final selection will be based upon aspects like cost-effectiveness (life cycle cost of treatment), the hindrance to traffic and safety, and environmental effects.

In the Dutch example provided in Table 5.1, the range of treatments listed has been aligned with the types of distress seen in the pavement surfacing; structural damage has been greyed as it should not be applicable for long-life pavements. The treatment selection criteria have been purposely omitted from this example. The treatment selection would be made on the condition assessment; the treatment selection criteria must be formed based on national experience and would be included in the aforementioned maintenance strategy. Any selection made using a national treatment selection strategy can only be an initial guide to the maintenance requirement of a particular pavement; local considerations such as lane availability, maintenance requirements on nearby pavements or the provision of materials will affect the selections of the most appropriate treatment.

5.6 Conclusions

It is evident that efficient (proper and timely) maintenance of road surfacings can have a significant role in ensuring the long-life of pavements. One of the preconditions of the effectiveness of maintenance activities is the reliable knowledge about every relevant pavement condition parameter (unevenness, surface distress, pavement texture and friction). On the basis of measurements obtained using, preferably, high-speed and multi-

functional measuring techniques, as well as applying well-established pavement performance models and intervention criteria, short-term and medium-term intervention needs can be determined.

The effective management of a proper combination of cyclic (scheduled) and reactive maintenance works is also a highly important task.

The selection of an appropriate maintenance treatment for a long-life pavement should take into consideration the performance, longevity and efficiency of the treatment as well as user delay costs of performing the maintenance operation. A strategy for the initial selection of maintenance treatments is required; however local conditions will have a significant effect on the final choice of treatment.

5.7 Best practice

The following preliminary advice for the best practice maintenance of long-life pavements can be given.

The relevant condition parameter of the pavement surfacing should be monitored at a frequency that is dependent on the rate of deterioration. Appropriate warning and intervention levels are to be selected to prevent the surfacing condition reaching a state (e.g. lack of impermeability) that negatively influences the structural performance (capacity) of the underlying layers.

Well-established prediction models are necessary for the medium and long-term maintenance planning. However, the optimum solution for maintenance should be sought by the appropriate selection of treatments that adequately address the degree and extent of distress in the pavement surface and considers local factors at a particular site such as the availability of road closures

5.7.1 Examples of Best Practice

Some case studies that may be considered as best practice are presented in Appendix D2 and are summarised below.

In the Netherlands, network level and project level maintenance assessment procedures are applied. Possible maintenance treatments are selected based on the dominant damage type. The final selection of technique considers sensitivity, the effect of functional properties, cost-effectiveness, the effect on traffic hindrance and safety, environmental influence.

In the UK, the UK Design Manual for Roads and Bridges contains guidance on the routine assessment of long-life pavements. Actual maintenance treatments are determined using financial and safety/environmental considerations. Whole life cost analysis is recommended. Crack sealing, surface dressing and surface course replacement are the most widely applied maintenance treatments. The importance of effective pavement drainage is highlighted.

In Austria, the maintenance of long-life pavements is a task managed using a pavement management system consisting of a database, analysis (pavement condition assessment, performance prediction, creation of maintenance strategy list, cost benefit calculation and optimisation), as well as treatment suggestion as output.

In Hungary, the maintenance of long-life flexible pavements is planned using the national pavement management system. The annual sufficiency rating of the whole national highway network was started in 1979. At the network level, funds are split with guidance from HUPMS (the Hungarian Pavement Management System), the further distribution of the financial resources is achieved with the help of the software, HDM-HUN. Project prioritisation is carried out based on internal rates of return.

6. Economic Analysis

A review of the requirements for the economic analysis of long-life pavements was conducted so that a method could be developed in order to provide a Europe-wide technique for the cost benefit analysis of the adoption of long-life pavements in comparison to determinate life pavements.

In order to assess the benefits of long-life pavements a methodology is required that will adequately compare the results of the cost benefit assessment of "traditional" pavements (i.e. those that do not satisfy the definition of long-life pavements) to the ones of long-life pavements. This methodology is relevant, but nevertheless raises certain issues; for example, the residual lifespan (assessed by the bearing capacity of the structure in terms of the total number of equivalent standard axle loads carried by the pavement before fatigue failure).

The results of such a comparison depend upon the length of the analysis period or life cycle to be considered. As a consequence the lifecycle, which is an outcome of pavement design, becomes one of the most significant elements of the cost benefit assessment, more significant perhaps that the bearing capacity of the structure which is the means to achieve the objective.

Furthermore, for a cost benefit assessment process to take into account the discounted value of a structure, one must be able to evaluate the full financial consequences of the investment needed to set up a LLP structure.

6.1 Cost/Benefit Analysis (CBA)

In order to assess the economic benefits of long-life pavements, the following aspects must be taken into consideration:

- The initial (construction) costs,
- The loss of pavement capital value due to a change in pavement condition (pavement deterioration),
- The agency costs of maintenance treatments and traffic management at road works,
- The costs due to road user delays at road works,
- The costs due to accidents involving road users and workers at road work sites,
- The environmental economical impacts of road construction and maintenance.

The choice to construct a long-life pavement may result in an increase of initial costs compared to traditional pavements, but overall the total amount of costs must be less in the long term for the design to be viable. In order to justify the choice of long-life roads, it is necessary to perform a cost-benefit analysis (CBA) on a life-cycle basis.

Some of the costs listed are relatively easy to determine and calculate, for example construction costs and agency costs, but for other types of costs the exercise may be much more difficult.

Appendix E1 contains a very simple example illustrating how this life cycle analysis can help to identify and then to justify an optimal maintenance strategy / option by taking into account the condition of the pavement and the traffic on a road network. Appendix E2 illustrates the importance of availability of technical-economic models for the following elements:

- user cost models in normal situation:
 - . travel time costs;
 - . vehicle operating cost;
 - . safety costs;
 - . discomfort costs;
- pavement performance models;
- pavement preservation model;
- models for extra user costs on work zone;
- models for agency costs;
- models for environmental costs.

6.1.1 Loss of capital value

The condition of in-service pavements gradually deteriorates, mainly due to the effects of traffic loading and climate. Timely and appropriate pavement maintenance reduces this depreciation to the benefit of both the road owners and road users. Information and data on appropriate pavement condition indicators together with pavement performance models of long-term pavement behaviour can assist road owners in developing optimal maintenance programmes of appropriate treatments at the appropriate time.

A literature review carried out in the FORMAT Project (Deliverable D3/4, January 2003) has shown that although considerable information is available on road infrastructure asset valuation and pavement performance/deterioration models, there is little published information on the evaluation of the costs of pavement deterioration. One reason is that, at present, Pavement Management Systems (PMS) do not normally include residual value of road pavements.

In the FORMAT literature review, there is a description of the methodology for the development of a model for evaluating pavement value at project level by calculating the costs of pavement deterioration and the benefits of maintenance. This will enable road owners to assess the current value of pavements and to evaluate the effect of maintenance treatments on the capital value.

For the evaluation of the costs of pavement deterioration, the different layers of the pavement structure are considered independently. Condition and effects of maintenance are determined separately for each of the layers, i.e. the surface layer, base layer (main structural element) and subbase layer. The sub-grade is not included in the calculations. A number of performance indicators (rutting, cracking, bearing capacity etc.) can be used to describe the condition of the pavement layers and forms the basis of the evaluation of the monetary value for each layer. The total capital value preserved in the pavement is the sum of the values associated with the different layers.

6.1.2 The evaluation of the costs due to road user delays

A review of existing models of user costs when road capacity is reduced as a result of road works has shown that they are essentially based on comparing, over successive time intervals, traffic flows and residual road capacities. When traffic flow exceeds capacity, the excess numbers of vehicles are summed to calculate queue lengths and then the delays to road users. The main differences between the various models are in the influencing factors that are taken into account such as impact of delays on traffic demand. The principal drawback of these models is that they neglect or underestimate the probabilistic aspect of traffic demand; this could be a key factor because when the traffic flow is close to road capacity, a small increase in the flow may lead to sizeable traffic delays.

Several model-related studies have been conducted on user delays at roadwork sites. A study was undertaken within the scope of the PAV-ECO project (PAV-ECO, 1999) undertaken by the LCPC and the CETE research facilities located in Nantes and Bordeaux (France); the corresponding model was published in 1999. The model was implemented as part of a software package ("ECCU") and used as a prototype to investigate the best traffic management options on road maintenance projects in France.

The "ISOHDM" programme (PIARC), a PIARC project in charge of producing the HDM-4 software and associated methods, continues to oversee development of a very similar model; the University of Birmingham is carrying out the development work on this programme.

U.K. Department of Transport lead a development of the QUADRO (QUeues And Delays at ROadworks) model with a number of partners including TRL (DMRB 14.1.0). QUADRO deals with both extra user delays due to road works and safety costs.

The "QuickZone" model (FHWA, 2001) was developed in the United States and is intended to calculate the traffic impact from work zone mitigation strategies and estimate the costs, traffic delays and potential backups associated with these impacts.

In the D3/D4 Delivery of the FORMAT project a method to develop a probabilistic model has been proposed that will be based on the research carried out in an earlier European project called PAV-ECO.

In the first initial step, a simple but efficient deterministic model for predicting daily traffic flows is to be developed; this model yields the most likely value of traffic flow at any time of day. The coefficients of the model may be estimated from actual traffic count data by means of non-linear regression. In the second step, a probabilistic component will be added to the deterministic model. The addition of the probabilistic component makes it possible to calculate the traffic flow level, which exhibits, at any given time, a probability of being exceeded. In the third step, the traffic flow model will be used to build the probabilistic "congestion" model, which provides queue length with corresponding extra user costs.

In practice, the target output from the probabilistic congestion model is a single value, i.e. the most probable value of time lost by users due to the road works. This result, which constitutes an input to cost-benefit analyses, is in fact equal to the "mathematical expectancy" of extra user costs and is evaluated by the model by means of integration.

6.1.3 The road safety costs at road works

The main difficulty of building a model for assessing the costs due to accidents near and at road works is due to the lack of relevant data. The UK and Germany do maintain fairly comprehensive databases of such information; however, in general there are only small databases of such information in Europe.

In the FORMAT project, a simplified model which estimates the extra costs due to the increase of risks of accidents on road work sites will be developed. This model will still be very basic but its development will aim at providing a better insight into the effects of safety management at works zones.

6.1.4 Environmental costs

Environmental costs to society due to road construction and maintenance result from the environmental impacts such as traffic pollutants, emissions and noise. Although the factors that need to be taken into consideration to include the impacts of these intangible elements in a whole life cost analysis framework are easily described, the deduction of environmental costs is an area where currently a considerable amount of research is on going.

In the FORMAT project, the three main areas identified for examining the environment-related impacts of maintenance are recycling of pavement construction materials, pollutant impacts related to changes in fuel consumption and noise impacts related to pavement maintenance.

6.1.5 Agency costs

Agency costs essentially consist of the direct costs of carrying out maintenance, traffic management costs at the road works sites as well as the non-pavement costs and general overhead costs involved in the organisation and mobilisation of the maintenance works.

The cost of carrying out any treatment and the output rate achieved are influenced by the combination of circumstances (e.g. location, the road type etc) under which the treatment is carried out. For any treatment, the combination of circumstances will result in a set of representative values rather than a single value for the unit cost and output rates. Unit rates for costs and output can be combined with measures of area and if appropriate, depth to give the total treatment costs. A detailed methodology has been developed for the estimation of unit rates taking into account scheme specific influencing factors and the determination of the total costs to the Agency of works and duration of implementing maintenance interventions.

6.2 Enquiry

An enquiry has been carried out concerning existing simple models that could be used for the CBA analysis on long-life pavements (LLP), compared to conventional road structures. A questionnaire was mailed to all the partners involved in the ELLPAG project in order to

gather information on simple models already implemented for each of the following aspects: asset loss, user costs, accident costs, environmental costs, agency costs. There were questions regarding:

- ✦ The availability of a simple model
- ✦ The type of model (theoretical, mathematical, etc.)
- ✦ The parameters details
- ✦ The field of application of the model
- ✦ The suitability for assessing fully-flexible LLP

The questionnaire was sent to the representative of European research centres involved in the ELLPAG project and the answers to the questionnaire are summarised hereafter.

6.3 Summary of the answers to the questionnaire

The following section is a summary of the responses to the questionnaire that was distributed to the ELLPAG members on the subject of the economic analysis of long-life pavements.

6.3.1 Answers and existing models:

Country	Existing Models				
	CBA Model for LLP	Asset Loss Model	Extra costs due to maintenance		
			Users Costs Model	Accidents Costs Model	Environmental Costs Model
BE ²	---	▲	✗	✗	✗
BE ³	---	✗	✗	✗	✗
NL		✗	✗	✗	✗
DK	---	✗	✗	✗	✗
PL	---	✓	✓	✓	✓
AT	✗	✗	✗	✗	✗
HU	✗	---	---	---	---
CH	✗	✗	✗	✗	✗
FR	---	---	---	---	---
GR	---	✗	✓	✗	✗
UK	✓	✓	✓	✓	✗

Table 1: listing of available models for Cost/Benefit Assessment of Long-life pavement

² Wallonia part of the country

³ Flanders part of the country

- ✗ No model available
- ✓ Model available
- ~ Model under construction
- No answer

6.3.2 CBA Model for LLP Economical Assessment

Only the UK confirmed that the economic aspects of long-life pavements are specifically considered. In addition, the UK provided some detailed information on the procedure applied for carrying out LLP economical assessment:

Cost Benefit Assessment of Long-Life Pavements in UK

The concept of long-life pavements (LLPs) has resulted from knowledge gathered over 15 years on the performance of heavily trafficked asphalt road pavements. Studies have shown that the deterioration of thick fully-flexible pavements is not structural, as the deterioration generally occurs at the surface in the form of cracking and rutting with no deterioration lower down in the pavement layers.

For new construction, to achieve this long-life behaviour, it is now believed that it is not necessary to exceed the pavement thickness required to carry traffic equivalent to 80million standard axles. If deterioration of the pavement surface is detected and treated before it impacts on the lower layers of the pavement, the pavement can be expected to remain serviceable without the need for structural maintenance. Pavement maintenance will be limited to the replacement of the surfacing at regular intervals and the underlying layers can be regarded as permanent.

Surface treatments cost less than structural treatments and are also carried out more quickly. Therefore, for pavements classified as long-life, it can be expected that the sum of initial construction costs and maintenance over the life of the road, including the costs associated with disruption to road users at maintenance works sites, will be lower.

Designs for new LLPs, based on research carried out at TRL (Nunn *et al.*, 1997) have been available in the DMRB since 2001 (DMRB 7.2.3). Criteria to identify LLPs on the existing trunk road network were used in the Highways Agency (HA) State of the Network database (SON), released in 1999.

Project and network level whole life cost models have been used to examine the impact of the improved understanding of the behaviour of flexible pavements on the maintenance requirements and budgets for trunk roads. The benefits of LLPs have been examined in terms of the initial and future costs for new pavements likely to be required over the period of the 10 year transport plan (to 2010/11) and for the maintenance of the existing trunk road network for the same period. Benefits from the use and presence of LLPs in the local road network have not been considered.

Estimated benefits in UK for new construction

In recent years, work on trunk roads has been aimed at making better use of the existing network rather than increasing the network size. There is now, however, a significant programme of improvements. Details of these works are not finalised but it has been assumed that 5 new motorway lengths and 66 all purpose trunk road (APTR) schemes will be required over the 10 year period. The estimated benefits result from a comparison of

the adoption of designs for LLPs, rather than the current designs to achieve a total design life of 40 years, and assumed distributions of traffic flows and lengths of maintenance works. The benefits from the construction of LLPs has been estimated to be €50M from the reduction in construction costs and €72M from reduced whole life costs of maintenance over the evaluation period of the analysis, a total saving over the ten year period of around €120M.

Estimated benefits in UK for maintenance of the existing network

A Network Whole Life Cost Model, developed on behalf of the UK Highways Agency, has been used to examine the change in the maintenance funding resulting from the identification of LLPs on the existing trunk road network. These changes result from the reduction in structural maintenance needed for LLPs compared with that based on the conventional understanding of pavement deterioration. The analysis examined the maintenance needed to retain the existing network condition over the period 2003/04 to 2005/06 and the period of the 10 year transport plan. Reductions in structural maintenance result from the change in the distribution of pavement residual life caused by the identification of LLPs. There is an increase in purely surface maintenance, however, as the same standards for surface maintenance are required for LLPs and non-LLPs. The changes in maintenance requirements in individual years may result in annual increases or decreases in maintenance costs. Over the analysis period, however, it has been estimated that there will be a total reduction in maintenance works costs of €110M, over the period of the 10 year transport plan, and a reduction in the costs to road users at maintenance works sites of €107M, over the same period, a total saving over the ten year period of around €220M.

Combined benefits

If the benefits of introducing long-life designs for network improvements are combined with the maintenance of the existing network with long-life designs, then a total saving of almost €350M is seen. This is a saving of very roughly 10% of the total spend over the same ten year period on capital and maintenance works on the 10,000km pavement network considered in this analysis. It should be further noted that this takes no account of the environmental benefits of a long-life design strategy where the avoidance of any strengthening and reconstruction operations should significantly reduce material usage and works traffic disruption.

Choice of Long-life or Determinate Life Pavement Design or Maintenance Design

In practice, there is no network-wide decision to use long-life designs in the UK but when considering both new pavements and maintenance design the choice includes long-life options and these options are judged using comprehensive whole life cost principles.

6.3.3 Asset Loss

Proposed models:

A specific OECD group, IM3 Group "Economic Evaluation of Long-Life Pavements", is currently developing and assessing a CBA model for long-life pavements, called PASI (Project Analysis System International). PASI has been developed for asset valuation and whole life costing in a wide range of environments and countries. It is being adopted by the OECD project investigating the potential for improving the life of long-life pavement surfacings.

This model is adapted from the UK SAS model. The following parameters are taken into consideration:

- Currency
- Traffic data (traffic level, % heavy vehicles)
- Discount rate
- Maintenance options
- Maintenance costs, user costs, traffic management costs, residual value, other costs discounted.

The model, which has been developed specifically for the economical assessment of high performance surfacing, is available on a spreadsheet. This model can be adapted for assessing a whole road structure, by taking into account the maintenance costs of the sub layers.

Other models are proposed from Poland and Belgium that use the output from multi-layer structural models to predict the residual life of the structural using the appropriate transfer functions.

Additional comments:

Long-life pavements will only suffer from functional degradation: rutting, ravelling, loss of skid resistance, evenness etc. For each of these properties a residual life can be determined (as is currently done in the Dutch multi-year programming system) that will give a dominant deterioration mode with associated residual life. The asset loss would be the investment that would be necessary at the end of the residual life to restore the pavement to the initial condition and corrected for the percentage of life consumption.

The possibilities for developing a longer life surfacing on a long-life pavement structure should also be considered. A longer life surfacing could further reduce the maintenance costs (direct or indirect) thus extending the benefit of long-life pavements; such issues are being considered in the IM3 project (OECD, 2002)

FWD measurements and an associated multi-layer model are used to predict “residual life value” in Belgium but it is not a *simple* model⁴. For PMS applications time evolution models can be used to extrapolate the road surface condition for the different parameters (rutting, roughness, etc.). Such a system may not be entirely relevant as an asset loss model for long-life pavements.

6.3.4 Extra costs due to maintenance

6.3.4.1 User costs

All the UK Highways Agency pavement whole-life cost models include user costs, including PASI. ‘User costs’ are defined as the costs of increased delays to the user and increased accidents because of the presence of traffic management as a result of maintenance works. However the secondary effects of such elements as fuel consumption, environmental pollution, or vehicle/tyre wear are not included.

⁴ A simple model takes into account only available data. So, complexity should stop when data are not available.

The BELMAN pavement management system from Denmark contains a simple model dealing with user costs; however the model does not include user costs due to road works. In Greece, the HDM-4 has been used to evaluate user costs.

The user costs model used in the Netherlands takes two steps in one time: road work -> traffic delays -> user costs. In the Netherlands user costs have been assessed at 13.5 Euros per hour lost travel time per user. Traffic delays due to road works are obviously very dependent on the organisation of the traffic management. For the Netherlands, a logical approach would be to base this assessment on the usual traffic measures and the associated reduced vehicle speeds. For a dual, three lane highway, this would mean four lanes of traffic on one single carriageway when the other is maintained over the full width.

6.3.4.2 Accidents costs

As for user costs, the accident costs model in The Netherlands takes two steps at a time: road works -> accidents -> costs. Published costs of accidents are available in The Netherlands and are very high. The appreciation of a mortal accident in The Netherlands was €1.3M in 1997 while a person needing hospitalisation was appreciated at €178,000. Accidents as a function of road works are again very dependent on the organisation of the maintenance operation. However, presently the regulations are so strict that it seems no longer relevant anymore to estimate accidents as a function of road works; maintenance is safe but at high costs. It is therefore more relevant to take account of the high extra costs associated with road works due to the safety measures.

6.3.4.3 Environmental costs

In whole life cost analysis, the inclusion of environmental effects is particularly important with respect to long-life pavement designs, e.g. taking account of the sustainability benefits of reduced use of new materials over the life cycle. However there is significant difficulty in quantifying such effects in monetary terms. This approach is not in use in the UK at present although, on behalf of the Highways Agency, TRL is currently exploring the application of environmental life cycle analysis for such purposes to try and meet current UK policy on this subject.

There are some figures available about appreciation of noise in The Netherlands, for example 0.2 Eurocent per vehicle kilometre for a passenger car outside city areas (1.3 Eurocent inside) and 8 Eurocent for heavy trucks. Similarly there are figures for emission (e.g. emission of one ton of CO₂ is appreciated at 50 Euro). The problem is to quantify extra noise and emissions due to maintenance. This is unlikely to be resolved in the short-term and will take a substantial study.

