



ROAD CONSTRUCTION AND MAINTENANCE – TWO INSEPARABLE TASKS

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Abstract

Road transport is playing an important role within the economy. One of the main aims is to provide a secure, improved and environmentally compatible road transport system within a transportation network with increased intermodal operability. As with respect to user costs and avoidance of congestion the availability of the main road network is becoming an important central focus, it is not enough to look at the design and construction phase only and to minimizing these costs of investments. It is indispensable to take into account also the other costs during the whole life time of the road, as maintenance and user costs, at least. This means that a complete view at the total life cycle costs is the necessary precondition for the decision about the design and construction of roads to receive an optimal solution. In many respects this is of course a challenging task, as on the one side the prognosis of the performance of the pavement over the whole lifetime and thus the calculation of the total costs for the road owner is difficult. On the other side also the calculation of realistic user and environmental costs has to be included as a basis for the final decision. The paper gives an overview of the necessary steps for calculation of life cycle costs for roads and includes proposals for a possible improvement of the actual decision procedure.

Keywords: road construction, pavement design, maintenance, user costs, life cycle costs

1 Introduction

In 2009 the European Commission published the communication “A sustainable future for Transport: towards an integrated, technology-led and user-friendly system” [1]. It relates to the White Paper of the Commission, issued in 2001, setting an agenda for the European transport policy throughout 2010.

This programme was updated in the mid-term review of 2006 and close to the end of the envisaged period the commission intends to look further ahead and to prepare the background for updated policy developments also taking into account the content of the Commission’s Green paper from 2009, which foresees the revision of the TEN-T Guidelines planned for end of 2010. Based on the trends and challenges affecting the European transport policy the communication is listing main subjects of policy objectives for sustainable transport:

- quality transport that is safe and secure
- a well-maintained and fully integrated network
- more environmentally sustainable transport
- keeping the EU at the forefront of transport services and technologies
- protecting and developing the human capital
- planning with an eye to transport: improving accessibility

As well as in these topics also at several other places of this paper the importance of proper maintenance and improvement of the transportation infrastructure are highlighted. Transport is an essential component of the European economy. The transport industry at large accounts for about 7% of GDP and for over 5% of total employment in the EU [1]. Looking at the modal split on freight transport within the EU [2] (see Fig. 1) one can see the important role of the road transport system. Thus also all the visions and ideas expressed for the transport infrastructure mentioned before are especially valid for the road infrastructure without any restrictions. Thus it is worth to look for measures and procedures to implement optimization of road construction and road maintenance in the decision process using already existing guidelines and research results for sustainable road construction and operation like

- strategic environment impact assessment [3]
- noise protection: e.g. directive 2002/49/EC [4] together with related research projects like SILVIA [5], SILENCE [6], CALM [7] etc.
- improved materials, recycling, long life pavements: e.g. SAMARIS [8], NR2C [9], ELLPAG [10], CERTAIN [11] etc.

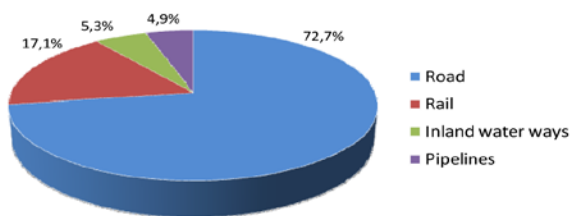


Figure 1 Modal split freight transport for inland modes, EU 27, 2007 [2]

2 Pavement design

The general requirements for adequate pavement design are

- structural efficiency during the whole design period
- taking into account the given random conditions like
 - design traffic load
 - bearing capacity of the subgrade
 - material properties of the pavement layers

2.1 Routine pavement design

In most cases nowadays generally routine pavement design is applied, using average or minimum values for the subgrade bearing capacity and for material properties and the fatigue behaviour of the layer material. The results are often design catalogues or tables like the Austrian rvs 03.08.63 [12], for instance (see Fig. 2 as example). These tables can be the results of empiric experience or of an analytical design procedure as used for the Austrian catalogue. The result of this guideline, which can be used easily, is a number of technically equivalent pavement solutions for specified load classes from which based on the availability of materials and on cost comparisons the optimal solution can be selected. At the same time also several alternative solutions are presented. Nevertheless, the result is still a general solution based on plausible assumptions. As some safety margins are applied for each of the input values, the chosen design will not always be the most cost effective solution. Therefore some improvement is necessary.

