Economic Evaluation of Pavement Maintenance

PAV-ECO

Danish Road Institute
Report 114
2002

Road Directorate
Ministry of Transport - Denmark

Road Directorate
Danish Road Institute
Elisagaardsvej 5
P.O. Box 235
DK-4000 Roskilde
Denmark
Telephone +45 46 30 70 00
Telefax +45 46 30 71 05

Title	Economic Evaluation of Pavement Maintenance PAV-ECO
Author	H.J. Ertman Larsen, G. Hildebrand and Robin A. Macdonald
Dated	April 2002
Copyright	Road Directorate, all rights reserved
Printing	Electronic edition
Published by	Road Directorate, Danish Road Institute
ISBN	87-90145-89-5
ISSN	0909-1386

Reports published by the Danish Road Directorate
can be requested from the Bookshop:
Telephone +45 46 74 01 07
Telefax +45 46 74 01 05
e-mail boghandel@vd.dk

Economic Evaluation of Pavement Maintenance

PAV-ECO

H.J. Ertman Larsen

Gregers Hildebrand

Robin A. Macdonald

Danish Road Institute
Report 114
2002

Contents

Preface

Economic Evaluation of Pavement Maintenance

The extent and condition of a country's road network largely influences its capacity to transport people and freight, and affects its economic growth. In Western Europe, the ever-increasing social services components of national budgets often reduce the financial resources allocated to other activities, such as transport infrastructure. To compensate, European countries have developed and apply national Pavement Management Systems (PMSs) to optimise maintenance management of their road networks. Although the ultimate goal of these systems is to optimise expenditure levels for the allocation and use of Maintenance and Rehabilitation (M/R) budgets, many PMSs are still limited to purely technical approaches. Maintenance needs are often prioritised on the basis of comparisons between the actual condition of the pavements acquired from surveys, and the desired condition, often expressed by road management authorities in terms of performance indicators such as structural life, evenness and surface condition.

Traffic is one of the main causes of road pavement deterioration and therefore it is essential to be able to produce accurate traffic forecasts. However, PMSs often do not consider road networks to be coherent systems of road sections with finite capacities. When over-capacity traffic finds other routes, the alternative routes are exposed to higher rates of deterioration. Thus pavement management strategies should be based on reliable traffic forecasts and traffic assignment models. In considering the impact of traffic change on maintenance investment strategies, two main issues were considered: traffic forecasting and traffic simulation models for use both at the network level and at the project level.

PAV-ECO also set out to develop an analytical framework based on traffic simulation allowing a consistent cost benefit analysis (CBA) for a range of pavement management strategies. The costs of each strategy (e.g., private investment costs, operating costs and public investment costs) were compared with possible social benefits. For realistic cost benefit analyses, dynamic effects that influence the costs and benefits were also considered (e.g., technical innovation in maintenance measures, changes in traffic parameters and their influence on the surface condition of roads). The Project conducted life-cycle cost analyses based on comparisons of financial costs to road agencies and economic costs to road users during the service life of roads, including long-term economic assessments of maintenance budgets. Road condition performance models and economic models were involved in this process; the former were developed within the PARIS European project (PARIS: Performance Analysis of Road Infrastructure - Final Report, European Commission, ref. RO-96-SC.404, November 1998).

Alternative M/R strategies used in Europe were identified through literature surveys and interviews conducted in fifteen European countries. The interviews were conducted by four of the partners, who approached road management experts and national road authorities in France, Belgium, Spain, Portugal, Slovenia; Norway, Sweden, Finland, Denmark; Switzerland, Hungary, Austria; UK, Ireland and the Netherlands. The questionnaire sent to the fifteen countries revealed a common pan-European approach to road maintenance and similar maintenance management practices. Thus PAV-ECO set out to investigate models for evaluating maintenance investment strategies at the project level, such as for instance, the direct costs of M/R works, road investment preservation by maintenance, user cost reductions due to improvements in comfort and safety conditions and reductions in travel delays due to reductions in congestion at M/R sites. For evaluating maintenance investment strategies at the network level, other models were investigated; these models considered the impacts of changes in traffic flow on maintenance needs, social economic effects from the maintenance of road infrastructure and the allocation of funds for different components (public and private) of road and road transport infrastructure. Vehicle operating costs in Europe were also considered, since the available models originally developed for predominantly tropical and sub-tropical climates and the mainly low volume traffic conditions in developing countries were not suitable for European road transport conditions.

PAV-ECO involved eight partners from seven European countries; it did not aim at developing a Europe-specific PMS, since many countries that have developed their own systems prefer to continue to use them routinely and to introduce improvements only. PAV-ECO therefore developed economic models for incorporation in existing PMSs, to widen their application to long-term social economic analyses, and thereby, to improve their ability to optimise limited national road transport M/R budgets.

Introduction

PAV-ECO was supported under the Transport Research and Technological Development (RTD) Programme of the Fourth Framework Programme of the Commission of the European Communities (CEC). The Project was entitled: the Pavement and Structure Management System; it was composed of two separate, but related, research projects that were financially supported by the CEC. PAV-ECO was initiated by the Forum of European National Highway Laboratories (FEHRL) and ran from October 1997 for a two-year period. This paper concerns the PAV-ECO Project only.

The PAV-ECO Project was undertaken by a Consortium of Partners consisting of the Danish Road Institute (Denmark), Anders Nyvig A/S (Denmark), Technical Research Center of Finland (Finland), Laboratoire Central des Ponts et Chaussées (France), University of Cologne (Germany), Laboratoire des Voies de Circulation LAVOC - EPFL (Switzerland), Viagroup SA (Switzerland) and Transport Research Laboratory (United Kingdom). The Danish Road Institute managed the Project.

Objectives

The objectives of the PAV-ECO Project were to develop economic models for the evaluation of life-cycle costs of pavements, and to study the effects on road infrastructure maintenance when new road links are added to a road network. The project objectives were accomplished considering:

- Optional application of different maintenance measures
- Impact of changed traffic flow on maintenance needs
- Social economic effects from maintenance of the road infrastructure
- Allocation of funds for different geographical regions and infrastructure components
- Vehicle operating costs appropriate to European conditions.

Dissemination of the results was ensured through:

- Policy and methodology proposals provided for European road owners
- International symposia for dissemination of the Project results
- International information databases.

In the Project, the objectives were addressed by research tasks (cf. next section). These Tasks expanded the capability of maintenance management and included the development of models to represent the normal financial and economic decision-basis upon which experienced maintenance engineers would plan maintenance interventions. For example, the problems to be addressed by road agencies include:

- Timely interventions on adjacent road sections
- Possible changes in future traffic flows through the road network
- Allocation of available road funding
- Increased traffic on diversion routes through the network during closure of road sections for maintenance.

Also, the global political and economical interests considered were:

- Preservation of the capital invested in the road pavement
- The overall rate of return from the entire maintenance plan
- Changes in total budget need for maintenance, when new roads are added to the existing network.