6.3.5 Agency costs

The following questions refer to the additional costs of long-life pavements over conventional pavements.

Consideration of additional construction costs

There will not necessarily be any additional costs when constructing long-life pavements in the UK. It is true that long-life pavements may need more careful construction practices and therefore the unit cost may be higher. However the thickness of long-life pavements could be less than the same determinate life designs.

Higher construction costs are anticipated in Belgium, Denmark, Greece and Poland due to additional thickness and/or the use of more expensive materials.

Consideration of LLP additional maintenance costs

The effect of long-life pavements on maintenance costs is expected by most contributors to be a reduction in costs. While there is no change in the cost of maintenance for functional characteristics, there should be no structural maintenance, reducing overall maintenance costs.

Consideration of LLP additional traffic management costs

Most contributors expect there to be no difference in the cost of traffic management operations for long-life pavements compared to conventional pavements but since there will be no structural maintenance, operations should be quicker and therefore reduce traffic management costs.

Consideration of LLP additional management costs regarding management costs for conventional pavement structures

Most contributors expected that the management costs associated with long-life pavements to be either no different or less than conventional pavements. Since no structural maintenance is anticipated, the significance (and therefore costs) of structural assessment measures are reduced.

A network including a significant proportion of long-life pavements may need a markedly different monitoring and maintenance policy. More emphasis may be needed on the surface characteristics and the frequency of monitoring may need to be higher to ensure that the surface deterioration does not escalate into structural deterioration.

6.4 Summary

6.4.1 Existing Models for Long-Life Pavements Cost/Benefit Assessment

6.4.1.1 UK Model

UK has developed a model and a procedure for assessing the cost/benefits of long-life pavements (LLP).

In fact, the road administration is currently using standard CBA models for assessing Long-life pavement construction and maintenance. A pavement is considered as Long-life when the deterioration occurs at the surface in the form of cracking and rutting with no deterioration lower down in the pavement layers. For new construction, to achieve this long-life behaviour, it is now believed that it is not necessary to exceed the pavement thickness required to carry traffic equivalent to 80million standard axles.

The estimated benefits result from a comparison of the adoption of designs for LLPs, rather than the current designs to achieve a total design life of 40 years, and assumed distributions of traffic flows and lengths of maintenance works.

Current project and network level whole life cost models are used to examine the impact of the improved understanding of the behaviour of flexible pavements on the maintenance requirements and budgets for trunk roads. However, the question should be raised whether the suitability and the accuracy of those models for LLP have been assessed, in particular the residual value of the structure at the end of the analysis period. It should also be assessed how some parameters are considered in the model, in particular the ones on environment, which can be one of the most beneficial aspects of long-life pavements due to the significant reduction of maintenance activities.

6.4.1.2 OECD Model

The PASI model, being considered by the OECD long-life surfacing Group, was briefly described earlier in Section 6.3.3. This model would be suitable for the economical assessment of long-life pavements. However, it has some limitations in that some elements of the model could be considered relatively simplistic, for example the environmental impact of maintenance is not considered and this is a fairly important aspect of the benefits of the usage of long-life pavements.

6.4.2 Asset Loss

There is one model proposed which seems to be suitable for the assessment of asset loss of long-life pavements.

Nevertheless, important questions have been raised on how to consider the asset loss of LLPs, in particular:

- What are the layers that are to be maintained during one life cycle and what layer are unlikely to require maintenance?
- How to capture the capital loss of perpetual layers, if any, when there is no maintenance expected during one life cycle.

6.4.3 Users Costs

Two models are proposed for the evaluation of user costs: QUADRO and the model developed in the HDM IV model.

There are other models in existence for assessing the user costs, but they are not inevitably adapted for users' costs assessment on work zones. Those user cost models should consider the time needed to go from a point A to a point B, considering the traffic flow and the residual road capacity at successive time intervals.

Statistics for unit user costs for several categories of users are usually available in the majority of the European countries.

6.4.4 Accident Costs

One model is proposed that integrates costs from delays and direct costs from accidents.

There are few studies that have been carried out for assessing the consequences of work zones on the accident rate. On the other hand, accident costs statistics are usually well defined in the majority of the European countries.

6.4.5 Environmental Costs

There is no existing model that is currently used for assessing the environmental costs due to road maintenance. It seems that is difficult to estimate the costs due to the impact of maintenance works on the environment. Nevertheless, it should be relatively easy to integrate specific models that consider the impact on a dedicated environmental parameter, like noise, pollution, etc. in micro simulation tools (software), for assessing the impact of a work zone. Some statistics are published in some countries for specific environmental costs.

6.4.6 Agency Costs

6.4.6.1 Additional costs regarding construction

The UK states that there are not inevitably additional costs due to the choice of a LLP structure, compared to a conventional one; long-life pavements may be traditional pavements with a higher quality standard. This stresses the necessity of a very precise and concise definition of a long-life pavement.

However, additional construction costs for long-life pavements would be considered in Belgium and The Netherlands. Those additional costs would be generated not only by the selection of better quality materials and thicker layers of the structure but also by an increase of the quality of the works (execution and controls).

6.4.6.2 Additional costs due to maintenance

The main difficulty for assessing costs due to maintenance of long-life pavements lies in the fact of knowing what types of maintenance are to be carried out on long-life pavements. Additional costs for a better execution quality could be considered as well.

6.4.6.3 Traffic Management

Possible extra costs on traffic management generated by long-life pavement construction and maintenance have not been determined. Traffic management would probably be similar to traditional management at work zones, and consequently there would be no additional cost on traffic management due to long-life pavement construction and maintenance.

6.4.6.4 Management

Both the UK and Belgium anticipate that there would be no difference in the management costs of long-life pavements. The Netherlands anticipate a reduction of some costs such as monitoring costs due to a reduction of the monitoring frequency of bearing capacity.

6.5 Conclusions

Three models have been identified, which seem to be adapted for the economic assessment of long life pavements. They are:

- The model developed and currently used by the UK for assessing the cost/benefits of Long Life Pavements (LLP).
- A model under development by OECD and called PASI (Project Analysis System International). This model is adapted from the UK SAS model.
- The model that is being developed in the FORMAT project

However, those models do not take into account all of the significant parameters for the economic appreciation of long-life pavements, for example dedicated environmental costs. Other parameters may be difficult to assess with sufficient accuracy due to the specific behaviour of long-life pavements such as the residual value of the structure and more specifically of the layers, which are not expected to show any distress.

At this stage, it does not seem possible to carry out a totally comprehensive Europe-wide cost benefit analysis on long-life pavements.

It is therefore considered that the development of a specific model for the economical assessment of long-life pavements that is adapted to the specific needs of these pavements is required.

In a first stage, one of the existing models could be selected, adapted and used for assessing long-life pavement solutions in comparison to traditional alternatives, considering the definition of long-life pavements in this report and some of the parameters that are considered to be necessary for a Cost/Benefit analysis of long-life pavements.

In a second stage, it will be necessary to develop a more precise, albeit more complex, model for the economical assessment of long-life pavements. This model should integrate the latest developments in cost/benefit analysis considering the needs for long life pavements.

In the reality, considering the state of the art assessment on CBA models and the development of an integrated CBA model carried out in the FORMAT project, as well as the responses of the ELLPAG members, the need of targeted effort on those aspects should be emphasised:

- A CBA model concept should be developed in accordance with the definition of Long Life pavements. The CBA model concept should also be in accordance with the specific needs for the economical assessment of such structures.
- An assessment of existing models for each dedicated parameter should be carried out taking into consideration the long-life pavement CBA model, as well as the future integrated model developed under the FORMAT project, and considering the needs for a dedicated economical model for assessing long life pavements. Based on the results of this assessment, a selection of suitable models will be carried out, and the potential gaps of models or adaptation of some selected existing models will be pointed out.
- An integrated model for the economical assessment of long life pavements should be developed.

Estimated benefits from the adoption of long-life designs

A cost benefit analysis has been carried out to estimate the comparative costs of improving and maintaining a core heavily trafficked road network of around 10,000km in length over a ten year period using long-life pavement designs as against more conventional determinate life designs. The savings in construction and maintenance costs for the new pavements amounted to around €120M and for the maintenance of the existing network amounted to €220M, a combined saving of just under €350M or around 10% of the total construction and maintenance budget over the same period. This illustrates the large potential benefits to be obtained from the adoption of the long-life pavement design principles on a heavily trafficked road network, before the consideration of the likely environmental benefits of such an approach.

7. Research Needs

Highway engineers in Europe are realising the importance of durable pavements that enable efficient maintenance operations. Understanding of pavement performance for heavily trafficked roads has in recent times led to the concept of long-life pavements. The concept relates to the structural aspects of the pavement and not the upper surface or surface courses. The requirements to produce long-life surface or surface courses are being clarified in other on-going projects such as the OECD/RTR IM3 “Economic Evaluation of Long-Life Pavements/Economical-technical Innovations in Long-Life Pavements for Heavily Trafficked Roads with Heavy Traffic (New Binders for Road Pavements)” and the European Union’s Fifth Framework project, “Fully Optimised Road Maintenance” (FORMAT).

Although long-life pavements have been implemented in Europe, there remains a degree of uncertainty regarding the mechanisms that provide their characteristics. In order to obtain a better understanding of these mechanisms, research needs have been identified by consultation with the members of ELLPAG and through the reviews that were carried out in this report: New Pavements, Assessment and Upgrading, Maintenance and Economic Analysis.

The result of the consultation exercise is provided in Appendix F and summarised in this chapter. The scope of the consultation included only long-life fully-flexible pavements although many of the questions posed could be applied more widely. Following a discussion of the research needs for long-life fully-flexible pavements, a summary under each of the topic headings (New Pavements, Assessment and Upgrading, Maintenance and Economic Analysis) has been formed.

7.1 Discussion

The following section is a discussion about the research needs for specific areas that have been grouped under the key topics in the report. The discussion was produced from a questionnaire that was distributed to the members of ELLPAG.

7.1.1 New pavements:

The significant material properties for long-life pavements

Due to the growth in heavy vehicle traffic, new trends in the automobile and tyre industries, and higher maximum limits for axle loads, traditional asphalt and binder tests are often inadequate for a reliable prediction of the properties and in-service performance of road asphalts. The problem facing designers of analytical models is the need to fully characterise the properties of the materials on the one hand, while on the other hand providing a realistic simulation of the traffic and climate-induced stresses to which pavements are exposed during their design lives of 20 - 30 years. Where long-life pavements are concerned, there is therefore an urgent need to develop test methods combined with better numerical forecast procedures to improve the economics and extend service lives.

There is general uncertainty regarding how to deal with material properties when designing a pavement. Some countries have design methods that also take high performance bituminous pavement layers into account. There is some knowledge available concerning material properties which must be considered and also some experience on new materials. However there is no knowledge on how to evaluate material properties and their evolution with time (e.g. healing effects, combined effects of traffic and thermal cycling, water, and ageing effects). Models that could describe these effects are not available nor are the validation exercises which could estimate the lifetime of a road structure.

It is known that the lower bituminous layers seem to deteriorate very slowly when properly protected by dense layers and also that rutting in the base layers can be relatively easily controlled. In the upper 100 mm of the pavement structure, severe conditions often exist due to rutting, stripping and ageing. It will be a challenge to design a long-life flexible pavement with optimum resistance to stripping and ageing, yet at the same time manage to control rutting.

The subbase layers need good drainage and the structural properties of the materials have to be adequate for their position in the road. Quality Control or Quality Assurance (QC or QA) procedures should ensure sufficient quality during production and construction. Good construction practices should be used at all phases of construction. Failure to do this may affect durability and long-term performance.

Fatigue testing and long-life pavements

The relevance of fatigue testing to the actual field performance of long-life pavements has been questioned because the link between the results of fatigue tests and the performance in full-scale experiments seems to be problematic. A wide range of fatigue tests exist that can provide a range of results due to differing stress situations; for this reason it has been hard to develop a common view.

An appropriate test method should be capable of predicting fatigue resistance in the actual pavement environment i.e. taking account of the complex stress conditions, temperatures and load spectra, effects of ageing and stripping, effect of initial cracks etc. Current laboratory testing methods do not appear to be able to adequately cover all these aspects. In particular, a method with a better predictive capability is necessary for very small strain levels or unconventional materials.

Pavement design linked to maintenance planning for long-life roads

The main benefit of long-life pavements is to reduce the impact of maintenance and rehabilitation activities on traffic and the environment on highly trafficked roads. Furthermore, long-life pavements can represent a higher investment compared to regular road pavements, and such investments must be cared for appropriately.

Provided that the subbase drainage functions well, and the upper layers are correctly maintained damage to the structure of long-life roads should not occur. Maintenance activities will focus on cracks and ruts that generally only affect the upper 100 mm of asphalt.

The members of ELLPAG generally agreed that the design of a long-life pavement should be an overall concept, including a plan of assessment and possible surface maintenance treatments.

Location of the threshold fatigue strain level

Some of the contributors reported that classical fatigue cracking is rarely seen in the bottom of thick, fully-flexible pavements.

In the UK, an in-depth study of the fatigue behaviour of several motorways that had exceeded their design life showed no sign of base deterioration. Furthermore, no evidence of fatigue weakening was seen in these pavements. Based on the observed performance of heavily trafficked pavements in the UK, a threshold strain level of approximately 70 microns has been determined.

In the Netherlands, calculated strain levels in pavements on the primary road network are often of the order of 50 microns; in these cases, fatigue problems do not seem to occur.

However, both the UK and the Netherlands indicated that a precise threshold level of strain, below which fatigue of the material does not occur, is not known and further investigation is needed.

The influence of ageing and stripping during structural deterioration, particularly fatigue

Pavement deterioration through fatigue is a function of traffic-induced strain and the fatigue characteristics of the asphalt base material. As asphalt materials harden due to ageing, traffic induced strains reduce as well as fatigue resistance of the base materials. In the UK, calculations have generally shown that the reduction in traffic-induced strain more than compensates for the increased susceptibility of the asphalt to fatigue damage.

This is partially confirmed by experience in the Netherlands that does not seem to indicate that pavement strength decreases with age as would be expected. Where there have been structural problems, these have only occurred in the first few years of a pavement's existence.

The need for structural pavement models to address contributions associated with ageing and stripping

In the lower bituminous layers, several contributors report that stripping is not a problem, and as a general rule this can be controlled by proper design and good manufacturing practice.

Recently, some pavement experts and researchers have claimed that cracking problems in thick bituminous pavements are dominated by top-down cracking. If this claim is correct, a structural pavement model which considers top-down cracking is needed to also describe the contribution from stripping and ageing, since this is the type of distress most present in uppermost layers.

The effect of healing on structural deterioration and how it is affected by ageing and stripping and by use of modified bituminous binders

The effect of healing is a subject where knowledge is very limited. It is accepted that some form of healing takes place because pavements outlast the life estimated using laboratory fatigue lives by a significant factor. However, the healing mechanism is not clear and it is only partly possible to investigate healing in the laboratory. Ageing may play a role in healing although it is unclear how, and it may be essential to know this for unconventional binders.

Modification of the bituminous binder may influence healing significantly. This is of crucial importance especially in the layer below the surface course. Ideally, the surface course should also exhibit long-life behaviour.

A structural model of long-life pavements, which introduces top-down cracking, will need to describe contributions associated with stripping and ageing; healing is a part of this process.

Are special Quality Control procedures and levels of tolerances required for long-life pavements?

No contributor reported that specific Quality Control procedures have been developed for long-life pavements. It is acknowledged that the Quality Control has an important role in the durability of all pavements.

Mandatory training programs for construction workers to ensure sufficient quality of the long-life pavement construction

No mandatory training programs have been reported for the construction of long-life pavements; asphalt contractors often control the training programs for their work force. There is no doubt that good execution of the work is a key factor and that training is important.

Denmark is considering mandatory training for the construction of long-life pavements, at least for the foreman of a team.

Crack propagation and fatigue cracking in thick bituminous pavements

Several contributors reported that traditional fatigue cracking is rarely observed in thick bituminous pavements. Recent experience has shown that the majority of cracks in thick bituminous pavements occur in the surface layers. They normally do not propagate deeper than approximately 100mm.

Some contributors reported problems with debonding and stripping associated with cracks developing at the surface.

The UK noted that although traffic is associated with the initiation of certain forms of surface cracking, traffic is unlikely to be responsible for the propagation of these cracks into the asphalt layer.

Development of design principles for long-life pavements using ALT (Accelerated Load Testing) trials

ALT trials have so far been of very limited use when assessing the long-term structural performance of long-life pavements as they do not accurately reproduce the environmental conditions that are present in the “real world”. However, ALT may give valuable information in regard to crack initiation and crack propagation, and ALT can be most relevant as an intermediate link between laboratory testing and field, e.g. to show that a laboratory test predicts good ranking.

7.1.2 Assessment, Upgrading and Maintenance

Rehabilitated long-life pavements by re-use of existing pavement materials.

Development of recycling processes is playing an increasingly important role. To promote the successful use of recycled materials in long-life asphalt roads, reliable methods must be devised to specify material properties based on fundamental tests and, if necessary, procedures developed to improve the required performance properties.

The contributors had differing opinions on recycling in long-life pavements probably due to the different degree of long-term experience in different countries. Some countries are confident when using recycled materials in all asphalt pavements while other countries have reservations when using them in a long-life pavement. The overall impression is that some valuable experience is available for use of recycled materials in the lower bituminous layers.

Designing or strengthening an existing pavement to create a long-life pavement

Most countries represented by the contributors seemed to possess the tools for upgrading an existing road to a higher road class. However, only the UK has described procedures for upgrading pavements to a long-life pavement standard (see Annex C1).

In general, thick pavements can be appropriate for upgrading to a long-life pavement. However, thin pavements may be less likely to be upgradeable to a long-life pavement by overlay as there are more likely to be problems in the existing structure.

Selection of maintenance strategies for long-life pavements

Non-structural maintenance treatments are usually applied to extend the lifetime of pavements or to improve different surface characteristics.

Since maintenance of the surfacing is all that is required with long-life pavements, research efforts in this area need to concentrate on extending the life of surfacings (i.e. rut and crack-resistance as well as maintaining skid resistance) and on determining the optimum strategy for the replacement of surfacings; for example, inlays versus overlays, the optimum timing of treatments, etc.

Two maintenance strategies can be proposed which suit the long-life fully-flexible pavement characteristics. A strategy using:

- thin surfacings which are fast to remove and repave, thereby minimising the duration of any maintenance works.
- high performance surfacing with an expected service life exceeding 20 years, thereby minimising the frequency of maintenance works.

The choice of strategy will depend on the outcome of economic analysis.

7.1.3 Economic Analysis

Life cycle analysis of long-life pavements.

Long-life pavements may well involve a significant, and additional, initial investment. To justify the initial investment, a life cycle analysis is essential to adequately account for the benefits received from the investment throughout the service life. More widely, there is an increasing demand for pavement engineers to base their design decisions using a life cycle analysis. A common standard is recommended, since it would:

- allow for economies in analysis cost due to more easily developing experience
- the results of the life cycle analysis will be more readily accepted
- allow development of widely accepted estimates of intangible costs such as socio-economic aspects and environmental issues.

A standardised life cycle analysis for road maintenance has become available in Austria. There is a need to develop a similar standardised approach for the life cycle analysis of long-life pavements.

7.2 Summary of identified research needs

7.2.1 New pavements:

In terms of deterioration, a large number of countries are reporting forms of deterioration in thick fully-flexible pavements that are consistent with the forms of deterioration in long-life flexible pavements. However, in general, there is uncertainty in how to address material properties during the design of long-life flexible pavements, such as how to evaluate the material properties and the evolution of the properties with time correctly, e.g. healing effects, combined effects of traffic and thermal cycling, water, and ageing effects.

The concept of long-life pavements is that no structural deterioration in the bottom of the bituminous base will occur; consequently, a threshold strain level seems to be relevant. The review clearly showed that currently no such reliable model, to address a threshold strain level in the bottom of the asphalt layers, is available. Also, knowledge is required on the initiation and propagation of surface cracks, especially how fatigue properties develop in the pavement due to ageing and stripping.

It seems that a common fatigue test method that is suitable for long-life pavement materials is not available. It would be advantageous to develop a test method, as the threshold strain level for classical fatigue is not relevant for flexible long-life pavements.

- The knowledge on healing mechanisms has been shown to be limited, especially for modified binders, which may influence healing behaviour significantly.
- A fatigue test method and associated test protocols needs to be developed to incorporate the complex conditions in a flexible long-life pavement.
- By examination of the construction of pavements and the deterioration that is occurring in particular countries, lessons can be learnt in order to produce explicit long-life pavement design methods that are consistent with a particular country's construction standard.
- Structural pavement models should be developed to address top-down cracking.
- There is a lack of performance models for long-life flexible pavements, which can take all the above mentioned effects into account and thereby give reliable estimates of the designed pavement lifetime.
- At present no countries have developed specific Quality Control procedures and levels of tolerances for the construction of new long-life pavements.

7.2.2 Assessment, Upgrading and Maintenance

Only the UK has fully adopted a concept for the assessment and upgrading of pavements to long-life pavements, which implies strengthening of the existing pavement to a level where further structural deterioration is not expected.

There seems to be a limit to the required pavement strength when upgrading an existing pavement and this possible existence of threshold strength can be considered one of high importance, irrespective if a long-life pavement strategy is followed or otherwise.

- Improved pavement assessment techniques are required (e.g. new investigation methods including non-destructive crack depth or the adaptation of existing technologies) and identification criteria for long-life flexible pavements.
- When a pavement is cracked and/or rutted, it is not known how far the pavement can be permitted to deteriorate before carrying out maintenance without compromising a long-life strategy.
- At present, no countries have developed specific Quality Control procedures and levels of tolerances for the upgrading and maintenance of Long-life flexible Pavements.