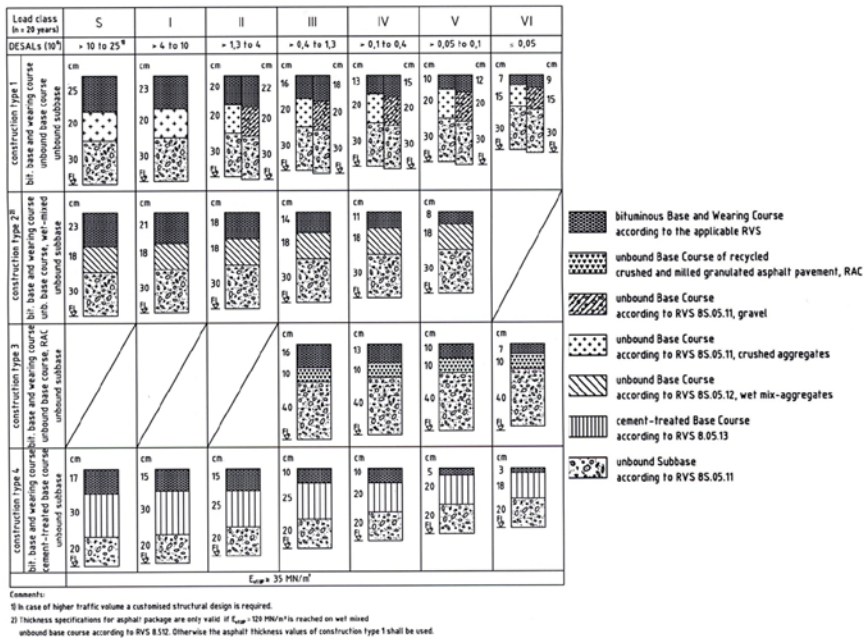


Figure 2 Design table for bituminous pavements, rvs 03.08.63, Austria [12]

2.2 Possible improvements of pavement design

An important improvement of the normally used routine pavement design can be reached by applying a specific analytical design calculation. The calculation procedure can be the same as the one used to draft the design tables but the input values can be improved very much based on actual test results to achieve exact and reliable information about the input characteristics. Performance based laboratory tests as regulated in the respective European standards (e.g EN 12697-1 ff for asphalt [13]) are the necessary preconditions to achieve this improvement. The European standard EN 13108-1 [14] also offers the basis for the description of the asphalt layers' quality based on functional, performance related requirements. Fig. 3 shows as example a test for the determination of the stiffness modulus and the fatigue characteristics of asphalt.

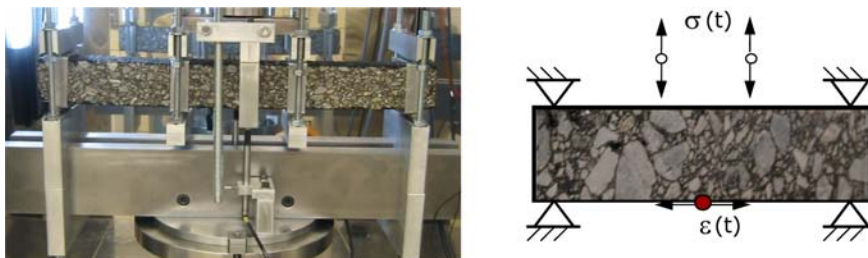


Figure 3 Performance related tests for asphalt (example)

Thus real given values of the expected bearing capacity of the subgrade, representative material characteristics of the pavement materials together with the respective fatigue laws can be implemented for the design calculation. These tests also offer the possibility to employ new,

innovative materials for the pavement layers, which are not yet standardised and for which not enough empiric results are available for general assumptions. Another big challenge within the specific design calculation is the assessment of the design traffic load. As generally known, for pavement design primarily the amount of heavy vehicles $AADT_{cv}$ is of interest as well as the prognosis for the traffic increase during the whole design period. The better the information about the actual traffic load and the envisaged increase the better the result of the pavement design will be. This traffic forecast is not always an easy task, as changes of the economy and variations in the traffic routes sometimes cannot be estimated easily in advance. However, a bigger challenge is to estimate the changes in the use of new tire types like the so called super singles and the acceptance of new vehicle concepts of longer and heavier trucks with different axle configurations, shortly called giganliners (see Fig. 4).