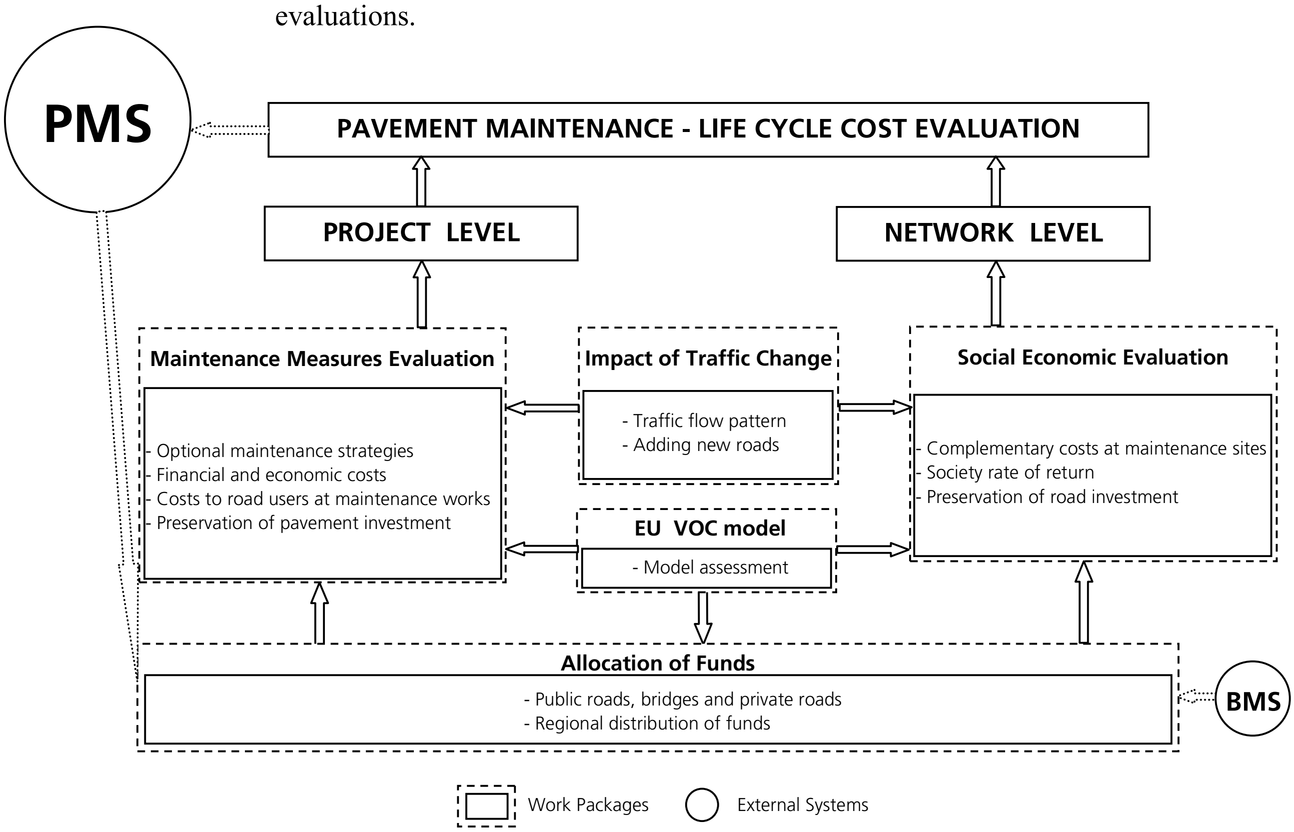
The PAV-ECO consortium aimed to develop economic models that could be used by different European road authorities to select and adapt appropriate models to enhance existing pavement management systems. Throughout its work, the PAV-ECO study considered mainly the project level, but the models developed for project level are also intended for inclusion in network analyses. While the national highway authorities can benefit from implementing the PAV-ECO results at national level, regional and local road authorities can implement these pavement management technologies at regional or local level, often with assistance from private consultants.

Organisation and scope of the Project

The contents of the PAV-ECO Project and the relations between different parts of the Project, as well as links to external systems, are shown in Figure 1. The Figure shows the following seven Project Components:

- Management
- Maintenance measures evaluation
- Impact of traffic change
- Social economic evaluation
- Allocation of funds
- EU vehicle operating cost model
- Dissemination and exploitation of results.

The Project Components were inter-related in their contributions to address the Project objectives and to describe the road infrastructure maintenance by life-cycle cost evaluations.



PMS =Pavement Management System
BMS =Bridge Management System
VOC =Vehicle Operating Costs
EU =European Union

Figure 1. Organisation of the PAV-ECO Project (PAV-ECO, 1997).

Maintenance Measures Evaluation

Maintenance Measures Evaluation describes the development of an analysis system for economic evaluation of alternative pavement maintenance and rehabilitation strategies for individual road projects. The economic evaluation is based upon comparison of optional maintenance strategies associated with the financial costs to the road owner, economic costs to the road users during the service life of the road and additional costs to road users caused by maintenance works. The analysis system provides information to decision-makers, allowing selection of the most cost-effective treatment and the timing of that treatment. Road owner costs, as well as road user costs and benefits directly associated with the pavement condition are included in the evaluation, which are based on the results and methodologies derived in this Project Component.

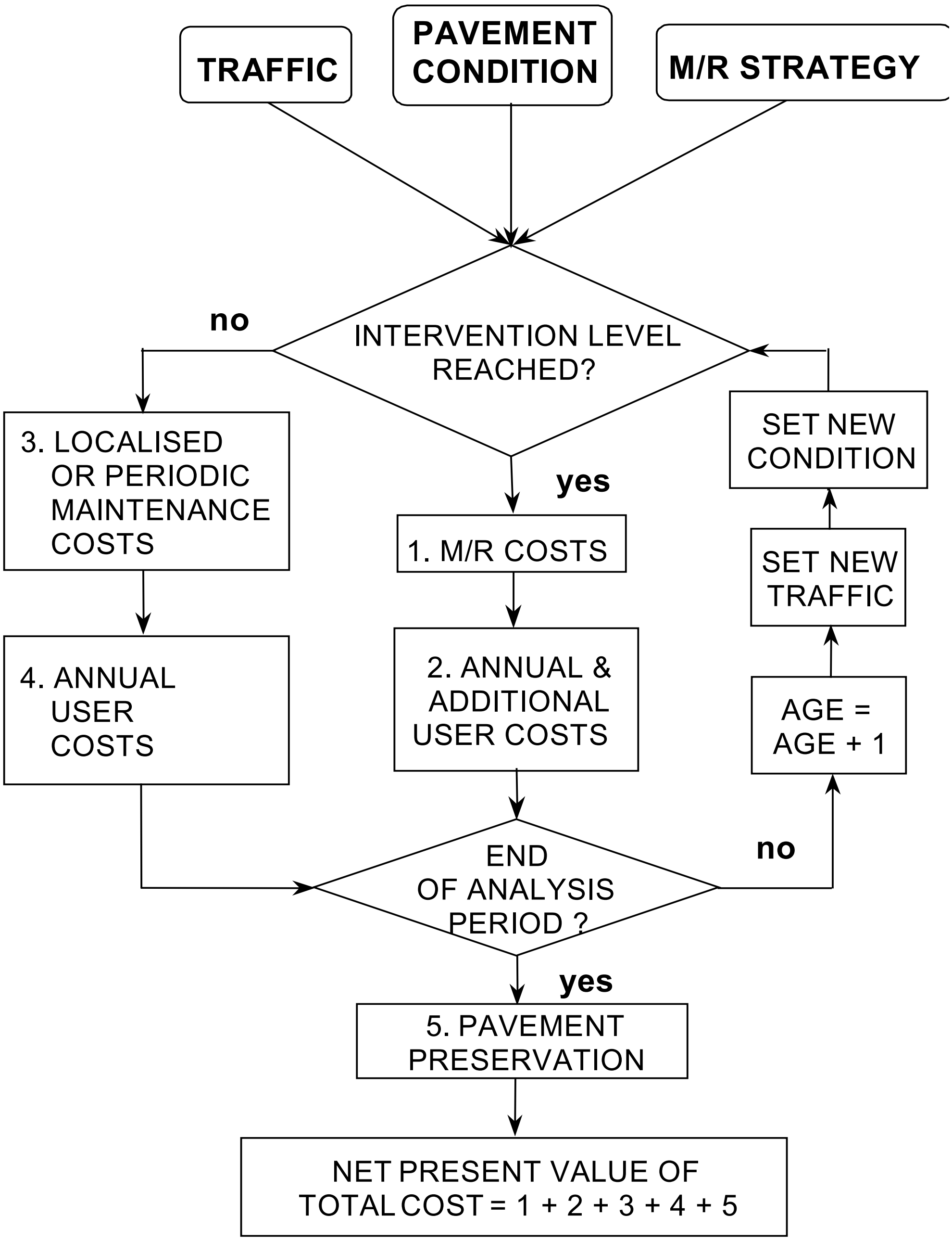
A literature review and interviews with representatives from road directorates in fifteen European countries established a basis for the study of the optional application of different maintenance measures. The literature review provided an overview of European road management and approaches to life-cycle costing, their components and the different models used (e.g., pavement deterioration and optimisation models). The interviews gave an overview of the road networks in various countries, and of the maintenance works and strategies used in those countries.