7.2.3 Economic Analysis

Models for the economical assessment of long-life pavements have been discussed in this report. However, these models do not take into account all the parameters that can have some significant incidence on the economical appreciation of long-life pavements, such as dedicated environmental costs, like noise for example. At present, other factors more specific to long-life pavements cannot be assessed with adequate accuracy such as the residual value of the structure.

At present it seems to be impossible to carry out Europe-wide cost benefit analyses on long-life pavements. This can only be achieved through the development of a standardised model for the economic assessment of long-life pavements, therefore such a strategy is urgently required.

8. Recommendations

The study of research needs and discussions has led to the following research recommendations on the design, maintenance and economical assessment of long-life fully-flexible pavements. Five key areas of research have been developed into recommendations, these are:

- To investigate the deterioration mechanisms of long-life fully flexible pavements
- To develop improved techniques for estimating the residual life of both determinate and long-life flexible pavements
- To trial the UK upgrading methodology on a Europe-wide basis
- To develop an optimum strategy for managing surface distress
- To develop a standardised and comprehensive cost benefit model for long-life flexible pavements

Investigation of the deterioration mechanisms of long-life fully flexible pavements

One of the principles of the long-life pavement concept is that the pavement does not incur structural deterioration due to traffic. One of the key theories that under-pins such a concept is the notion of the threshold level for strain below which damage in the structural layers does not occur.

Such a concept is implicitly tied to the measure of traffic loading and the fatigue response of the material. Therefore, research into the mechanisms of long-life fully-flexible pavements should be conducted in three main topics:

- Clarification of the measures of traffic loading
- Demonstration of the fatigue life sensitivity to low strain levels
- Investigation of the effect of rest periods and healing

Most design methods in Europe use some form of simple load equivalence relationship including a reference standard axle and an exponent of damage. Throughout Europe, there are a range of reference standard axles and exponents in use. Such a range of parameters for load equivalence makes comparison difficult between the design and assessment methods in different countries. Moreover, confidence in the definition of threshold strain (or a threshold structural strength) requires that a single method or a reliable conversion between methods be sought.

The concept of long-life fully-flexible pavements is supported by the notion that at low levels of strain, structural damage by fatigue does not occur. It is unlikely that these mechanisms can be proved in a laboratory study within a reasonable time-scale. However, investigations at a number of levels of strain could provide evidence that fatigue damage is less significant at low strain levels. Material from in situ pavements should be used to complement the results of the study with laboratory prepared mixes.

Rest periods and the healing effect can be investigated using a particular level of strain from the strain level study. As for the strain level study, it is unlikely that the study will provide a proof of the mechanism within a reasonable time-scale, however extrapolations of the results to realistic traffic loading intervals on heavily traffic routes could be beneficial.

Research is recommended by the ELLPAG members in these three topics. The outcome of the research will provide a reference text for the comparison of pavements throughout Europe. Such a text will enable a common approach to be developed for the design and detection of pavements that exhibit long-life behaviour. It will also enable advances that are made in one country to be more easily adopted in other European countries.

The investigations of fatigue damage at low strain levels and rest periods will provide more confidence in the concept of long-life pavements which has, for the most part, been justified on the basis of practical experience. A better understanding of the mechanisms behind the creation of long-life pavements will improve the design of such pavements and enable informed decisions to be made on their use.

The development of improved techniques for estimating the residual life of both determinate and long-life flexible pavements

Residual life calculations are an important part of the pavement management procedure. Such calculations should enable maintenance expenditure to be appropriately assigned and budgeted.

A number of countries have become aware of problems for predicting the residual life of thick, fully-flexible pavements. The UK have accepted that, in some cases, thick-fully-flexible pavement have an indeterminate life and for these pavements have developed a long-life approach for the assessment and maintenance of these pavements. Experience in the Netherlands is that pavements generally outlast the residual life estimations following structural assessments.

Residual life is a term used to describe the period (in terms of time or traffic) until major structural maintenance is required. Such estimations are based upon classical mechanism of structural pavement deterioration such as fatigue of the base layers. Long-life pavement theory challenges these classical approaches to deterioration.

The ELLPAG group recommend that research is conducted into the mismatch between residual life calculations and observed performed. The research should:

- Review cases where residual life estimations were pessimistic. The review should include the techniques used for assessment, and the type of pavement
- Improve the understanding of the role of assessment techniques. A detailed study should also look at the applicability of the deterioration assumptions in the context of thick, fully-flexible pavements.
- Develop improved assessment techniques for thick and long-life pavements.

The research project trial will result in:

- Improved methods for the assessment of existing pavements.
- Savings in maintenance expenditure.
- More appropriate budgeting for major maintenance expenditure.
- Improved methods for contractual arrangements.

Carry out trials of the UK upgrading methodology on a Europe-wide basis

The UK has established a methodology for the upgrading of existing pavement to long-life pavement. This method involves an assessment of the pavement in terms of deflection and thickness.

Upgrading an existing pavement to a long-life pavement involves two processes:

- the physical operation of performing the upgrade treatment and,
- the adoption of long-life approach to future assessments and maintenance.

The methodology has been used in the UK for more than five years and the experience suggests that the method is performing satisfactorily. The UK practice could be implemented more widely throughout Europe since it is based upon simple, widely available tools for assessment. The ELLPAG group recommends that a trial of the UK system in a number of European countries could be undertaken. Following successful trials, the implementation of the existing method could be made in a relatively short period and the benefits that have been gained using this system in the UK could be obtained more widely throughout Europe.

The trial will assess:

- The applicability of the UK upgrading methodology in other countries.
- Possible refinements of the methodology.
- The likely economic benefits of the upgrading methodology in each participating country.

A successful trial will result in:

- A proposal for a Europe-wide policy on upgrading existing structures to long-life pavements

The development of an optimum strategy for managing surface distress

The long-life pavement concept requires that any deterioration in the surfacing is remedied in a timely fashion. The occurrence of deterioration in long-life pavements is usually evident on the surface of the pavement. The research needs identified that there is little knowledge on the nature, or progression of distress in long-life pavements; therefore, precisely what is meant by 'timely fashion' cannot be defined.

In the UK, the current policy for the maintenance of long-life pavements is to apply remedial treatments to the surfacing as soon as possible after the deterioration was detected. This policy ensures that the structure of the pavement is rarely at risk. However, such a policy will induce interventions at the earliest possibility and is therefore probably not the most efficient or sustainable practice.

The most efficient and sustainable practice would be to intervene just before the deterioration in the surfacing begins to affect the structure of the pavement. Such a policy would maximise the period between interventions, thereby minimising disruption and potentially reducing the volume of materials that are consumed over the lifetime of the pavement.

In order to move towards the optimum management strategy for long-life fully-flexible pavements would require four broad areas of research to be undertaken:

- Develop monitoring methods to accurately determine the degree of surface deterioration in long-life pavements. These methods should be non-destructive and be rapid so that monitoring can be conducted relatively frequently at a reasonable cost without significant disruption.
- Conduct research using the newly developed monitoring methods to identify the rate of deterioration and to quantify the risk of sudden, unforeseen developments in deterioration occurring in such a way that the structure of the pavement may be affected.
- Identification of intervention levels for non-structural deterioration. The research work should attempt to define the quantities of non-structural deterioration beyond which some structural deterioration is likely to occur.
- Develop an integrated maintenance strategy of monitoring and treatment so that the whole life costs of long-life pavements after construction are minimised. Such a strategy should consider the functional requirements of the pavement in addition to the structural requirements. The whole life cost elements should account for the special economic issues that surround long-life pavements.

The optimised strategy for maintenance will ensure that the full benefits that could be available from the adoption of the long-life pavement concept are harnessed.

The development of a standardised cost benefit model for long-life pavements

The review of economics for all types of long-life pavement identified a need for a specific model. This model should aim to adequately account for the benefits of long-life pavements. The development of such a model should be an enhancement of an existing model since, the main issues arise from the handling of particular types of costs.

Adequate models for environmental costs should be developed. This model will not attempt to quantify every environmental benefit, but will concentrate on key sustainability indicators.

A method of accounting for the residual value in long-life pavements should be developed.

The standardised model will be developed in partnership with a number of countries so that it covers the main components of life cycle costs that are required for each country. It is anticipated that the model will be constructed in a modular fashion so that it can be adapted to existing practices as required, or be used to make Europe-wide comparisons.

The standardised model will enable the economic benefits of long-life pavements to be assessed throughout Europe. It will also improve the economic appraisal of such pavements within each European country and thus may further promote their use.

9. References

AASHTO (1993). AASHTO guide for design of pavement structures. American Association of State Highway and Transportation Officials.

AUSTROADS (1992). "Pavement design – a guide to the structural design of road pavements".

COST Action 333 (1999). Development of a new bituminous pavement design method. COST.

COST Action 343 (2003). Reduction in Road Closures by Improved Maintenance Procedures. COST.

DESIGN MANUAL FOR ROADS AND BRIDGES. The Stationary Office, London, UK.

Also available on-line at www.archive.official-documents.co.uk/document/ha/dmrb/index.htm

HD 26/01: Pavement Design (DMRB 7.2.3)

HD 29/94: Structural Assessment Methods (DMRB 7.3.2)

HD 30/99: Maintenance Assessment Procedure (DMRB 7.3.3)

The QUADRO Manual (DMRB 14.1.0)

DOMENICHINI L. et al. (1993). "Criteria for the design of catalogue pavement structures", Fondazione Politecnica per il Mezzogiorno, Napoli 1993, (in Italian).

DWW (1998). Handleiding Wegenbouw – Ontwerp Verhardingen (Road Design Manual – Vol Pavement Design).

FHWA (2001), Quick-Zone 1.0: A better approach to Work Zone Planning, FHWA Focus, Washington DC.

FORMAT (2002). Inception Report, FORMAT Deliverable Report D1, July 2002.DWW Delft, The Netherlands

FORMAT (2003). Optimised Pavement Condition Data Collection Procedures, FORMAT Deliverable Report D3/D4.

HAAS, R, WR HUDSON and JP ZANIEWSKI (1994). Modern pavement management Krieger Publishing Company, P.O. Box 9542, Melbourne, FL 32902-9542, USA

KTI (2000). Hungarian Design Method. ÚT 2-1.202:2000

LAVOC Swiss Standard SN 640 324

NUNN ME, A Brown, D Weston and JC Nicholls (1997). Design of long-life flexible pavements for heavy traffic. TRL Report 250, TRL, Crowthorne, UK

NUNN, ME, and DB Merrill (1997). Review of flexible and flexible-composite pavement design methods. TRL Paper PA3298. Transport Research Laboratory, Crowthorne, UK.

OECD (2002). Economic Evaluation of Long-Life Pavements. OECD Special Research Project.

PAV-ECO (1999). Work Package 1 – Task 3: Cost to road users at maintenance sites – Technical annex”, CETE du Sud-Ouest, Bordeaux, France.

PIARC. HDM Volume 4, ISOHDM project, available on the web site: <http://hdm4.piarc.org>

QUADRO Highways Agency, UK, available on the web site: <http://www.archive.official-documents.co.uk/document/ha/dmrb/index.htm>

RVS (1998). Richtlinien und Vorschriften für den Straßenbau (Austrian standards for pavement design) : RVS 3.63 Bautechnische Details, Oberbaubemessung, 1998. Österreichische Forschungsgemeinschaft Straße und Verkehr. (in German)










RStO86 (1989). Guidelines for the standardisation of the upper structure of traffic bearing surfaces. RStO 86. Roads and Traffic Research Association.

SETRA-LCPC (1997). Guide technique French Design Manual for Pavement Structures. Ref. D9511 TA.

TRB (2001). Perpetual bituminous pavements. Transportation Research Circular 503. Transportation Research Board.

VTI (2003). ATB VÄG, VV Publ. 2003:111

ANNEX A. ELLPAG Membership

Partner Organisation	Alternative Organisation Name
 Belgian Road Research Centre (BRRC)	Centre Recherches Routiers (CRR)
 Danish Road Institute (DRI)	
 Dienst Weg-en Waterbouwkunde (DWW)	
 Institut für Strassenbau und Strassenerhaltung (ISTU)	
 Kozlekedestudományi Intézet Rt (KTI)	
 Laboratoire Central des Ponts et Chaussées (LCPC)	
 Laboratoire des voies de circulation (LAVOC)	
 National Technical University of Athens (NTUA)	
 Road and Bridge Research Institute (RBI)	Instytut Badawczy Dróg i Mostów
 TRL Limited	

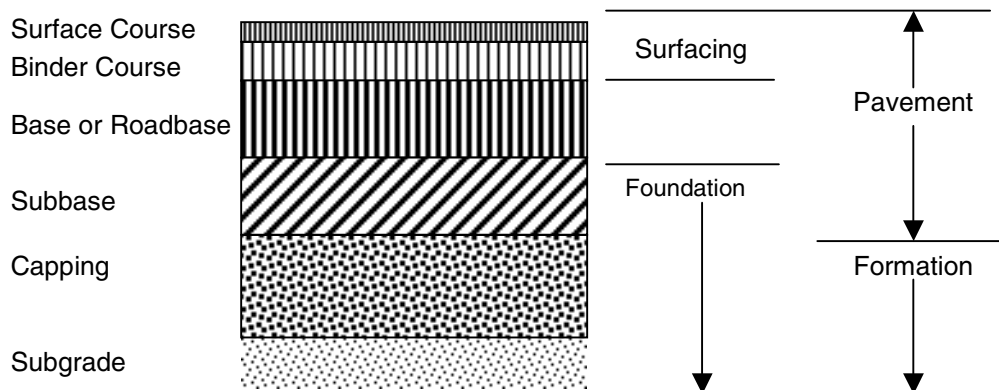
Contact with the above organizations can be made through their respective FEHRL research coordinators whose current names and addresses are available via the FEHRL website (www.fehrl.org).

Contributions of road administrations from the following countries are gratefully acknowledged: Austria, Belgium, Denmark, United Kingdom, France, Greece, Hungary, The Netherlands, Poland and Switzerland.

Annex B. New Pavements

GLOSSARY

The following definitions of layers have been used throughout this section.



Surface: the interface between tyre and surface course.

Surface course: the layer at the top of the pavement which is in contact with the tyre

Binder course: a layer between the surface course and the base

Base or Roadbase: the main structural layer of the pavement.

Formation: the level at the bottom of the pavement layers.

Foundation: comprises all layers below the base layer (Subbase, capping and subgrade)

Pavement: comprises all layers above the formation including the subbase layer

Fully-Flexible Pavement: A pavement with a bituminous surfacing and with a roadbase with or without a hydrocarbon binder.

Semi-Rigid Pavement: A pavement with a bituminous surfacing and one or more course treated with cementitious binders and which make a significant contribution (or courses treated with hydrocarbon binders and which by their stiffness or thickness cannot be considered as structurally flexible).

Rigid Pavement: A pavement substantially constructed of cement concrete.

REFERENCE AXLE

The reference standard axle used in the computed design traffic is denoted by a numerical subscript as follows:

msa_{80} = million standard 80kN axles

msa_{100} = million standard 100kN axles

msa_{130} = million standard 130kN axles

ANNEX C. Assessment and Upgrading

C1. Assessment and Upgrading in the UK

C1.1 Introduction

This note summarises the current UK position on assessing existing pavements in order to determine whether they are already long-life fully-flexible and on upgrading pavements to long-life status.

This note should be read in conjunction with the UK Design Manual for Roads and Bridges (DMRB 7.2.3 and DMRB 7.3.3); this document is available on the Internet at the following address:

<http://www.archive.official-documents.co.uk/document/ha/dmr/index.htm>

C1.2 Background

The existence of fully-flexible pavements with the potential to have structural lives far in excess of those conventionally associated with such pavements (i.e. long-life) was recognised in the UK in the mid 1990s. Advice to UK maintenance engineers was drafted and incorporated in the DMRB in 1999 (the DMRB contains guidance on assessing maintenance need on the Highways Agency's network i.e. the motorway and trunk roads).

C1.3 Assessment

Usually, the need for a structural investigation will be triggered by a routine network level survey; either a machine-based survey or a manual visual survey. Alternatively, a survey may be needed where there is a proposed change in use for an existing pavement, for example a road widening or major re-alignment. The hierarchical approach to maintenance assessment is exemplified by the Highways Agency's (HA) approach, shown schematically in Figure C1 (reproduced from DMRB 7.3.3). Routine surveys take place periodically and, depending on the outcome of these surveys, they could trigger a more detailed visual survey. If this confirms that there are visible defects, then this should prompt a further review of available information and a pavement investigation. It should be noted that Deflectograph surveys are no longer routinely carried out on the HA network but are instead undertaken on potential maintenance scheme sites.

The Deflectograph has been the primary tool on the HA network for determining maintenance need on flexible pavements for the past decade. The deflection design method, described in detail in LR 833 (Kennedy and Lister, 1978), relates the deflections measured by the Deflectograph to the total life of the pavement. Armed with a knowledge of the traffic carried to date, the forecast future traffic and construction details, it is possible to estimate the remaining life of the pavement and the thickness of overlay

required in order for the pavement to achieve a future design life. The relationships, first presented in LR 833 (see Figures C2 and C3 for examples), have been significantly revised over the years and, most recently, have been modified to take account of long-life pavements.

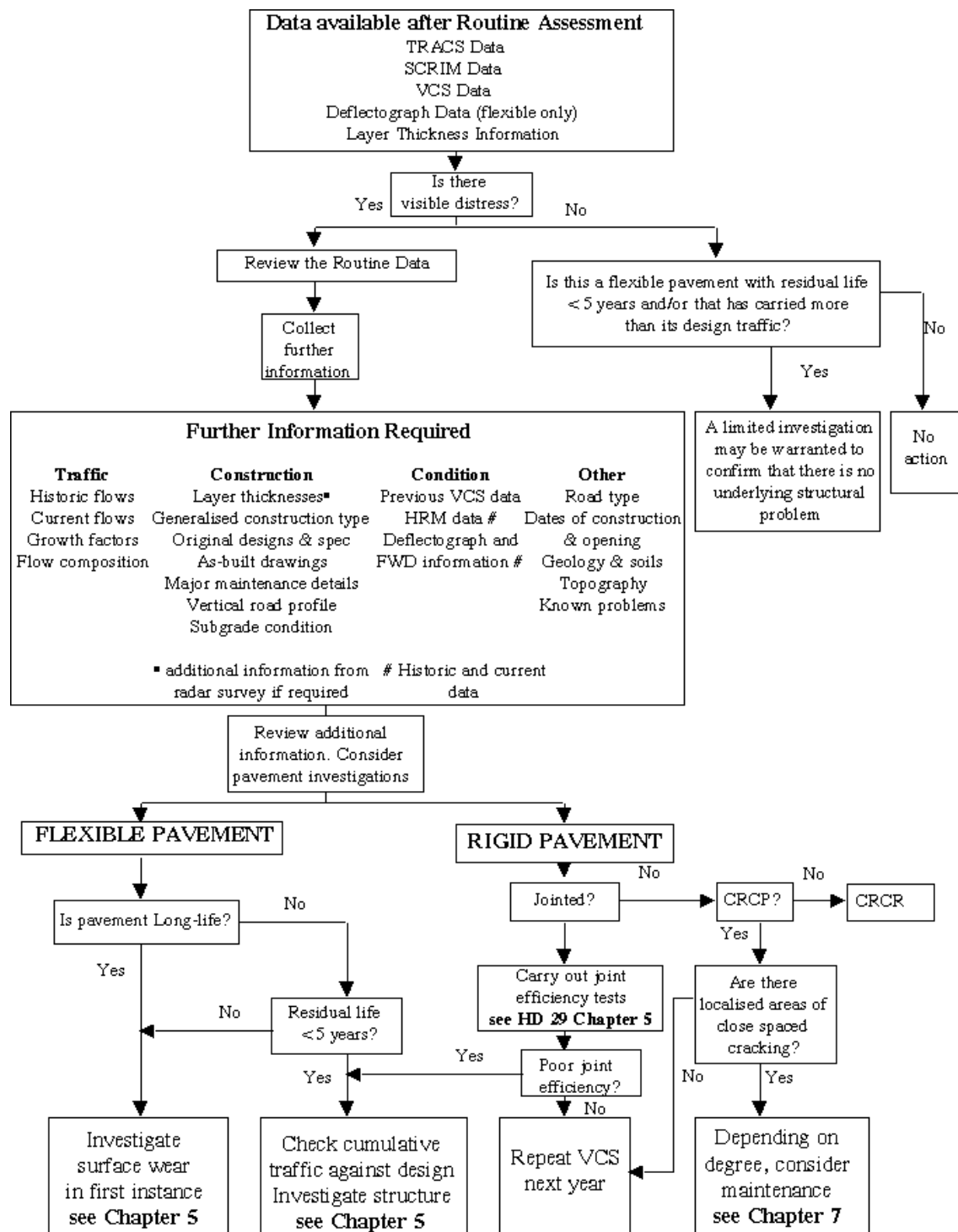


Figure C1 Hierarchical approach to maintenance assessment (Reproduced from DMRB 7.3.3)

They are now embodied in the latest version (Version 3) of the computer program PANDEF (Highways Agency, 1993) and in the Highways Agency Pavement Management System (HAPMS) CONFIRM software.

