

Pavement and Structure Management System

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Final Report for Publication

Economic Evaluation of Pavement Maintenance



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Preface

This report is the Final Report of the PAV-ECO Project. PAV-ECO was a part of the Project “Pavement and Structure Management System” that covered two separate, but related, Research Projects, which were carried out under partial funding from the Transport Research and Technological Development Programme of the Fourth Framework Programme of the Commission of the European Communities. The PAV-ECO (Economic Evaluation of Pavement Maintenance) Project was initiated by the Forum of European National Highway Laboratories (FEHRL); it started on 14 October, 1997, and ended on 13 October, 1999. The aim of the PAV-ECO Project was to develop economic cost models for evaluation of the life-cycle costs of pavements, and the effects on road infrastructure maintenance when new roads are added to the road network. The proposed economic cost models are applicable for the European countries, and the models will improve the efficiency of the decision-making process by bringing together scientific and technical excellence and inventiveness from leading countries developing life-cycle cost approaches and pavement maintenance performance models. All references to the Project in this Final Report refer to the PAV-ECO Project only.

The PAV-ECO Project had a total of six Work Packages, comprising maintenance measures evaluation, impact of traffic change, social economic evaluation, allocation of funds, evaluation of existing vehicle operating cost models and, finally a work package covering dissemination and exploitation of results. This report summarises the work done in these Work Packages, presents the outcome of the Project and draws the overall conclusions and recommendations from the study. It is the final Deliverable from the Project to the Commission of the European Communities.

The Danish Road Institute was responsible for the overall management and co-ordination of the Project, while six different Partners managed the six Work Packages. With only eight Partners in the Project, all Partners were members of the PAV-ECO Technical Committee, providing the overall technical input during the Project and acting as authors and as a sounding board for this Final Report.





Contents

Preface	3
1. Executive Summary	9
1.1 Background of the PAV-ECO Project.....	9
1.2 Organisation of PAV-ECO	9
1.3 Technical Contents of PAV-ECO.....	10
1.4 Dissemination and Exploitation.....	11
1.5 Conclusions and Recommendations.....	11
2. The Partnership	13
3. Objectives of the Project	15
3.1 Target Audience.....	15
3.2 Objectives	15
4. Means used to achieve the Objectives	17
4.1 Organisation of the Project	17
4.2 Work Programme.....	17
4.3 Management Input	19
4.3.1 Joint Management Organisation	19
4.3.2 Management of the PAV-ECO Team.....	20
4.4 Management and Progress Reports	20
4.5 PAV-ECO on the Internet.....	21
4.6 Quality Assurance.....	21
References	21
5.1 Maintenance Measures Evaluation	23
5.1.1 Introduction.....	23
5.1.2 Interviews and literature review	23
5.1.2.1 Literature survey.....	23
5.1.2.2 Interviews of European Road management and technical progress	23
5.1.3 Pavement Management Systems	24
5.1.3.1 Databases	24
5.1.3.2 Evolution of Pavement Management Systems	25
5.1.3.3 General functions of a modern PMS	26
5.1.3.4 Maintenance and Rehabilitation (M/R) Action Models	26
5.1.3.5 Pavement Deterioration Models	26
5.1.3.6 Cost Models.....	27
5.1.3.7 Optimisation Models	28
5.1.4 Pavement management in European countries	29
5.1.4.1 Administrative organisation of road networks in Europe...29	
5.1.4.2 Functional classification of roads for maintenance purposes.....	30
5.2.4.3 Maintenance agents and management sectors	30
5.1.4.4 Extent of Maintenance on national networks	31

5.1.4.5	Maintenance and rehabilitation strategies on national networks.....	31
5.1.4.6	Benefits from maintenance and rehabilitation.....	32
5.1.5	Maintenance strategies used in European Countries	33
5.1.6	Framework for life-cycle cost analysis on individual road projects.....	33
5.1.6.1	Discount rate.....	35
5.1.6.2	Net Present Value of total cost	36
5.1.7	Agency costs	36
5.1.7.1	Localised or periodic maintenance costs	36
5.1.7.2	Cost of routine and structural maintenance	37
5.1.8	Road user costs	38
5.1.8.1	Annual user costs.....	38
5.1.8.2	Costs of deferred maintenance.....	39
5.1.8.3	Additional time costs due to maintenance works	40
5.1.8.4	Additional vehicle operating costs (VOC) due to maintenance works	41
5.1.8.5	Additional accident costs due to maintenance works	43
5.1.9	Preservation of pavement investment.....	44
5.1.10	Conclusions.....	46
References	.....	48
5.2.	Impact of Traffic Change.....	49
5.2.1	Introduction.....	49
5.2.2	Analytical approach for traffic forecasting.....	50
5.2.2.1	Recommendations for traffic forecasts in pavement life-cycle cost analysis.....	51
5.2.3	Traffic simulation models.....	53
5.2.3.1	Origin-Destination (OD) based models - national models.....	54
5.2.3.2	General road-type-based models	55
5.2.3.3	Simple link-based model	55
5.2.4	Traffic model at Network level.....	55
5.2.4.1	Requirements for modelling the route choice behaviour.....	55
5.2.4.2	Impact of traffic growth.....	56
5.2.5	Traffic model Project level	59
5.2.5.1	Model structure.....	59
5.2.5.2	The user interface	61
5.2.4	Conclusions.....	63
References	.....	63
5.3	Social Economic Evaluation.....	65
5.3.1	Introduction.....	65
5.3.2	Society Rate of Return.....	66
5.3.2.1	Structure of the analysis.....	66
5.3.2.2	Methodological procedure	68
5.3.2.3	Results of the CBA	76
5.3.3	Preservation of Road Investment.....	81
5.3.4	Conclusions.....	87
References	.....	88

5.4	Allocation of Funds	
5.4.1	Introduction.....	89
5.4.2	Literature Review	89
5.4.3	Literature Review	92
5.4.3.1	England.....	92
5.4.3.2	Switzerland	93
5.4.3.3	France	96
5.4.4	Methodology for fund allocation	96
5.4.4.1	Method 1: Life-cycle cost ratios.....	97
5.4.4.2	Method 2: Condition Targets.....	98
5.4.4.3	Method 3: Minimum acceptable condition.....	99
5.4.4.4	Method 4: Life-cycle cost multiplier	101
5.4.5	Bridges	103
5.4.6	Public versus Private Finance	103
5.4.7	Example Applications.....	104
5.4.7.1	Sensitivity Analysis – England.....	104
5.4.7.2	Fund allocation for pavements within a single region using Danish data	107
5.4.7.3	Analysis of Regions in Finland.....	110
5.4.8	Discussion.....	112
5.4.9	Conclusions.....	113
References	.....	114
5.5.	EU VOC models	115
5.5.1	Introduction.....	115
5.5.2	Description of the HDM-4 model.....	116
5.5.3	Sensitivity analysis of the HDM-4 models.....	117
5.5.4	Description of other VOC models	118
5.5.5	Comparison between HDM-4 and the German model	120
5.5.6	Conclusions.....	124
References	.....	125
6.	Dissemination and Exploitation of Results	127
6.1	Intellectual Property Rights	127
6.2	Dissemination	127
6.2.1	General Dissemination Activities	127
6.2.2	Dissemination of the results during the Project	128
6.2.3	Dissemination of the results after the conclusion of the Project.....	129
6.3	Exploitation	130
References	.....	131
7.	Summary, Conclusions and Recommendations.....	133
7.1	Summary.....	133
7.2	Conclusions	135
7.3	Recommendations.....	137
References	.....	139



List of Appendices

- Appendix 1: List of Deliverables
- Appendix 2: Newsletters
- Appendix 3: Conferences and Workshops
- Appendix 4: List of Technical Committee meetings
- Appendix 5: Participants in the Research Project
- Appendix 6: FEHRL
- Appendix 7: Glossary
- Appendix 8: Acronyms



1. Executive Summary

1.1 Background of the PAV-ECO Project

PAV-ECO is a part of the Project entitled Pavement and Structure Management System, which covered two separate, but related, research projects, carried out under partial funding from the Transport Research and Technological Development Programme of the Fourth Framework Programme of the Commission of the European Communities. The two Projects were PAV-ECO (Economic Evaluation of Pavement Maintenance - Life-cycle Cost at Project and Network Level) and RIMES (Road Infrastructure Maintenance Evaluation Study). PAV-ECO was initiated by the Forum of European National Highway Laboratories and officially started on 14 October 1997 and ended on 13 October 1999.

The Swiss Partners in the PAV-ECO Project, Viagroup SA and Laboratoire des Voies de Circulation LAVOC – EPFL, joined the Project as entirely self-funded Partners with the approval of the European Commission.

1.2 Organisation of PAV-ECO

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 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.

The objectives were addressed by five Work Packages, with each Package broken down into research tasks. A sixth Work Package addressed dissemination and exploitation of the Project findings.

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

The Danish Road Institute managed the Project.

1.3 Technical Contents of PAV-ECO

The first part of the PAV-ECO Project dealt with interviews of representatives from road directorates in fifteen European countries and a literature review, in order to establish a basis for the work on optional application of different maintenance measures. The interviews identified a need for models for the economic evaluation of alternative pavement maintenance and rehabilitation strategies for individual road projects. Furthermore, most road authorities in Europe recognised a need for developing economic models for the estimation of additional user costs due to maintenance work zones, as well as pavement preservation, since such models are currently available in only a few countries. A framework was developed for comparison of life-cycle costs of different maintenance strategies at project level, which involves calculation of road owner and road user costs over the length of the selected analysis period.

Estimation of traffic volume and distribution is important in pavement life-cycle cost analysis. Most current pavement management systems use simple linear traffic forecasts without considering the risk of reaching the capacity limit. PAV-ECO provides a description of the determinants for traffic forecasts and suggests new traffic simulation models for both network and project level. A simple, prototype traffic assignment model has been developed to illustrate the distribution of traffic during maintenance works.

To help identify which pavement maintenance strategy to adopt for a road, or a network, PAV-ECO presents a method for determining the most effective maintenance strategy, considering not only investment costs, but also social costs for time, vehicle operation, accidents, air pollution, and CO₂-emissions. A case study, including road sections in Denmark, France and Germany, illustrates the use of this type of analysis and shows how the total costs of maintenance measures involving low expenditures carried out frequently compare with measures involving higher costs, but carried out less frequently.

The problem of establishing appropriate fund allocation methods for highway networks was investigated with a literature survey and the development of a spreadsheet-based model that uses a life-cycle cost approach, taking into account both costs to the road owner and the road user. The methodology developed can be used to apportion parts of a total budget. For example, funds can be distributed between regions, pavement types and bridge types, taking into account traffic levels and the condition of the network, as well as the lengths of pavement types and numbers of each bridge type. In addition, the method can be used to assist in the decision-making regarding the use of public or private funds to finance part of the network. Example budget allocations have been carried out for networks in England, Denmark and Finland.

Vehicle operating costs form a significant component of the life-cycle costs associated with each link in a road network. The level of vehicle operating costs depends upon the condition of the pavement, the physical characteristics of the road link and the traffic flow on the road. The variation in the increase in costs in relation to the deterioration of the road network is of particular interest, rather than the total vehicle operating costs. Therefore, a range of vehicle operating cost models has been evaluated to assess their suitability for inclusion in life-cycle cost models for roads in Europe. A comparison between a complex and a simple vehicle operating cost model was carried out, which

showed that the simple model was appropriate for high-standard European roads, such as motorway and primary road networks.

1.4 Dissemination and Exploitation

In addition to the technical and scientific Deliverables from the PAV-ECO project, a major effort was made with regard to dissemination and exploitation of the findings from the Project. The partners in PAV-ECO had no ambitions for the commercial exploitation of the results from the Project, so all findings from the work are available, in the public domain.

Dissemination from PAV-ECO took place during the Project and will continue after the completion of the study. Two major sources of external information from the Project were the PAV-ECO Newsletter and the PAV-ECO Internet website. The Newsletter was published three times; at the start, midway and after termination of the Project. The PAV-ECO website was created at Project commencement and will be maintained until the end of 2000.

During the Project, the Partners of the PAV-ECO consortium presented Project findings on several occasions. The major event for dissemination was the 2nd European Road Research Conference held in Brussels in June 1999; another dissemination activity during the Project included a presentation of the Project in Canada in May 1999.

A number of dissemination activities have been planned for the first year following the conclusion of the Project. Four abstracts have been submitted for the 1st European Pavement Management Systems Conference to be held in Budapest in September 2000, and a presentation is planned for the Nordic Road Association Conference in June 2000. In parallel, some of the Partners also have made national or regional arrangements to promote the PAV-ECO Project results in the spring of 2000.

The primary implementation of the Project findings lies with road authorities in Europe. While the national highways authorities can benefit from implementing the PAV-ECO Project results at the national level, regional and local road authorities implement pavement management technologies at regional or local level, often with assistance from private consultants.

1.5 Conclusions and Recommendations

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

- A framework was developed for the comparison of life-cycle costs of different pavement maintenance strategies and treatments at project level. It involves the 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 distribution on road networks.
- A case study of a social economic life-cycle cost evaluation of three different maintenance strategies has shown how a low-frequency strategy with intensive

maintenance can be compared with a high-frequency strategy with less-intensive actions.