Figure 4 New tire and vehicle concepts as challenge for pavement design

In spite of all the additional efforts for testing and difficulties with defining the realistic traffic load the specific pavement design offers important benefits to the road administration as

- better adaptation to the existing subgrade situation
- realistic estimation of the design traffic load
- better utilisation of the material properties of the pavement layers
- possibility for the application of recycled and/or innovative materials and alternative pavement solutions (this is of special interest for alternative bids and performance related contracts)

Fig. 5 shows an example for a design diagram based on the Austrian design standard but using improved asphalt layer quality.

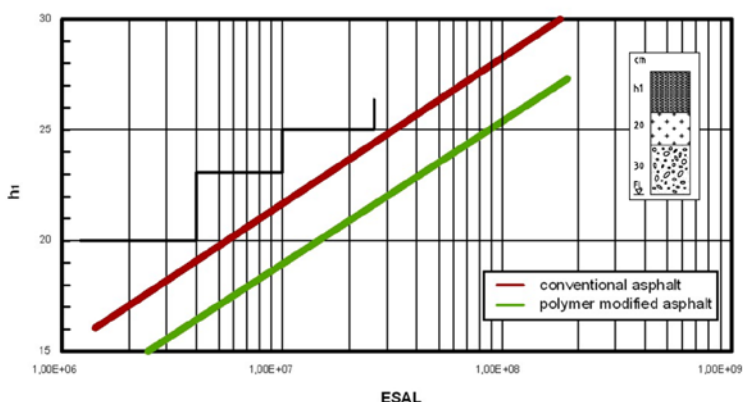


Figure 5 Example for a pavement design diagram with improved asphalt layer quality [15]

Finally it has to be mentioned that the choice of the optimal cost effective pavement solution sometimes may be restricted by given random conditions as

- difficult assessment of real construction costs under competitive situation
- restriction of frequent changes of pavement type (asphalt or concrete) within a given network section
- specific high requirements on noise reduction to be fulfilled with porous asphalt only

Thus the freedom for the choice between various solutions can be somehow limited but the result is still well adapted to the given requirements and takes into account all the given input parameters in an optimal way.

3 Optimized solution, life cycle costs

Looking at the pavement design alone, optimisation normally leads to the solution with the lowest initial costs, i.e. lowest investment costs for the new construction or the strengthening measure. Therefore it is necessary to include not only the construction costs but also the maintenance costs and user costs into the decision process.

3.1 Assessment of maintenance costs

From the road administration's viewpoint the calculation or forecast of the maintenance costs for the whole expected lifetime of the pavement is the main focus. The choice with the minimal sum of the initial construction costs and the expected maintenance costs throughout the whole life cycle in compliance with the given quality requirements defines the most economic solution.

The term maintenance comprises the routine maintenance as well as the rehabilitation and strengthening procedures, their methods and measures, intervals of application and the necessary traffic management at the construction site during the works together with the attributed costs.

Routine maintenance is done periodically during the year to repair local small defects in the pavement in order to fulfil safety requirements and to avoid faster deterioration (crack filling, pothole repair etc.). The amount of works and the respective costs vary with the type of pavement and the quality of the construction. Normally realistic cost assumptions are available from operational experience.

Costs of the traffic management during the maintenance works at the sites are very much relying on the maintenance treatment (e.g. milling and applying a new surface layer or replacement of base layers as well) and thus from the duration and productivity of the works. Also of interest is whether the repair is made lane by lane or for the full width of the carriageway (on motorways) with the deviation of the traffic flow to the other carriageway. For these costs normally a catalogue of possible measures is set up which contains the various maintenance types, their productivity and the recommended types of traffic management. All these costs are then summarized as the total costs for the respective maintenance measure.

The main part of the maintenance planning is the decision what type of maintenance treatment has to be applied and when this treatment should take place. The basis for this decision is the condition of the given pavement with respect to different performance indicators. In Austria as in many other countries as well (see e.g. [16]) the following single indicators (technical parameters) are used [17]:

- cracking
- surface defects also taking into account the structural capacity and the maintenance history
- longitudinal roughness
- skid resistance
- rutting

These single performance indicators are then combined to a pavement and distress index (representative for the structural situation of the pavement) and a comfort and safety index (representative for the requirements of the road users). For this combination it is necessary to transfer the various single technical parameters to condition indices following a normalisation procedure leading to condition classes (see Fig. 6).