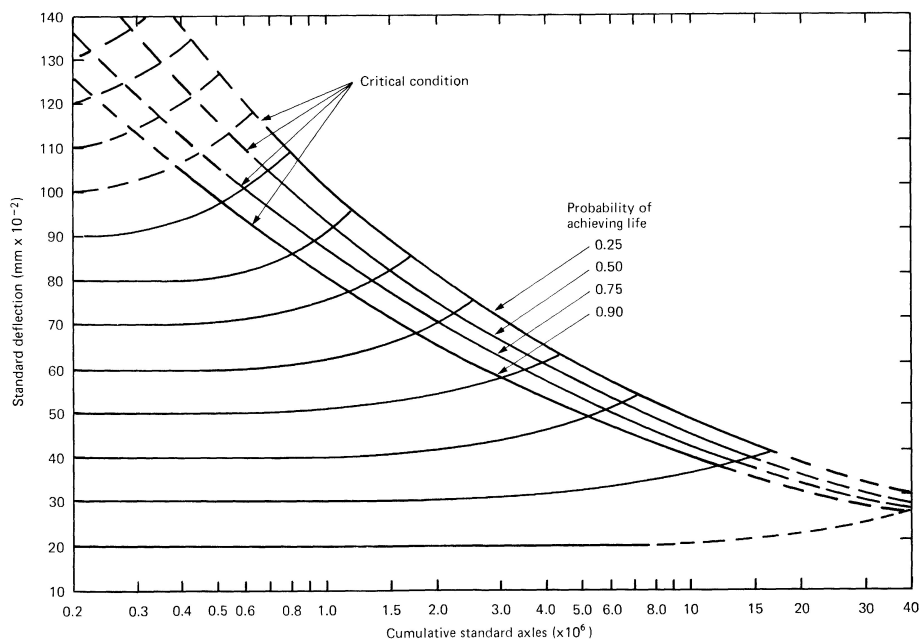


Fig. 12 RELATION BETWEEN STANDARD DEFLECTION AND LIFE FOR PAVEMENTS WITH BITUMINOUS ROAD BASES

Figure C2 Deflection versus life curves as used in deflection-design method
(Reproduced from Kennedy et al., 1978)

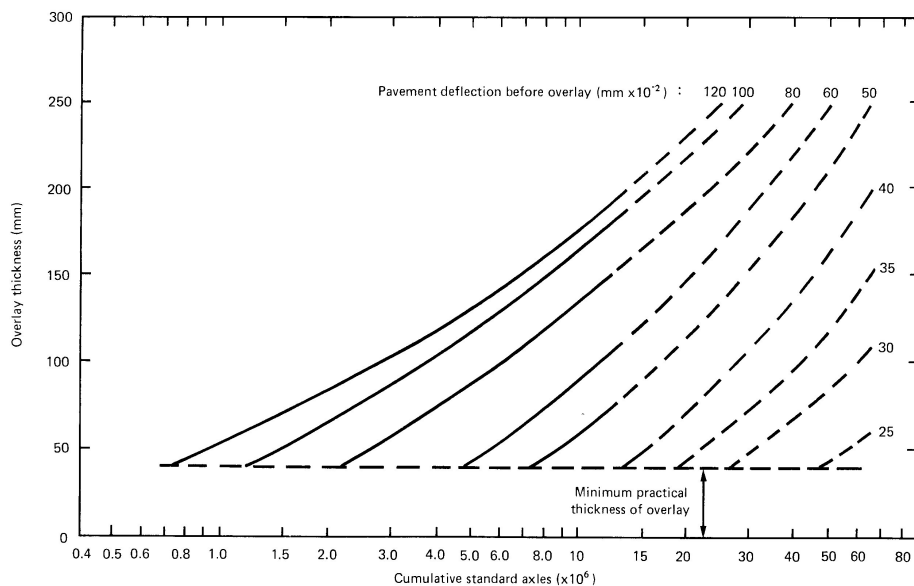


Fig. 18 OVERLAY DESIGN CHARTS FOR PAVEMENTS WITH BITUMINOUS ROAD BASES (0.50 PROBABILITY)

Figure C3 Overlay design chart as used in deflection-design method
(Reproduced from Kennedy et al., 1978)

Deflectograph surveys were, until recently, undertaken routinely on the whole of the HA network on either a three-yearly or five-yearly rolling cycle (i.e. a third or a fifth of the network has been covered each year). However, because of the slow speed and the

desire to move to traffic speed surveys in order to minimise delays to road users, Deflectograph surveys are no longer undertaken routinely but instead are targeted at sites where major maintenance is proposed.

The deflection design method was updated in 1999 to incorporate recent thinking on the behaviour of thick, well built flexible pavements. Such pavements, known as *long-life pavements*, do not generally deteriorate structurally, that is they do not suffer from structural deformation or from structural fatigue (i.e. cracks initiating at the bottom of the asphalt layer). Instead, deterioration is confined to the surfacing layers and usually takes the form of rutting in the surfacing and cracking in the surfacing. The design chart, incorporated in PANDEF and CONFIRM, which is used to identify such pavements at the network level, is reproduced in Figure C4.

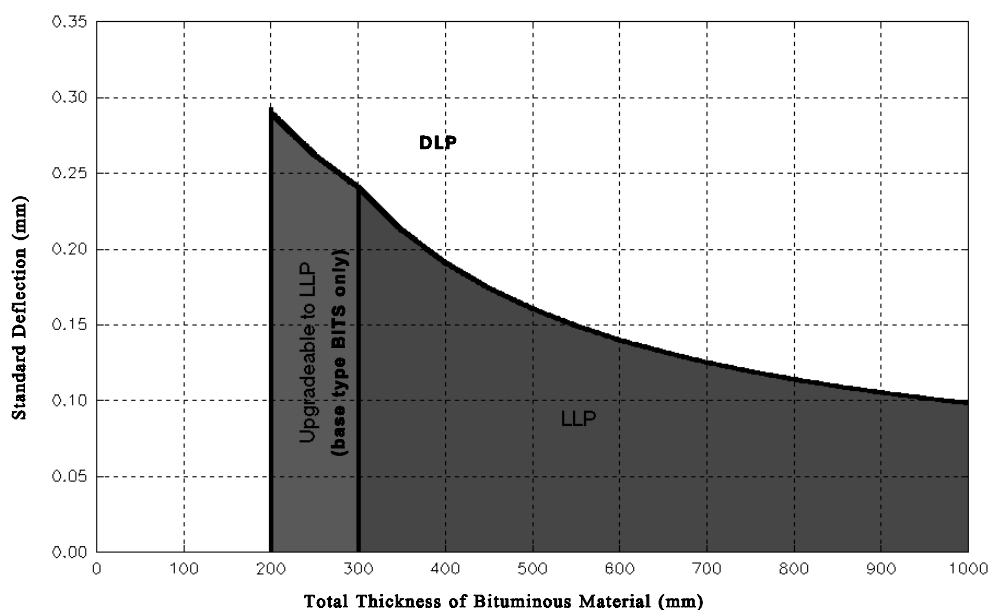


Figure C4 Design chart used to identify long-life pavements at network level
(Reproduced from DMRB 7.2.3)

Figure C4 is described in detail in Appendix 3 of HD29/94 (DMRB 7.2.3). Essentially, long-life pavements (LLPs) are pavements with 300mm or more of bituminous material **and** with all their layers in good condition. Deflection has been used as a proxy for layer condition and the limits in Figure 4 have been defined based on acceptable layer stiffness values. If all materials are in good condition, it would be expected that overall deflection should decrease with increasing bound layer thickness. In reality this approach is likely to be conservative, especially for very thick (e.g. circa 500mm+) pavements where even conventional theories on strains would predict immeasurably long lives to fatigue failure.

In practice, the use of Figure C4 is intended to provide the engineer with an initial categorisation of their pavement – to help them to decide whether any defects found at the surface are likely to be structural or non-structural. Furthermore, although each and every deflection reading obtained can be used to categorise a pavement as LLP etc., the criterion is usually applied to the 85th percentile deflection value in every 100m length (for the Deflectograph there are usually around 30 pairs of deflection readings in a 100m. For each longitudinal position, the higher of the two deflections (left or right wheel track) is

used so it is effectively the 85th percentile value of the higher (“maximum”) deflection that is used.

Investigations (DMRB 7.3.3) should focus on confirming whether or not problems extend beyond the surface layers. Principally, the invasive investigations are:

- coring through cracks to determine depth of cracking;
- coring to provide material for visual inspection and laboratory testing
- testing of unbound layers by DCP.

In addition, FWD testing to determine layer stiffnesses may be undertaken. However current UK practise is to limit the use of the FWD to determining layer stiffness i.e. the calculation of stresses, strains and estimating residual life is not permitted on the HA network

Some detailed points to note.

- 1) Pavements originally constructed with a lean concrete base are considered as LLP fully-flexible provided they have 300mm of bituminous cover.
- 2) New pavements constructed specifically to be LLP using high modulus base materials may not meet the thickness criterion of 300mm and are in fact identified as upgradeable (ULLP). However, guidance has been issued explaining that such pavements are long-life.

C1.4 Upgrading

Fully-flexible pavements with between 200mm and 300mm of bituminous material can, provided their deflection is low enough and they are found to be structurally intact, be upgraded to long-life status by overlaying with enough bituminous material to bring their total thickness of bituminous material up to 300mm. Thus a pavement with a thickness of 260mm and a low enough deflection (Figure C4) could be upgraded to LLP by overlaying with 40mm. If there were deterioration present in the 260mm thick pavement then provided it were in the top of the pavement (e.g. cracking to a depth of 40mm) then removal of the 40mm followed by a 80mm overlay would be used to upgrade the pavement to LLP status. Clearly, if the pavement is found to have more deep-rooted problems then simple upgrading would not be possible.

The decision to upgrade a pavement to LLP status is not a purely technical one. It will also depend on whether it is economically advantageous to do so. For example, there will be pavements that fall into the ULLP category for which a simple inlay (to existing levels) or a thin overlay (i.e. keeping the total bituminous thickness below 300mm) will be sufficient. Clearly, the level of future traffic and the need to minimise the whole life cost of maintaining the pavement will be critical here.

Key indicator for long pavement life

In the UK, the key indicator for long pavement life is a combination of asphalt thickness and standard deflection. This combination is plotted in a simple graph (see Figure C4) which then predicts whether the pavement is long-life (LLP), upgradeable to long-life (ULLP) or not long-life (DLP).

Measurements

In the UK, the measurements are usually done with the Deflectograph in both wheel tracks of the commercial vehicle lane. Usually the 85th percentile of the highest of both

deflections is taken for each 100 m length. These measurements used to be done routinely in the past but are now only performed at targeted sites where major maintenance is proposed.

Process of converting the data into indicator for long-life

In the UK, the deflections are normalised to standard deflections, i.e. the deflection at standard temperature. Then they are combined with the thickness of the bituminous layers to obtain the data point in the graph (Figure C4) which predicts whether the pavement is long-life. basically the requirement for this is that the thickness of the bituminous layers is at least 30 cm, together with a thickness dependent deflection requirement which is added as an indicator that the bituminous layers are also in good condition. Some guidance has been issued to cater for pavements with high modulus bases, so they can still be classified as long-life when appropriate, even if the layer thickness is less than 30 cm.

C2. Assessment and upgrading in the NL

C2.1 Background

In the Netherlands the long – life concept is not implemented in the form of designing fatigue – free structures but by following a design and maintenance strategy that will, given the anticipated traffic and the anticipated maintenance strategy, never exceed a limited extent of fatigue.

Therefore it is not really assessed in the Netherlands whether the pavement is “perpetual”, but it is assessed whether there is still sufficient residual time up to the (limited) degree of fatigue where maintenance is due. If so, the pavement still falls in the long-life strategy. Figure C5 gives an illustration of this for a pavement that has not yet been overlaid.

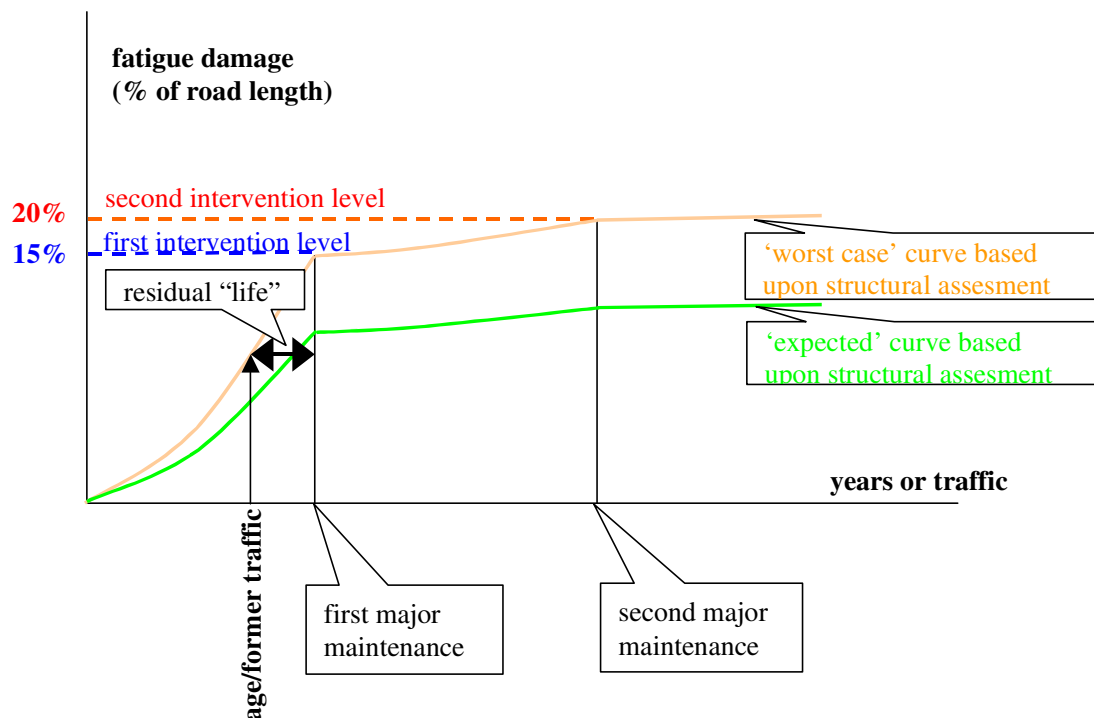


Figure C5 Residual “life” for pavement that has not yet been overlaid

This strategy is actually developed for flexible pavements where the residual life is basically a function of asphalt strain, former and future traffic. In some cases it may come out that this residual “life” is very long, like more than 20 or 30 years, considering the traffic loading. This happens especially with pavements that have a lightly bound road base, giving low asphalt strains, and/or are very thick, e.g. due to frequent profiling layers in areas which suffer from uneven settlements. These pavements can therefore practically be considered “perpetual”⁵ (possibly there is even a strain value below which fatigue is no longer occurring at all, but this is not known).

For bound road bases, the residual life based upon asphalt strains sometimes comes out even higher. If there are no problems with reflection cracking, fatigue in the bound road base or climatic degradation of the materials, these pavements can also be considered “perpetual”. For instance a pavement with a sand cement road base in which the strains in the sand cement never exceed a value of 50 $\mu\text{m/m}$, which is free from reflection cracking and which has no degradation of the sand cement from frost-thaw cycles and such, can be considered “perpetual”. So in this case the strain value in the sand cement road base could be considered as long-life – indicator.

Unfortunately for a number of asphalt and road base materials, fatigue properties (or strain values where they can be considered fatigue – free) are not available. This problem

⁵ Not only is a residual life figure of, for instance, 37 years rather meaningless (it would be impossible to achieve this accuracy), but also the pavement will be receiving functional maintenance well within its residual life. This will not only add further to the structural strength but also allow renewed assessment and any possible problems to be quickly corrected.

will get more urgent with the quick appearance of innovative materials. Whether such a pavement will be long-life is hard to predict. A proposed method to deal with this in DBM – contracts in the Netherlands is to follow the deflections over a number of years. If the deflections in an “untrafficked” line (between wheel tracks) of the pavement do not increase in time and the deflections in the trafficked parts do not significantly deviate from the untrafficked values, both during a substantial period (say 10 years), the pavement will very probably be long-life.

C2.2 Assessment

In all cases the measurements are done with FWD. However, bearing capacity is not monitored routinely in the Netherlands. Usually structural assessment is only done when

- there seems to be a structural problem, based upon visual damage
- there is major maintenance on the pavement and the authority is not sure if the residual structural life is in line
- emergency lanes are converted into extra driving lanes; a hot item at this moment

The reason for this is that structural problems are so rare that they do not justify a systematic monitoring with especially the associated traffic hindrance and safety issues.

Process of converting measurements into an indicator of long-life

As explained above, basically the indicator for long-life will be the structural residual life (until a limited degree of fatigue); in some cases it is just the stain in a bound road base which must be below a certain level.

The process is therefore normally a back-calculation of layer moduli from FWD deflections. From this, strains are calculated. These can be compared directly against reference values; asphalt strains are used in fatigue calculations in which the expected residual life is calculated based on former and future traffic. This process is described by the Dutch CROW organisation in publication 92 (“Deflection profile not a pitfall anymore”) and is implemented in computer codes like the CARE program. Figure C6 below shows the results of a residual life calculation based upon asphalt strains.

Residual life (asphalt concrete strain criterium)					
Reliability level [%]	Residual structural life [years]	Expected degree of fatigue [%]	Reliability factor [-]	Reliability using field calibration [%]	
95	< 0.0	very high	[15 %]	5.4	91
90	2.9	some	[7 %]	3.7	87
85	5.4	small	[4 %]	2.9	82
80	7.8	small	[3 %]	2.4	77
75	10.2	small	[2 %]	2.0	73
70	12.5	small	[1 %]	1.7	68
60	17.3	very small	[0 %]	1.3	59
50	22.4	very small	[0 %]	1.0	50
30	35.2	none	[0 %]	0.6	
15	> 50.0	none	[0 %]	0.3	
10	> 50.0	none	[0 %]	0.3	
5	> 50.0	none	[0 %]	0.2	

Asphalt concrete modulus [MPa] : 6984 Asphalt concrete thickness [m] : 0.190
 Asphalt concrete strain [mikron/m]: 89.3 Edge effect reduction [m] : 0.000
 Maximal Miners ratio [-] : 0.54 Thickness for calculations [m] : 0.190

Figure C6 Result of residual life calculation in NL method

In this example, a safe (85% reliable) residual life estimation gives 5.4 years residual life. According to this safe prediction, 4% of the road section length would have reached the moment of crack initiation and it would last 5.4 years until this has increased to the value where overlaying would be necessary (at 15% of road section length). So this pavement can not be considered long-life, but has no urgent structural problems, still fits in a long-life design + maintenance strategy and can be easily overlaid to prolong the structural life⁶.

C2.3 Upgrading

In case there is still residual value but the residual life is not long, an overlay can be calculated to retard further development of fatigue damage. In the Dutch method it is assumed that the extent of crack initiation after the first overlay may increase a bit further, until 20% of the pavement section length. In combination with the estimated present fatigue damage and the expected future traffic this results in an overlay thickness. The traffic after overlaying is usually calculated for another 20 years. Basically therefore the pavement after overlaying can be considered to be practically long-life, and it would require relatively little extra overlay thickness to extend this value to e.g. 30 years.

⁶ (Note: the designer is not obliged to stick to the 85% reliability. He can go to lower reliability levels if he has strong indications, from the observed behaviour of the existing pavement, that this reliability level is too high. This is sometimes done when the safe calculation predicts no residual life but the pavement shows no serious structural distress. This process requires a lot of engineering judgement and is not dealt with here).

For pavements that have already passed the limit value of 20% damage, an overlay can not directly be calculated. However in this situation one could expect visible occurrence of structural damage locally. Therefore in this case the solution is to make local repairs and then apply an overlay. The thickness of this overlay is calculated in such a way that it only gives a further increase in fatigue damage of maximally 5% over the anticipated new service period.

It is of importance that the repairs are sufficiently effective. Partial inlays will not remove structural cracks over the full depth, but will just retard the recurrence of these cracks. To achieve real long-life pavements, repairs will normally have to be over the full construction depth. In cases where there is extensive damage, it will therefore not be practically feasible to make repairs but reconstruction will be needed.

Key indicator for long pavement life

In the NL, there is not so much a long-life design, but a long-life design + maintenance strategy (see section 1.3). Therefore the key indicator is the residual time left until the moment that a limited degree of fatigue has been attained and the pavement should be overlaid to enable a next life stage without structural problems. When this residual time is sufficient, the pavement still fits in this long-life design and maintenance strategy.

Measurements

In the Netherlands, the measurements are usually done using the FWD. Like in the UK, this will only be done when major maintenance or reconstructions are planned and there are questions if the pavement will have sufficient bearing capacity to be free from structural maintenance for a long period. The deflections are usually measured in and between the wheel tracks.

Process of converting the data into indicator for long-life

In the NL, the deflections are used in a full residual life calculation. However, as stated this is not the residual time until the end of pavement life but until the moment that maintenance is due according to the long-life design and maintenance strategy. This implies back-calculation of moduli, calculation of stresses and strains, estimation of former and future traffic etc. The method was standardised by CROW and is available in computer codes.

C3. Detailed Entries to the Assessment and Upgrading Questionnaire

Respondent	
AT	ISTU
PT	LNEC
SE	VTT
GE	BASt
HU	KTI
DK	DRI
NL	DWW
CH	LAVOC

PART 1 - ASSESSMENT

Table C3.1. Assessment Method

	AT	PT	SE	GE	HU	DK	NL	CH
In my country there is there a specific method to assess whether a fully-flexible pavement is long-life from a structural point of view.								
In my country there is an agreed method to assess the structural condition of flexible pavements, but it does not specifically deal with the question whether the pavement is long-life.	X				X	X	X	X
In my country there is no agreed method of pavement structural condition assessment, but there is one method that can be considered best practice.		X	X	X				

Table C3.1 Comments

AT	The Austrian method indicates if an overlay is possible or a fully re-construction is necessary.
PT	The Portuguese method that is considered to be best practice consists of using FWD deflections and performing a mechanistic analysis.
GE	The Greek method does not specifically indicate whether a pavement is long-life. With this method it is checked whether the structural condition of the pavement is still ok, or if there are hints for a future damage.
HU	The Hungarian method does not specifically indicate whether a pavement is long-life.
NL	The Dutch method does not specifically indicates whether a pavement is long-life (although it will indicate when residual life is more than 30 years) but it does indicate if the pavement still fits in the long-life design and maintenance strategy used in the Netherlands.
CH	There is no definition of long-life pavement in Switzerland and consequently no method for assessing such structure.