- A method for the allocation of funds to different parts of the road infrastructure has been developed that takes into account the long-term maintenance costs of the road, as well as its condition and extent.
- For a high-standard European road network, the variation in vehicle operating costs is limited, and as a consequence a simple vehicle operating cost model can be used.

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.
- 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 a dynamic situation, where a succession of maintenance measures is considered.
- Maintenance budget allocations should be made on a life-cycle cost basis rather than on the basis of the current condition and extents of the parts of the network.
- A simple model including vehicle speed and road gradient should be used for the calculation of vehicle operating costs for the European road network.



2. The Partnership

The PAV-ECO Project was carried out by a consortium of eight Partners from five EU Countries and one Associated Country. Most of the PAV-ECO Partners are either institutes under their national road agencies or closely related to road authorities, and as such they represent the end users in the Partners' home countries. All have participated in the research work because of their advanced engagement in pavement management development and abilities in their respective fields in the Project.

The Swiss Partners in the PAV-ECO Project, Viagroup SA and Laboratoire des Voies de Circulation LAVOC – EPFL, joined the Project as entirely self-funded Partners with the approval of the European Commission.

The PAV-ECO Partners were the following:

- Ministry of Transport, Road Directorate, Danish Road Institute (DRI)
- Anders Nyvig A/S (ANAS), Denmark
- Technical Research Centre of Finland (VTT), Finland
- Laboratoire Central des Ponts et Chaussées (LCPC), France
- University of Cologne, Institut für Verkehrswissenschaft an der Universität zu Köln (UoC), Germany
- Laboratoire des Voies de Circulation LAVOC - EPFL, Switzerland
- Viagroup SA (Viagroup), Switzerland
- Transport Research Laboratory (TRL), United Kingdom.



3. Objectives of the Project

The PAV-ECO Project was undertaken on the basis of the Project Inception Report (PAV-ECO, 1997). This was written in accordance with the Actual Cost Contract No. RO-97-SC 1085/1189, between the European Community represented by the Commission of the European Communities represented in turn by the Director General of Transport, or his authorised representative, and the PAV-ECO Consortium. The Commission and the Contractors have agreed to a Project entitled: "Economic Evaluation of Pavement Maintenance - Life-cycle Cost at Project and Network Level - PAV-ECO". The agreement was concluded based on the PAV-ECO Proposal for EU DG VII, RTD-Programme Reg. No. 183453 of March 1996.

3.1 Target Audience

This Report is aimed at road pavement management engineers generally, as well as highways engineers and administrators in road authorities and other interested organisations in Europe and in other countries around the world. While the national highways authorities can benefit from implementing the PAV-ECO Project results at the national level, regional and local road authorities implement pavement management technologies at regional or local level, often with assistance from private consultants.

3.2 Objectives

The Project objectives were to establish financial and economic models for the evaluation based on life-cycle costs for:

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

and to ensure exploitation of the results through:

- Policy and methodology proposals provided for European Road Agencies
- International symposia for dissemination of Project results
- CORDIS and IRRD information databases

In the Project these objectives were addressed by Work Packages, each of which was broken down into research tasks. 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.

The problems to be addressed by road agencies, include:

- Timely interventions on adjacent road sections
- Possible changes in future traffic flows through the 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 which could be used by different European road authorities to select and adapt appropriate models to enhance existing systems. Throughout its entire work, the PAV-ECO consortium considered mainly the project level, but models developed for project level are intended for inclusion in network analyses.

4. Means used to achieve the Objectives

4.1 Organisation 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 4.1, following. The Figure shows that the Project was divided into the following Work Packages:

0. Management
1. Maintenance measures evaluation
2. Impact of traffic change
3. Social economic evaluation
4. Allocation of funds
5. EU vehicle operating cost model
6. Dissemination and exploitation of results.

4.2 Work Programme

The work content was grouped into five Work Packages for the main development aspects of the Project and one Work Package for the dissemination and exploitation of the Project results. The Work Packages were inter-related in their contributions to address the Project objectives and to describe the road infrastructure maintenance by life-cycle cost evaluations. Figure 4.1 depicts the organisation of the PAV-ECO Project.

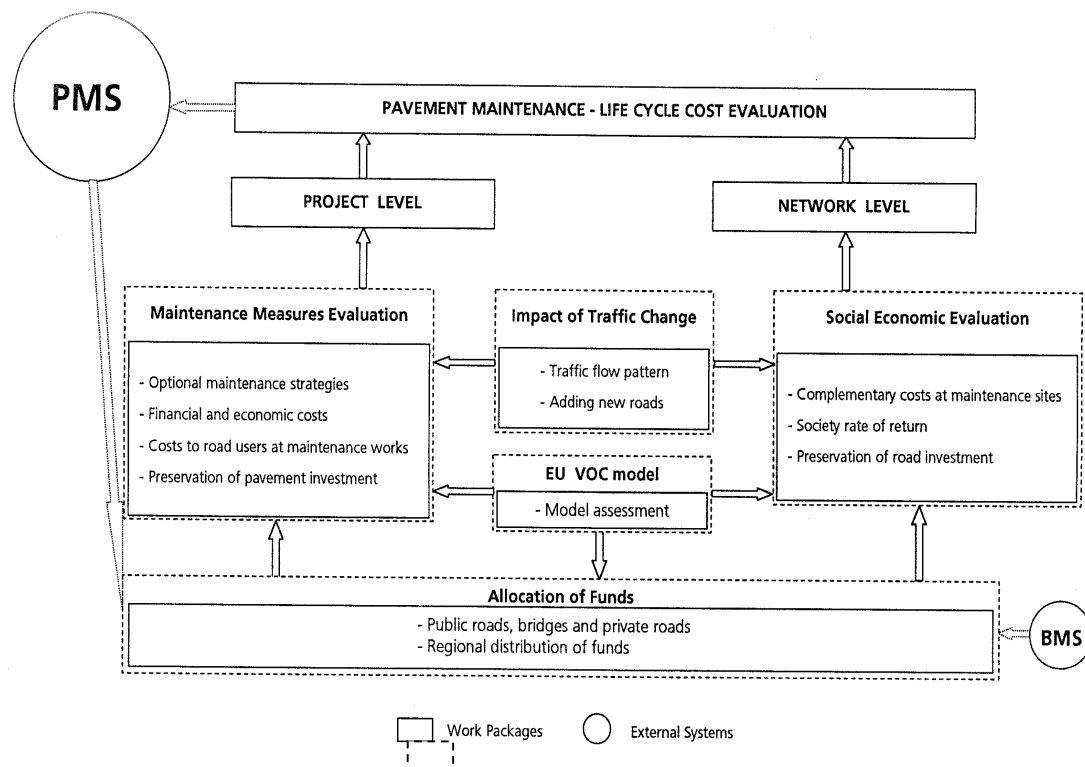


Figure 4.1 Organisation of the PAV-ECO Project [PAV-ECO, 1997].

Brief descriptions of the objectives of Work Packages 1 to 6 are given in the following. Work Package 1, 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 on a comparison of optional maintenance strategies associated with the financial costs to the road owner, economic costs to the road user 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, which allows the 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, based on the results and methodologies derived in this work package.

Methods for the computation of realistic traffic data on a road network are the subject of Work Package 2, Impact of Traffic Change. This information was used in other Work Packages for analyses of optimum maintenance management strategies and calculations of social economic parameters of certain 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 addition of new roads to a network under capacity restraint conditions (e.g., lane closures).

Road agencies in European pavement management systems primarily consider alternative maintenance strategies on a financial basis. This approach is insufficient, however, for decision-makers interested in considering the social economic effect of road pavement condition. Work Package 3, Social Economic Evaluation, provided models for the social economic evaluation at network level with the purpose of including the models in maintenance management procedures.

Work Package 4, Allocation of Funds, describes the study to develop models to improve the allocation of budgets for maintenance and achieve better value for money. The two main areas considered were the regional allocation of funds from a central budget and 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.

Work Package 5, EU VOC models, 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 objective of the Project component described in Work Package 6, ensured the dissemination and Exploitation of Results, was to ensure the dissemination of results of PAV-ECO to the European community. This has been achieved through presentations to European road agencies and at international Symposia. Demonstrations of the results of the Project throughout Europe have been in the form of workshops and demonstrations; and these will continue after completion of the Project.

4.3 Management Input

4.3.1 Joint Management Organisation

In order to co-ordinate both the PAV-ECO and RIMES research teams, from Project commencement, a general agreement was reached between the two research teams that Mr. Ivar Schacke, of the Road Directorate, Denmark, would act as Joint Co-ordinator for the two Projects.

Mr. Ivar Schacke and the two Project Co-ordinators, Mr. Hans Ertman Larsen from PAV-ECO and Dr. Henry Kerali from RIMES, formed a Project Steering Committee (PSC), dealing mainly with administrative issues from the two Projects. This three-member group ensured the proper flow of information between the teams and to the EU.

Figure 4.2 depicts the Project management structure for PAV-ECO.

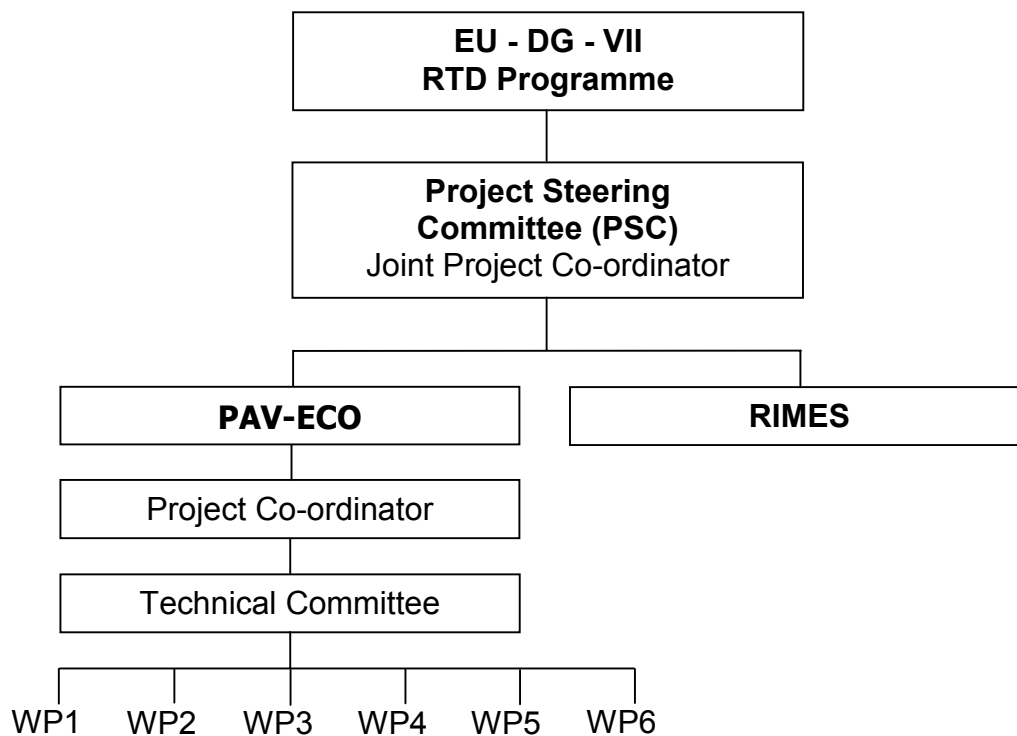


Figure 4.2 Project management structure for PAV-ECO.

4.3.2 Management of the PAV-ECO Team

The general management structure for the PAV-ECO Project consisted of three management levels:

- Project Co-ordinator
- Technical Committee
- Work Package Leader

Figure 4.2, preceding, shows the Project management structure for PAV-ECO.

The Project Co-ordinator was responsible for co-ordination of the Project activities and liaison between the Project team members, the Technical Committee, the Project Technical Committee (PSC) and the EU Commission. He was responsible for the day-to-day supervision of the planning, budgeting and accounting on the basis provided by the other Partners. He took care of and co-ordinated communication between the Partners and managed exploitation and dissemination of the Project results.

The Members of the Technical Committee supervised the strategic management of the Project encompassing technical aspects, financial control and exploitation matters. Their responsibility areas ensured the availability of required resources. The Technical Committee met regularly at approximately three-monthly intervals, as listed in Appendix 4. In addition to the Technical Committee meetings, ad hoc Working Package meetings were held as necessary. The Technical Committee members are listed in Appendix 5.

The Work Package Leaders were the following:

- Work Package 1: Mr. Antti Ruotoistenmäki, VTT
- Work Package 2: Mr. Søren Hansen, Anders Nyvig A/S
- Work Package 3: Professor Dr. H. Baum, UoC
- Work Package 4: Mr. Richard Abell, TRL
- Work Package 5: Mr. Jean-Claude Turtschy, LAVOC
- Work Package 6: Mr. Philippe Lepert, LCPC

The Work Package leaders were responsible for the detailed management and reporting of the tasks by the task leaders in the Work Package. The Work Package Groups met according to the specific needs of the tasks under the chairmanships of the individual Work Package leaders.