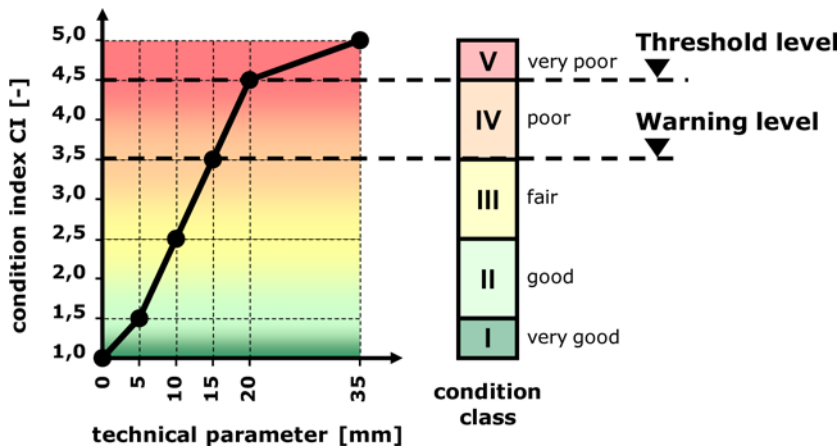


Figure 6 Normalisation of technical parameters according to [17]

Finally the two indices are combined to a total condition index which normally is taken for the following decision procedure (see Fig. 7).

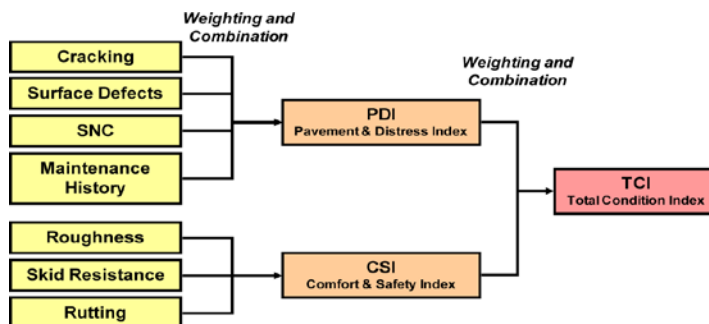


Figure 7 Performance indicators and total condition index according [17]

The requirements for the pavement condition during the whole design period or life cycle respectively are defined by two different condition levels, as indicated in Fig. 6 as well:

- warning level, condition class 3.5. At this stage a maintenance measure should be planned
- threshold level, condition class 4.5. At this stage a maintenance measure has to be conducted

These two intervention levels are the basis for the decision when and what type of repair method has to be conducted. For this decision it is necessary to develop a prognosis of the development of the pavement condition, a so called performance model or deterioration function. This function is then used to predict the change of the indicator values and thus the time of the necessary maintenance measure (see also Fig. 10 ff).

The development of these performance models can be conducted on different ways. Within the Austrian PMS [17] the empiric method was used. An example for the deterioration function for rutting is shown in Fig. 8.

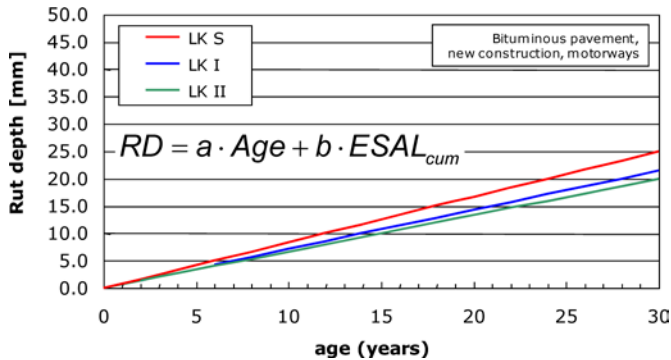


Figure 8 Example, Performance model for rutting according to [17]

The development of these performance models is the most crucial point and a basic task of pavement management systems. As long as standard-type pavements with traditional layer materials are concerned empiric results from the database analysis – as applied within the Austrian PMS for instance – are a pragmatic solution for the prognosis. But there is nevertheless a rather big remaining risk for the accuracy of the forecast as the prognosis is starting from the new pavement at the beginning of the life cycle and has to look forward to a long period of operation, up to 20 or 30 years. If innovative, new materials and/or non standardised pavement types are used a better solution could be to make the prognosis on the basis of analytical calculations, similar as they were applied for the pavement design. A first assumption can be made based on the existing empiric functions which can be adapted according to the results of the analytic calculation.