Figure 2 provides a general framework for life-cycle cost analysis. The following cost elements of the framework were considered:

- Agency financial costs for the different maintenance treatments
- Annual road user costs
- Costs to road users from deferred maintenance
- Additional road user costs due to maintenance works in terms of higher travel time costs, vehicle operating costs and accident costs
- Pavement preservation at the end of the analysis period relating to pavement condition (the latter representing a measure of the value of the pavement).

When alternative maintenance/rehabilitation options are compared for their cost-effectiveness, the salvage value of the pavement should also be considered. Residual life and salvage value are dependent upon pavement condition. This Project defines residual life or remaining life as the number of load applications or time to reach intervention level, and salvage value is defined as the monetary value of the residual life. Pavement preservation is defined as the cost of maintenance required at the end of the analysis period to restore the pavement structural condition to initial level. Therefore, the higher the salvage value of the pavement, the lower the cost of rehabilitation and pavement preservation will be. An illustration of the concepts of pavement salvage value and pavement preservation is given in Figure 3.

A framework was developed for comparison of the life-cycle costs of different maintenance strategies and treatments at the project level. It involves calculation of the road owner and user costs over a selected analysis period. The costs occurring in the future are discounted back to the beginning of the analysis period. Most road authorities in Europe recognise the need for developing economic models for estimating additional road user costs due to maintenance work zones and pavement preservation, even though such models are used only in a few countries.



M/R = Maintenance and Rehabilitation

Figure 2. Framework of life-cycle cost analysis on individual road projects (PAV-ECO, 1999a, 1999b and 1999c).

Maintenance work zones cause additional costs to the road users, mainly in terms of increased travel time. Maintenance works also affect vehicle operating costs through fuel consumption, speed and/or lengthier diversion routes. Additional road user costs due to deferred maintenance and poorer pavement condition can be calculated from the changes in vehicle operating costs.

Comparisons of alternative maintenance strategies and treatments at project level were made considering the road agency and road user costs that take place during the analysis period. The analysis period represents the pavement life-cycle and the costs associated with the analysis period are referred to as the life-cycle costs of the road pavement. The objective of life-cycle cost analysis at project level is to compare different maintenance alternatives, therefore only those costs that vary between the alternatives, were included in the analysis considered in the study. Road agency and user costs occurring within the analysis period are usually discounted to the base year and summed to give the total life-cycle costs. The final decision regarding maintenance treatments at project level can then be made with regard to the lowest total life-cycle costs.

This part of the Project was managed and undertaken by the Technical Research Centre of Finland (VTT), and is documented in PAV-ECO, 1999a, 1999b and 1999c.

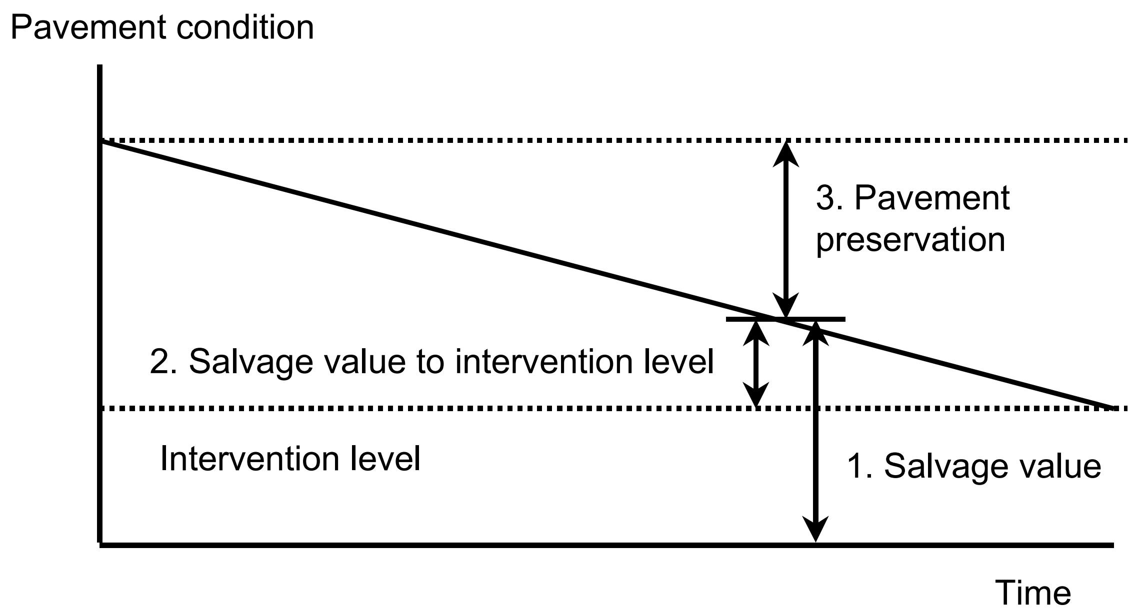


Figure 3. Illustration of the concepts of pavement salvage value and pavement preservation (PAV-ECO, 1999c).

Impact of Traffic Change

Methods for the computation of realistic traffic data on a road network were considered in the Impact of Traffic Change project component. This information was used in other Project Components for analyses of optimum maintenance management strategies and for calculation of the social economic parameters of specific strategies.

The work comprised identification of the determinants for traffic supply and demand, as well as a description of a traffic forecast method. This Project Component further included an analysis of both methods for the computation of traffic flow patterns and the effect of the addition of new roads to a network under capacity restraint conditions (e.g., lane closures).

In the PAV-ECO Project, the impact of traffic change has been dealt with in two ways:

1. Traffic forecasts. These are descriptions of the determinants for supply and demand of traffic. In various countries there is a wide spectrum of traffic information. The determinants for traffic forecasts have been identified (Table 1) and these have served as the guidelines for establishing traffic forecasts and for assessing their accuracy.
2. Traffic simulation models. The uses of traffic simulation models both at the network level and at the project level have been considered.

- At the network level, a traffic simulation model for consistent analysis of alternative maintenance management strategies is described
- At the project level, two situations are considered: (i) for a complex road network, traffic models and calibration methods are described and (ii) for simple road networks, a prototype traffic assignment model has been developed.