4.4 Management and Progress Reports

During the Project, four Progress/Management Reports were delivered at intervals of six months. The Final Consolidated Progress Report was submitted at the end of the Project.

Each Work Package Leader submitted a monthly Status Report to the Project Co-ordinator about the progress of the Task Groups, resources used, percentage completion for on-going activities and included an up-dated detailed schedule for the succeeding



activities, highlighting the deviations from the Work Schedule. Also, the Work Package Leaders provided the four Progress Reports which were submitted together with an Internal Report every three months.

4.5 PAV-ECO on the Internet

The PAV-ECO Project established a homepage on the Internet (Lepert, 1999) at the address: <http://lavocwww.epfl.ch/ProjetsEuropeens/pav-eco/>. The website consists of two parts: an open part which is publicly accessible, and another part which could only be accessed by the PAV-ECO Partners.

The public (open) part of the website consists of a general description of the Project and its Partners (with direct links to the latter), as well as providing access to submitted Deliverables produced by the PAV-ECO Project. The internal part of the homepage consisted of minutes of meetings, time and activity schedules, activity reports, and draft versions of documents awaiting publishing. Once the EU Commission approved a Deliverable, the Executive Summary for the Deliverable was transferred to the public part of the website.

The PAV-ECO homepage was developed and kept up-to-date during the Project period and will continue to be maintained until the end of year 2000.

4.6 Quality Assurance

To obtain the required result of the PAV-ECO Project efficiently, it was important to control the following aspects: Quality (meeting the requirements set); Time (within the available two years); Finance (within the framework of the budget); Organisation (the interrelation and division of tasks, including liaison with the RIMES Project); Information (reports, Internet, etc.)

Technical reviews of the work carried out and the products developed were undertaken before a Deliverable was accepted as complete. The Technical Quality Assurance ensured that each Work Package had a Monitoring Group consisting of one or two Partners, who were not involved in the particular Work Package. The Monitoring Group was responsible for the quality of the work carried out and that the expected Deliverables were provided.

References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.



5.1. Maintenance Measures Evaluation

5.1.1 Introduction

The objective of the PAV-ECO Project has been to develop economic analysis models for use in Pavement Management Systems (PMS). The principal objective of Work Package 1 was the development of an analysis system for the economic evaluation of alternative pavement maintenance and rehabilitation strategies for individual road projects. The need for such economic models has been confirmed mainly through interviews of road directorates in fifteen European countries and a literature review.

The literature review provided an overview of PMS, their components and different models their use involves (e.g. pavement deterioration and optimisation models). Based on the interviews, it was possible to have an overview of the road networks in various countries, and the maintenance works and strategies used in different countries.

The framework of life-cycle cost analysis on individual road projects is described. The economic evaluation is based on the comparison of the financial costs to the road agency (cost of maintenance / rehabilitation works and pavement preservation at the end of the analysis period), economic costs to road users during the service life of the road (annual road user costs and additional road user costs caused by maintenance works associated with alternative maintenance strategies).

5.1.2 Interviews and literature review

From the beginning of the Project, it was clearly recognised that there was a need to gather information on pavement maintenance and rehabilitation practices in Europe. To gather this information, both a literature survey and direct investigations were carried out by the task Partners. The organisation and results of this information gathering work is synthesised in the following pages. It is described in full details in the final report of the Work Package 1, Task 1 of the Project [Lepert 1999].

5.1.2.1 Literature survey

A literature survey was conducted by the Partners of the task, namely LCPC, VTT, DRI, Viagroup and TRL. The objective of the literature survey was to give a stronger theoretical basis to the information gathering process, and to build a framework in which the information collected during the interviews about the actual maintenance practices in each country could be described. More than 200 papers, in French, English and German were read, of which more than 60 of them have been synthesised for the report.

5.1.2.2 Interviews of European Road management and technical progress

To complete the information gathering, direct investigations were carried out in fifteen countries by the four major task Partners as outlined in Table 5.1.1.

Table 5.1.1 Interviews of Pavement management experts in European road directorates.

LCPC	VTT	ViaGroup	TRL
France	Norway	Switzerland	UK
Belgium	Sweden	Hungary	Ireland
Spain	Finland	Austria	Netherlands
Portugal	Denmark		
Slovenia			

Some other countries were approached by the Partners (Germany, Italy), but for different reasons it was not possible to meet the people from these countries. In the countries listed in Table 5.1.1, each of the Partners interviewed road managers (usually at the national Road Directorate) and experts in the various countries. To prepare these interviews, a guide was produced which summarised the topics to be discussed during the interviews. It also involved an appendix with the terminology used in the PAV-ECO Project, based on international references [PIARC 1998, MELTT 1997].

5.1.3 Pavement Management Systems

The literature review provided an overview of the PMS and their current state of development and use in Europe, today. This overview is summarised in this section. The interviews of the Road Directorates provided more information on the situation of European countries with respect to the maintenance and rehabilitation organisation, and the way they are using PMS. This is reported in section 5.1.4.

Almost all of the interviewed countries use a PMS of some sort to identify sections which require maintenance works on the (main) national roads. In some European countries, such as France, local authorities (mainly department councils) use the same PMS as the national authorities, but employ different strategies. In some other European countries, for example, the United Kingdom and Denmark, the PMS used by local authorities (counties, cities and municipalities) may be different from the PMS used for the national road network. Although the systems operating in European countries may differ slightly in their scope, concepts and analytic approaches to address various management and engineering decisions, the basic elements are the same. The network is characterised by data stored in a database. These data are processed according to some methods based on four types of models : Maintenance and Rehabilitation Models, Pavement Deterioration Models, Cost Models and Optimisation Models. In the following sections, the most common techniques and models used in the basic elements are presented.

5.1.3.1 Databases

For effective management of a road network, it is necessary to know the present condition of the network. The database is therefore the core of a PMS. It should contain inventory data, and condition (or monitoring) data [OECD 1987, Caroff & Leycure 1993]. The inventory data generally includes administrative and geographical classification (category and localisation), geometric characteristics (cross section), pavement

data (type, structure and age), traffic (vehicle composition, volume, growth rates), accidents (location, type, cause), climate and environment. Monitoring data gives information on structural and functional condition. Structural condition is generally characterised by cracking extents, and by bearing capacity. Pavement functional condition includes longitudinal unevenness, rutting and skid resistance measurements and ravelling extents. Although functional data and bearing capacity are generally obtained by automated surveys, the most reliable method for cracking and ravelling surveys is still visual inspection by trained operators [Lepert 1994a, Lepert 1994b]. This type of visual inspection is routinely carried out in many European countries, including the Netherlands, Denmark, the United Kingdom, Hungary, France and Belgium.

Initially systems for storing the data included functions to sort or combine the data. These functions were very simple, and did not make it possible to automatically process the data by applying logical methods for maintenance management. Therefore, more sophisticated systems were developed, sometimes accompanied by computerised systems for road management, which could process the data contained in the databases. They were the first PMSs.

5.1.3.2 Evolution of Pavement Management Systems

The PMS, which provided the first methods for maintenance management, were rather simple. The condition of the pavement was estimated by a single measure of condition (e.g. the longitudinal unevenness) and the maintenance treatment options were also limited to overlays of variable thickness to improve the unevenness, and, if necessary, to strengthen the pavement structure [Martin & Roper 1997]. A maintenance/rehabilitation strategy was then defined by a simple relationship between the condition measurement and the thickness of the overlay which should be applied.

The systems became more sophisticated when two objectives were addressed, using two indicators. For instance, the system developed by the BRRC (Belgian road research centre) for the maintenance of secondary roads is based on two condition indicators [Veverka & Gorski 1990, BRRC 1994]. The first one, calculated from automated measurements, characterises the structural condition, and the second one, derived from a visual survey of surface distresses, the condition of the wearing course. The diagnosis of the pavement is derived from analysis of these two condition indicators. The maintenance programme is established by applying a maintenance strategy which indicates, according to the diagnosis and the category of road, the maintenance works required, from seven possible treatments.

During recent years, several factors have led to an evolution of the methods and tools used in maintenance management. Firstly, the variety of maintenance operations undertaken in road maintenance management has increased. Secondly, it is now possible to select a treatment for each type of pavement deterioration, from a variety of treatments which increases every year [Brosseau 1996]. On European road networks, managing authorities no longer estimate the condition of the network simply on the basis of one or two indicators, but on a set of four to ten indicators which describe the structural condition of the road pavements, the service offered to the road users, the environmental disturbances, etc. Finally, the rapid development in the performance of computers has made it possible to perform the systematic multi-criteria analyses which are essential to

make use of the new engineering knowledge. The development of modern PMS is the consequence of these evolutions.

5.1.3.3 General functions of a modern PMS

Today, a complete PMS achieves two objectives: the selection of an optimal maintenance policy and strategies, and definition of the maintenance programme according to this optimal policy and strategies. These objectives are usually addressed by two stages of the PMS process. Sometimes this may involve using two types of PMS. To optimise the maintenance policy, only global parameters are considered to characterise the network. Statistical probability based approaches and methods can therefore be used to find a global optimum. When defining an actual maintenance programme, over one or several years, all the required maintenance works must be identified and this implies that only deterministic engineering models can be applied. In fact, the first stage of the PMS system identifies the policy and strategies that the second stage should use.

In the two stages of the PMS, the policy and strategies are not described in the same way. They are generally probabilistic matrices in the first stage and decision grids or trees in the second. Consistency between the different applications of the common concepts is always difficult to ensure [Flintsch & Zaniewski 1997, Li et al. 1997a]. Some research is underway to overcome this difficulty with a new type of optimising semi-deterministic system that takes advantage of the increased processing power of computers [Courilleau et al. 1998, Li et al. 1997b]. The basic principle of this new approach is to apply the programming deterministic model in an iterative process over the whole life-cycle of the pavements with the condition of the pavements being updated each year using pavement deterioration models, and maintenance effects models.

5.1.3.4 Maintenance and Rehabilitation (M/R) Action Models

Maintenance/rehabilitation Action Models (a concept equivalent to maintenance strategy) are mainly implemented in deterministic programming systems. They are concerned with selection of the most feasible M/R techniques based on given road information. Typical M/R Action Models consist of decision grids or decision trees, based on one or several condition indicators or measures. Thresholds are defined for each indicator, and the combination of these thresholds defines a number of condition states (cells of the grids, or branches of the trees). M/R techniques are specified for each state in the decision grids. Usually, these techniques are standardised, or at least recommended, for certain types and levels of pavement distress. Most PMSs include the classification of road condition, critical deterioration levels of the road and the corresponding maintenance and rehabilitation techniques [Kerali & Snaith 1992].

5.1.3.5 Pavement Deterioration Models

Pavement deterioration models predict the rate of change of pavement condition under the influence of traffic, climate and material ageing [COST 324, 1997]. Figure 5.1.1 is a schematic illustration of how deterioration prediction would be applied to a pavement section to estimate the rate of deterioration and the maintenance requirements each year.

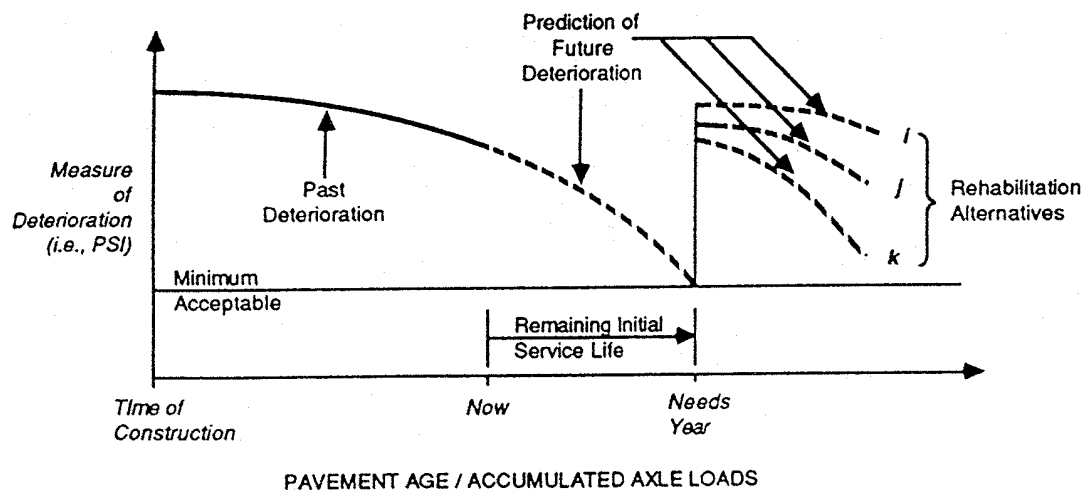


Figure 5.1.1 Use of a deterioration model to predict future distresses of an existing pavement [Haas et al, 1994].

The three basic approaches for modelling pavement deterioration are currently [Gschwendt & Stano 1993, Kristiansen 1993, Schmidt & Lund 1993, Tapio & Mannisto 1993]:

- Deterministic models, which predict the change in condition indicators for the pavement according to time, traffic loads, traffic flow, etc. These models are based on either an extrapolation from historical data or a calculation from the critical stresses or strains caused by heavy traffic loads and they are mainly used in deterministic systems.
- Life-cycle probabilistic models, which predict the change in condition indicators with time after a maintenance treatment has been applied, up to the failure of the pavement [Lepert et al. 1998]. These models are also mainly employed in deterministic systems.
- Markov probabilistic models which use the probabilities of different pavements undergoing the transition from one condition state to another as a function of time and age. Such models usually deal with global condition indices, and are almost exclusively used in statistical optimisation systems.