During the lifetime of the pavement normally periodic updates of the maintenance plan are required based on the results of periodic condition assessments and measurements. In this case the predicted pavement condition can be adapted to the results of the actual condition survey and thus the reliability of the prognosis can be improved very much (see Fig. 9).

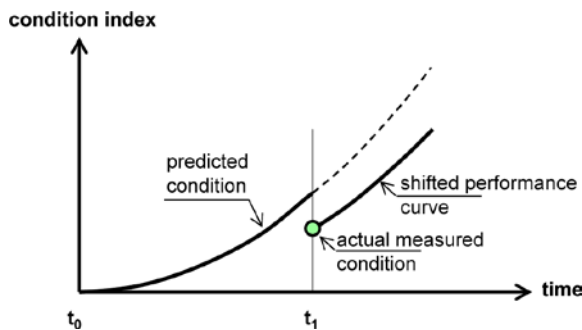


Figure 9 Adaptation of the performance function to measured condition

Nevertheless, the decision about the optimal solution for a pavement choice based on life cycle costs has to be done at the beginning of the project and thus has to accept all the inaccuracy of the long term prognosis described above.

Figures 10 to 13 show an example of the estimated maintenance needs for different technically equivalent pavement types

- concrete pavement
- asphalt pavement, full construction
- asphalt pavement, 2-stage construction

and the related life cycle costs (construction and maintenance costs, NPV). (NB.: this example is valid for a given specific situation only and cannot be generalized nor can the results be extrapolated to other random conditions).

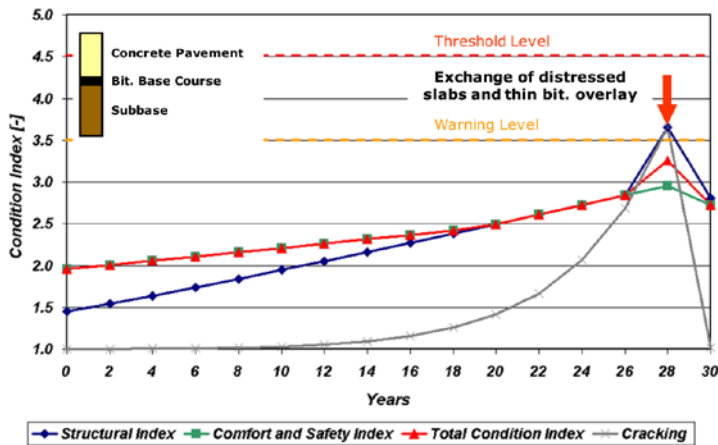


Figure 10 Development of pavement condition and measures – concrete pavement (example) [18]

Total thickness according to design

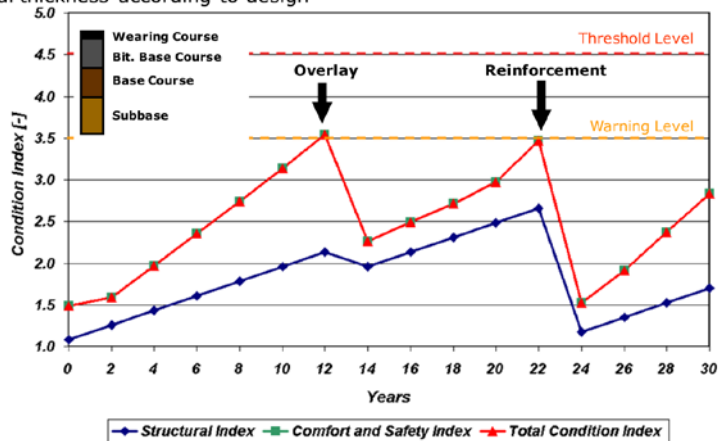


Figure 11 Development of pavement condition and measures – asphalt pavement, full construction (example) [18]