With approach (1) above, the determinants of transport demand and supply were estimated; the relevant influencing factors, both for passenger transport and for freight transport, are presented in Table 1, below. A traffic-forecasting model should be constructed so that it provides the capability of taking all relevant determinants of traffic development into account.

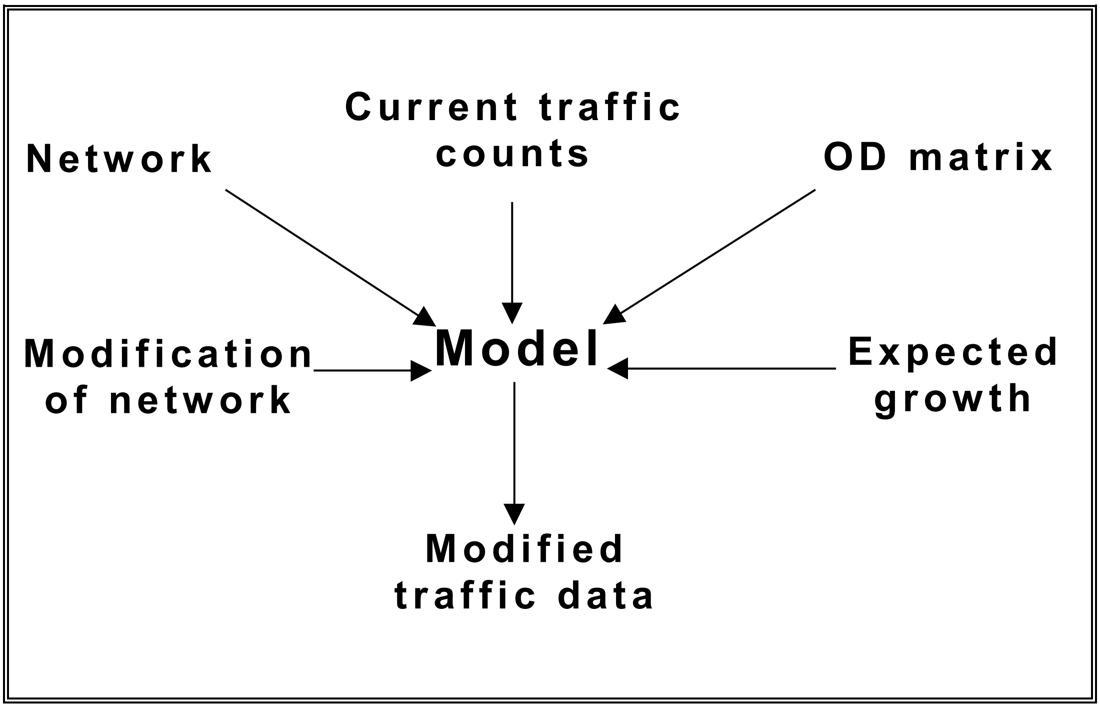
Table 1. Main determinants for traffic demand.

Determinants for the demand of road freight transport	**Determinants for the demand of passenger transport**
Structural data	Socio-demographic structure
Structural effects of production	Average traffic speed
Spatial distribution of companies	Spatial distribution of population
Structural changes in industry and retail	Substitution of traffic
Modal split	Modal split
Change of transport distance	Changes in distances traveled
Structure of vehicle fleet	Development of motorization (car density)
Organisational structures in road freight transport	Average car occupancy
New options in freight transport	New offers
	Choice of route

With approach (2) above, a distinction is made between network level traffic models and project level traffic models. Network level models are used to assess the efficiency of specific pavement maintenance strategies shown by benefit-cost ratios.

These models do not necessarily need to be specifically linked, but can also be based on general parameters such as road type, road configuration, traffic volumes, and road length. Project level models, however, need to include the specific road sections or routes through the network. Both network and project level models have to work within a framework, as shown in Figure 4.

Changes in road transport are caused by many factors, including traffic volumes, the structure of the vehicle fleet and enlargement of the road network by the provision of new roads. These changes affect both the pavement condition and the required pavement management measures. It is necessary for management systems to be able to take these future changes into account in planning future maintenance interventions.



OD matrix = Origin and Destination matrix

Figure 4. Input and output to / from a traffic simulation model (PAV-ECO, 1999d).

Depending on the subsequent development of road transport, the optimal choice of activity may be more frequent use of certain measures, or a preference for different kinds of maintenance treatment. This inter-dependency works in both directions. Transport demands and changes in modal split are influenced by road construction or maintenance management strategies, and the extent of road works is affected by the amount of road traffic.

Heavy vehicle traffic is one of the main reasons for deterioration of the road pavement structure; furthermore, when combined with car traffic, the total vehicle traffic is the main demand variable affecting roadway capacity. It is therefore essential, when developing an optimum maintenance management strategy, to be able to produce accurate traffic forecasts. In existing maintenance management systems, this very important factor is most often reduced to simple linear forecasts for each link or section in the road network.

Most life-cycle cost analyses do not take into consideration that a road network is a coherent system of road sections with a finite capacity. Simple linear traffic forecasts can lead to traffic on some road sections exceeding capacity. If the over-capacity traffic is diverted to other routes, over-capacity traffic on the network will be different; and the maintenance measures will have a different time schedule. The road section under consideration will require less maintenance since the traffic carried by that section is reduced. The roads carrying the diverted traffic overflow will, however, have a higher deterioration rate. Thus it is important to base the maintenance management strategy on reliable traffic forecasts and traffic assignment models.
This part of the Project was managed and undertaken by Anders Nyvig A/S, Denmark, and is documented in PAV-ECO, 1999d.

Social Economic Evaluation

European road owners involved in the application of pavement management systems primarily consider alternative, competing maintenance strategies on a roads-oriented economic and capital investment basis. This approach is insufficient, however, for decision-makers interested in considering the social economic effects of road pavement performance and conditions. The subject of Social Economic Evaluation provided models for the social economic evaluation at road network level, for the purpose of including the models in maintenance management procedures. This Component considers the social economic evaluation of alternative pavement management strategies. The following alternative topics have been considered:

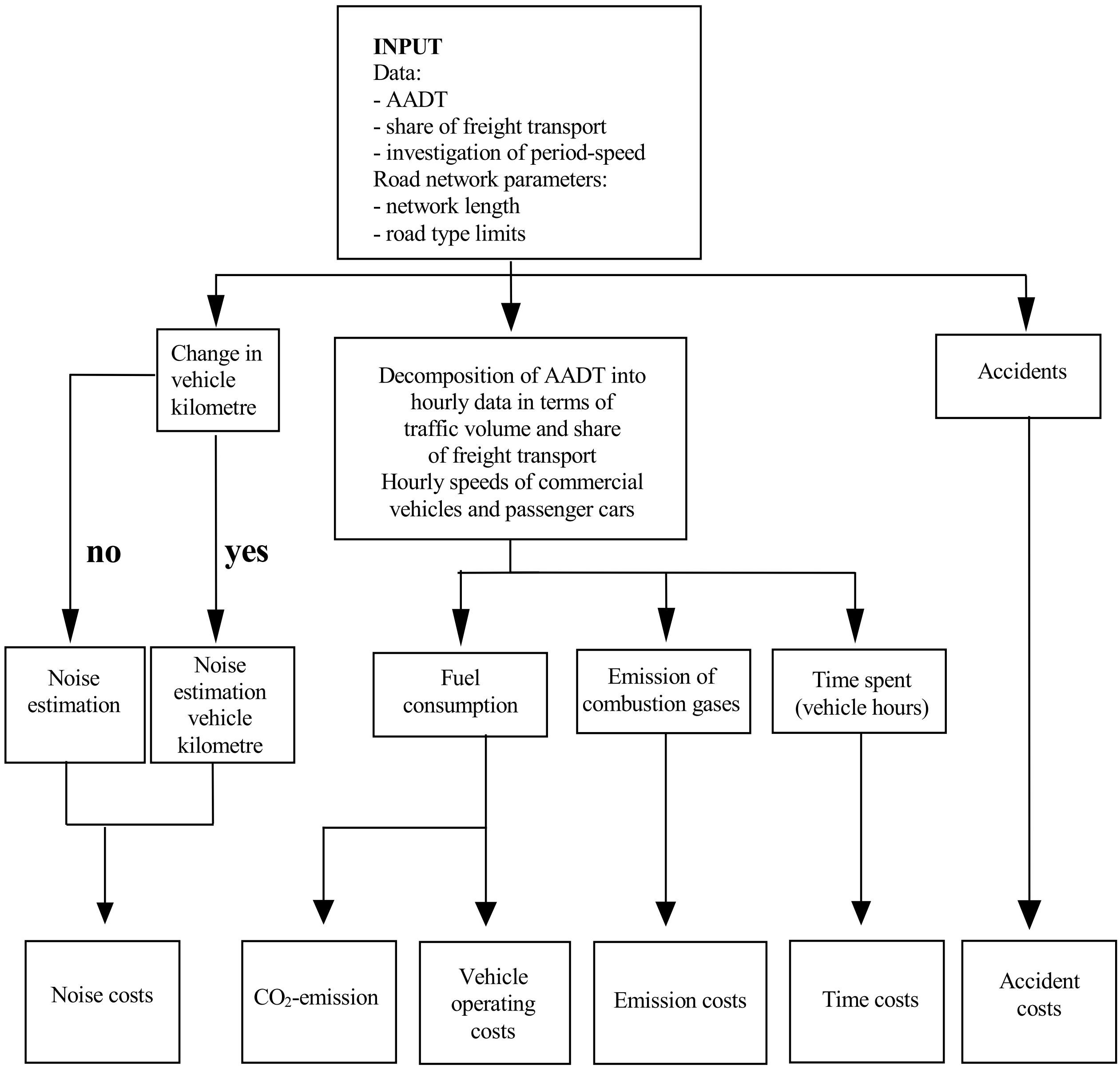
- Society rate of return (improvement in social costs from a pavement maintenance strategy relative to the investment costs of the same strategy) resulting from the use of alternative strategies under static conditions
- Society rate of return resulting from the use of alternative strategies under dynamic conditions.

Furthermore, the preservation of the road network investment is discussed in this section.

A traffic simulation model was proposed, which transforms the quantitative traffic parameters (traffic volume, share of freight transport) for the road network being evaluated into social costs in monetary terms. The structure of the Traffic Simulation Model is shown in Figure 5.

Financial analysis of maintenance investment costs is the procedure commonly applied when organisations responsible for road maintenance management make investment decisions, but this is insufficient for an economic assessment, from the point of view of the overall economy of a country.

The most effective pavement maintenance strategy can be considered as the one that requires minimum total life-cycle costs for preserving the road investment, or for maintaining the road condition at its initial condition. The costs involved consist of the investment costs and the social costs (time, vehicle operation, accidents, air pollution, and CO_2-emissions) that result from the disruption to traffic caused by work sites. Investment costs, which are usually assessed by road agencies, alone are insufficient for an economic assessment, from the viewpoint of the overall economy; social costs arising from the traffic at work sites should also be considered.



AADT = Annual Average Daily Traffic
CO_2 = Carbon dioxide

Figure 5. Structure of the traffic simulation model (PAV-ECO, 1999e and 1999f).

Evaluation of the social economic effects from maintenance of the road infrastructure considers the society rate of return resulting from the use of three alternative maintenance strategies. Situations where a single measure, or a succession of measures within the strategy, were considered. This type of analysis illustrates how low-budget maintenance measures carried out often can be compared with more extensive maintenance measures carried out less frequently. Preservation of investment costs at the network level was also considered and a model was presented that makes it possible to determine the long-term costs of a maintenance strategy to maintain the road condition at a certain level, and thereby assess maintenance strategies according to their investment cost-effectiveness (see below for a discussion of the latter).

The approach that has been chosen for modelling in this study is based on estimation of the overall road condition. With this method, the state of deterioration of the whole road structure is determined using seven condition indicators (longitudinal and transverse profile, surface layer cracking, surface layer defects, surface texture, skid resistance, and structural adequacy) (COST 324, 1997) and appropriate pavement deterioration models. From the ranges and values of the condition indicators, a maintenance treatment is selected which will reinstate the existing pavement to its initial condition. The costs of preservation of road investment is then given by the updated cost of the maintenance treatment. Figure 6 shows the principle of this method.

Regarding long-term investment costs, the most effective maintenance strategy is one requiring minimum investment costs to maintain the road condition at a standard required by the road owner. As road deterioration does not develop linearly with passage of time, but progressively, it was shown to be more cost-effective to carry out low-expenditure measures often, rather than costly measures less frequently during the analysis period.

The study went beyond consideration of the investment costs only and also considered the social costs resulting from hindrance to traffic by work sites. Three selected maintenance strategies are analysed with reference to their investment cost-efficiencies and social costs as a whole. For example, Strategy A may require more maintenance investment than Strategy B, but produce lower social costs. If the social costs savings are higher than the additional investment costs, Strategy B is held to be more cost-efficient than Strategy A. In this way, the selected strategies are analysed for their cost-efficiency, from the point of view of the overall economy. This type of analysis, with respect to the overall economy, was carried out under static conditions and under dynamic conditions. In static analysis, only a single measure (i.e., maintenance treatment) within a strategy is considered. In contrast, dynamic analysis considers the succession of measures (the frequency of the measure, and the interval between the measures) within a certain period for each strategy; in addition, a positive traffic growth is assumed within the period considered.