5.1.3.6 Cost Models

Cost models are briefly addressed in this part for consistency and completeness. They are fully addressed in sections 5.1.7 and 5.1.8. Cost models involve agency costs, which include initial capital costs of construction, maintenance costs, residual value at the end of the design period, engineering and administration, and user costs, which include travel time, vehicle operating costs (VOC), accident costs and user discomfort. Cost models also involve additional user costs in work zones, mainly determined by the increase in travel time induced by the reductions in speed approaching and within these

work zones. VOC depend mainly on variables that do not vary significantly at work zones, compared with the normal operating situation. As explained later, modelling accident costs at work zones is not easy, as there is little data with which to derive statistical models.

5.1.3.7 Optimisation Models

The optimisation process determines the best possible use of available resources for pavement management purposes. The most common approach in these optimisation processes is a cost/benefit analysis. The principle of the method consists of comparing alternative maintenance and rehabilitation strategies or policies on the basis of total or partial transport costs (road construction and maintenance, normal user costs and extra costs at work zones) or economic rates of return (reductions in user costs, infrastructure depreciation, noise and pollution resulting from maintenance), which ultimately constitute the objective function to be minimised. Costs and benefits are discounted to a present value [Hein et al. 1994, Gáspár & Rosa 1994, Abell & Ramdas 1995, Nielsen & Larsen 1994]. Different techniques to identify the optimum solution are briefly introduced in the following subsections. These techniques, except the first one, are usually implemented in statistical optimisation systems.

The first technique, used in VIAGERENDA [Veverka et al. 1990, BRRC 1994] is based on the comparison of the global quality index with an appropriate intervention threshold for repair. A break-even approach is used in the optimisation, which compares the costs of local repairs with the terminal annuities needed to create sufficient capital to be able to finance general maintenance or strengthening work at a later date. The total of these costs depends on the number of years, and its minimum value, corresponding to the optimal period at which general maintenance or strengthening can be initiated, thus eliminating local repairs. The number of years, given by the optimal period, can be used as an input to global quality index prediction models to calculate intervention levels.

The second technique used a dynamic programming model, applied to a Markov process, to describe the transition from one pavement condition to another by a built-in optimisation process. The aims of the technique are to find the optimum condition of the road which can be reached and maintained with a view to minimising total costs to society (user costs + agency costs), and to set a global annual maintenance schedule to achieve this optimum level. The model classifies roads into a certain number of condition categories and allows for several rehabilitation measures (ranging from periodic maintenance to reconstruction). By selecting optimum measures for each possible condition, the model attempts to find a level of repair that provides the equilibrium between higher user costs caused by a lower level of maintenance and higher agency costs due to appropriate maintenance. For each condition state the results show the percentage of road length of the network requiring maintenance treatment. It should be noted that in an optimisation of this type any budgetary constraint does not lead to modifications in maintenance priorities, but to modifications in road condition standards [Haas et al, 1990, 1994].

The third technique is based upon a maintenance economy optimisation model for application under resource constraints. A cost/effect matrix is applied to each homogeneous section of the managed network. The matrix provides a link between the road condition (columns of the matrix) and the maintenance operations (rows in the

matrix). The elements characterising maintenance operations are cost, efficiency and time for implementation. For each quality criterion describing the condition of a road section a time progression model is defined, or a probability of survival of each of the maintenance activities. Therefore, each matrix element represents the effect of the maintenance operation on the quality criterion concerned. The values of

the elements are estimates of maintenance effectiveness assessed by monitoring past works. An objective function is defined to minimise the summation of the costs. This summation relates to the road sections under analysis, the available maintenance strategies, the types of distress and the number of years in the analysis period. The objective function may also be subjected to other constraints, such as only one maintenance strategy at a time per road section, restrictions on availability of manpower, etc. The approach is based on the effective gradient method, which evaluates the ratio between the effectiveness of maintenance of one road section and for one maintenance strategy, and the increase in the maintenance effectiveness for all sections taking the available resources into account [Haas et al, 1990].

5.1.4 Pavement management in European countries

From the literature review presented in the previous section one could say that there appears to be neither lack of technical concepts, nor lack of engineering tools for pavement maintenance management. Furthermore, maintenance policy and maintenance strategies (also called M/R Action Models) are now strongly established concepts, which are central to any PMS. But, although these concepts are well established theoretically, their implementation varies between countries. The context of maintenance activities is not the same in all countries, as the traffic, the climate, the types of pavement are diverse. The distresses which occur on European road pavements, and therefore the indicators which must be used to characterise the condition of the pavements and their maintenance needs, also vary. Different maintenance treatments are also used in these countries. To examine the up-to-date position on all these questions, this section investigates the state of road maintenance management in several European Countries.

5.1.4.1 Administrative organisation of road networks in Europe

The general administrative organisation of road management is not very different from one country to another:

- in some countries there are networks of toll motorways, which are often owned by the national authorities but funded by tolls and operated by private companies;
- the national network is owned and generally funded by the national authority, but in a few cases by the regional administrations (Belgium, Switzerland);
- the regional networks are owned and funded by the regional authorities, in fewer cases by the national government (Slovenia, and Nordic countries to some extent);
- the local networks are owned and funded by municipalities.

The traffic on these networks may, however, be very different from one country to another. For example, the average traffic on national roads varies from less than 4,000 vehicles / day to more than 30,000 vehicles / day but the actual highest flows can exceed 200,000 vehicles / day. Variations in the wear caused by traffic (represented by % of trucks), as well as in climate conditions, amplify the diversity of the conditions road pavements have to accommodate.

5.1.4.2 Functional classification of roads for maintenance purposes

Apart from the administrative organisation of the networks there may be a functional classification of the roads within the network. This classification is considered when the managing authority assigns different objectives of maintenance to the different categories, for example, preventive maintenance on one category and curative maintenance on another. Such a functional classification of the roads is based:

- in France and the United Kingdom, on the function of the roads,
- in Switzerland, on the number of lanes,
- in Austria, on the capacity of the roads,
- in Portugal, on the economic importance of the roads.
- in Slovenia, for national roads, on the level of traffic and the economic function (e.g. links between main cities, between communities, etc.).

In most of the other countries, such as Spain or Belgium, there is no explicit road classification. The traffic is used as a variable to choose or calculate the most appropriate maintenance work to meet the maintenance objective, but there is not a different objective assigned to the different roads in the same network.

5.1.4.3 Maintenance agents and management sectors

In general, the allocation of funds between the different parts of a network is decided by the Road Management Service of the owner, the latter being also usually the fund provider. There is more diversity between the different countries, as far as maintenance programming is concerned. In some cases, programming is centralised (Spain, Slovenia, Portugal on the main highways), but in most cases it is decentralised to the districts or even to the agencies. In some circumstances, the programming of some maintenance works may be sub-contracted to private operators. Execution of periodic maintenance shows an even larger diversity. In some countries, it is wholly performed by private companies (Spain, Slovenia), whereas in some others it is wholly performed by agencies (UK, Ireland, Finland, Switzerland). In most cases, it is shared between private companies and agencies, in various proportions, but increasingly by the private sector (e.g. Portugal). Routine and structural maintenance activities are always sub-contracted to private companies.

Finally, these findings, which describe present, and probably transient, situations, outline a general trend which is supported by a more careful analysis of the minutes of the interviews, that the role of the private sector in the management and performance of road maintenance is increasing. Routine and structural maintenance is performed by the private sector. Routine maintenance is already contracted out in some countries, and

others are starting to follow this approach. The length of toll motorways is increasing faster than free (public) motorways in the countries where they exist (France, Spain, Slovenia). In some countries, privatisation of some highways is under consideration (Finland), or even planned, as in Austria where free motorways are managed by special companies which are to be privatised in the near future. In the United Kingdom, where private companies already manage some lengths of the national network, the first toll motorway is under construction. There are also a number of tolled bridges in the

national network. Private companies are also preparing to build and or manage specific roads in the local network, but there are no schemes of this type yet in operation.

Privatisation does not always mean management by a private company. Most of the companies which are managing road networks, such as toll motorway companies, are public, or at least mixed (semi-public), companies. These are managed as private companies, and the funds, especially for maintenance, do not come from the national budget. Usually more than half of their shares are publicly owned. On the contrary, in the United Kingdom, private companies receive Government funding.

5.1.4.4 Extent of Maintenance on national networks

The extent of maintenance may be roughly evaluated through the global budget assigned to the work, as well as through the frequency of maintenance works. Of course, it is difficult to obtain, let alone to compare financial information from the different sources. The road administrations may cover very different types of networks and furthermore, different types of maintenance. Nevertheless, it would appear, from information from Denmark, France, Belgium, Spain, Switzerland and Slovenia, that the expenses for all types of maintenance on the national networks of these countries vary from 11,000 euro/km to 30,000 euro/km (1998). No specific study has been conducted, in any country, into the frequency of maintenance works on the national network. Although such analyses would be desirable, data are still not yet available.

A more detailed analysis of the interviews shows a general trend to reduce the budget allocated by the national government to the maintenance of national roads. This was observed in Denmark, Finland, Belgium, Spain, United Kingdom, Netherlands, for example. As a consequence, in these countries, one of the major concerns of road directorates is to develop a technical-economic analysis to support the need for, at least, stable maintenance budgets.

5.1.4.5 Maintenance and rehabilitation strategies on national networks

A strategy is a set of decision rules, corresponding to a maintenance objective, which makes it possible, from the values of pavement condition indicators, to identify the sections which require maintenance, to define the works to be undertaken, and the appropriate order for these maintenance operations. As previously mentioned, different strategies are applied, depending on the country and on the category of roads.

Strictly speaking, a set of indicators is not common to all countries. Some countries give a large importance to longitudinal and/or transverse unevenness, Norway and Sweden, for example. In some other countries, like the United Kingdom, France and Spain, longitudinal unevenness is not a criteria for maintenance decisions. In these countries, surface distress, like cracks, have a dominant role in programming criteria. These differences are easily explained by the differences in pavement structure and the intensity of traffic and climate, in these countries. Nevertheless, all the condition indicators used on European networks can be included in a common and single group, including longitudinal and transverse profiles (unevenness and rutting), bearing capacity (deflection), surface defects such as cracks or wearing course distresses, and skid resistance.

Furthermore, there is an increasing number of European Projects which aim at, or involve some actions for, harmonising these parameters (e.g., PARIS).

It is still difficult, to compare intervention thresholds between the different countries. A common feature is that the thresholds depend mainly on the road classification, or, when such classification does not exist, on the traffic. The higher the category or the traffic, the lower the intervention threshold.

Based on these indicators and thresholds, the maintenance strategies apply decision rules and criteria to determine which sections of road to maintain, and the order for maintenance. The priority of maintenance sections depends generally on the road category and the traffic, and is determined by a combination of the indicators. In a few cases, the priority results from an optimisation study (Slovenia, Denmark). As a general feature, higher maintenance objectives and higher intervention priorities are assigned to important roads, which implies a preventive maintenance strategy is adopted if the pavement is already in good condition, and reconstruction if the pavement is in poor condition. On roads of less importance, the maintenance objective and priority are lower, and this implies operation of some kind of curative maintenance.

As far as maintenance techniques are concerned, these can be grouped into three families: localised or periodic maintenance, routine maintenance and structural maintenance (see Table 5.1.2). Within each group, the characteristics of the components (binder, aggregates) employed in the maintenance materials and the maintenance processes differ between countries, according to the climate and traffic.

5.1.4.6 Benefits from maintenance and rehabilitation

The benefits from maintenance may be evaluated technically, and from an economic point of view. The technical benefits from maintenance are measured by a follow-up of the condition of the roads, using different indices. These indices are calculated by combining condition indicators, and are often the same as those used in the maintenance and rehabilitation strategies. In principle, the economic benefits from maintenance work should be assessed by benefit-cost studies. Interviews clearly showed that such studies were rare. And if there were some studies conducted in the past [Appy et al, 1985], they were more qualitative than quantitative. Also a few studies have been conducted, based on a rather simple approach to the maintenance management, similar to those in HDM-III.

5.1.5 Maintenance strategies used in European Countries

From the preceding, it is clear that as far as the 15 interviewed Road Administrations can be considered as representative of European countries in general, large similarities can be seen between these countries. The administrative and political context is not so different between the countries. There are, in all countries, three or four different levels of network (national, regional, local, concessional) owned, funded and managed by relatively autonomous authorities. The economic context is characterised by two on-going processes: the stabilisation and sometimes reduction in the public maintenance budget, especially on highway networks, and the growing influence of private sector

(including public autonomous companies) in road management, and especially maintenance activities. Technical approaches to maintenance, at least on the national networks, are quite similar, using the same concepts and therefore, similar tools.