Table C3.2. Reference for Assessment Method

AT	STRASSENPLANUNG - BAUTECHNISCHE DETAILS RVS 3.64: Oberbauverstärkung von Asphaltstrassen
HU	National Standard
DK	Only available in Danish
NL	Deflection profile not a pitfall anymore. CROW Record 17, 1998
CH	SN 640733b, Ausgabe 1997-10 (No copy allowed! (copyright))

Table C3.3 Principle of the Method

	AT	PT	SE	GE	HU	DK	NL	CH
Comparison of deflections against reference values or graphs.	X				X			X
Calculation of residual life from deflections using empirical formulas.			X					

Table C3.3 Comments

Table C3.4 Application of the Method

Table C3.5 Minimum Structural Information Required by the Method

[illegible]

Table C3.4 and C3.5 Comments

CH	The structural assessment of the pavement can be performed either by using deflection (in such case, a reinforcement overlay thickness is provided considering the bearing capacity, and the traffic, and the design life) or by using the Structural Number method (in such case, the structural residual value is estimated, by considering the state of each layer. Then the reinforcement that is necessary is calculated by considering the difference between the Structural Number that is necessary and the residual Structural Number.
----	---

Table C3.6 Criteria Checked by Method

	AT	PT	SE	GE	HU	DK	NL	CH
Asphalt fatigue criterion	X	X	X		X	X	X	
Including crack propagation phase								
Subbase deformation criterion				X		X		
Subgrade deformation criterion	X	X	X	X		X	X	
Others, namely: CH	Structural Number or Pavement deflection value							

Table C3.7 Result of the Method

	AT	PT	SE	GE	HU	DK	NL	CH
Indicates whether or not the pavement is adequate	X	X		X				
Indicates whether or not individual pavement layers are in a sound condition	X			X?				
Directly gives overlay requirement								X
Residual life in years			X		X	X	X	

Table C3.8 The Meaning of Residual Life if Calculated

	AT	PT	SE	GE	HU	DK	NL	CH
Remaining time/traffic until pavement needs reconstruction								
remaining time/traffic until pavement needs structural repairs + overlay			X					
Remaining time/traffic until pavement needs overlay only		X			X	X	X	
Remaining time/traffic until renewed assessment is necessary								

Table C3.9 General Structural Condition of Primary Network

	AT	PT	SE	GE	HU	DK	NL	CH
Structural damage is no longer significant in the maintenance of our primary network	X			X	X		X	X
Structural damage is still significant in the maintenance of our primary network		X				X		
Our network is adapted to EC axle loads	X	X		X		X	X	X
our network is not yet adapted to EC axle loads			X		X			

Table C3.10 Experiences with the Assessment Method on the Primary Network

	AT	PT	SE	GE	HU	DK	NL	CH
Calculated and observed structural condition are usually in agreement								
Calculations generally seem to underestimate the residual life for the primary network	X				X	X	X	X
Calculations generally seem to overestimate the residual life for the primary network								
Usually no comparison is made of calculated and observed structural condition		X	X					

Table C3.6 to C3.10 Comments

SE	Action is underway in Sweden to test the methods.
CH	<p>As the maximum axle load in Switzerland is different from the axle load adopted in the EC, some evaluations have been carried out, in order to assess the structural adequacy of your primary network to the future traffic from the EC with the EC axle loads. From the structural viewpoint, it doesn't seem that there will be any structural issue when the trucks coming from the EC will be allowed to circulate in Switzerland with the maximum EC axle load.</p> <p>Assessment of pavement life expectancy shows that pavement behave twice longer (40 years and over) than expected (design life equals 20 years). However, one should consider that the design life doesn't consider any maintenance carried out during that period, as in the reality, pavement maintenance is carried out regularly.</p>

PART 2 - UPGRADING

Table C3.11 General views on Upgrading

	AT	PT	SE	GE	HU	DK	NL	CH
In my country there are specific guidelines to upgrade a fully-flexible pavement to long-life								
In my country there are guidelines to upgrade flexible pavements, although they do not explicitly aim at long-life	X	X	X			X	X	X
In my country there are no specific guidelines to upgrade fully-flexible pavements				X	X			

Table C3.11 Comments

DK	We use exactly the same procedure for upgrading as for new design.
----	--

Table C3.12 Reference for Upgrading Method

A	RVS 3.64 Oberbauverstärkung
HU	National Standard
NL	Deflection profile not a pitfall anymore. CROW Record 17, 1998
CH	SN 640733b, Ausgabe 1997-10

Table C3.13 The Principle of the Method for Determining Overlay Thickness

	AT	PT	SE	GE	HU	DK	NL	CH
Overlay thickness follows directly from deflections via tables or graphs	X				X			X
Stresses and strains are iteratively calculated as a function of overlay thickness until pavement life, calculated on the basis of asphalt fatigue criteria etc, is in agreement with future traffic		X	X				X	

Table C3.14. Method of dealing with Structural (Full Depth) Cracks for Determination of Overlay Thickness

	AT	PT	SE	GE	HU	DK	NL	CH
There is no correction of overlay thickness for cracking because cracking already gives lower effective (back-calculated) moduli for the existing layers and therefore automatically lead to extra overlay thickness		X			X			
There is no correction of overlay thickness for cracking because cracks are supposed to be repaired first							X	
There is a correction of overlay thickness for cracking, depending on severity of cracks and depth of repairs								X
Badly cracked structures are considered as unbound road bases		X	X					
Badly cracked structures are not considered as unbound road bases but are fully reconstructed	X	X			X		X	

Table C3.14 Comments

NL	Cracks are supposed to be repaired first. However cracks are not always repaired over the full depth. Sometimes only 8 to 12 cm is milled and replaced at the locations of cracking before the overlay is applied. Empirical rules of thumb are used to verify if the total thickness of repairs + overlay will retard the cracks for a sufficient number of years
CH	The residual "a" coefficient of a layer for calculating the structural number is depending on the state of the layer. Therefore, the residual "a" value of a bituminous layer is considering the presence and the severity of cracks.

Table C3.15. Typical design period for upgrading

AT	Usually the overlay is designed to give another 20 years design life (i.e. until the next structural maintenance will be necessary)
PT	10 to 20 years. If it is major rehabilitation it is 20 years, as in new construction
SE	Usually the overlay is designed to give another 20 years design life (i.e. until the next structural maintenance will be necessary)
HU	Usually the overlay is designed to give another 15 years design life (i.e. until the next structural maintenance will be necessary)
NL	Usually the overlay is designed to give another 20 years design life (i.e. until the next structural maintenance will be necessary)
CH	Usually the overlay is designed to give another 20 years design life (i.e. until the next structural maintenance will be necessary)

Table C3.16 Design traffic for upgrading

AT	Calculated for 20 years, standard axle = 100kN
PT	Depends on the road
SE	Usually calculated for 20 years, depending on situation (standard axle = 100kN)
HU	Usually calculated for 15 years, depending on situation (standard axle = 100kN)
NL	Usually calculated for 20 years, depending on situation (standard axle = 100kN)
CH	Usually calculated for 20 years, depending on situation (standard axle = 8,1t)

Table C3.17 Construction practices and materials

PT	<p>On badly cracked areas, the existing or part of the existing asphalt layers are removed.</p> <p>When there are localised problems with foundations, the pavement is totally removed in that area.</p> <p>Recently, the following techniques have been recently used sometime with success (not always unfortunately, possibly due to lack of experience from the contractor):</p> <ul style="list-style-type: none"> - Use of high modulus base, in order to reduce the overlay thickness; - In situ recycling of existing pavement (using emulsion or emulsion + cement), to become the base. Construction of new layers on top of it. - Use of geotextiles, or geogrids.
HU	<p>For the primary network, asphalt concrete with max 12 mm grain size aggregate is the normal surface course option. Typical thickness: 30-50 mm. Usually first some profiling will be necessary, sometimes with local repairs. This will be done using dense crushed stone asphalt concrete.</p>
NL	<p>For the primary network, porous asphalt with 11/16 aggregate is the normal surface course option due to the government policy about noise reduction. Usually first some profiling will be necessary, sometimes with local repairs. This will be done using crushed stone asphalt concrete which is a dense graded material; the open graded binder courses that would be used under dense surface courses are normally not used under porous asphalt. Existing dense asphalt surface courses can be maintained if the rate of rutting has been less than 1 mm per year in former years; if not they will first be milled out. Existing porous asphalt surface courses are usually removed. Surface cracking will also be milled out. Local structural (full depth) cracks will be repaired, but not always over the full depth. The materials are described in the RAW standard specifications.</p>
CH	<p>For the primary network, dense bituminous mixtures (AC) and very thin bituminous mixtures with 0/11 grading aggregate are the normal surface course options. Usually first some profiling will be necessary, sometimes with local repairs. Existing dense asphalt surface courses can be maintained if the depth of rutting is less than 1 cm; if not they will first be milled out. Existing Surface cracking will also be milled out. Local structural (full depth) cracks will be repaired, but not always over the full depth.</p>

Appendix D. Maintenance of Long-Life Fully-Flexible Pavements

D1. General Guidance on the Establishing maintenance Procedures for Long-Life Pavements

D1.1 Criteria, prediction models and needs

D1.1.1 Establishing criteria

A criterion is a specified limit for some measure of pavement behaviour, response, performance, deterioration, or operating characteristic against which comparisons of actual measurements or estimates can be made. If the measurement or estimate exceeds the limit, then a deficiency or need exists.

The basic reason for establishing criteria at the network level is to provide an objective basis for identifying current needs and estimating future needs. At the project level, criteria have usually been in terms of specifications.

The following factors can affect the limits (criteria):

- type and functional class of facility,
- size of pavement network and type of agency,
- resources, budget and policies.

D1.1.2 Prediction models

The serviceability-performance concept has been a valuable part of pavement technology since the 1960's. Development of good models for predicting performance has been a major challenge for pavement engineers.

In order to estimate needs years for the sections in a highway network, it is necessary to predict the rate of change of those measures for which criteria have been established.

The basic requirements for any prediction model include the following:

- an adequate data base,
- inclusion of all significant variables affecting deterioration,
- careful selection of the functional form of the model to represent the physical, real-world situation,
- criteria to assess the precision of the model.

Two basic types of prediction models are: deterministic and probabilistic. Subtypes of deterministic models: purely mechanistic, mechanistic-empirical, regression and subjective. The probabilistic models can be survivor curves or transition process models.

PARIS-project financed partly by the European Union as a part of 4th Research & Technological Development Framework Programme created performance models of various condition parameters (rutting, unevenness, cracking, ravelling etc) for Northern, Central and Southern Europe.

D1.1.3 Determining needs

The year in which a pavement section deteriorates to the minimum acceptable level would also be the action year for maintenance-rehabilitation if sufficient funds are available. However, under condition of limited resources, the action year may have to be deferred, particularly if other sections in the network carry a higher priority. Alternatively, the action year can be advanced which may be desirable for certain sections such as those carrying high traffic action year is to change the minimum acceptable level for the measure of pavement deterioration.

D1.2 Maintenance management

The contribution of pavement surfacing maintenance to the long-life of the structure could be really effective only if the maintenance activities are systematised, scientifically planned actually properly managed.

The management of pavement maintenance can be considered to include the following tasks:

- to examine, appraise and validate local conditions,
- to prepare realistic works programmes in order of priority,
- to determine levels of funding required,
- to prepare arguments that justify proposed works and costing, together with the consequences of alternative courses of action,
- to ensure that actions taken demonstrate the advantages claimed,
- to improve the gathering, recording and use of available data.

The management of cyclical (scheduled) and reactive works are to be treated separately.

D1.2.1 Cyclical (scheduled) works

The scheduled works mainly dependent on environmental effects are being used increasingly for a wide range of activities because it simplifies planning, programming and budget formulation. They include such activities as road cleaning, drainage maintenance and vegetation control. The frequency of cyclical works should be based on historical experience. Reference to the policy framework should assist with determining frequencies by defining standards and intervention levels.

Programming cyclical works can only be undertaken in a satisfactory manner within budget constraints where there is a detailed item inventory for the road network with reliable associated cost. The required budget for any particular cyclic activity is the product of the quantity of the relevant inventory item by its unit cost and the number of times a year that the activity will be undertaken.

Database management software is available to assist with managing cyclic maintenance activities stored about the road network and its item inventory. Such software can typically undertake the following functions:

- a.) perform quantity calculations on the network and inventory data, typically of counts, lengths or areas,
- b.) multiply the results of the calculation by a maintenance frequency and unit rate,
- c.) report on the quantities and costs accumulated by various criteria determined from network or inventory data,

D1.2.2 Reactive works

These are works that are carried out to respond to minor defects caused by a combination of traffic and environmental effects. Reactive maintenance works result from:

- routine inspection and assessment procedures,
- road accident reports,
- complaints from the public.

The following types of inspection are in common use:

- safety inspections (required to identify where immediate, urgent or emergency works are needed),
- detailed inspections (required to identify where reactive maintenance works are needed, although a safety inspection would normally be carried out at the same time),
- special inspections (an unscheduled inspection required where a defect has been brought to the attention of the road administration as the result of an accident report, a complaint from the public, or by notification from some other source),
- monitoring inspections (undertaken to provide a check that work has been carried out to agreed requirements, or to feed back experience of actual performance into the management process).

Inspections for periodic works identify the need for maintenance to be programmed in the subsequent budget period, while routine inspections identify reactive works that need to be scheduled into the current year's programme. On the more heavily trafficked roads detailed inspections may be carried out several times a year. On motorways for example, safety inspections may be carried out daily. Inspections can also provide the basis of statistical comparisons and technical audit of work already undertaken for budgetary control and resource management purposes, or for the comparison of performance against standards and intervention levels. Inspection frequencies should be defined as part of the policy framework to ensure consistency across the network, but recognising the frequencies may vary depending upon road hierarchy. Standards and intervention levels for the reactive works identified by the surveys may also vary in a similar manner.

There are several differences between the management of reactive works and those of periodic works. These latter ones have much longer durations and are generally easier to define than reactive works.

As a result, treatment selection and prioritisation methods are relatively easy to apply. The use of such methods is not normally realistic for reactive works, and less formal methods need to be used with the consequence of sub-optimal works being undertaken when budgets are constrained.

The difficulty of specifying reactive work requirements means that defining appropriate standards and intervention levels is more difficult. The cost of surveys to identify reactive

work requirements is a much higher proportion of the cost of the works than for periodic maintenance, calling into question the viability of undertaking surveys in all situations.

Computer systems are available for controlling the day-to-day operational requirements associated with maintenance operations. These, typically, are based around the use of performance standards for works activities. Such systems can assist with the issuing of work instructions and recording work accomplishment, and can produce useful summaries of productivity and resource utilisation at appropriate intervals of time. Other systems are also available for assisting with the management of routine maintenance. As an example, the UK Department of Transport Routine Maintenance Management System has the following features:

- identification of the required cyclical, maintenance and inspection activities based on a section's recorded inventory information,
- recording of inspections and the defects found, allowing direct entry into a data logger,
- classification of defects to give different repair interval requirements,
- automatic or manual matching of defects found in inspections with those already existing on the network,
- creation of works orders for both cyclical and reactive maintenance.

D1.2.3 Scheduling

The responsibility for managing routine maintenance operations will depend on who is responsible for undertaking the various activities: the road administration itself, maintenance management consultants, work contractors, or a mixture of all three. A key management task in this area is the scheduling of works. A works diary provides a basic management tool for both scheduling future works and for recording past works. It will need to be updated frequently and, in many situations, the logging of events will be required every day. It provides a useful source of information when dealing with enquiries and complaints from the public and elected representatives.

Irrespective of where the responsibilities lie, the essential process of scheduling is the same. Cyclical, reactive works and inspections can be treated as discrete „projects“ each with a start and an end, and with a duration and resource requirements. The scheduling problem of each of these projects can be treated as a conventional network analysis and can be solved using critical path techniques. Thus, scheduling can be considered as a project management task.

D1.3 Maintenance treatment selection

D1.3.1 Generalities

The use of standard rules for treatment selection ensures that a consistent approach is taken to planning and specifying works throughout the road administration. This helps to ensure that funds are spent to greatest effect, and that each road and part of the network receives its fair share of the budget. The rules should affect the standards and the intervention levels defined in the policy framework. Two different types of rules are available:

- scheduled (fixed amounts of work per unit time period),
- condition-responsive (work when condition reaches "intervention level").

The scheduled type of rule is often used where need is related to environmental conditions. The approach is also relevant where the deterioration rate is stable. Routine maintenance of a cyclical nature is normally carried out on a scheduled basis.

Whereas scheduled rules are relatively easy to specify and implement, there are several methods of specifying condition-responsive rules. It involves the use of intervention levels which, when exceeded, trigger different treatments. As the decision-making process moves from planning to operations and from network to project level, the treatment selection methods tend to involve the use of a large number of indicators and the use of more detailed rules. The following general types of method are available for condition-responsive treatment selection:

- defect-based rules,
- condition index-based rules,
- complex rules.

In addition, a fourth class of method is available that uses no rules. Instead, an „optimisation” approach is used for treatment selection. Subsequently, this approach will be briefly dealt with.

D1.3.2 Optimised selection of maintenance techniques for implementation

The maintenance techniques to be selected should contribute to the long-life of asphalt pavements. That is why they have to be efficient in repairing the deficiencies identified. Their longevity should minimise the number of road closures for future maintenance activities. The performance of the maintenance treatments has to be favourable with respect to any specific requirements for the network where the road is located.

It is also an objective for road user delays and accidents and thus costs during the application of maintenance treatments should be minimised through reducing the size and duration of road closures. Furthermore, life-cycle costs associated with maintenance activities have to be minimised. Finally, other local factors can also influence the final selection.

COST Action 343 "Reduction in Road Closures by Improved Maintenance Procedures" ran from 1999 until 2003 developed a flowchart procedure to guide the engineer through the process of selecting the most appropriate pavement maintenance options for a particular project ensuring that the selected maintenance treatment options have sufficient life expectancy, while minimising the disruption of traffic. The aim of this procedure is to help road practitioners to generate a list of possible maintenance treatment options that are suitable for maintaining a given road pavement, taking into account the pavement condition and the prioritised performance properties for the road. Apart from these criteria, which give the best options from the point of view of efficiency and longevity, other criteria are considered in the selection procedure to reduce road user delays during the application of maintenance treatments. The future performance requirements are also prioritised, taking into account the type of network, the traffic levels and other aspects related to the specific road site.

This should ensure that the performance of the maintenance treatment will satisfy the requirements of the road users. (The development of the procedure was based on the information collected and stored in the database of pavement maintenance options used throughout Europe). The maintenance activities considered in the procedure includes treatments for repair of localised defects and surface treatments required by road safety

standards, as well as strengthening treatments required by decreasing serviceability and structural degradation. The general procedure for selection of maintenance treatment options at project level conditions has the following steps:

- establish performance requirements and identify the problem,
- select maintenance treatment options from the point of view of efficiency and longevity,
- select maintenance treatment options from the point of view of user delays and performance properties,
- assess local conditions (assess local availability of maintenance treatment options, and perform life-cycle cost analysis of maintenance treatment options),
- select maintenance treatment for the project.

D2. Case Studies

Subsequently, some case studies are presented for introducing several national practices of the maintenance of long-life fully-flexible pavements.

D2.1 The Netherlands

In practice, most of the Dutch motorway network can be considered long life and the vast majority of maintenance is surface course maintenance. Therefore it should be readily applicable for long-life pavements.

The maintenance assessment process has two levels: network level and project level. Usually road sections are assigned an intervention year at network level and are then inspected further at project level in that intervention year.

a.) Network level assessment

The assessment of damage is (still) a combination of measurements and visual inspection. Part of the measurements are done by the ARAN which scans the primary network every two years. ARAN determines transversal profile, longitudinal profile and cross-fall (transversal slope). Furthermore it makes a video recording of the pavement. At this moment, efforts are made to use the laser texture depth measurement also for the detection of ravelling. Skid resistance is measured with a separate vehicle. Cracking and ravelling are at this moment still recorded by two-yearly visual inspection. Deflection testing is not done at network level.

The damage types transversal unevenness (rutting), longitudinal unevenness, loss of skid resistance and loss of cross-fall are classified according to severity (3 classes). For this purpose the measured values are averaged per 100 m section to arrive at a quantitative severity value.

For ravelling and cracking no measurement values are available; these damage types are expressed qualitatively by recording which percentage of a 100 m section has slight

damage, which percentage has moderate damage and which percentage has severe damage. Additionally, it is assessed which percentage has slight “combined surface damage” (i.e. both ravelling and cracking), moderate “combined surface damage” and severe “combined surface damage”. These damage types (ravelling, cracking and combined surface damage) therefore have an “extent” in addition to a “severity”.

The results are compared against intervention levels. Severe damage is not allowed to occur for any of the damages. For ravelling, cracking and combined surface damage, intervention will also be necessary at moderate severity, if the extent of moderate damage is high. These comparisons will lead to immediate maintenance or, if no intervention level is yet reached, each damage type will be extrapolated in time to obtain the intervention year.