2-stage pavement construction

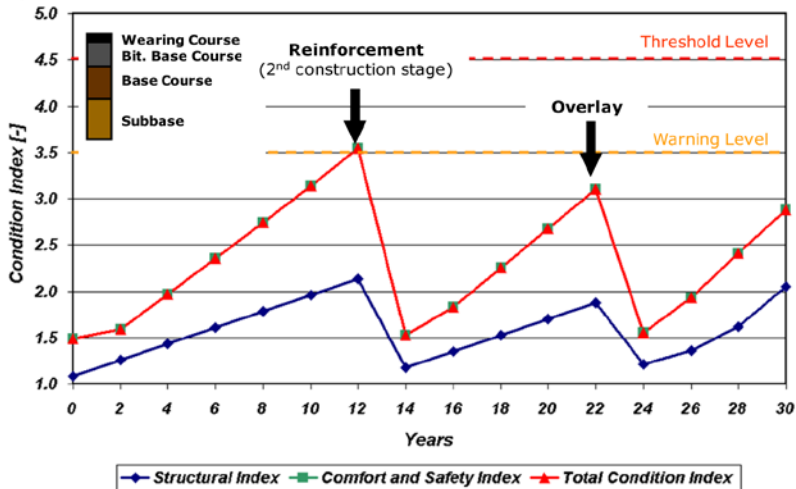


Figure 12 Development of pavement condition and measures – asphalt pavement, 2-stage construction (example) [18]

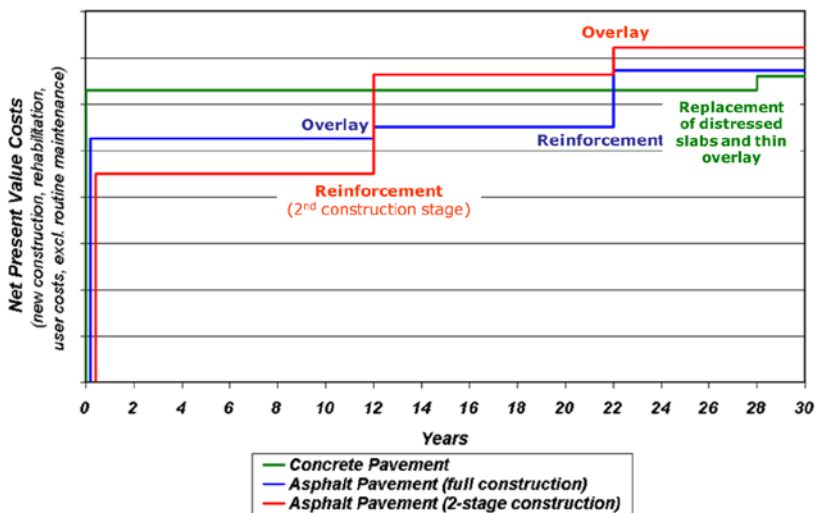


Figure 13 Comparison of total costs (construction and maintenance costs) [18]

3.2 Additional aspect user costs

As mentioned already taking into account construction and maintenance costs for the whole life cycle of the pavement or the road respectively only covers the interests of the road owner. Road users' aspects are sometimes included – especially within PPP-projects – when non-availability costs during the repair works are considered as well.

Nevertheless a total economic view also has to include full user costs for the decision about the pavement construction. This of course is not of main interest at the planning of a new

construction but is of high importance for the choice of the applicable repair method during the lifetime of the road.

Two main types of user costs can be distinguished:

- condition related user costs
 - additional time costs
 - additional vehicle operating costs
 - additional accident costs
- user costs related to construction sites
 - additional time costs
 - additional vehicle operating costs
 - additional accident costs

A research project on the implementation of a user cost module for the Austrian PMS [19], which was finished recently, developed a methodology for calculating the respective user costs and for applying it within the maintenance planning. Fig. 14 gives an example for condition related user costs expressed by user cost savings as a consequence of a maintenance measure compared to the “do nothing” procedure. In Fig. 15 an example for construction related user costs is given for different maintenance works.

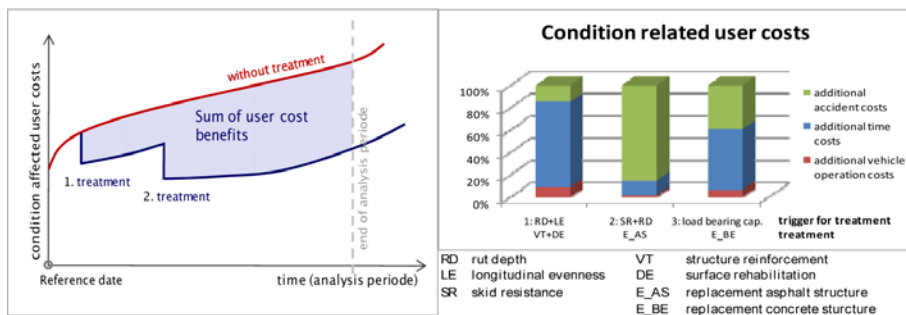


Figure 14 Condition related user costs, savings compared to “do nothing” [19]