As far as maintenance strategies and policies are concerned, the same framework of concepts are used all over Europe, with different parameters adjusted to local conditions. The main differences lie in the technical adaptation of these concepts to the local context. Obviously, and even if the comparison is restricted to national networks, there are different climates, different levels of traffic, and different wear effects of heavy traffic. As a consequence, pavements are constructed by different methods, and thus deteriorate in different ways. The types of distresses which appear on these pavements and their severity differ from one country to another. Therefore, the condition indicators which are used in the maintenance strategies applied vary according to these local distresses, although they are picked out of a common group of indicators. In the same way, the maintenance techniques are quite similar, although the characteristics of the treatment components vary according to local resources or climatic constraints.

Finally, rather than identify a limited (finite) number of alternative strategies, a common structure for maintenance strategies can be defined which makes it possible to generate a continuous range of strategies (and therefore, of policies). This concept of an adjustable maintenance strategy is an extension, rather than a contradiction, of the concept of alternative maintenance strategies. This concept of adjustable maintenance strategies can be, and is in most cases, implemented in the pavement management systems.

5.1.6 Framework for life-cycle cost analysis on individual road projects

Comparisons of alternative maintenance strategies and treatments at project level are 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, are included in the analysis. Road agency and user costs occurring within the analysis period are discounted to the base year and summed to give the total life-cycle costs.

Figure 5.1.2 provides a general framework for life-cycle cost analysis. Such frameworks are presented, for example, in [He et al, 1997]. The following cost elements of the framework are discussed in the subsequent sections:

- 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.

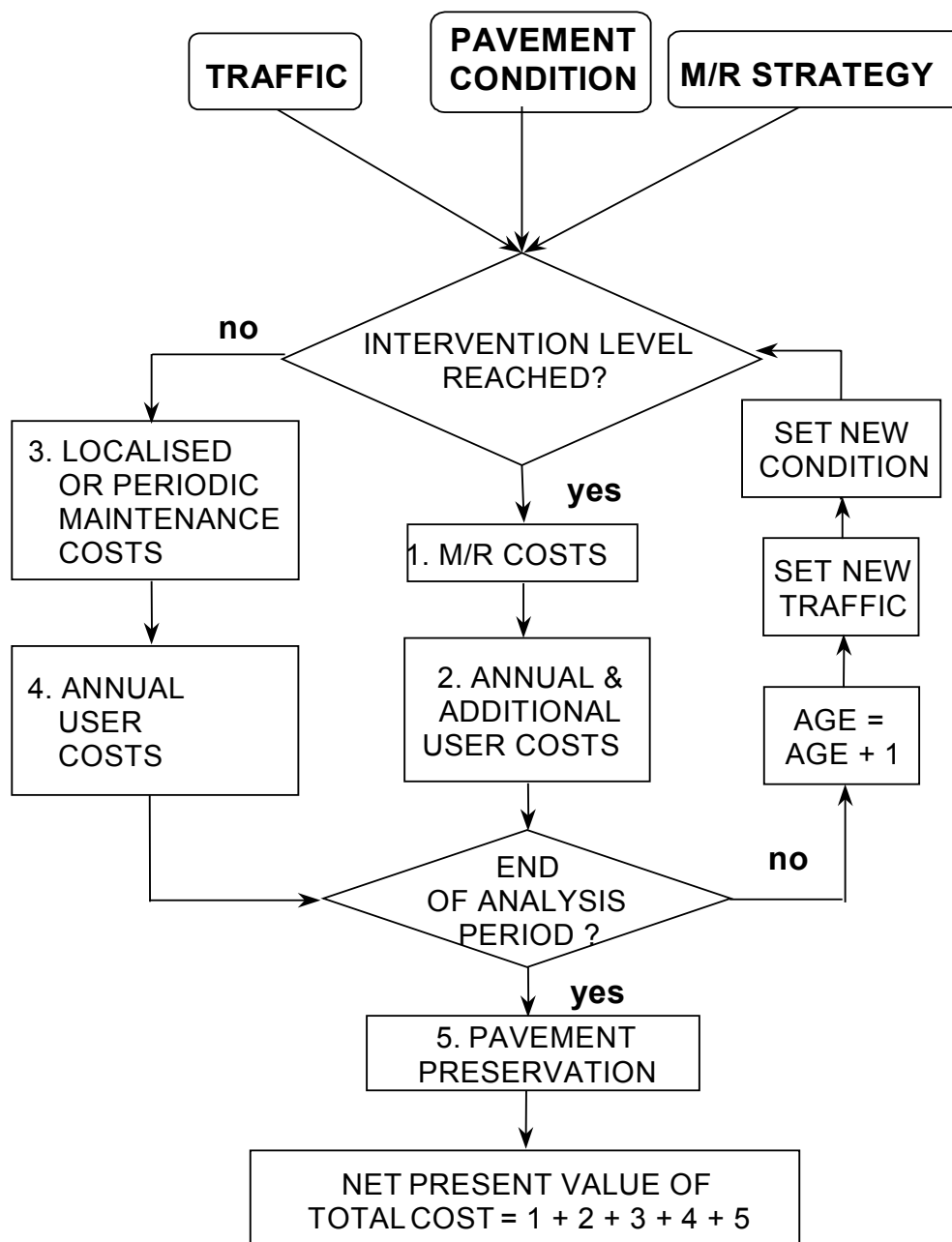


Figure 5.1.2 Framework of life-cycle cost analysis on individual road projects.

5.1.6.1 Discount rate

In comparing the life-cycle costs of alternative maintenance strategies with costs occurring at different times, it is not appropriate to simply compare the sum of the total costs over the period. The costs must be transferred to a common point in time (e.g. the start of the analysis period) to enable comparisons to be made between different patterns of spend. This is achieved through discounting the future costs.

The selection of the discount rate used in the calculations has a big effect on the results. Therefore a realistic estimate of the discount rate is essential. In general, the discount rate used varies with the expected rate of return from the investment, the type of asset, etc. In the private sector required rates of return from investments are high and this results in the use of high discount rates for the financial evaluation of investments. In the public sector, the rates are often fixed by the funding authority who again take into

consideration the required rate of return. In general this tends to be lower than private sector rates. High discount rates favour options with low capital cost, short life and high recurring costs. The opposite is true for low discount rates.

The real interest rate is proposed to be used as the discount rate here. The real interest rate is estimated from the following formula:

$$R = (1 + i) / (1 + q) - 1 \quad (5.1.1)$$

where

R = real interest rate

i = nominal interest rate

q = inflation rate

This can be simplified as the difference between the nominal interest rate and the inflation rate, in order to obtain a result approximately equal to that determined from Equation 5.1.1, above.

The real interest rate remains quite constant, because the nominal interest rate follows, in some way, the inflation rate. With the present economic situation in Europe, the inflation rate is less than 2 %, and the nominal long-term interest rate is 5 - 6 %. The real interest rate is then approximately 3 - 4 %, which should be used as the discount rate. It should be noted, however, that some countries use discount rates higher than this level. These concepts are discussed more thoroughly in economic texts, as for example in [Begg, 1991; McGraw-Hill, 1977].

An example of discounting future costs to the present value can be illustrated by considering a maintenance treatment to be carried out after five years time. If the same treatment would cost 100,000 euro today, then the real treatment cost in five years time is also 100,000 euro. However, not spending that money for five years means the capital can be used in other ways for that period and the effective treatment cost is the 100,000 euro and that can be estimated by discounting the treatment cost.

5.1.6.2 Net Present Value of total cost

The Net Present Value (NPV) of the total costs over the analysis period is calculated for the comparison of alternative maintenance/rehabilitation works and/or strategies. The costs to the road agency and to the road users from each year are discounted to present value using the present value factor (PV factor). The present value factor depends on the discount rate and the year of the analysis period in which the costs occur, and is calculated using the following formula [Begg, 1991]:

$$\text{PV factor} = \frac{1}{(1+i)^n} \quad (5.1.2)$$

and

$$\text{NPV} = \sum_{n=0}^N \frac{C_n}{(1+i)^n} \quad (5.1.3)$$

where PV factor is the present value factor
i discount rate, e.g. 2% => *i* = 0.02
n time, years
 NPV net present value, euro
C cost component, euro
N length of the analysis period, years

5.1.7 Agency costs

To calculate the agency costs of maintenance / rehabilitation works over the analysis period, information is needed about the cost of works and the lifetime of pavement structures and maintenance / rehabilitation works. The types of maintenance techniques used in Europe were investigated in the interviews of European road directorates, and the costs of these works are summarised in Table 5.1.2. Pavement life models for use in pavement management systems have been developed, for example, in the Performance Analysis of Road InfraStructure (PARIS) Project [PARIS, 1998].

5.1.7.1 Localised or periodic maintenance costs

Localised or periodic maintenance costs are the annual costs to the road agency. They have a preventive effect on the deterioration of the pavement structure (e.g. prevent moisture from entering the structure and improve riding quality). Usually they are not programmed in pavement management systems, but are applied as needed over part or all of the pavement surface. Therefore performance modelling for these types of works is not needed. The costs of localised or periodic maintenance may be included in the life-cycle cost analysis, if they are different between the different alternatives. This may be the case at the programming level, where different maintenance programmes are compared. At the project level, where different maintenance measures on a specific road section are compared, the difference in these costs may be marginal and may therefore be left out of the analysis.

5.1.7.2 Cost of routine and structural maintenance

Costs of routine and structural maintenance are road agency costs, and are included in pavement life-cycle cost analysis at project level. Periodic maintenance has a preventive effect on the deterioration of the pavement structure, applied over all of the pavement surface. Structural maintenance, by definition, increases the structural capacity of the pavement. These works are programmed in pavement management systems, based on predicted pavement performance.

Table 5.1.2 Summary of unit costs and working rate of the different maintenance techniques used in Europe (pavement width 7 m).

a) Localised or periodic maintenance

Name	Unit cost (1000 euro/km)	Work rate (h/km)
Crack sealing	0.1 – 6	1 – 3
Pothole filling	0.1 – 6	1 – 3
Patching	5 – 29	1 – 3
Reshaping	6 – 28	1 – 3
Chipping	*	*

b) Periodic maintenance

Name	Unit cost (1000 euro/km)	Work rate (h/km)
Surface dressing	8 – 58	4 – 7
Slurry surfacing	15 – 45	5 – 7
Thin overlay	11 – 100	3 – 6
Milling	*	*
Repaving	15 – 45	3 – 4

c) Structural maintenance

Name	Unit cost (1000 euro/km)	Work rate (h/km)
Medium and thick overlay	23 – 190	7 – 14
Partial reconstruction	50 – 270	30 - 100 days/km

* no data is available for these maintenance techniques

5.1.8 Road user costs

5.1.8.1 Annual user costs

User costs include travel time costs, vehicle operating costs (VOC) and accident costs and they relate to different pavement characteristics in the way described in Figure 5.1.3.

This Project concentrates on the economic evaluation of maintenance of an existing road network, therefore user cost elements affected mostly by pavement design (capacity and geometry) are not considered in this context. The social costs of traffic and maintenance (e.g., pollution and noise) are considered at the network level analysis in Chapter 5.3, but not on individual road projects in this Chapter.

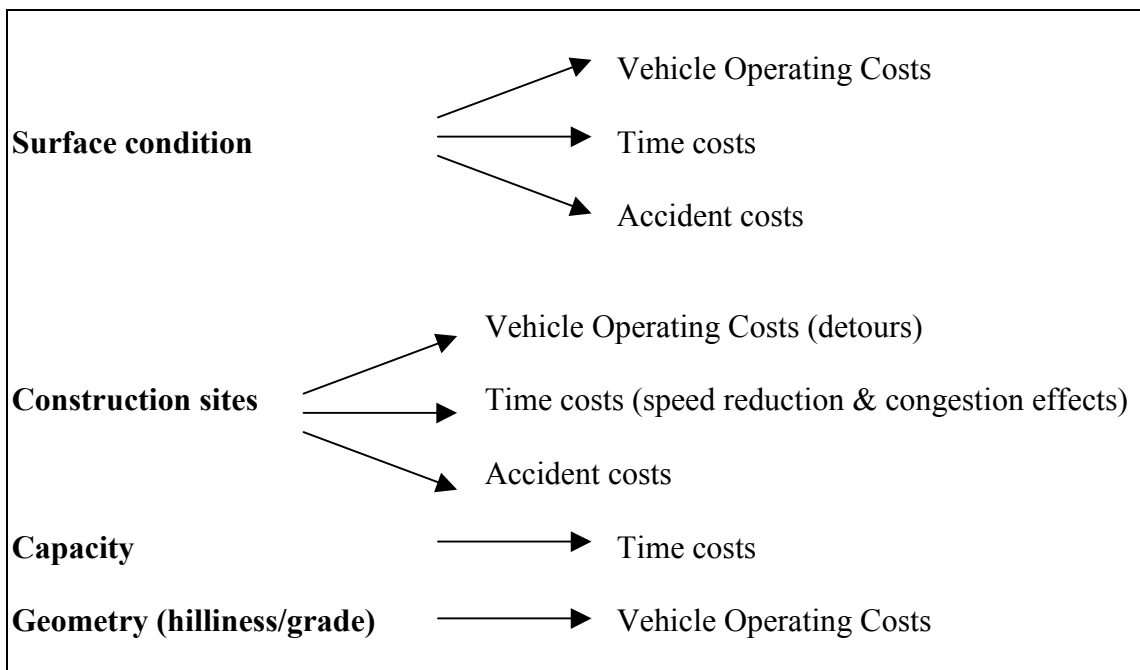


Figure 5.1.3 Range of user cost components.