For efficiency reasons, pavement sections that adjoin a section which needs maintenance in a given intervention year but do not yet need maintenance themselves in that year, can be still planned for maintenance if the damage is expected moderate at the time of intervention.

b.) Project level assessment

To decide upon the best maintenance treatment, the damage is assessed in more detail in the intervention year. Especially cracking may need further investigation to determine the origin and cause of the cracking. This will lead to a further subdivision of cracking into surface and transversal cracking at one hand and structural damage at the other hand.

Next step is to determine the dominant damage type. If only one type of damage has reached the intervention level, the matter is clear. If a combination of several types of damage have reached the intervention level or none of them have reached the intervention level but combination of damages leads to the decision of maintenance, the type of damage which requires the most heavy maintenance treatment is supposed to be dominant. When types of damage are sorted with decreasing “heaviness” of the maintenance treatments, one gets the following order: insufficient cross-fall, longitudinal unevenness, structural damage, surface and transversal cracking, ravelling, transversal unevenness, loss of skid resistance.

c.) Selecting possible maintenance treatments

After assigning the dominant type of damage, a maintenance measure is selected. Table D1 gives an indication of the possible and the most effective treatments.

Table D1. Final selection of maintenance treatments

Dominant damage type	Type of maintenance treatment	
	Non-porous surface course	Porous surface course

	Surface course Conservation	Surface course regeneration course	Surface course replacement	Overlay	Rut filling	Longitudinal reprofiling	Cross-fall correction	Porous surface course replacement
Structural damage				X				X
Surface and transversal cracking	X	X	X	X				X
Ravelling	X	X	x	X				X
Longitudinal unevenness				X		X		X
Transversal unevenness		X	x	X	X			X
Loss of skid resistance	X	X	x	X				X
Insufficient cross-fall				X		x	X	X

x: possible treatments

X: most effective treatments

If several maintenance treatments are possible, the final selection will be based upon aspects like:

- effectivity and sensitivity (e.g. for weather conditions)
- effectivity to functional properties (e.g. skid resistance, unevenness, noise)
- cost-effectiveness (life cycle cost of treatment)
- effects on traffic hindrance and safety (short application time, possibility for night work, durability)
- environmental effects (use of natural raw materials, prevention of pollution, effects on noise).

D2.2 United Kingdom

The advice for the maintenance of long-life roads in the UK is contained in the Design Manual for Roads and Bridges (DMRB 7.3.3); Specific advice on the maintenance assessment of long-life roads is provided in DMRB 7.3.3 Chapter 2.

The routine assessment of these pavements is currently performed by SCRIM and TRACS (measuring profile, texture, cracking and geometry). Visual Condition Surveys and Deflectograph surveys may then be required on identified schemes with more detailed surveys and investigations where required. If wear is suspected to be confined to the surfacing additional data such as the age of the surfacing can be used to enhance the interpretation of the data from routine assessments. The interpretation of these routine data is provided for in DMRB 7.3.2 Chapter 6 where specific advice on long-life roads is given.

"Implicit in the definition of long-life pavements is a structure of adequate strength manifested by a substantial thickness of bituminous material and low deflections. The low deflections are indicative of a generally sound pavement with good foundation support. The comparison of information gathered on the test areas should concentrate on depth of cracking, rutting and other material deterioration. The findings will give an indication of the

rate of progress of the damage and will assist in deciding on the timing and extent of remedial treatment.

If no evidence of damage is found below the surface layers, this will confirm that the pavement is structurally sound and effort should be concentrated on deciding on a suitable surface treatment. If damage extends downwards into the lower layers, the more extensive investigations will need to be carried out."

The treatment of long-life roads is, as with all roads on the UK trunk road network, determined using financial and safety/environmental considerations. The DMRB recommends that a whole life cost analysis should be used to assess the comparative costs of different treatment options.

Since the advice for the assessment of deterioration in long-life flexible roads is confined to the surfacing, treatments appropriate to the surfacing are those that will be recommended for long-life roads. The type of treatment advised depends on the extent of the deterioration and the degree of penetration of any cracking into the surfacing:

- Crack sealing is recommended for small, widely scattered cracks.
- Surface dressing is recommended for more extensive but shallow cracks or skidding resistance problems. The use of surface dressing requires particular care for high-speed roads and can be an issue in noise sensitive areas.
- Replacement of the surface course, and possibly the binder course, is recommended when cracks are deeper or there is extensive rutting, to prevent these defects affecting the lower, structural layers.

In line with the long-life road philosophy, the DMRB recommends that timely surface treatment can be effective in halting deterioration before serious damage to the remaining structure takes place.

An important aspect of long-life roads is the maintenance of good support from the foundation. It is therefore implicit that the drainage of the foundation is maintained to a high standard. The DMRB does not cover any specific advice for the maintenance of drainage, however it does highlight that drainage failures can lead to significant softening of the unbound layers, as well as the subgrade. This reduces the support to the bound layers, causing failure of the pavement as a whole. If drainage faults are found, the DMRB stresses that it is essential that they be rectified as soon as possible.

D2.3 Austria

The maintenance of long life pavements is a task of the Austrian pavement management system. This system consists of a multitude of elements and sub-elements, which could be summarised as follows (see also Figure D1):

- Standards and instructions for data collection (e.g. catalogue of pavement distress, instruction for collection of traffic data, etc.)
- Road data base (including all information and relevant data for maintenance)
- Elements for developing PMS-models (e.g. performance prediction models of pavement condition, cost models for maintenance treatments, etc.)
- Catalogue of treatments (including type of treatments, trigger limits, treatment effects, etc.)
- Budget preconditions (e.g. limits of the yearly budget, discount rate, etc.)

- PMS-analysis (combines the information and data with models and general framework conditions for cost-benefit analysis and optimisation)
- PMS-output (suggestion for maintenance program of pavements).

The main elements of the system for the practical application, apart from the importance of each single component, are the road data base, the PMS-analysis and the PMS-output.

a.) Data Base

The Austrian road data base VIABASE_AUSTRIA has been filled with already existing and new data of the road network. At the moment this data base includes all the information and relevant data for maintenance such as:

- net-specific data (km-signs, node information, operator, etc.)
- pavement construction data
- pavement condition data
- traffic data
- road geometry data.

The individually adapted structure of the data base allows a separate administration of different data and data groups related to their entity and extension (section based data, point data, historic data, etc.). For the combination of these information special data transformation tools are available in VIABASE®, such as concurrent transformation, transformation by the smallest common denominator, time dependent query, etc. This flexible handling makes it possible an easy and effective processing of data, resulting in calculation of special characteristic values of each data group (e.g. Austrian structural number, cumulative ESALs, calibration factors for performance prediction models of pavement condition, etc.), which are the input for the analysis system.

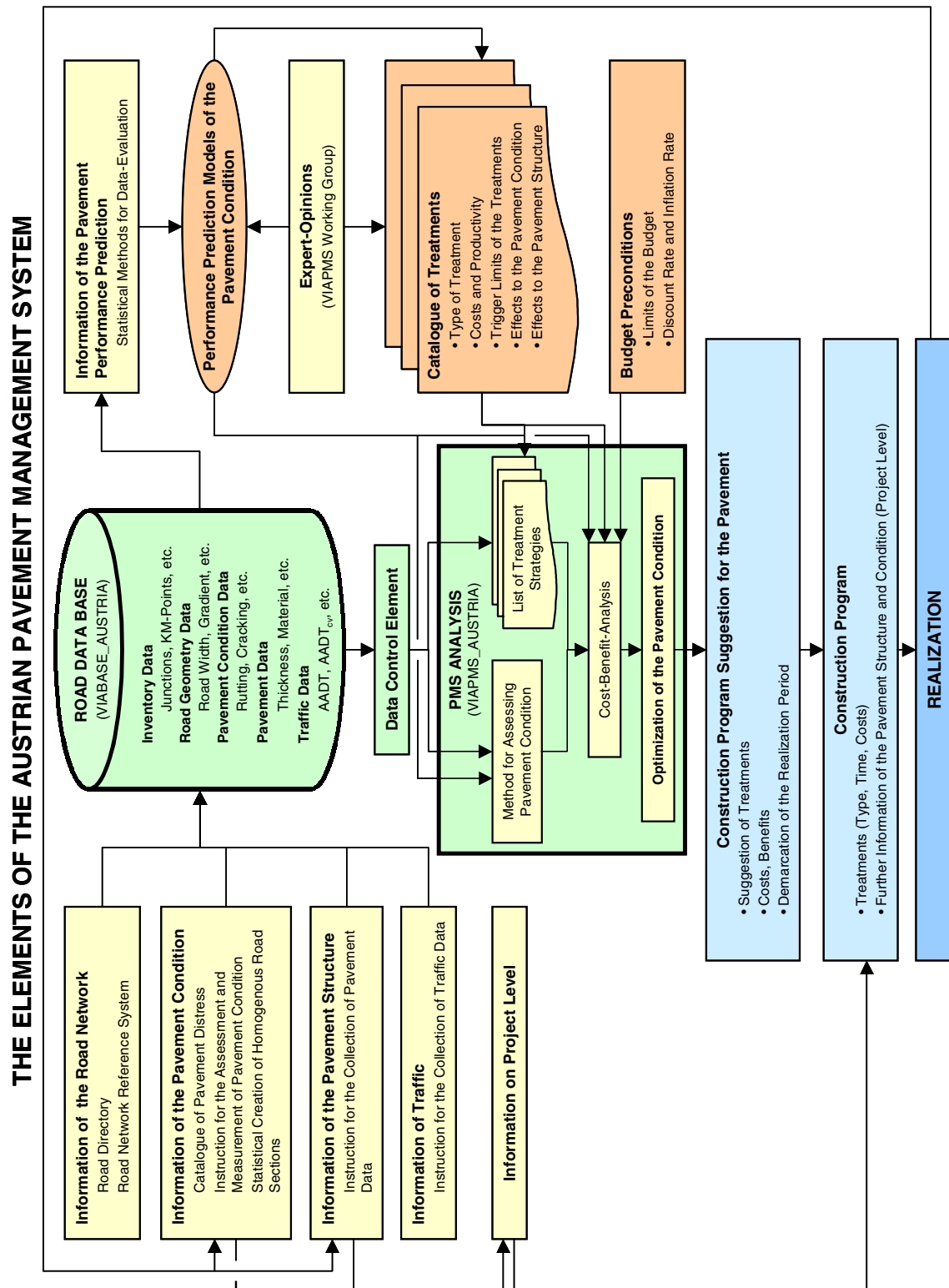


Figure D1 Elements of the Austrian PMS

b.) Analysis

Life-cycle-analysis for road maintenance became a standard in Austria in 2000 by using VIAPMS[®] analytical software. The decisive factor for a decision in favour of VIAPMS[®] - in comparison to other systems - had been that algorithms and models can be modified and defined by the user. That allows an individual adaptation to the road network and general framework conditions. The analysis of each single road (maintenance) section passes a string of single steps which could be summarised as follows:

- Method for assessing pavement condition
- Performance prediction of road condition
To estimate future road condition, deterministic performance prediction models which are related to each single condition attribute and to different pavement types are used in the system.
- Creation of a maintenance strategy list
According to pavement condition a list of possible maintenance treatments, which are defined in a special maintenance treatment catalogue (see Table D2), will be produced. The catalogue includes information of treatment costs, triggers to different pavement characteristics, reset values to different pavement characteristics, etc.

Table D2. Excerpt of the asphalt pavement treatment catalogue in the Austrian PMS

Treatment types for asphalt pavements			
Abbreviation	Treatment type	Description	Costs per unit [€/m ²]
FR_A	milling of asphalt	milling of a part or the complete surface course	3
OB_A	bituminous surface treatment	surface treatment on existing asphalt surface course	5
DD_A	thin overlay on asphalt	thin overlay on existing asphalt surface course	12
FD_A	milling and overlay	milling of the complete surface course and reconstruction	15
FV_A	milling and reinforcement	milling of the complete surface course and reinforcement of the bituminous base	30 for D _{Verst} =12 cm
EN_A	reconstruction of asphalt pavement	complete reconstruction of the asphalt pavement	51 for LK S

- Cost-Benefit Calculation

During the cost-benefit calculation all suggested treatments are compared with each other to find the most efficient maintenance strategy. Therefore the incremental benefit-cost ratio is determined. This is necessary to exclude uneconomic strategies for optimisation. Benefit is defined as the impact of a measure on pavement condition related to the "Do-Nothing-Strategy", with the impact being weighted according to traffic load. A full economic assessment of single measures (including calculation of road user costs) will not be carried out for the time being.

- Optimisation

To find out the most effective maintenance strategy under given budget preconditions the computer-assisted management system employs a deterministic optimisation model using the incremental-benefit-cost ratio (IBC-technique). The system optimises (maximises) the benefit of treatments related to pavement condition in terms of the total condition index over all sections of the investigated road network.

c.) PMS-output

The PMS-outcome comprises information at network-level as well as treatment suggestions for each investigated road section. To describe the development of pavement condition and maintenance funds during the analysis period, the section based results are combined. Different budget scenarios can be compared and can be an objective basis for effective maintenance work and for decisions at network level.

D2.4 Hungary

The maintenance of (long-life) flexible pavements in Hungary is planned using our PMSs based on the information stored in OKA (National Road Data Bank).

The sufficiency rating of the whole Hungarian national highway network of 30 000 km total length has started in 1979. Since then, the visual condition survey of pavement surface aided by keyboard type Road master has been performed every year. Unevenness have been measured every 3 years. Before 1991, Bump Integrator was used for the characterisation of this condition parameter. Since 1991, a Swedish laser-RST (Road Surface Tester) has been applied for unevenness measurement of the Hungarian national highway network. From the same year on, RST has characterised the rut depth, the macro-texture and micro-texture of pavement surfaces, as well. The frequency of the measurement of pavement structure bearing capacity is 5 years. Before 1993, Lacroix-deflectographs, since then, KUAB falling weight deflectographs have been used with 200 m spacing on the road sections.

A special subsystem of OKA (National Road Data Bank) was developed for enhancing the quality of condition data base stored. It has two main tasks:

- condition data time series of various pavement sections are created to ensure the eventual condition data extrapolation for medium and long term planning of interventions,
- the condition data stored can be updated several years after the past condition survey using pavement performance models or the average actual condition improving effects of maintenance-rehabilitation activities.

More detailed condition survey is being done before the intervention year of a pavement section. The results of this visual and measuring evaluation are considered in the project level PMS.

For network level funds split, HUPMS (Hungarian Pavement Management System) is available. This system is based on Finnish HIPS and an earlier Hungarian PMS-version (MPMS). It utilises Markov-type transition probability matrices. The optimum criterion of

the system is the minimum value of the sum of agency and user costs of the whole highway network considered.

The further distribution of the financial means destined to regions and intervention types and determined by using HUPMS is performed by HDM-HUN (HDM-Manager of World Bank adapted to Hungarian conditions). The prioritisation of projects is done using their ranking in accordance with internal rates of return.

Typical maintenance measures applied in Hungary as a function of critical (dominant) damage type:

- surface (non-fatigue) cracking: crack sealing or surface dressing (mainly bituminous emulsion, rarely cutback bitumen type),
- worn and/or slippery surface: single or double surface dressing, eventually thin asphalt layers,
- ravelling and/or potholes: patching, possibly subsequent surface dressing,
- rutting: rut repair (by milling and/or filling) possibly followed by a new thin asphalt surface course,
- uneven surface: levelling course and/or milling of bumps, possibly followed by a new asphalt surface course,
- combination of pavement surface defects: replacement of the surface course.

Recently a research work has been carried out in Hungary to evaluate the actual condition improving effects of various maintenance techniques (surface dressing, thin asphalt layers etc.) The results obtained can be considered as information about the contribution of the respective maintenance procedures to the (long) life of pavements. The typical levels of condition parameters (unevenness, rut depth, surface defects, micro and macro roughness) before intervention and the actual condition improving effects were evaluated using the results of 5-year long condition data series before and after maintenance treatments based on a big sample of some 1500 sections. The influences of traffic size, initial condition state and pavement type were also investigated.

Appendix E. Economics

E1. The UK Perspective on the Economics of Long-Life Pavements

Background

The concept of long-life pavements (LLPs) has resulted from knowledge gathered over 15 years on the performance of heavily trafficked asphalt road pavements. Studies have shown that the deterioration of thick fully-flexible pavements is not structural, as the deterioration generally occurs at the surface in the form of cracking and rutting with no deterioration lower down in the pavement layers.

For new construction, to achieve this long-life behaviour, it is now believed that it is not necessary to exceed the pavement thickness required to carry traffic equivalent to 80million standard axles. If deterioration of the pavement surface is detected and treated before it impacts on the lower layers of the pavement, the pavement can be expected to remain serviceable without the need for structural maintenance. Pavement maintenance will be limited to the replacement of the surfacing at regular intervals and the underlying layers can be regarded as permanent.

Surface treatments cost less than structural treatments and are also carried out quicker. Therefore, for pavements classified as long-life, it can be expected that initial construction costs and maintenance over the life of the road, including the disruption to road users at maintenance works sites, will be lower.

Designs for new LLPs, based on research at TRL (TRL Report 250, 1997) have been available in the Design Manual for Roads and Bridges (DMRB 7.2.3) since 2001. Criteria to identify LLPs on the existing trunk road network were used in the Highways Agency (HA) State of the Network database (SON), released in 1999.

Project and network level whole life cost models have been used to examine the impact of the improved understanding of the behaviour of flexible pavements on the maintenance requirements and budgets for trunk roads. The benefits of LLPs have been examined in terms of the initial and future costs for new pavements likely to be required over the period of the 10 year transport plan (to 2010/11) and for the maintenance of the existing trunk road network for the same period. Benefits from the use and presence of LLPs in the Local Road network have not been considered.

Estimated benefits in UK for new construction

In recent years, work on trunk roads has been aimed at making better use of the existing network rather than increasing the network size. There is now, however, a significant programme of Improvements. Details of these works are not finalised but it has been assumed that 5 new Motorway lengths and 66 APTR schemes will be required over the 10 year period. The estimated benefits result from a comparison of the adoption of designs for LLPs, rather than the current designs to achieve a total design life of 40 years, and assumed distributions of traffic flows and lengths of maintenance works. The benefits from

the construction of LLPs has been estimated to be €50M from the reduction in construction costs and €72M from reduced whole life costs of maintenance over the evaluation period of the analysis.

Estimated benefits in UK for maintenance of the existing network

The Network Whole Life Cost Model, developed on behalf of the HA, has been used to examine the change in the maintenance funding resulting from the identification of LLPs on the existing trunk road network. These changes result from the reduction in structural maintenance needed for LLPs compared with that based on the conventional understanding of pavement deterioration. The analysis examined the maintenance needed to retain the existing network condition over the period 2003/04 to 2005/06 and the period of the 10 year transport plan. Reductions in structural maintenance result from the change in the distribution of pavement residual life caused by the identification of LLPs. There is an increase in purely surface maintenance, however, as the same standards for surface maintenance are required for LLPs and non-LLPs. The changes in maintenance requirements in individual years may result in annual increases or decreases in maintenance costs. Over the analysis period, however, it has been estimated that there will be a total reduction in maintenance works costs of €110M, over the period of the 10 year transport plan, and a reduction in the costs to road users at maintenance works sites of €107M, over the same period.

Choice of Long-life or Determinate Life Pavement Design or Maintenance Design

In practice, the UK Highways Agency has not made a network-wide decision to use long-life designs but ensures that when considering both new pavements and maintenance design, the choice includes long-life options and these options are judged using comprehensive whole life cost principles.

E2. An Introduction to Economic Analysis of maintenance

This annex comes from the D3/D4 Delivery of the FORMAT project.

This annex aims to provide a simple introduction to the economic analysis of maintenance strategies. Its purpose is to provide an easy-to-understand presentation of the objectives and framework of this analysis, and to introduce the role of the different models in this framework. To meet this goal, some figures are proposed below which describe simplified models. Although they display the basic trends of the models with some realism, their values cannot, in any way, be considered as representative of a real situation. These figures aim at nothing but illustrating a general approach.

E2.1 Models for economic analysis of maintenance

The following simple example illustrates how the economic analysis can help to identify and then, to justify, an optimal maintenance strategy, taking into account the condition and the traffic on a road network. It illustrates the importance of availability of technical and economical models, such as:

- user cost models in normal situation:
 - travel time costs;
 - vehicle operating cost;
 - safety costs;
 - discomfort costs;
- pavement performance models;
- pavement preservation model;
- models for extra user costs on work zone;
- models for agency costs;
- models for environmental costs;

E2.2 Case study

Some simple diagrams are sufficient to introduce the basic concepts of economic models and their contribution to road maintenance management in normal situations (i.e. without road works). The diagrams deal with the following case study:

- Network: a route 100-km long;
- Pavements width 7 m;
- Traffic: Only trucks (HGVs) (250 veh. > 5 tons / day);
- Index of Quality proportional to the cost of renewal work (0 = very bad, 1 = excellent).

E2.3 User costs models (illustration)

User costs mainly include travel time costs, vehicle operating costs, safety costs, and discomfort costs.

The costs of travel time are assessed by macro-economic studies. These generally provide a cost per category of vehicles: personal car, professional car, van, truck, bus, etc. Thus, the costs of travel time are, usually, in inverse proportion to vehicle speeds. In the demonstration case, only trucks travel along the network (Figure E2.1).