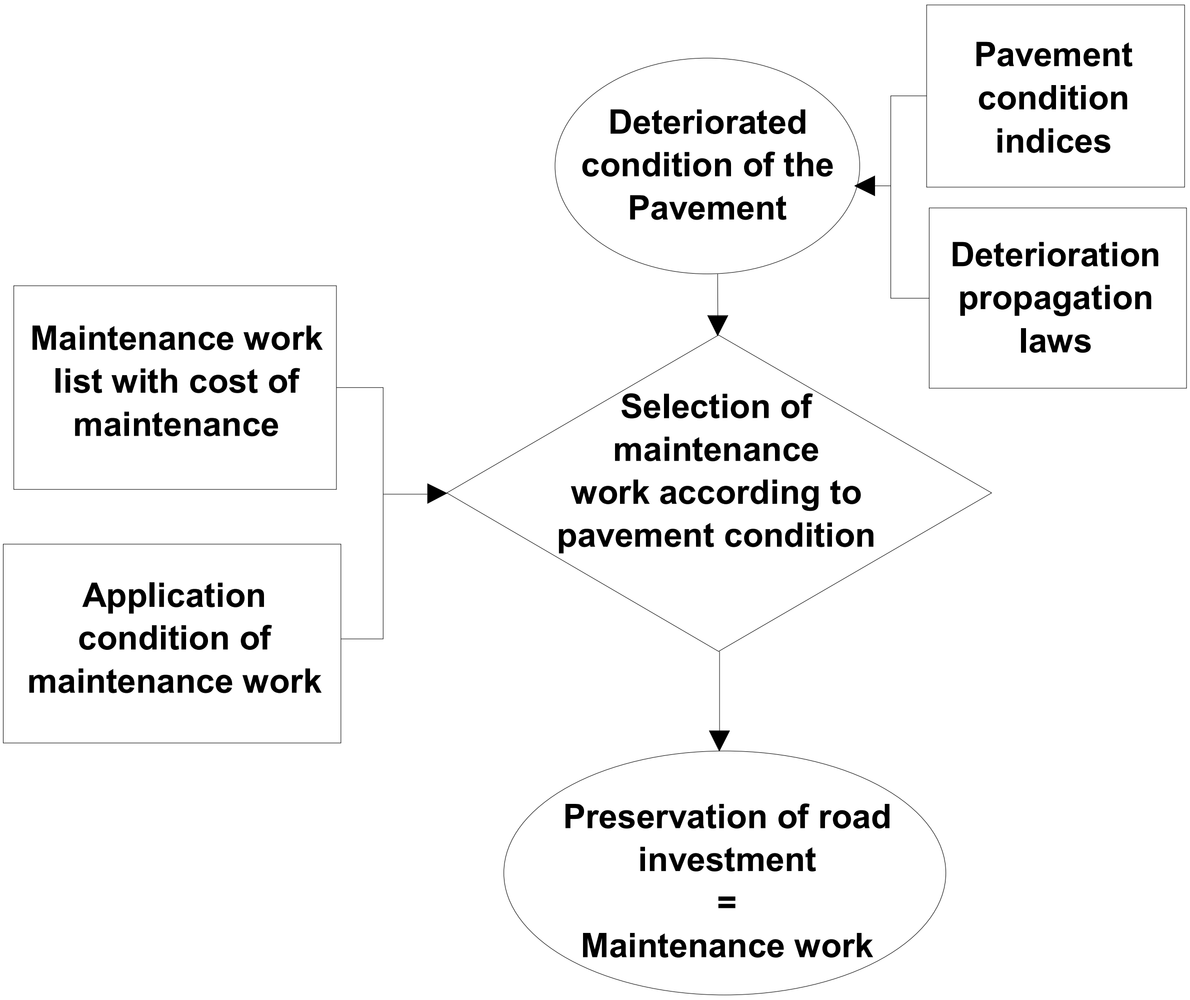


Figure 6. Diagram of the proposed method for determining the preservation of road investment. (PAV-ECO, 1999f, Preservation of Road Investment).

Comparison of the two forms of analysis demonstrates clearly that the end results can change depending on the analysis approach. In a static analysis, the strategy with the lowest expenditure per measure is the most efficient, because the investment costs and the social costs are minimal. In a dynamic analysis, another strategy might be the more efficient as low-expenditure measures are carried out more often, rather than high-expenditure measures applied only occasionally, within the project period.

This part of the Project was managed and undertaken by the University of Cologne, Germany, and is documented in PAV-ECO, 1999e and 1999f.

Allocation of Funds

The Project Component considering the Allocation of Funds describes the study to develop models to improve the allocation of budgets for maintenance and to achieve better value for money. The two main areas considered were the regional allocation of funds from a central budget and the interactions between the maintenance requirements of different features of the road infrastructure (e.g. pavements, bridges, etc.), respectively. Methods evaluated for the allocation of budgets range from simple ranking methods based on, for example, pavement condition and traffic level, to life-cycle cost methods.

One of the aims of the PAV-ECO Project was to establish models for the evaluation of pavement maintenance on the basis of life-cycle costs. Traditionally, budgets for road maintenance have been based on historic levels of spending, an assessment of current condition of the network and sometimes on non-technical considerations.

A literature survey of more than 100 articles (which was conducted in parallel with the questionnaire survey reported in the section on Maintenance Measures Evaluation, earlier in this paper), on the ways in which maintenance funds are allocated between regions, pavement types and pavements and bridges, showed that most contained information on revenue sources for capital and maintenance budgets, but little on the allocation of budgets. In particular, few references were found describing how funds are allocated between roads and bridges. There are many examples of pavement management systems, bridge management systems and other maintenance management tools that help to allocate funds by the prioritization of works, but there is no generally accepted way of deciding what budgets to allocate to the different systems. In some cases, this extends further, where the management system is designed for one aspect of maintenance (e.g., structural maintenance is considered by pavement management systems), and there is no way of determining the budget for structural maintenance, as against routine, or cyclic maintenance.

The literature review has shown that to obtain a 'fair' distribution of funds between regions and pavement and bridge types, an allocation must be carried out using a reproducible, systematic and standardized procedure, which ideally allows more detail as decisions are made at lower levels. In allocating funds it is becoming increasingly important to take into account the long-term performance, as well as the current condition of the road. Both the literature survey and a review of current practice have, however, shown that suitable tools for allocation of funds between infrastructure components or geographical regions based on life-cycle costs are not yet available. The work carried out in this Project, nevertheless, provides a method that can be used with existing management systems, and the overall approach in the method can be improved as better life-cycle cost models are developed.

An essential part of an effective highway management system is the ability to assess the size of maintenance budgets. In the study, a method has been developed which can be used to allocate budgets between different parts of the network. These parts may be geographical areas, type of infrastructure (e.g., pavements or bridges) or parts managed by different organisations. Rather than rely on the existing condition of the network, the method uses the life-cycle costs to help ensure current budget allocations provide long-term value-for-money, taking account not only of the costs to the road authority, but also the costs incurred by road users at maintenance works sites. The approach developed uses the outputs from life-cycle cost analyses of parts of the network, in a spreadsheet model, to calculate relative weightings for the budget to be used for each part of the network. Factors affecting the maintenance needs of pavements and bridges need to be weighted to take into account their relative priorities. To calculate appropriate weights, four methods using life-cycle costs were examined, with one method selected for further work. This model is capable of considering more than one target condition for the network and to differentiate between the condition of pavements or bridges, their size and the traffic to be carried. The two target conditions may be considered as representing a desirable condition and a minimum acceptable condition, and the weights devised take into account the margin of deterioration (i.e., the worsening in condition that can be tolerated if there are insufficient funds for the full allocation).

Application of the model to allocate funds between regions, roads and structures was demonstrated, taking into account both the works costs and the costs to the road user, for parts of the network categorised by size, level of condition and traffic. The new approach uses the long-term future costs arising from maintenance strategies to allocate current budgets while also taking into account the higher long-term costs that can arise from provision of insufficient funds.

This part of the Project was managed and undertaken by the Transport Research Laboratory (TRL), United Kingdom, and is documented in PAV-ECO, 1999g.

EU VOC models

The EU Vehicle Operating Cost (VOC) models component reviewed existing vehicle operating cost models, which might be suitable for inclusion in life-cycle cost models for roads in Europe. Furthermore, the work identified the particular requirements for the use of vehicle operating cost models in Europe.

The major objective of the evaluation of vehicle operating costs models appropriate to European conditions involved a review of the HDM-4 (University of Birmingham, 1999) vehicle operating cost model to assess its suitability for inclusion in European life-cycle cost models. Furthermore, a comparison was carried out between the HDM-4 model and a simpler German vehicle operating cost model. Based on the results of this work, a simple model was proposed for use in life-cycle analyses in European countries.