In many modelling approaches the VOC are affected by poor pavement conditions (e.g. HDM-III, HDM-4, which are based upon experiences from countries with emerging economies). In a number of European countries, modified HDM-III models are used to calculate user costs. The main factors affecting vehicle operating costs are the costs of fuel, lubricants, tyres, repairs and depreciation [OECD, 1987]. In some countries, comfort costs are also taken into account (readiness to take a diversion route when it is available), and time costs and accident costs. In some systems, time delays and additional vehicle operation costs during maintenance are also considered.

At the high maintenance standards applied in European countries, the VOC does not depend on pavement condition. Within the European context, the VOC can be divided into two parts: the constant (per vehicle category) part that depends on the capital and maintenance costs of vehicles, and the variable part that depends on the fuel consumption, and thus speed. If the total VOC is analysed, it may be observed that, for a medium passenger car type, the part relative to fuel consumption is approximately 40%, and

60% for the rest. In this study, a VOC model based on the German VOC model has been used. The advantage of this type of model lies in its simplicity. Based on empirical analyses, it must always be checked that the vehicle fleet is representative for the country in which the method is to be used.

If the objective is to use a VOC model as a parameter in a maintenance programme, it would be significant only in the way the VOC varies as a function of the road condition. A study carried out by one of the PAV-ECO Project Partners (Viagroup) has shown, for the case of the national Swiss road network, what are the relative proportions of the various types of costs (VOC, accidents, time) of the yearly expenditures set aside for maintenance of the network. The results show that only a small part (< 2%) is due to vehicle operating costs. If a study of the whole network is considered, the proportion of segments in poor condition is very small. Given these results, the tendency would be to say that the assessment of a VOC, in a road network situation comparable to that in Switzerland (which may be considered as applying almost all over Europe), is not to be considered. Effort should instead be concentrated on the development of models which permit the assessment of time costs, accident costs or external costs generated by vehicle use.

However, the usefulness of determining such a parameter as part of a decision making tool for the maintenance of a road network may be questioned, considering the small influence that this has on yearly maintenance expenditures. With respect to the European road network conditions, the variation of VOC caused by the road deterioration is very low. The variation of VOC due to a detour road (closure due to maintenance work zone) will therefore only be considered. In that case, the German model type will be recommended for European applications. The VOC models are discussed in more detail in Chapter 5.5.

5.1.8.2 Costs of deferred maintenance

The costs of deferred maintenance are influenced by the determinant cost elements, which are essentially VOC, reflecting increased fuel consumption and vehicle wear (maintenance and repair costs) due to poor surface conditions. In principle, additional accident costs could also be included, as these could be caused by poor safety-related characteristics (low friction values and/or higher risk of hydroplaning due to rutting); these could be considered from the point of view of costs of deferred maintenance. However, there is insufficient background data available in Europe showing accident rates in relation to pavement condition. This is so far understandable, as in most cases more than one single factor (the majority of which are not related to the surface condition) can contribute to an accident.

Time costs are not considered to be a determinant factor in determining the costs of deferred maintenance. Therefore, for the case of deferred maintenance the cost calculation is:

$$\text{Costs of deferred maintenance} = \text{AADT} * \text{L} * \text{T} * \Delta\text{VOC} \quad (5.1.4)$$

where AADT is average annual daily traffic, vehicles/day
L section length, km
T duration of deferral, days
 ΔVOC additional VOCs per km and per day, euro

5.1.8.3 Additional time costs due to maintenance works

Time costs are the most significant user cost element in developed countries. Maintenance work zones cause additional time costs to road users in different ways:

- speed reductions in work zones due to speed limitations,
- congestion and loss of capacity in work zones,
- possible use of lengthier alternative routes.

The calculation of additional time costs is based on an assumption of the average time loss of passenger cars and heavy vehicles as the result of reduced speed. As an input to calculations the average daily traffic volumes are used. Traffic flow models established in Chapter 5.2 are used for calculating traffic redistributions due to work zones. The capacity of the road is an input to this model and its value is determined by the user. Since the model is only capable of handling average daily traffic volumes, the effect of peak hours on (average) capacity has to be estimated based on models not covered in this context and / or using engineering judgement.

The following input data are needed for each vehicle category for calculating additional time costs:

- traffic volumes
- additional time delays due to work zone speed reductions
- unit rates of time value

Vehicle categories should be defined so that they represent the vehicle fleet using the specific road or (part of) road network. The unit rates of time value should be selected to represent local economic conditions. Many European road directorates have defined the vehicle categories and time values applicable to their own countries.

The additional time costs are calculated as the difference in the total travel time between the with-case and the without-case. The with-case is when maintenance is applied on the project road and the without-case is the normal operating situation. The additional time cost for each vehicle category is calculated by multiplying the difference in traffic time per vehicle by the traffic volume, time values associated with that vehicle category and duration of maintenance works. To obtain the total additional time cost, the calculation has to be repeated for all vehicle categories on the project road and on the alternative routes. The additional time cost is calculated from the following formula:

$$\Delta C = T * \sum \{ (t * N)_{\text{(with-case)}} - (t * N)_{\text{(without-case)}} \} * C/t_{VC, i} \quad (5.1.5)$$

where	ΔC is	additional time cost, euro
	T	duration of work zone operation, days
	t	travel time, minutes
	with-case	operating with maintenance
	without-case	normal operating situation
	N	traffic volume per vehicle category, veh/day
	C/t	cost unit rate per vehicle category, euro/minute
	VC	vehicle category
	i	number of considered routes (project road and alternative routes)

Traffic volume varies hour by hour and congestion during peak hours causes time losses not covered by this kind of analysis. To tackle this issue, a substantial effort was made to develop and calibrate empirically a suitable model [PAV-ECO, WP1.3 Annex, 1999]. This model takes into account the traffic demand, the type of road, and the traffic management measures necessary for evaluating the resulting loss of time experienced by road users at maintenance sites, and the corresponding additional road user costs. The residual capacity of the work site depends on various characteristics:

- geometric characteristics: all the geometric factors associated with the reduction in lanes, the central reservation crossing and the various technical characteristics of the work site
- traffic: distribution (by vehicle category) of the traffic upstream of the works area (light traffic, heavy traffic, commercial traffic, leisure traffic, etc.)
- environmental factors: weather conditions, for example

The traffic engineers involved in road design and construction projects often use guides based on field data, e.g., the Highway Capacity Manual (HCM) [TRB, 1994]. These must be regularly brought up to date, because both driving habits (and therefore gaps between vehicles in high traffic density, and so capacity) and vehicles constantly make progress, and also because they are only valid for those field conditions for which they were established.

5.1.8.4 Additional vehicle operating costs (VOC) due to maintenance works

In case of maintenance work zones, the vehicle operating costs (VOC) change due to longer distances travelled when taking alternative routes or reduced speed through the work zone. In the first case, both the constant and variable parts of VOC are affected and usually the VOC are increased. In the latter case, as the driving speeds reduce, fuel consumption decreases until at very low speeds, it begins to increase again. The variable part of VOC may therefore increase or reduce but the constant part is generally unaffected.

Additional vehicle operating costs (VOC) due to maintenance work zones are calculated using a model based on the German vehicle operating cost model [EWS-97, 1998]. The operating costs of each vehicle category is calculated as the sum of constant costs and variable costs:

$$VOC_{VC} = CR_{VC} + \frac{1}{10} CF_{VC} * FP \quad (5.1.6)$$

where	VOC_{VC} is	vehicle operating cost by vehicle category, euro/ (100 vehicle km)
	CR_{VC}	unit cost by vehicle category, euro/ (100 vehicle km)
	VC	vehicle category
	CF_{VC}	fuel consumption by vehicle category, g/km
	FP	fuel price, euro/kg

The vehicle operating costs (VOC) change due to the longer distance travelled when taking a detour, or due to the reduction in speed through the work zone. In the first case, both components of VOC, that to fuel consumption, and that due to depreciation, vehicle maintenance, etc., are affected and usually increase the VOC. In the second case, the effect of the work zone may be to increase or decrease the VOC. As the driving speed reduces, fuel consumption decreases until at very low speeds, it increases again. The constant component of VOC is generally unaffected.

The following vehicle categories are used:

- Passenger car (P)
- Light truck (LT)
- Heavy truck (HT)
- Semi-trailer (ST)
- Bus (B)

Total VOC is calculated using the following formula:

$$VOC = \frac{1}{100} * \sum_{D=1}^2 \sum_{VC} VOC_{VC} * Q_{D,VC} * LG \quad (5.1.7)$$

where	VOC is	total vehicle operating cost, euro/ (100 vehicle km)
	CR_{VC}	cost unit rate of vehicle category, euro
	VC	vehicle category
	D	direction
	LG	length of section i, km
	Q	traffic volume (per direction and per vehicle category), vehicles / day
	VOC_{VC}	vehicle operating cost per vehicle category, euro/ (100 vehicle km)

The additional VOC are calculated for the project road and alternative routes as the difference in the total VOC between the with-case and the without-case.

$$\Delta VOC = T * \sum [VOC_{(with-case)} - VOC_{(without-case)}]_i \quad (5.1.8)$$

where	Δ VOC is	additional VOC, euro
	T	duration of work zone operation, days
	with-case	with maintenance
	without-case	normal operating situation
	i	number of considered routes (project road and alternative routes)

5.1.8.5 Additional accident costs due to maintenance works

Accidents are caused by many factors, but in terms of maintenance works, the accident rates are influenced by the surface conditions (poor skid and / or rutting properties, especially in wet weather conditions) and by the existence of work sites. Accident costs are often estimated using average accident rates, according to, for example, road class, and the average social costs of death and / or injury.

It is generally accepted that work zones increase the risk of accidents and there is a need for quantifying this effect. However, relevant literature is fairly limited. Attempts in earlier studies [ARROWS, 1998] to find this information reached the same conclusion. There does not appear to be any reliable and well-documented models for predicting work zone accidents. Some attempts to establish simple models have been made [PAV-ECO, WP 1, 1999; Pal and Sinha, 1996], but they are not sufficiently developed for use in PMS and they are also based on a limited amount of data.

The main reasons for the limited research in this area are [ARROWS, 1998; Pal and Sinha, 1996; Soares and Najafi, 1999]:

1. Only 2-3 % of total traffic accidents happen within work zone areas, which means existing research resources are focused on accidents in general.
2. Statistical analysis of work zone accidents is very difficult. The relatively small number of accidents is not sufficient for the development of reliable models.
3. Information in existing databases is often inconsistent and suffers from lack of important information.

There are difficulties in drawing common conclusions, based on studies in different areas or countries. The basic information for the studies are highly variable, statistical approaches are not the same, local guidelines for carrying out maintenance work are different, and so on.

Based on the accident data currently available, it does not seem possible to develop a sophisticated and accurate model for predicting the number of accidents or accident rates for work zones. However, local studies may be used for developing simple models, using basic parameters such as duration and length of work zone, volume of traffic and accident rates recorded prior to setting up the work zone. The question still arises whether these models would be sufficiently reliable for project level evaluation. Accident costs are normally large compared to other project costs, and trying to incorporate them in project evaluations, without taking into the account the uncertainties in the models, might be unreliable. Before adding accident costs to VOC and delay costs for

work zones, it is necessary to evaluate the magnitude of these costs, and the extent of these uncertainties.

5.1.9 Preservation of pavement investment

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 is, the lower the cost of rehabilitation and pavement preservation will be.

The salvage value of the pavement at the end of the analysis period must depend on the condition of the pavement at that time, and hence, the type and timing of maintenance works carried out during the analysis period. (e.g., a pavement in need of structural maintenance at the end of the analysis period will have a lower residual value than a pavement recently strengthened). There are several different ways to relate the pavement condition and its value / cost of rehabilitation. Some of these options are illustrated in Figure 5.1.4. The pavement salvage value is usually expressed in terms of the remaining value before the pavement fails completely and can no longer be trafficked (option 1). In this case, the salvage value is equal to the proportion of the initial construction cost representing the remaining life to failure. This cannot be calculated directly as the residual life to zero value cannot be easily determined.