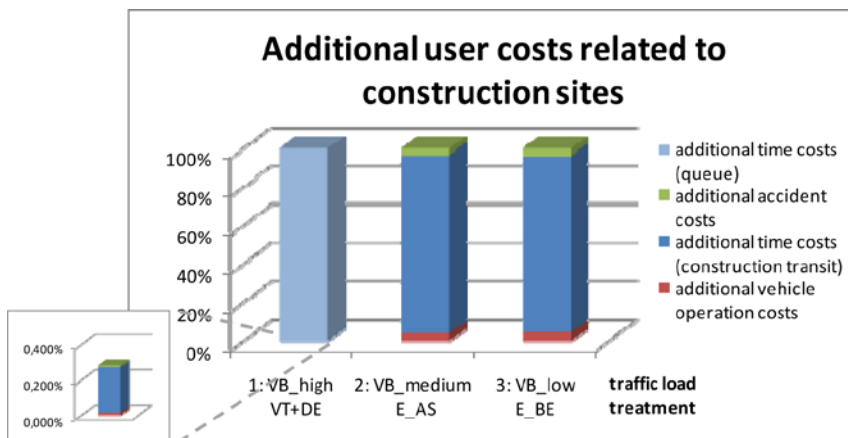


Figure 15 Additional user costs related to construction site (example) [19]

It has to be pointed out that optimisation looking at the user costs alone normally favours surface measures and restricts the application of more severe structural repair works. Therefore

it is necessary to set a clear limit for the structural condition index (for instance the warning level) to avoid, that only “cosmetic maintenance” is conducted. Details can be taken from [19] and another paper at this conference [20] describing the procedure and the recommendations for implementation.

3.3 Environmental aspects

In addition to the consideration of the construction costs and the road users' costs environmental costs can be of special interest as well for the optimisation process within life cycle cost calculation. Main aspects can be besides others

- noise
 - emission of pollutants
- reuse and recycling of materials.

To some extent these aspects will be included already in the choice of pavement type and other measures during the decision for the new construction. This can be clearly related to requirements of noise protection (low noise surface layers, noise protection barriers). It also can influence the method of surface renewal during the lifetime of the road with respect to higher costs and perhaps shorter lifetime of the surface layer. Hence these environmental requirements can be included into the applied decision procedure.

Recycling of materials can also be included in the decision about the costs of the new construction and the choice of the appropriate repair method as well. Besides the savings of the material costs also saving in transport can be taken into account.

The emission of pollutants is considered in the procedure for users' cost estimation described in chapter 3.2 above. In connection with the condition related user costs fuel consumption depending on the longitudinal evenness is calculated and from this result the respective emissions are derived. Nevertheless, there is still a lack of basic parameters to consider environmental aspects from the total economic view. First steps have been started to evaluate environmental impacts in monetary form in some countries but there is still a huge research need to derive applicable indicators. This also was one of the conclusions of the COST-354-project [16].

4 Conclusions

A secure and environmentally compatible road network providing a high level of service to the road users is an important partner within the transportation network. To fulfil this requirement an integrated decision procedure for design and construction including also the planning of the maintenance needs during the total life time of the pavement and the road respectively is necessary. Improved pavement design procedures based on performance related testing of the layer materials and applying analytical design calculation methods can increase the performance of the pavement and promote the use of new innovative and/or recycled materials. Modern pavement management systems are available to conduct the planning of the necessary maintenance works during the lifetime of the pavement. They need accurate pavement performance models to forecast the time and the type of maintenance measure to be applied. These tools are widely available and in use in many countries. However, the decision about the choice of a new road construction often still is made on the basis of the initial investment costs alone. Therefore the inclusion of the expected maintenance costs by lifecycle cost assessment is a necessary requirement to assure an optimal cost effective result and to adequately use the available road administration's budget.