Vehicle operating costs comprise all the ownership costs incurred during the operational life of a vehicle. Vehicle operating costs form a component of the life-cycle costs associated with each link in a road network, with the level of costs depending on the condition of the pavement, the physical characteristics of the road link and the traffic flow on the road.

Based on a bibliographic study, and on a report prepared by the Partners of the RIMES Project (PAV-ECO, 1999h), a review of the various VOC models used in Europe was carried out. Eight models were presented: HEN 2 (United Kingdom), FINVOC (Finland), VETO (Sweden), BELMAN (Denmark), and ARIANNE (France), as well as models from Norway, Hungary and Germany. (In the following, reference is made to statistical and empirical models; simply described, a statistical model is based on empirical considerations whereas a mechanistic model is based on theoretical principles.)

A mechanistic VOC model would be preferred in economic appraisals because it would:

- allow analysis at any level of input data aggregation, from micro-level analysis of local improvements to road network investment strategies development
- accept any vehicle type specification, including the heaviest truck combinations and emerging vehicle technologies
- cover all classes of vehicle operation, including congested and urban driving conditions.

No existing model satisfies the above requirements. The next best choice is the mixed statistical / mechanistic type of model. By default, the HDM-4 and the VETO VOC sub-models are the models of choice. Finally, it is possible to consider the HEN 2 and FINVOC, the ARIANNE and German models, and the other models in a similar manner.

The German model was chosen for a subsequent comparison with the HDM-4 model for the following reasons:

- The model was proposed by economic experts
- The model was developed by the German Partner of the PAV-ECO Project, with a detailed description given of the Project.

The model seemed relatively similar to the HDM-4 model concerning the parameter types necessary for its use.

Table 2, on the following page, presents the tabular form used for comparison of the model characteristics of both models, in order to identify and highlight the important parameters used in each model.

The HDM-4 model is by far the most detailed of all of the available models that permit an assessment of VOC. It is also the model that shows the largest sensitivity regarding the data considered, but it is also the most complex.

Regarding the twelve parameters of the HDM-4 models, the sensitivity analysis showed that only three of them (speed, gradient and unevenness) had any significant effect on the VOC, by taking account of the maximum conditions of degradation of the Swiss national network. Nevertheless, only a negligible part of the Swiss network (<3%) presents an unevenness value affecting the VOC. The unevenness parameter can thus also be regarded as negligible.

If the primary road networks in the European countries are considered to be similar to that of Switzerland, meaning that the VOC variation is very low, it can be concluded that a sensitive VOC model, such as that used in HDM-4, is not useful and therefore a more simple model, which includes the vehicle speeds and the road gradients as parameters, such as the German model, is more suitable for European conditions.

Table 2. Comparison of HDM-4 and the German model.

	HDM-4	**German model**
Components	Fuel consumption Oil consumption Tyres consumption Parts consumption Labour hours Service life (depreciation)	Fuel consumption Cost unit rates (fixed)
Models (number of options)	Free speed Constraining speeds (5) Congested speed Fuel Tyres Oil Parts Service life (depreciation) Labour hours	Fuel consumption (functions depending on vehicle type) Speed (functions depending on vehicle type)
Congestion taken into account	Yes Affects the speed, considers acceleration as well as an increase factor for fuel consumption.	Yes Affects the speed and fuel consumption.
Parameters (number of options)	Vehicle characteristics (61) Default values (24) Variables (12)	Vehicle characteristics (1): (type of vehicle) Variables (6): traffic volume for passenger and freight vehicles, road type, permitted maximum speed, gradient of the section, bendiness of the section)

Consequently the German model was selected for use in the subsequent calculations of VOC in the work reported (PAV-ECO, 1999h). This means that the main components in the VOC calculation were related to travel time and road geometry.

This part of the Project was managed and undertaken by EPFL-LAVOC, Switzerland, and is documented in PAV-ECO, 1999h.

Dissemination and Exploitation of Results

The objective of this Project Component, entitled the Dissemination and Exploitation of Results, was to ensure the dissemination of PAV-ECO results to the European community and internationally. This has been achieved through presentations to European road agencies and at international symposia, via the internet, and via direct contacts to the end users of the PAV-ECO findings. The primary implementation of the Project results lies with road authorities across Europe, at all levels of pavement management - national, provincial and municipal.

Implementation

Firstly, new developments in pavement management are normally implemented at the national level, where the primary road network calls for state-of-the-art technology for the management of its maintenance and rehabilitation. This implementation at the national level will be pursued through the FEHRL, which comprises the national road research laboratories from 23 European countries, to achieve direct implementation of the Project results at national level. Once implemented at that level, it is anticipated that new developments will work their way down to the lower levels of pavement management, insofar as these are appropriate for the types of road networks managed by provinces and municipalities.

A second avenue for reaching road authorities, at specifically the lower levels of pavement management, is through private consulting firms that develop, maintain and operate pavement management software. If private consultants implement new pavement deterioration models in their software, the desired effect on road pavement management practitioners will follow. Private consultants were heavily involved in the Project, and will contribute to the exploitation of the models in their day-to-day contacts with national, regional and local road authorities.

This part of the Project was managed and undertaken by LCPC, France, and is documented in PAV-ECO, 1999i.

Conclusions and Recommendations

The PAV-ECO Draft Final Report was submitted in December 1999, to the Commission of the Economic Communities entitled: Pavement and Structure Management System; Final Report for Publication; Economic Evaluation of Pavement Maintenance. Project for EC-DG-VII RTD Programme - Contract No. RO-97-SC 1085/1189, Brussels, Belgium.

Conclusions

The essence of the numerous significant findings of the PAV-ECO Project can be represented by the following conclusions:

- A framework was developed for the comparison of life-cycle costs of different pavement maintenance strategies and treatments at project level. It involves calculation of the road owner and user costs over a selected analysis period.
- There is a need in life-cycle cost analyses for more accurate traffic data, as well as more advanced models for traffic distributions on road networks.
- A case study evaluation of the social economic life-cycle costs of three different maintenance strategies has shown how low-frequency relatively high-budget maintenance actions can be compared with restricted-budget maintenance actions.
- A method for the allocation of funds to different parts of a road infrastructure has been developed that takes into account the long-term maintenance costs of a road, or road network, as well as its condition and physical dimensions.
- For a high-standard road network such as that existing in a number of European countries, vehicle operating costs vary only slightly due to the road network condition, and as a consequence, a simple vehicle operating cost model can be used.

Recommendations

From these conclusions, the following recommendations regarding the use of the PAV-ECO Project results can be made:

- The concept of pavement preservation should be applied to the life-cycle evaluation of road pavements.
- A more advance traffic distribution model (e.g., an origin-destination model) should be used for traffic simulation at both network and project level.
- Evaluation of social economic effects from pavement maintenance should be carried out for the dynamic maintenance scenario, where a succession of maintenance measures is considered.
- Maintenance budget allocations should be made on life-cycle cost bases, rather than historically, or based on the current condition and physical dimensions of the road network.
- A simple model including vehicle speed and road gradient should be used for estimating vehicle operating costs for the European road network.

Acknowledgements

The financial support for the PAV-ECO Project received under the Fourth Framework Programme of the Commission of the European Communities, Directorate General VII, is gratefully acknowledged. In addition, the contributions from the two Swiss partners who were self-financed during the course of the project are also gratefully acknowledged.