The salvage value, in this case, can be estimated by using the formula:

$$\text{Salvage value} = \text{Initial construction cost} - \text{Pavement preservation} \quad (5.1.9)$$

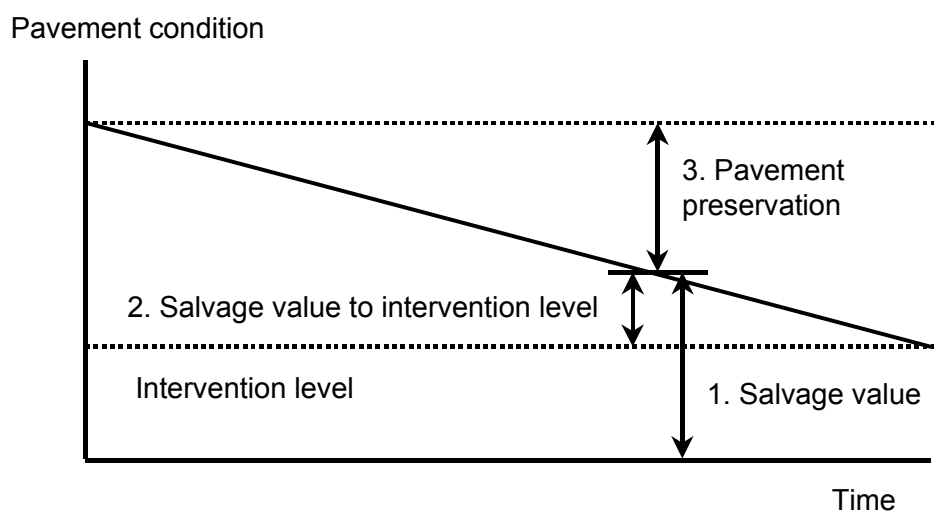


Figure 5.1.4 Illustration of the concepts of pavement salvage value and pavement preservation.

In Figure 5.1.4, option 2, the salvage value is expressed in terms of the (residual) life to the next intervention. In this case the salvage value can be calculated using models that predict pavement behaviour to the intervention level. It is equal to the proportion (related to the intervention level being used) of the treatment cost representing the remaining life to the next intervention level. The time to next intervention level depends on the type and timing of the previous treatment and the performance of the pavement following that treatment.

$$\text{Salvage value} = \text{Cost of last treatment} * \frac{\text{Residual life of the treatment}}{\text{Design life of the treatment}} \quad (5.1.10)$$

This option provides a method to compare alternative maintenance/rehabilitation actions at the project level. However, one drawback of this option is that intervention levels vary, e.g., according to the chosen maintenance strategy.

Pavement preservation is expressed as the cost of rehabilitation to bring the road into its initial condition. This is illustrated in Figure 5.1.4 option 3. The cost of rehabilitation depends on the measures that need to be taken to restore pavement serviceability. If only maintenance works that affect the surface courses are required, the salvage value of the pavement will be higher and pavement preservation value will be lower. However, if the lower pavement layers have to be reconstructed, the salvage value of the pavement will be lower and pavement preservation value will be higher. Where the subgrade also requires reinforcement, the pavement may be considered to have very little or even a negative salvage value, as the cost of removing and reconstructing the structure (pavement preservation) can be higher than the cost of new construction.

This definition of pavement preservation provides a method to compare alternative maintenance/rehabilitation actions at the project level and it is used further in this report. This is also the approach taken in Chapter 5.3, where pavement preservation is considered at the network level.

Comparisons of alternative maintenance strategies are carried out over a defined analysis period. The condition of the pavement at the end of the analysis period depends upon the types and timings of the treatments carried out, e.g., the strategy giving lower life-cycle costs may leave the pavement in need of structural maintenance, while the alternative strategy with high life-cycle costs may leave a pavement recently strengthened. To allow for an appropriate comparison of alternative strategies a computational method for the determination of pavement preservation has been developed and it comprises the following stages:

1. The time from the last maintenance work to the intervention level for structural maintenance (if no maintenance is done) is estimated using pavement performance models.
2. The pavement condition at the end of the analysis period is estimated using pavement performance models.
3. The type of structural maintenance work is chosen that will restore the pavement to its initial condition. The cost of the work is determined.
4. Pavement preservation is computed from the following formula:

$$PP = \left[\frac{CI_{END}}{CI_{INT}} * 100\% \right] * C \quad (5.1.11)$$

where PP is estimated pavement preservation, euro
 CI_{END} pavement condition index at the end of the analysis period
 CI_{INT} pavement condition index at the intervention level of structural maintenance
 C cost of structural maintenance work, euro

The ratio of the pavement condition index at the end of the analysis period to that at the intervention level for structural maintenance represents the relative portion of the restoration cost that has been used. The concept of pavement preservation is illustrated in Figure 5.1.5.

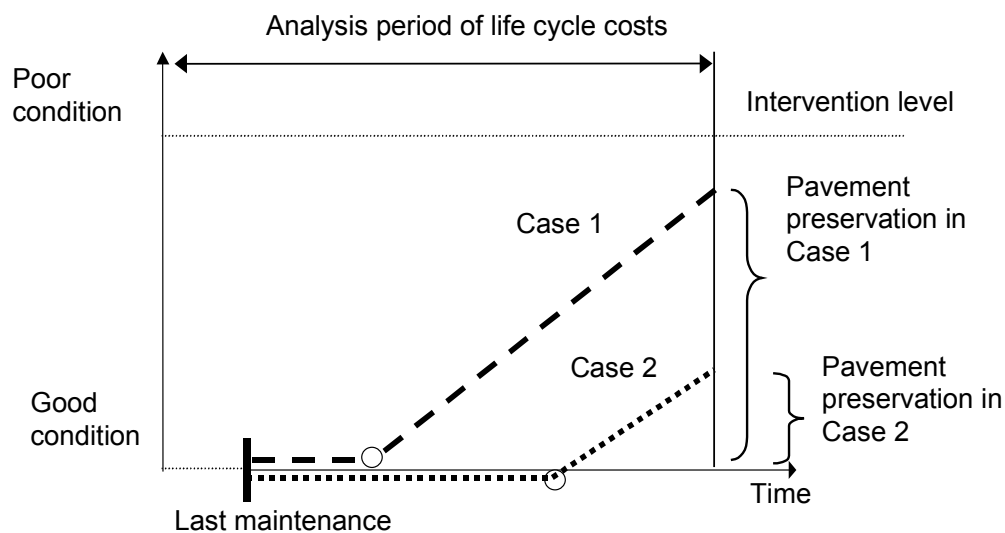


Figure 5.1.5 Concept of pavement preservation.

5.1.10 Conclusions

A framework for the comparison of life-cycle costs (LCC) of different maintenance strategies and treatments at project level has been developed. Its use involves the calculation of agency and user costs over the length of selected analysis period regarded as the pavement life-cycle. The costs that differ between alternatives are taken into account and costs occurring each year are discounted to the beginning of the analysis period.

General conclusions for the aspects of the Project described in this chapter on Maintenance Measures Evaluation can be stated as:

- The varying costs of maintenance works have been collected for periodic maintenance, routine maintenance and structural maintenance.
- Annual user costs are calculated in a number of European countries using a modified HDM-III model or national models. At the high level of maintenance applied in

those countries the VOC do not depend on pavement condition. In the case of work zones, the VOC are affected by fuel consumption and thus speed and / or lengthier routes.

- Additional user costs in cases of high unevenness levels due to deferred maintenance can be calculated from the changes in VOC due to road condition.
- Virtually no literature references were found with models developed for estimating additional user costs due to maintenance work zones.
- The need for development of models for estimating additional user costs due to maintenance work zones and pavement salvage value / pavement preservation is recognised by most road authorities, even though such models are in use only in a few countries.
- A model has been proposed to estimate additional time costs and additional VOC due to maintenance work zones as the difference in costs between the with maintenance case and the without maintenance case.
- A model based on the German VOC-model has been used to estimate additional VOC due to maintenance work zones.
- For the estimation of additional costs, the traffic distribution and vehicle speeds (and change in travel time) on the relevant network (project road and one or two alternative routes) due to work zones are required.
- Without roadworks the accident rate depends on, e.g., road geometry, surface condition, climatic conditions and traffic volume; the accident rate increases when roadworks are underway. Models for the estimation of the additional accidents costs could not be established. The existing data is diverse and too limited in quantity for the development of reliable models.
- Local studies may be used for the development of simple models for accidents at road works; parameters such as duration and length of work zone, traffic volumes and accident rates without the work zone could be used. However, the use of such models for project evaluation is questionable, mainly because accident costs are high and uncertain compared to other project costs.
- A method based on pavement condition at the end of the analysis period has been developed to estimate pavement preservation as the relative proportion of the cost of rehabilitation to restore the road pavement to its initial structural condition.
- Other possibilities include considering the pavement salvage value as the present value of the existing structure. This is determined indirectly as the difference between the present value of the initial construction cost and the cost of pavement preservation.



References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.

5.2. Impact of Traffic Change

5.2.1 Introduction

Changes in road transport are caused by many factors, including traffic volumes, 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 provide the capability to take these future changes into account in planning future maintenance interventions.

Depending on the subsequent development of road transport, the optimal choice of activity may be more frequent use of certain measures or 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 on 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 parameter 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.

In the PAV-ECO Project, the impact of traffic change is 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 and these have served as the guidelines for establishing traffic forecasts and for assessing their accuracy.
2. Traffic simulation models. The use 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.

5.2.2 Analytical approach for traffic forecasting

The evaluation of long-term maintenance management strategies has to consider the actual and the future traffic loads on the road infrastructure. The future development of traffic influences the spectrum of traffic loads on the road infrastructure and, related to this, the lifecycle of the infrastructure.

In this approach the determinants of transport demand and supply are estimated, and relevant influencing factors, both for passenger transport and for freight transport, are presented in Table 5.2.1.

A traffic-forecasting model should be constructed so that it provides the capability of taking all relevant determinants of traffic development into account. This approach is based on a series of different modules. To generate definite traffic forecasts, every module can be built with a different degree of fine-tuning. The degree of fine-tuning depends on the different states of data material available. Listed below in Table 5.2.1., are the main data groups relevant for the model.

Table 5.2.1. 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 travelled
structure of vehicle fleet	development of motorisation (car density)
organisational structures in road freight transport	average car occupancy
new options in freight transport	new offers
	choice of route

Changes in the supply of infrastructure also have an effect on long-term transport demand. The development of road infrastructure condition and supply, capacity supply and quality changes by other means of transportation have an impact on transport demand and its distribution (modal split). The following determinants have to be considered:

- actual traffic volume
- indicators of infrastructure condition
- traffic congestion
- extension of infrastructure

- intermodal transport
- quality (costs, speed and reliability)
- prices and taxes

5.2.2.1 Recommendations for traffic forecasts in pavement life-cycle cost analysis

Existing forecasts do not cover the special requirements of pavement life-cycle cost analysis. From those requirements and from the state of the art of existing forecasts the following can be derived:

1. There is a need for forecasts that predict vehicle kilometre of passenger and freight transport and furthermore the proportions of the two segments in the road network.
2. The forecast result (vehicle kilometre) has to be added to the initial distribution of vehicle kilometre among different road types of the network.
3. The road network has to be characterised with regard to the criteria capability. Different load factors, resulting in different costs of the road transport can be defined. These cost effects have to be considered in the optimisation strategy of pavement management.

In order to support future traffic forecasts a catalogue has been developed (Table 5.2.2). It contains a ranking of determinants of transport demand and supply, which are a recommendation and a support for decision-makers in the framework of pavement management.

The categorisation can be explained as follows:

- The minimum requirement of every traffic forecast is the consideration of determinants of the category essential parameters. Otherwise the quality of the forecast results is insufficient.
- The additional consideration of determinants of the category important parameters enables a higher degree of estimation significance. Therefore, forecasts for countries which have an extensive statistical database, should take these determinants into account.
- Even if the impact of consideration of the additional parameters has a positive impact on the quality of the prognosis results, the improvement is not as strong as in the previous case. These determinants represent options and requirements for future traffic forecasts.

The extent of data considered in a prognosis is predominantly determined by the extent of available statistical data.

Table 5.2.2 Determinants of the development of demand and supply of transport.

Determinants of the demand for transport		
	Freight transport	Passenger transport
Essential Parameters	<ul style="list-style-type: none"> – Structural data (GNP/GDP, economic integration, population, employment) – structure of vehicle fleet 	<ul style="list-style-type: none"> – Socio-economic structure (population trend, age structure, economic development, number and size of households, structure of income and employment, mobility) – Motorization (car density) – Traffic average speed – Average car occupancy
Important Parameters	<ul style="list-style-type: none"> – Modal split – Structural effects of production – Structural changes in industry and retail 	<ul style="list-style-type: none"> – Modal split – Spatial distribution of population – Changes in travel-distances – Route choice
Additional Parameters	<ul style="list-style-type: none"> – Spatial distribution of companies – Organisational changes in road freight transport – Changes of transport distance – New options in freight transport 	<ul style="list-style-type: none"> – Substitution of traffic – New offers
Determinants of transport supply		
Essential Parameters	<ul style="list-style-type: none"> – Actual traffic volume – Average speed distribution on different road types – Planned extension of infrastructure 	
Important Parameters	<ul style="list-style-type: none"> – Modernity degree – Intensity of road works – Predicted wear of roads 	

5.2.3 Traffic simulation models

The traffic simulation model is of great importance for the final pavement maintenance strategy and has to be able to handle many future conditions, as well as many different road administrations and levels of information. Moreover, the traffic simulation model serves different purposes in the pavement maintenance process.

In the PAV-ECO Project there is a difference between the network level traffic models and the project level traffic models. The 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 linked specific, but can also be built on the more general road-type parameter. The project level models, however, need to include the specific road sections or routes through the network. Both the network and the project level models have to work within a framework as shown in Figure 5.2.1., below.