Including the road users' cost in the consideration is becoming more and more important, especially for the high level road network carrying a big amount of traffic. Technically this leads to pavement types with a longer lifetime – so called long life pavements – needing only surface maintenance at longer intervals (see e.g. [10]). One problem which is not really

solved for the practical implementation of user costs is the fact that additional construction costs of long life pavements have to be covered from the road administration's budget, while the respective savings are the benefits of the users. A similar problematic is existing with the consideration of environmental costs. Here new approaches for the distribution of financial resources within the different budgets are necessary.

Optimisation and integrated planning of construction and maintenance is indispensable not only for the road network but also for the rail system as well. The general procedure is applicable for both systems provided the necessary internal tools like performance models are available. This is an additional important argument to support the trend of co-modality leading to an optimized transport network.

References

- [1] EC, DG TREN: A Sustainable Future for Transport: towards an integrated, technology-led and user-friendly system, Luxembourg, 2009.
- [2] EC, DG TREN: EU energy and transport in figures, Luxembourg, 2009
- [3] OECD: Environmental Impact Assessment of Roads, Road Transport Research, Paris, 1994
- [4] EC-Directive 2002/49/EC: Assessment and Management of Environmental Noise, Brussels, 2002
- [5] EU-project SILVIA: "Guidance manual for the implementation of low-noise road surfaces", final project report, GROWTH project GRD2-2000-31801 (SILVIA - Sustainable Road Surfaces for Traffic Noise Control), Brussels, 2004.
- [6] EU-project SILENCE: Quieter Surface Transport in Urban areas, 2005 – 2008, www.silence-ip.org
- [7] EU-project CALM & CALM II: Coordination of European Research for Advanced Transport Noise Mitigation, www.clam-network.com
- [8] EU-project SAMARIS: Sustainable and advanced Materials for Road Infrastructure, 5th FP, <http://samaris.zag.si>
- [9] EU-project N2RC: New Road Construction Concepts, 6th FP, 2003 – 2007, <http://nr2c.fehrl.org>
- [10] ELLPAG: European Long Life Pavement Group, multinational project, phase 2- and phase 3-report, Brussels, 2009, www.fehrl.org
- [11] EU-project CERTAIN: EC funded Coordination Action 6th FP, 2006 – 2009, including: SPENS, Sustainable Pavements for European New Member States, <http://spens.fehrl.org> ARCHES, Assessment and Rehabilitation of Central European Highway Structures, <http://arches.fehrl.org>
- [12] RVS 03.08.63, Oberbaubemessung (Pavement design), Austrian Transport Research Association (FSV), Vienna, Austria, 2008.
- [13] EN 12697-1 Bituminous mixtures – Test methods for hot mix asphalt
- [14] EN 13108 -1 Bituminous mixtures – Material specifications – Part 1: Asphalt Concrete
- [15] Litzka J., Molzer C. & Blab R.: Modifikation der österr. Methode zur Dimensionierung des Straßenoberbaues (Modification of the Austrian Pavement Design Method), Schriftenreihe Straßenforschung, Heft 465, BMWA, Wien 1996
- [16] Litzka J., Leben B., La Torre F., Weninger – Vycudil A., Antunes M., Kokot D., Mladenovic G., Brittain S. & Viner H.: The Way forward for Pavement Performance Indicators across Europe. Final Report of COST Action 354. FSV Vienna, Austria, 2008
- [17] Weninger-Vycudil A.: Entwicklung von Systemelementen für ein österreichisches Pavement Management System (Development of Systemelements for an Austrian Pavement Management System), Mitteilungen des Institutes für Straßenbau und Straßenerhaltung der Technischen Universität Wien, Heft 14, Wien 2003 and Weninger-Vycudil A., Simanek P., Rohringer T. & Haberl J.: Handbuch

Pavement Management in Österreich (Handbook PMS in Austria, in German). BMVIT, Schriftenreihe Straßenforschung. Heft 584, Wien, 2009

- [18] Litzka J.: Pavement Maintenance Planning for PPP-Projects, Proceedings of the International Conference UACG, Science & Practice, Sofia, 2009
- [19] Brozek B., Litzka J. & Weninger-Vycudil A.: Entwicklung eines Nutzerkostenmoduls im österreichischen PMS (Development of a user cost module for the Austrian PMS), Schriftenreihe Straßenforschung, Heft 585, BMVIT, Wien 2009
- [20] Brozek B. & Litzka J.: Optimized Road Maintenance for Road Users, Proceedings CETRA 2010, Opatija, 2010

1 EDUCATION