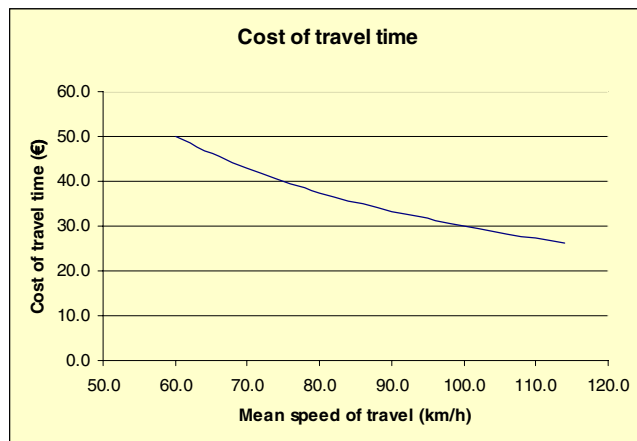


Figure E2.1: Typical travel time cost model used for demo

The vehicles operating costs (VOC) mainly consist of costs for fuel and for tyres, plus vehicle maintenance and repair costs, including spare parts. These costs are affected by external factors such as road and traffic conditions, which are the same for all vehicles (but do not necessarily affect all vehicles equally), as well as internal factors, such as the vehicle characteristics, the driver behaviour, the vehicle load, etc. A distinction is generally made between running costs, which are caused by the use of the vehicle, and the fixed costs (licence, insurance, etc.). Other costs, like engine oil, contribute a small percentage to VOC. Other factors that influence VOC are mainly the road characteristics (unevenness, slope), and the speed of the vehicles. Vehicle lubricant costs, which include costs associated with the consumption of engine oils, other oils and grease, are a minor element (< 3%) of the total VOC. Figures D2.2, below, illustrate these two aspects of the VOC model.

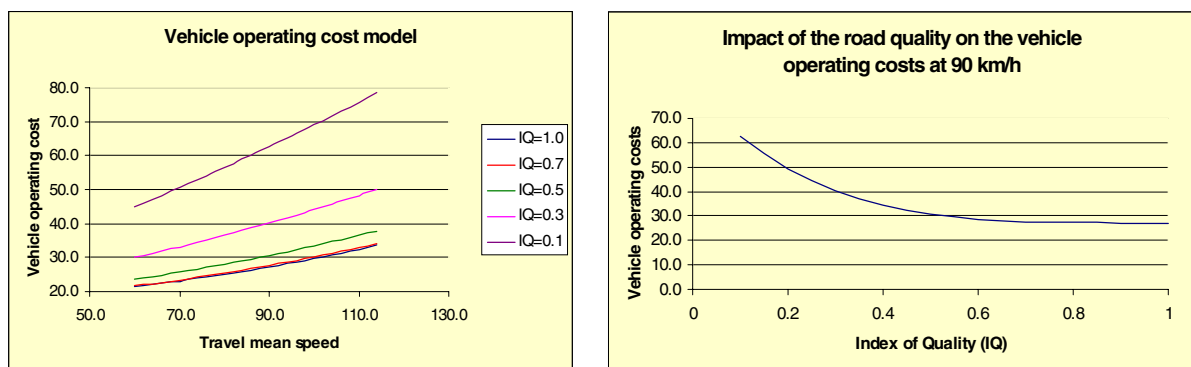


Figure E2.2: Typical vehicle operating costs model used for demonstration

The travel risks clearly increase with speed of travel and the condition of the road. This progression is not, linear, either with speed, or with pavement condition. In normal circumstances, risks remain limited and quite stable as long as the vehicle speed stays below the speed limit for which the road was designed. It rapidly increases as the speed goes beyond this limitation. This increase is more pronounced if the pavement is in bad condition.

Important note: Although the condition of the pavement, for example the skid resistance, is not a dominant parameter in road safety (driver behaviour, road geometry, quality of paintings or signs are a much greater influence to users safety), it can contribute to increased user risks, all other parameters being equal. For this reason, identifying the increase of risks due to pavement deterioration is a difficult problem, which has not yet been solved. Different studies have been conducted which have led to inconsistent, even contradictory, conclusions. Solving this situation is not an objective of FORMAT. Nevertheless, it is a very important challenge for the future, and will require a large amount of efforts.

Figure E2.3 presents a simplified model, sufficient for the demonstration.

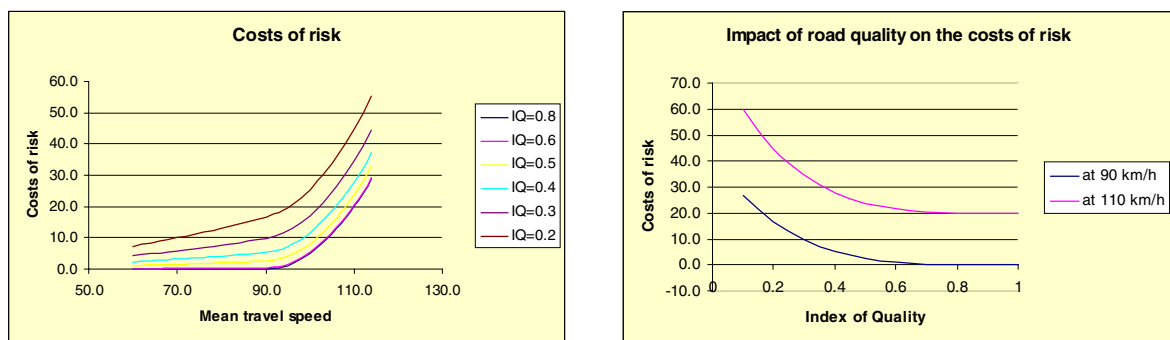


Figure E2.3: Typical user risk costs model used for demonstration

The discomfort cost, which holds for goods deterioration as well as the passengers' displeasure, follows the same trends. These trends are illustrated on Figure E2.4 below.

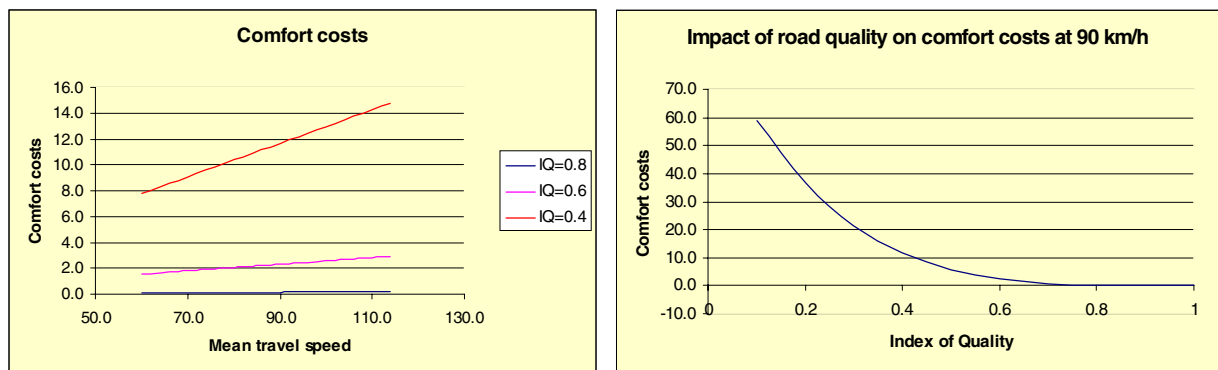


Figure E2.4: Typical user comfort costs model used for demonstration

The user costs is, as previously said, a sum of all these individual costs. It therefore depends on the speed of the vehicles and on the condition of the roads. Figure E2.5, below, illustrates these relationships, using the previous models (Figures E2.1 to E2.4).

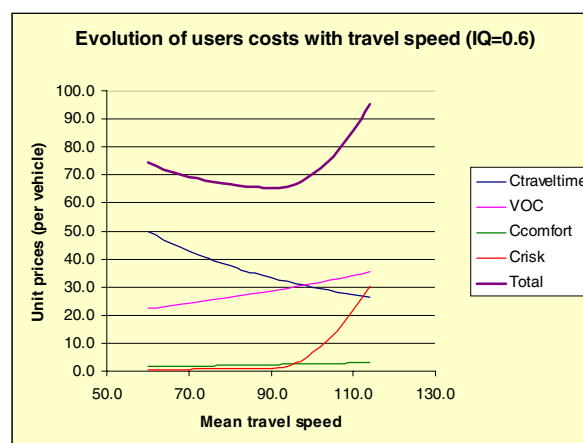


Figure E2.5: User cost as a sum of elementary costs

This figure clearly shows that there is an optimal speed for a given road condition. Below this speed, the cost of travel time increases. Beyond this optimum, the cost of vehicle operation, risk and discomfort rapidly rise to an unacceptable level.

This optimal speed varies with the road condition, as displayed on Figure E2.6. The optimal speed is higher, and the user cost lower, on roads in good condition.

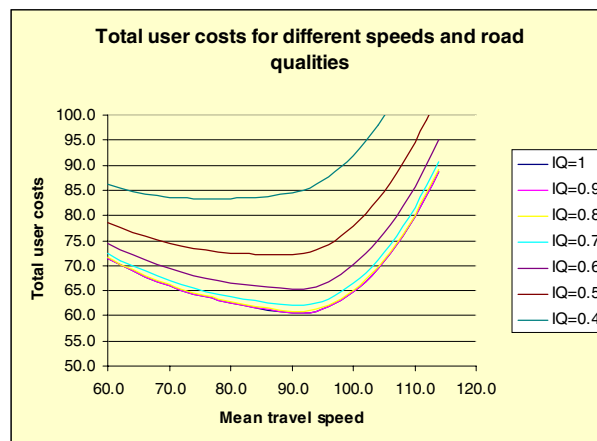


Figure E2.6: User cost depending on road condition

E2.4 Maintenance strategies – maintenance costs

Traffic and climate deteriorate pavements. The rate of deterioration depends on the “strength” (R) of the pavement. “Strength” which is a concept that encompasses its design, climate, traffic, the quality of construction, the sequence of past structural maintenance treatments, etc. In this simple demonstration, the “quality index” expresses the level of deterioration of the pavement. It decreases with time, faster on a weak pavement than on a strong one.

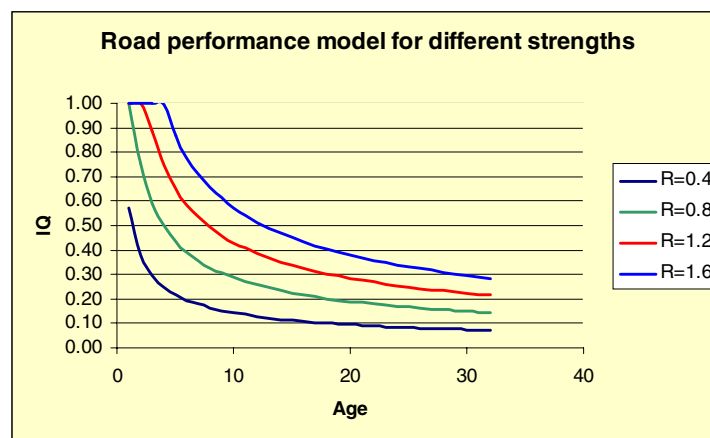


Figure E2.7: Evolution of the quality index on pavements with different strength

As a first consequence of this deterioration, the pavement needs maintenance treatments to continue providing users with the service they expect. Different strategies are possible for this maintenance. Roughly speaking, one can maintain the pavements by performing either light but frequent works (patching, surface dressing, thin asphalt overlays, etc.) or structural overlays, spaced in time. Between these two extremes, a range of strategies is available, to the maintenance managers (Figure E2.8).

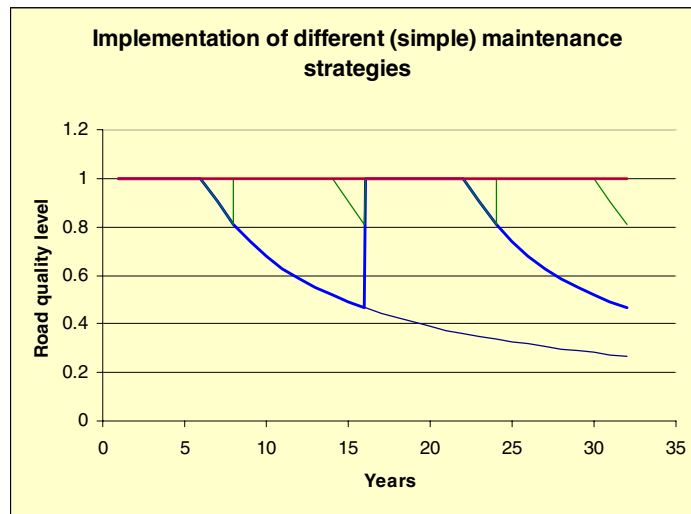


Figure E2.8: Illustrations of different maintenance strategies

This maintenance has a cost, mainly due to the works costs themselves and to the extra user costs on works zones. Basically, these extra user costs are due to the increase in travel time along the route, caused by the reduction of speed along the works. They are considerably higher when some congestion occurs at the entry of the work zone, which is the case if the reduced capacity along the works zone is lower than the traffic demand during some periods of the day. Figure E2.9 displays these simple models which are used in the demonstration.

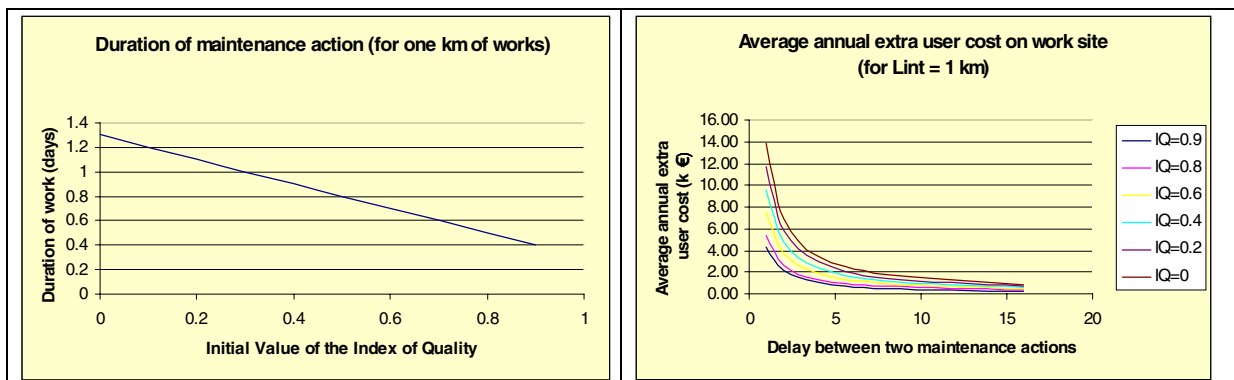


Figure E2.9: Model of extra user cost on working zones

These works make it possible to maintain the road in a “mean condition” (the average value of the quality index over the analysis period) which depends on the frequency of maintenance. A strategy of “frequent works” provides a good mean condition of the road, on which the user costs are minimal, but induces a high level of disturbance for the users. This means higher extra user costs on works zones. A strategy of structural maintenance works spaced in time provides a road with lower mean condition, with higher user costs, but with less congestion due to works. Figure E2.10 illustrates how these costs vary according to the maintenance frequency.

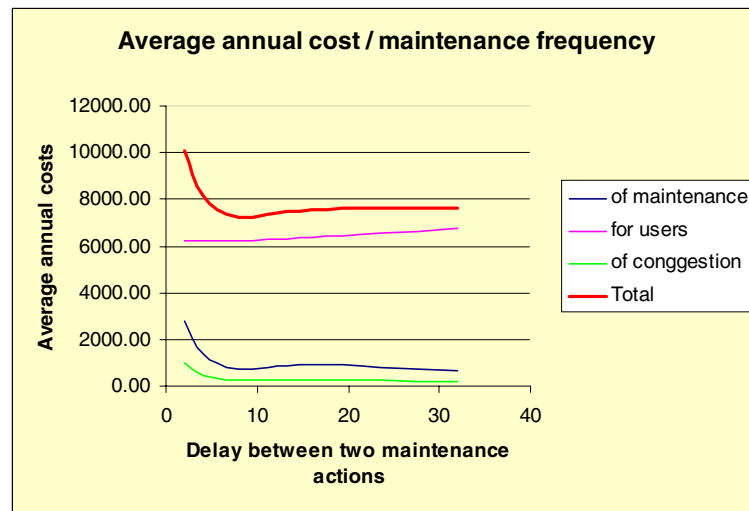


Figure E2.10: Average annual cost due to maintenance for different strategies characterised by the delay between two consecutive works on the same section

Note: The strategies used for the demonstration are selected in such a way that the pavements are renewed at the end of the analysis period; this option avoids the need to evaluate the reduced value of the pavement due to deterioration (pavement preservation). The Figure E2.10 shows an optimal maintenance strategy (minimum total cost). A “more frequent” strategy will induce high works cost (due to the fixed part of each work cost) and high extra user costs (due to frequent traffic slowing or event congestion). On the contrary, a “less frequent” strategy induces high user costs. The optimal strategy mainly depends on the strength of the pavements.

Appendix F. Research Needs

QUESTIONNAIRE RESPONSES TO KNOWLEDGE GAPS

The responses from the questionnaire gave several contributions to cover knowledge gaps in regard to design, construction and maintenance of long-life flexible pavements. Below contributions from the participating countries are referred. In the column at right the relevance of the questions are indicated by H: High; M: medium & L: Low.

New Pavements:

Table F1. How material properties are addressed in the context of LLP

UK	A requirement for LLPs is that good construction practice should be used, which suggests that all materials should be well designed (e.g. adequate binder to suit the aggregate grading, low air voids content, etc.) and compacted; failure to do this may affect durability. The foundation layers need good drainage and structural properties of the materials have to be adequate for their position in the road.	H
PL	There are some functional tests that connect material properties with life of pavements.	M
NL	The Dutch have questions about fatigue resistance of asphalt and possible threshold strain levels; these are dealt with in the questions below.	H
AT	Often the properties and the long-term behaviour of bituminous and unbound materials are not known, especially as regards "innovative" materials.	M
CH	For thick flexible pavements, the Swiss suspect that fatigue failure is no longer relevant but other types of distress are often. There is a question of how best to treat the surface course for thick pavements; should this layer have a normal lifespan and be replaced cyclically or should this layer also be 'long-life'?	H
BE	The properties that have to be considered are known in Belgium and there is a lot of knowledge about properties of new materials. However, a significant amount of knowledge is lacking: how to evaluate the material properties and the evolution of the properties with time correctly. (e.g. healing effects, combined effects of traffic and thermal cycling are never considered, water, all kind of ageing effects). Furthermore, there is a lack of models to describe this behaviour, a lack of validation and lack of knowledge how to couple all different aspects together in order to estimate the lifetime of a road.	H
GR	Research on material properties for long-life is in progress in Greece, especially in the area of modified and recycled materials but the final outcome of this research is yet to be finalised.	H
DK	Materials for the base layers need to be designed durable and resistant to rutting. Experience has shown that bituminous base layers below approximately 100 mm from the surface deteriorate very slowly when properly protected by dense layers above. Furthermore, rutting seems to be relatively easy to control in the base layers. Therefore Danish experience has shown that bituminous base layers can be successfully produced using conventional Marshall design procedures and utilising low cost constituent materials.	H

	<p>However, in the top 100 mm of the pavement structure severe conditions are present in regard to rutting, stripping and ageing. Prescribed design procedures for bituminous mixtures to be used in the top 100 mm are yet to be available in Denmark. Resistance to rutting seems to be under control. Long term performance in regard to stripping and ageing is not yet known. The challenge seems to be how to design for optimum resistance to stripping and ageing and achieve control of rutting; the full-scale, highly equipped wheel tracking device at the Danish Road Institute could assist in this challenge. Good drainage systems are essential for the performance of the entire pavement.</p>	
--	--	--

Table F2. Is “the right” fatigue test method available at present?

UK	The long-term full-scale pavement trials and investigations of heavily trafficked roads have not revealed any conclusive evidence that the classic fatigue cracking is a major distress mode in the UK. However, a criterion that limits the flexure of the asphalt layers makes sense and it is likely to be a good proxy that helps to prevent other mechanisms of pavement deterioration occurring.	M
PL	There are at least 3 tests that seem to be relevant: the two point bending test, the four point bending test and the tension-compression test. The problem is how to compare results between them. The indirect tension test is not considered to be a suitable test method for fatigue.	M
NL	The “right” method should be capable to predict fatigue resistance in the actual pavement, with the complex stress conditions, temperature and load spectra, effects of ageing and stripping, effect of initial cracks etc. The usual laboratory testing methods (four point bending in NL) cannot cover all of these aspects; therefore, it is normally used with significant empirical shift factors. It is even questionable if the test should only cover crack propagation or only crack initiation. A method with a better predictive value is necessary for situations where it is necessary to move outside the empirical frame of reference, e.g very small strain levels or unconventional materials.	H
AT	Due to the strong growth in heavy vehicle traffic, new trends in the automobile and tyre industries, and higher maximum limits for axle loads, the traditional asphalt and binder tests are often inadequate for a reliable prediction of the properties and in-service performance of road asphalts. The problem facing designers of analytical models is the need to fully characterise the properties of the materials on the one hand while on the other also providing a realistic simulation of the traffic- and climate-induced stresses to which pavements are exposed over their design lives of 20 to 30 years. Where LLP are concerned, there is therefore an urgent need for more comprehensive test methods combined with better numerical forecast procedures to improve the economics and extend the service lives.	H
CH	As Swiss response in Table E1	H
BE	The relationship between fatigue testing and field performance is dubious. The different tests for fatigue are not comparable because the stress situations are not the same in each test; the interpretation of the test is also questionable. However fatigue is only one of the aspects to take into account for long-life pavements and materials used in LLP should therefore not be evaluated by fatigue testing alone.	M
GR	There is confidence in the existence of suitable fatigue test, but only in combination with in situ tests.	H
DK	The comparison of laboratory fatigue tests and field performance is questionable. In addition, there is some uncertainty about exactly how thick bituminous pavements behave. Thick bituminous pavements in Denmark have rarely shown examples of classical fatigue cracking from the bottom.	H

Table F3. Is a plan of maintenance necessarily connected to the design on long-life pavements?