The contributions of the Consortium Partners and the members of the Technical Committee, as well as others, who participated significantly in the preparation of the Final Report and other reports within the scope of this Project, are also gratefully acknowledged. This paper was written for the 20th ARRB Conference, held in Melbourne, Australia, 19 - 21 March 2001, by Robin A. Macdonald (Senior Researcher) from the Danish Road Institute; it is based on the Draft Final Report of the PAV-ECO Project.

References

COST 324, 1997. Long-Term Performance of Road Pavement, Final Report of the Action, European Commission, Directorate General Transport, Brussels, Belgium, April 1997.

PAV-ECO, 1997. PAV-ECO Project Inception Report. Pavement and Structure Management System: Economic Evaluation of Pavement Maintenance. Project for EC-DG-VII, RTD Programme, Contract No. RO-97-SC 1085/1189, Brussels, Belgium, November 1997.

PAV-ECO, 1999a. Work Package 1, Maintenance Measures Evaluation – Task 1 Report, Optimal Maintenance Strategies. LCPC, France, March 1999.

PAV-ECO, 1999b. Work Package 1, Maintenance Measures Evaluation – Task 2 Report. Financial and Economic Costs. Viagroup SA, Switzerland, April 1999.

PAV-ECO, 1999c. Work Package 1, Maintenance Measures Evaluation – Task 3, Work zone effects on road user costs, and Task 4, Pavement preservation, Report. VTT, Finland, April 1999.

PAV-ECO, 1999d. Work Package 2, Impact of Traffic Change – Task 1, Traffic flow patterns, and Task 2, Adding of new roads, Report. Anders Nyvig A/S, Copenhagen, Denmark, May 1999.

PAV-ECO, 1999e. Work Package 3, Social Economic Evaluation – Task 1, Complementary costs at maintenance sites, and Task 2, Society rate of return, Report. UoC, Germany, October 1999.

PAV-ECO, 1999f. Work Package 3, Social Economic Evaluation – Task 3, Preservation of road investment, Report. LAVOC, Switzerland, March 1999.

PAV-ECO, 1999g. Work Package 4, Allocation of Funds, Report. Tasks 1 and 2. Transport Research Laboratory, UK, December 1999.

PAV-ECO, 1999h. Work Package 5, EU VOC models, Report. LAVOC, Switzerland, March 1999.

PAV-ECO, 1999i. Work Package 6, Dissemination and Exploitation of Results, Task 1, International symposium for the exploitation of results, and Task 2, Implementation of results at national level, Report. LCPC, France, September, 1999.

University of Birmingham, 1999. HDM-4 Analytical Framework and Model Descriptions. The Highway Development and Management Series, Volume 4. PIARC World Road Association, Paris, France, December 1999. ISBN 2-84060-062-5.

Rapporter/Reports

Nr./No
År/Year

90/99 Friktionsmålinger
Sammenlignende målinger mellem ROAR og Stradograf
(Bjarne Schmidt)

91/99 Grundere til broisolering
- typegodkendelse
- materialevalg
(Jeanne Rosenberg)

92/99 The Structure of Polymer Modified Binders and Corresponding Asphalt Mixtures
(Vibeke Wegan, Bernard Brûlé)

93/99 PIARC World Road Association
International Experiment to Harmonise Longitudinal and Transverse Profile Measurement and Reporting Procedures, Draft Report
(Bjarne Schmidt, Jim Wambold, Akira Kawamura, Guy Descornet)
(Electronic edition)

94/99 Evolution and Harmonization of Evenness Evaluation Techniques
(Bjarne Schmidt)
(Electronic edition)

95/99 Investigation of Gyratory Compaction used for Asphalt Mix Design
(Jørn Raaberg)
(Electronic edition)

96/99 Development of Models for Economic Evaluation of Pavement Maintenance: the PAV-ECO Project Providing an Efficient and Socially Acceptable Road Transport Network
(Gregers Hildebrand, Philippe Lepert)
(Electronic edition)

97/99 Development of a Laser-Based High Speed Deflectograph
(Gregers Hildebrand, Søren Rasmussen, Raúl Andrés)
(Electronic edition)

98/99 Accelerated Pavement Testing
1999 International Conference
October 18-20, Reno, Nevada
(Carsten Bredahl Nielsen, Per Ullidtz, Wei Zhang, Susanne Baltzer, Robin A. Macdonald)
(Electronic edition)

99/00 Stabilitet og holdbarhed af danske asfaltbelægninger
(Jeanne Rosenberg, Jørn Raberg)
(Electronic edition)

100/00 Responses and Performance of a Test Pavement to two Freeze - Thaw Cycles,
Danish Road Testing Machine RTM2: 1998
(Wei Zhang, Robin A. Macdonald)
(Electronic edition)

101/00 Responses and Performance of a Rehabilitated Test Pavement to Accelerated Load Testing
Danish Road Testing Machine RTM3: 1999
(Wei Zhang, Robin A. Macdonald)
(Electronic edition)

102/00 Responses and Performance of a Rehabilitated Test Pavement to one Freeze - Thaw Cycle
Danish Road Testing Machine RTM3: 2000
(Wei Zhang, Robin A. Macdonald)
(Electronic edition)

103/01 Sensors for Pavement Instrumentation
- Application in the Danish Road Testing Machine
(edited by: Gregers Hildebrand)
(Electronic edition)

104/00 Examination of pollution in soil and water along roads caused by traffic and the road pavement
(Knud A. Pihl, Jørn Raaberg)
(Electronic edition)

105/00 Thin pavements with synthetic binder used in Denmark
(Jeanne Rosenberg)
(Electronic edition)

106/00 Surfacing of concrete bridges
(Vibeke Wegan)
(Electronic edition)

107/01 Danske asfaltbelægningers sporkøringsmodstand
(Carsten Bredal Nielsen)
(Electronic edition)

108/01 Effect of Design Parameters on Polymer Modified Bituminous Mixtures
(Vibeke Wegan)
(Electronic edition)

109/01 Microstructure of polymer modified binders in bituminous mixtures.
(Vibeke Wegan, Carsten Bredal Nielsen)
(Electronic edition)

110/01 Estimation of Permanent Deformation in Danish Motorway Pavements
(Carsten Bredahl Nielsen)
(Electronic edition)

111/01 Examination of Rutting and Weathering Characteristies of Various Danish Road Classes
(Jørn Raaberg, Jeanne Rosenberg)
(Electronic edition)

112/01 Technical Performance and Long-Term Noise Reduction og Porous Asphalt Pavements
(Jørn Raaberg, Bjarne Schmidt)
(Electronic edition)

113/02 Ubundne bærelag af knust beton
- Vejledning
- Leveringsbetingelse
- Almindelig arbejdsbeskrivelse
(Ole Milvang-Jensen, Knud A. Pihl, Flemming Berg)
(Electronic edition)

114/02 Economic Evaluation of Pavement Maintenance
PAV-ECO
(H.J. Ertman Larsen, G. Hildebrand, Robin A. Macdonald)
(Electronic edition)

Road Directorate
Niels Juels Gade 13
P. O. Box 1569
DK-1020 Copenhagen K
Denmark
Telephone: +45 33 93 33 38
Telefax: +45 33 15 63 35

Road Directorate
Elisagaardsvej 5
P. O. Box 235
DK- 4000 Roskilde
Denmark
Telephone: +45 46 30 70 00
Telefax: +45 46 30 71 05

Road Directorate
Thomas Helsteds Vej 11
P.O. Box 529
DK - 8660 Skanderborg
Denmark
Telephone: +45 89 93 22 00
Telefax: +45 86 52 20 13