UK	<p>Damage to the structure long-life roads is unlikely provided that other elements of the pavement, such as the subgrade, function well. Maintenance treatments will focus on treatment of the cracks and ruts that generally only affect the upper 100 mm of asphalt. Other types of wear will also occur in the surfacing. Loss of skidding resistance and surface texture can occur; fretting and unevenness of the surface course may also develop over time.</p> <p>Intervention to remedy these defects will provide an opportunity to take care of cracking and rutting damage even though they may not trigger intervention criteria. Economic and social criteria will help to provide justification for this intervention.</p>	H
NL	<p>It is not necessary to connect a plan of maintenance to the design of long-life pavements. There are two ways to achieve a long-life quality pavement:</p> <p>(1) Initially build a very strong pavement (which means the maintenance plan is not critical) or</p> <p>(2) Follow a LLP design and maintenance strategy, which means the pavement is not initially built fatigue – free, but the normal overlay cycle ensure that fatigue failure will never be reached.</p>	H
AT	The design of a LLP should be an overall concept, including a plan of possible surface maintenance treatments but no structural maintenance.	H
CH	The plan of maintenance is connected to the design of long-life pavements because the main reason for LLP is to reduce the impact of maintenance and rehabilitation on the traffic and the neighbourhood on highly trafficked roads.	H
BE	Design and maintenance are highly related and it would be attractive to optimise both of these. However, in a first phase it is already an important task to be able to predict the lifetime of a new road so that no structural maintenance will be necessary during a given number of years. A second phase could then be to couple this to a maintenance plan and to take each maintenance step into account to estimate the remaining lifetime. This second phase is a big challenge.	H
GR	Pavement monitoring and potential maintenance of upper layer(s) (surface course...) should be planned at the time of construction so that unforeseen events are unlikely and the pavement will last.	H
DK	Long-life pavements represent a higher investment compared to regular pavement design; such investments must be looked after appropriately. Furthermore, disruption to traffic is one of the main reasons to introduce LLP. Consequently, a proper maintenance plan is necessary to minimise any disruption to traffic. The maintenance plan will necessarily depend on the design and the materials to be used. Therefore, a maintenance plan seems to be naturally connected to the design of long-life pavements.	H

Table F4. Is the correct threshold strain level known where asphalt fatigue is no longer relevant?

UK	An in depth study of the fatigue behaviour of several motorways that had exceeded their design life showed no sign of base deterioration. Furthermore, no evidence of fatigue weakening was seen in these pavements. Based on this observed performance of heavily trafficked pavements in the UK, the threshold strain level is believed to be in the region of 70 microstrain; this is an area that needs further research and refinement.	H
NL	The 'correct' threshold strain level is certainly not known. The strain levels on the Netherlands primary road network often are in the order of 50 microstrain; in these cases fatigue problems never seem to happen.	
BE	A single threshold level of strain is unlikely to exist but it is a phenomenon that happens at all strain levels. Naturally, the lower the strain level, the less fatigue. At a given strain level, it is likely that other failure mechanisms will become more predominant than fatigue. The question is therefore how to set a number of load cycles (depending on traffic level and lifetime to achieve) and to design the structure such that the strain levels that are involved can guarantee that no fatigue failure happens before the number of load cycles are applied (with a certain probability of course). There is always the question about whether the fatigue models are correct and about all unknown influencing factors: influence of healing, thermal cycling which happens on the field, but not in a test, effects of water and ageing.	M
GR	The threshold strain level is currently under investigation but there is not enough experience to make a statement on this.	H
DK	The 'correct' threshold strain level is not known	H

Table F5. How will ageing and stripping influence the fatigue law of an asphalt material?

UK	<p>Ageing, shown by increasing stiffness or changing fatigue life, is not included in the UK methodology. If good construction practice is adhered to, stripping should not be a problem; the surface of the road should be impermeable and the foundation should allow water to escape.</p> <p>Pavement fatigue is a function of the traffic-induced strain and the fatigue characteristics of the asphalt base material. As the materials hardens with age, these two factors are compensated to varying degrees. Calculations have generally shown that the reduction in traffic-induced strain more than compensates for the increased susceptibility of the asphalt to fatigue.</p>	H
PL	Fatigue resistance is known to reduce due to aging and stripping, but this is not taken into account for fatigue life calculations.	L
NL	<p>Ageing can be expected to have a two-fold effect. On one hand the asphalt will become stiffer, leading to lower strain levels. On the other hand the asphalt will become more brittle and initial cracks will propagate more quickly. The net result is hard to predict. However experience in the Netherlands does not seem to indicate that pavement strength decreases with age. If structural problems occur, this usually happens in the first few years of the pavement existence.</p> <p>Stripping is obviously highly detrimental to fatigue properties; when it occurs, the result is disintegration of the material. It would be difficult to express this mode of failure in terms of reduced fatigue life.</p>	H
AT	There is not enough knowledge on the effect of these changes in materials on fatigue to comment.	
CH	The influence of age and stripping on fatigue is unknown.	H
BE	These aspects will certainly have a large influence, but there effect is not yet understood.	H
GR	There is not enough knowledge on the effect of these changes in materials on fatigue to comment.	M
DK	Ageing and stripping has, in Denmark, shown to be significant in the top 100mm of the pavement structure. However, for materials placed deeper than 100mm, problems associated to ageing and stripping seem not to influence pavement performance. It is very obvious that a material, which has lost cohesion due to stripping will be weaker in terms of fatigue. How the fatigue properties develop depending of stripping and ageing is not known.	H

Table F6. Should structural pavement models for flexible pavements address contributions associated to ageing and stripping?

UK	Ideally, models should address the contributions of ageing and stripping. This would require an incremental, iterative approach such as implemented AASHTO 2002 method. The question is whether we can define the ageing/stripping behaviour with sufficient confidence as an input to a model?	M
PL	Structural models should take into account ageing and stripping but seems to be a big challenge.	M
NL	Effects of aging should certainly be addressed in some way. For conventional materials and designs the information is more or less available in the form of empirical shift factors. A more fundamental / explanatory description is necessary when moving to unconventional materials or very low strain levels. Stripping is normally no problem for structural layers. It sometimes occurs in situations where water can enter and remain in the pavement. For LLP I think this should be dealt with by good design and construction practice and then it is not necessary to account for this in design models.	H
BE	Structural models should take into account ageing and stripping but this will be a very difficult task. Ageing will be less important for lower layers, but a reduction in the adhesion of the material leads to a decrease of the stiffness modulus and to a change in the fatigue properties. On the other hand, UV-ageing will stiffen the binder and will increase the stiffness modulus. These aspects are currently not taken into account in structural design models, but they will certainly affect the lifetime;	H
GR	It is not necessary to include ageing and stripping in structural models unless experience shows that these mechanisms are important. In any case the use of modified bitumen could provide a solution for potential problems.	M
DK	It is very obvious that a material, which has lost cohesion due to stripping, will be weaker in fatigue. In addition, ageing will make the material stiffer, which affects the fatigue properties. A structural pavement model, that can introduce top-down cracking, will need to describe contribution associated to stripping and ageing.	H

Table F7. How does healing influence structural deterioration? Does the healing mechanism depend on ageing and stripping, and the use of modified bituminous binders?

UK	There is little detailed knowledge of this in the UK. It is suspected that healing is important and may partly explain why we do not observe classical fatigue damage.	H
PL	When healing appears, the fatigue life will increase. Otherwise there is not the experience to comment.	L
NL	The only known fact is that there must be some kind of healing because pavements last longer than are estimated from laboratory fatigue tests. However, what exactly the mechanisms are is not clear. In fact what healing is considered to be a collection of many influences which finally result in a shift between the behaviour in the laboratory and in service. Therefore it will only partly be possible to measure healing in laboratory. Even if it is possible (which is very difficult, time consuming and expensive), it is likely that there will still be shift with practice. Ageing can play a role in this explaining this shift. While it is currently unclear, it is essential to know if this shift is different for unconventional binders.	H
CH	Healing can have a significant effect on LLP	H
BE	Very little knowledge is available. It is believed that it will be very difficult to obtain correct or indeed useful answers to these questions because it will depend on: rest periods, damage level, the degree of ageing, temperature, probably on humidity. There is almost no knowledge about all this mechanism, but it certainly has an impact. The best way forward for structural design at this moment might be to neglect this effect, knowing that it will only be a positive effect over the lifetime. Some modified binders exhibit more healing behaviour but it is not clear whether that is a general tendency.	M
GR	Healing is still under consideration in Greece.	H
DK	A structural pavement model, which introduces top-down cracking, will need to describe contribution associated to stripping and ageing. Healing will be a part of these processes. Modification of the bituminous binder may influence healing significant. This is of crucial importance especially in the layer right under the surface course. The surface course should also exhibit LLP behaviour.	H

Table F8. How to set Quality Control procedures and levels of tolerances appropriate to long-life pavements.

UK	A similar response to that in Table E1 is given: Good construction practise is essential!	H
PL	No experience.	L
NL	For long-life fully-flexible pavements built with conventional mixes, the procedures and tolerance levels can be identical to the conventional ones. For unconventional. e.g. polymer modified mixes, there is no universal solution. Currently, a product approval scheme for innovative materials is being developed; however, quality control is often product specific for unconventional materials.	H
AT	In Austria, the quality control follows a standard, which is probably similar to most European countries. There is no specific procedure for LLP.	H
CH	In Switzerland, the quality control follows a standard, which is probably similar to most European countries. There is no specific procedure for LLP.	H
BE	The requirements for QC procedures are not sufficiently known. Based on the actual knowledge (which as stated earlier neglects a lot of factors) certain levels can be given for some properties, like stiffness, permanent deformation. These level do not really guarantee a long lifetime; they work in a qualitative way on a basis of comparison but certainly not quantitatively. The levels make possible the best selection of materials and ensure that quality is as good as be.	H
GR	Since LLP is not the major type for road constructions, there is limited experience on the subject.	H
DK	Reliable performance related QC procedures are in regard to LLP still unknown.	H

Table F9. Will implementation of mandatory training programs for the construction workers be necessary to ensure sufficient quality of the works when constructing within LLP standard?

UK	The need for this is likely to vary from country to country. It is not considered to be necessary in the UK.	M
NL	In many cases, where a poor quality has been manifested, it unlikely to be a matter of poor workmanship from the construction workers but of poor production quality control, poor logistics or poor process management (e.g. decision to continue works in spite of bad weather conditions).	L
CH	Quality should have a significant effect on the LLP lifespan	H
BE	Training is very important, but may be not mandatory. The design is only one factor in determining the life span of the pavement, good execution of the work is a key factor too. Hence training is important, but control of the work done is more important.	M
GR	Training programs would be both necessary and useful	H
DK	In Denmark, the asphalt contractors have arranged training programs for the workers for many years. However, the current training is not mandatory. There is no doubt that good execution of the work is a key factor in terms of constructing LLPs and that training is important. Mandatory training when constructing LLP standard, at least for the foreman of a team, should be considered.	M

Table F10. Diagnoses concerning crack propagation. Do you know how fatigue cracking develops in thick bituminous pavements?

UK	<p>Traditional fatigue cracking is rarely, if ever, observed on the UK trunk road network. Surface cracking can develop with age due to shrinkage/brittleness in the binder. Surface cracks generally propagate no more than 100mm into the surfacing.</p> <p>Surface cracking is seen in the wheel path, however it is considered that this type of cracking is most likely to be propagated by factors other than traffic. Traffic is unlikely to be responsible for the propagation of these cracks into the asphalt layer although it may initiate a surface crack.</p> <p>This is certainly an area requiring further work.</p>	H
PL	While typical fatigue cracking starts at the bottom of asphalt layers and goes up, sometimes the crack starts at the top of the structure (on surface).	M
NL	Recent experience has shown that the majority of cracks in thick bituminous pavements are in the surface courses. They normally do not propagate down deeper than 30-40% of the asphalt thickness. In many cases you find some kind of debonding at this depth. With the porous asphalt that is now extensively used, the importance of surface cracking seems to be diminished.	M
AT	Concerning the standard pavements in Austria (max thickness 250 mm), it is always assumed that the initial fatigue crack starts from the bottom of the bituminous pavement. Crack propagation in thick bituminous pavements is yet been investigated in a scientific way.	H
CH	Cracks tend to develop from the upper side of the pavement; this may not be fatigue cracking.	M
BE	Classical fatigue cracking is not very important for thick pavements; the strain levels at the bottom of the bituminous under layers are too small to induce cracking. However, cracking may occur starting from the top or just a few cm from the top. Traffic can induce high strain levels there, which can lead to cracking in such pavements.	M
GR	There is a lot of work on the subject (see also LOIZOS, A., KOLIAS, S. "Practical Aspects Concerning the Applicability of Tri-Axial Failure Regimes in the Design of Pavements". Int. Symp. on Testing and Evaluation of Construction Layers in Pavement Engineering, Dresden 1998, p. 363-376). Furthermore, it should be noted that in several cases monitoring of pavements with more than 15cm bituminous upper layer showed the existence/initiation of top-down cracking.	H
DK	Thick bituminous pavements in Denmark have rarely shown examples of classical fatigue cracking originating from the bottom of the asphalt layer; however, in some instances surface cracking has appeared. These surface cracks are likely to be caused by stripping in the surface course or in the binder course; in a few occasions top down fatigue cracking is seen.	M

Table F11. How can the response from ALT trials be used to develop design principles in regard of LLP?"

UK	ALT trials are of very limited applicability when assessing the long-term structural performance of LLPs as they do not accurately reproduce the environmental conditions that are present in service.	L
PL	Appropriate shift factors are need to covert the results of LAT trials to in-service performance.	M
NL	ALT is not considered suitable for use in the context of LLP. For example to determine threshold strain levels; a very large number of load repetitions is required. Also in ALT, the effect of ageing is neglected. Fatigue experiments with the Dutch ALT facility have shown that these tests are only practically feasible for relatively thin pavements.	L
AT	In Austria there is hardly any experience with ALT. The ALT-facility in Bratislava/Slovakia was used once to validate some Austrian standard pavements.	H
CH	ALT trial can be very useful for the LLP technology, as RLT trials cannot be considered. However, as the failure modes and behaviour of LLPs are significantly different from traditional structures, it should be necessary to reconsider the ALT experiments parameters.	H
BE	ALT trials can be very useful. They should be able to give a better answer than laboratory tests, because they are somewhat closer to real conditions. They can be most relevant as intermediate link between laboratory testing and field, e.g. to show that a laboratory test predicts good ranking, as they are very time consuming and costly.	M
GR	In Greece there are not enough data and experience to comment on the subject.	H
DK	ALT is limited in regard to long term environmental effects. However, ALT may give valuable information in regard to crack initiation and crack propagation.	M

Assessment, Upgrading and Maintenance

Table F12. Rehabilitated pavements by re-use of existing pavement materials. Do you know how to upgrade the recycled pavement materials?

UK	Currently, recycled materials are only allowed in roads up to 30msa. Research is on-going to extend this traffic range, however it is unlikely that this will cover LLPs. (Note: A more versatile method of pavement design is being developed that will allow a much wider range of materials to be used. This method is likely to assist the use of recycled materials in long-life pavements)	M
PL	Recycled pavement materials are used in Poland	M
NL	In the Netherlands there is extensive experience with re-use of recycled materials. In asphalt (except surface course) usually 50% of old asphalt is currently re-used. It is possible to achieve good mix quality and performance in terms of fatigue and deformation properties with recycled materials.	M
AT	The requirements on the quality of recycled materials are recorded in the Austrian standards (RVS 8S.01.3 Wiederverwendbare Baustoffe, in German). The development of recycling processes plays an increasingly important role. To promote the successful use of recycled materials in asphalt roads, reliable methods are to be devised for the specification of material properties based on fundamental tests and, if necessary, procedures developed for an improvement of the required performance properties.	M
CH	The question should be whether it is necessary to use recycled pavement material on LLP? In other words, is it necessary to take a risk (in the quality) by using recycled material, as application of LLP is likely to be economically limited to highly trafficked roads?	M
BE	Re-use is very important and should be encouraged. However, the method of upgrading the recycling materials is not obvious. The effects of renewing agents in case of bituminous binders are known to have a limited affect; research is needed in that field to know in what proportions re-use can be applied in order to guarantee a sufficient lifetime (especially adhesion aspects are important).	H
GR	There is significant experience in Greece and the most recent activities included in situ recycling using foamed asphalt.	M
DK	Recycled materials should be upgraded to match the quality required. On Danish, high-volume roads recycled asphalt pavement can only be used in the bituminous base.	M

Table F13. Upgrading of existing pavements. Do you know how to design/ strengthen an existing pavement to LLP standard?

UK	<p>Potentially, any existing pavement can be upgraded to LLP status i.e. weak/thin pavement structures may require reconstruction or very substantial overlay.</p> <p>The current UK definition of LLP requires pavements to be in good structural condition (deflection criterion) and to have at least 300mm of bituminous material. However, pavements with between 200mm and 300mm of bituminous material which are generally in good condition (meet a deflection criterion and contain no rutted or cracked materials) can be upgraded to LLP status by an overlay to bring their bituminous thickness up to 300mm. If the surfacing of the pavement to be upgraded is rutted or cracked then current advice is that this should first be removed before being overlaid.</p> <p>Pavements thinner than 200mm are less likely to be upgradeable to LLP by overlay as there are more likely to be problems in the existing structure.</p> <p>Research required in this area includes the effect of overlaying cracked or rutted materials. Also, how much deterioration can we leave in place without compromising long-term pavement performance?</p> <p>An analytical approach (i.e. limiting-strain-based approach) is not used in the UK to design an upgrade treatment. This is another potential area for development.</p> <p>Research is on-going in the UK into a method of designing upgrade treatments.</p>	H
PL	Mechanistic design and appropriate software (BISAR, NOAH, VEROAD) are known and used	M
NL	The Dutch design and upgrading method is calibrated against experience, which shows that pavements, designed according to the Dutch design method, normally have no structural problems. However, it may be that for high traffic volumes there is some over design due to extrapolation, because the traffic loads and hence the pavement thicknesses at the time of calibration of the method were considerably less than presently experienced.	H
AT	In Austria, there are guidelines to upgrade flexible pavements although they do not explicitly aim at "long-life" (see response in Appendix C). Based on deflection measurements the residual life of the pavement is derived from graphs. The overlay is designed to give another 20 years design life.	M
CH	See comment in Table E1.	H
BE	A lot of knowledge is available. Strengthening of existing pavements is based on evaluation and on site measurements of the existing pavement to estimate the remaining material properties. Structural design models, but usually based on classical design criteria, are then used to evaluate the lifetime and to calculate the design. For strengthening there are the same challenges as for the construction of LLP pavements in general: see Table F1. Additional research and validation is needed.	H
GR	There are several studies towards this goal, but they are still at a preliminary stage	H
DK	Danish procedures utilise a pavement design program based on FWD data to strengthen the structure.	H

Table F14. Selection of maintenance strategies. Do you know how to address maintenance in the context of LLP?

UK	<p>See the response in Table E3.</p> <p>Since maintenance of the surfacing is all that is required in LLPs, work needs to concentrate on extending the life of surfacings (i.e. rut- and crack-resistant as well as maintaining skid resistance) and on determining the optimum strategy for replacing surfacings. For example, inlays versus overlays, the optimum timing of treatments, etc.</p>	H
PL	No experience.	L
NL	Practically, the primary road network in the Netherlands is free from structural problems and all maintenance is surface course maintenance. Therefore, a maintenance strategy for LLP is unlikely to be much different from what is currently carried out.	M
AT	<p>Flexible pavements of the high-level road network in Austria are designed for 20 years, a differentiation between long-life-pavements and other pavements is usually not being carried out. Structural maintenance treatments are also designed for these time periods. Non-structural maintenance treatments are usually applied to extend the life time of pavements or to improve different surface characteristics.</p> <p>The selection of the maintenance treatments is part of the Austrian Pavement Management System, which aims in an optimisation of the benefit of treatments related to pavement condition over all road sections of the investigated network.</p>	M
CH	As there is no LLP technology in Switzerland, such knowledge is not available.	H
BE	As there is no LLP technology in Belgium, such knowledge is not available.	H
GR	Since the implementation of LLPs is in a preliminary stage, little experience is available. However the overall matter is under consideration, mainly due to the potential implementation of LLP in 'BOT' projects.	H
DK	Denmark does not have a maintenance strategy dedicated to LLP. However, there must be two directions. One can either put down high performing surface courses with expected service life exceeding 20 years, or one can decide to utilise thin surfacings, which are fast to remove and repave. The choice is also a question of cost.	H

Economic Analysis:

Table F15. Life cycle analysis. Do you need a common standard on how to conduct a life cycle analysis?

UK	Yes – but this is an issue for all pavements. Better deterioration models are essential for this	H
NL	More and more pavement engineers are required to base their pavement design decisions on a life cycle analysis. However it is a very labour intensive matter and many (especially the socio-economic) aspects are difficult to quantify. If was a common standard, it would: - be much easier to do after a few times (building of experience) - increase the acceptance of the results - allow development of widely accepted estimates of e.g. socio-economic aspects	H
AT	Life-cycle-analysis for road maintenance became a standard in Austria in 2000 by using the analytical software VIAPMS®.	M
CH	It is obviously necessary to have a common standard, which helps to share the knowledge on LPP technology	H
BE	At least some guidelines would be very helpful. We are far from having standards for life cycle analysis.	M
GR	Up to now there are only University research studies on the subject, however signification investigation has started in the light of implementing LLP in PPP/BOT projects	H
DK	LLP will be more expensive. To justify the investment life-cycle-analysis will be necessary.	H

Supplementary comments:

The representatives from the UK also feel there are other relevant areas where gaps in knowledge exist. These include assessment techniques (e.g. new investigation methods including non-destructive crack depth and the adaptation of existing technologies) and identification criteria for LLPs.