The models have to be able to take a range of input data describing the existing situation, the present network and traffic, and the expected future situation, regarding network modifications, traffic growth and origin-destination relations for the traffic in the analysis area if information exists. The output from the models will be the modified traffic data, with regard to amounts of traffic split up into vehicle categories and resulting travel speeds for the relevant vehicle categories.

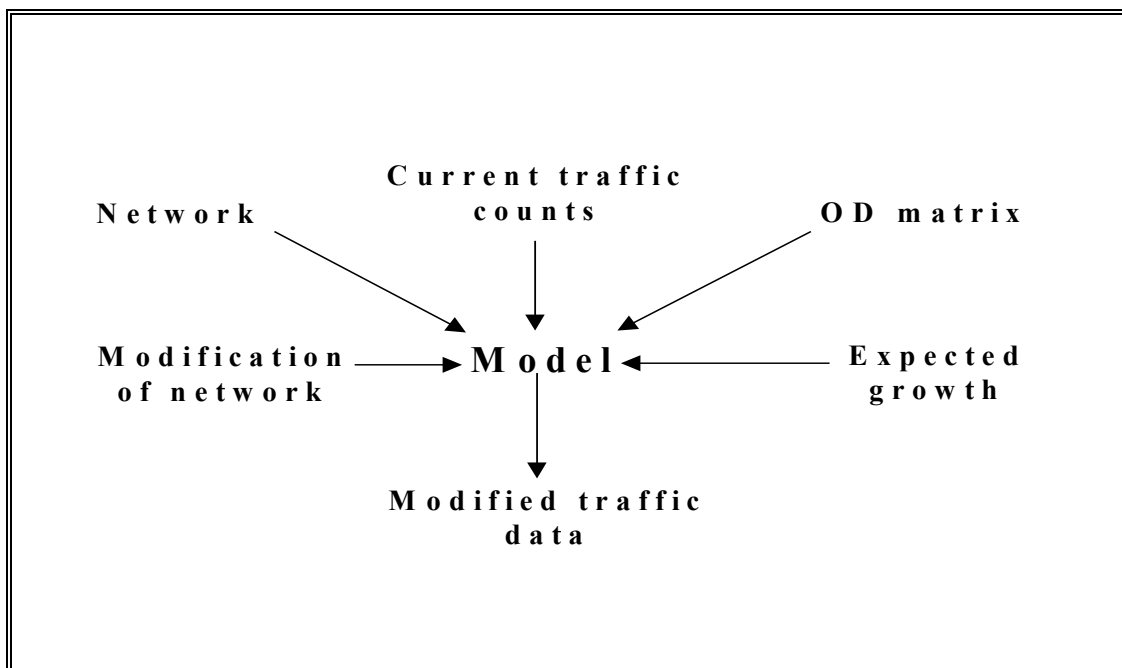


Figure 5.2.1 Input and output from traffic simulation model.

In the network level models, the input and output data are grouped into road categories which represent all road sections within this group. In the link-based models data are related to each specific road section and represent the actual data for this section, such as length, speed and, capacity.

One network level model and two project level models are described in Chapter 5.2. For the work described in Chapter 5.3, the University of Cologne developed a network level general simulation model. In Chapter 5.2, ANAS describes an enhanced project level link-based OD-model and describes the development of a demonstration model of a simple project level route-based model in a spreadsheet that allows traffic distribution on three alternative routes.

5.2.3.1 Origin-Destination (OD) based models - national models

The most appropriate model for use in a pavement maintenance system is a model, which can serve all purposes, both at the network level as well as at the project level. These types of model are well known from strategic traffic planning [Nielsen, O.A., 1994]. They are used by many road authorities to assess the consequences of new roads and land use planning.

These models are often developed as multi-modal models including the competition between traffic modes - cars and public transport. When assigning traffic to the road network the models most frequently uses capacity restraint assignment methods to simulate the link-based traffic as accurately as possible.

These model types are built on a solid knowledge of population, vocation and socio-economic parameters (age, income, car ownership, etc.) split up into relatively small traffic zones. Through one or more calibration processes an OD-matrix for each mode of transport can be estimated as a function of the level of service provided by the different mode networks.

Similarly a model of the network is based on detailed knowledge of road configuration, speed/flow relations as a function of capacity and road type, junction modelling and traffic behaviour. The matrices are once again assigned to the network with a capacity restraint assignment model, which is calibrated to simulate actual behaviour from measured traffic data.

From these models, link-based traffic data come as default values, and values for society's benefit-cost calculations due to changes in the road network can be calculated. Once the model structure has been developed, it is relatively easy to make consistent traffic evaluations both of the impact of changes in the road network on network and project level - addition of new roads, speed reductions, capacity improvements, etc. - as well as for changes in the socio-demographic, socio-economic and/or the production structure of the society. Another advantage of this model is that it provides reliable traffic data on the part of the network where no traffic counts have been carried out.

This kind of model requires a high level of knowledge and structural information, but also a centralised road administration, which is common in small countries. Denmark and Sweden are examples of countries having nationwide models of this type. In Germany, for example, it has not yet been possible to establish a national model, because of the administrative structure. The different Bundesländer (the states in Germany) have varying priorities that hinder the adoption of a common national link-based model. Other countries have not yet collected sufficient structural information to enable them to develop the model.

5.2.3.2 General road-type-based models

Where sophisticated OD based models do not exist, a more general model can be used to provide input for the socio-economic evaluation of pavement management measures. In the PAV-ECO Project a model based on road types and traffic volume is developed, where the network must be categorised into road types, road configuration, traffic volumes and length. With the input of network changes, for example, due to maintenance works, an iterative model balances the new traffic volumes as a function of speed/flow formulas for each road category. This model can be implemented in every road administration, regardless of the level of structural data, as no trip matrix is necessary.

5.2.3.3 Simple link-based model

At the project level, where no OD-based general model exists, the task is to balance traffic from a road section under maintenance works to relatively few alternative routes. This reallocation of traffic is done intuitively in most cases today. In the PAV-ECO Project a simple model is introduced based on the Smock algorithm [PAV-ECO, WP 2, 1999]. The Smock algorithm is used in many of the more sophisticated assignment models. With inputs of traffic, capacity and travel time parameters for the alternative road network, the model, in an iterative process, balances the traffic volume until a stage is reached when no car can reduce travel time by changing route. The outputs from the model are traffic volumes split into vehicle categories and the final travel speeds on the alternative routes.

5.2.4 Traffic model at Network level

5.2.4.1 Requirements for modelling the route choice behaviour

Traffic growth and network extensions will change the traffic flow throughout the road network and thereby influence the optimal pavement maintenance management strategy. The following approach refers to the network level, where the available statistical data are generally limited. Therefore, the approach is based on a simplified method. It enables estimations of the future traffic situation and the route choice behaviour of road users. The method will be demonstrated by an example based on data from the German motorway network (the example assumes that additional traffic will remain entirely on motorways).

The analysis of the impacts of bottleneck on traffic flow in road networks represents the interface of project and network level. The assignment of traffic should principally be done with regard to the exact conditions of the relevant network. ANAS [Anders Nyvig A/S, 1996; PAV-ECO, WP2, 1999] demonstrated the simulation of traffic flow for the area of Copenhagen. Those models, which require extensive statistical data (origin-destination matrices), provide accurate and realistic results. Nevertheless, their application depends on the extent of available statistical data. The simplified method for the network level is therefore a second-best procedure. It is a pragmatic approach, which is suitable for the case of limited data input.

5.2.4.2 Impact of traffic growth

The determination of the effects of traffic growth will be carried out by a sequence of different steps. Figure 5.2.2., on the page following, illustrates the structure of the model.

The first step in the model is analysis of the initial traffic situation and requires the examination of empirical data. For the German motorway network, detailed data from traffic counts at 434 census points in 1995 are available (the data of each census point refers to an appropriate motorway section). The decisive data components are: average daily traffic volume, distribution of traffic over the period of one day, average share of freight vehicles and road type (number of lanes). This information must be available for each relevant section of the network.

The evaluation of pavement maintenance management strategies has to include an estimation of the future traffic situation, which is the next step. Traffic forecasts contain information about the development of traffic volume for a certain time horizon. The forecasted traffic growth generally refers to the area of a whole country. Regional differentiations are not included. Therefore, the estimation of the future traffic volumes for the German motorway network is based on general indicators. In 1995, the ifo-Institute for Economic Research [ifo-Institute, 1995] published a traffic forecast for Germany for the year 2010 (Table 5.2.3).

Table 5.2.3 Traffic forecast for 2010 in Germany.

Year	Vehicle kilometres			Index
	Car Traffic	Freight Traffic	Total	
1992	470,9	62,2	533,1	100,00
2010	633,1	77,8	710,9	133,35

The total growth between 1992 and 2010 is approximately 33 %, corresponding to an average annual growth rate of 1.61%. Applying this growth rate enables the approximate determination of development of traffic volumes in the period between 1992 and 2010. Within this framework, the count data of 1995 will be projected to 2010.

For each network section, traffic volumes for 2010 have been calculated. Assuming a constant extent of the network, the forecasted traffic volume may exceed the existing capacity of a road. To take this into account, for each road type, appropriate capacity limits have to be defined. Table 5.2.4 lists the capacity limits for German motorways.

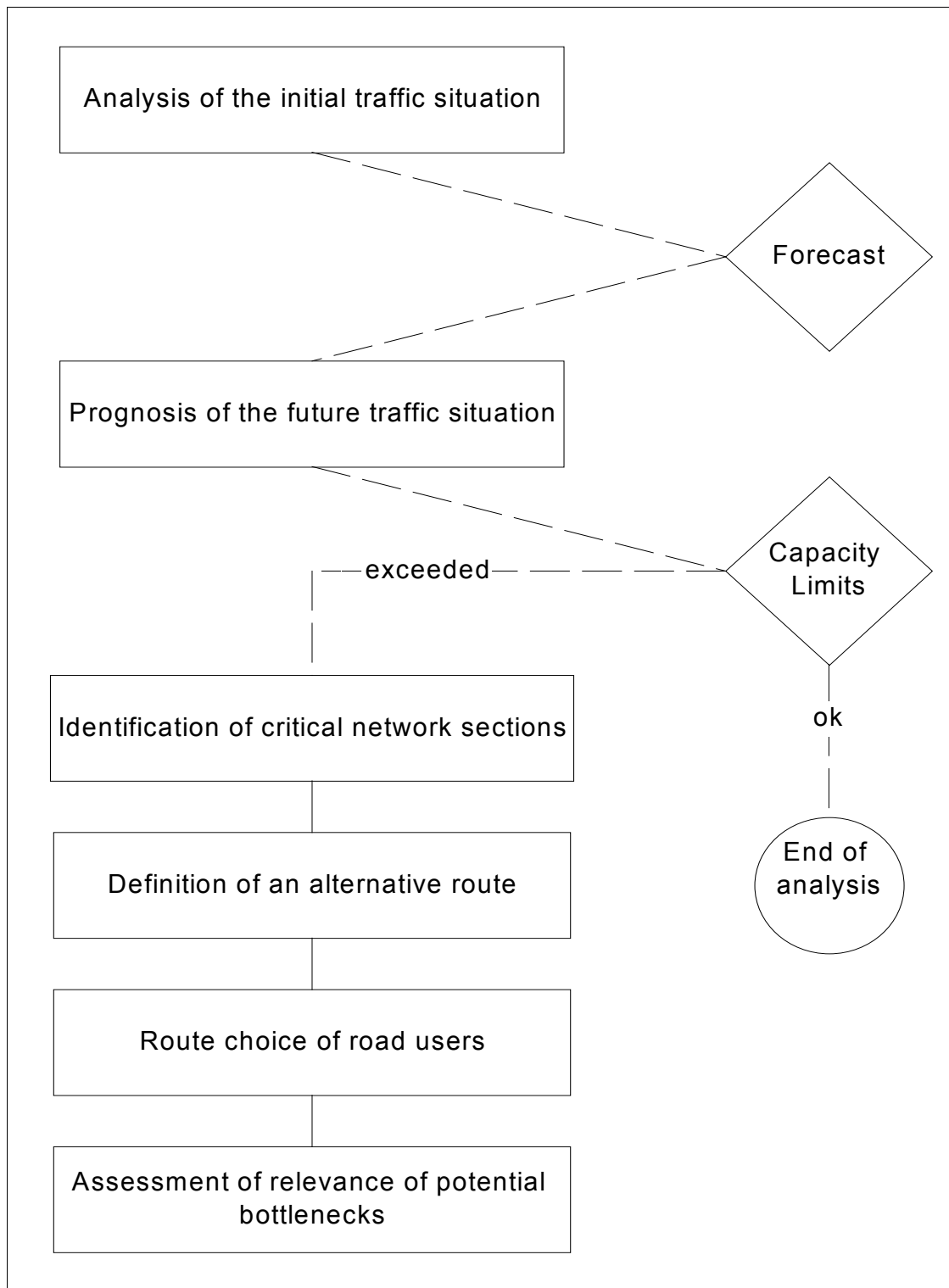


Figure 5.2.2 Structure of the network model of traffic development.

Table 5.2.4 Capacity limits for German motorways.

Motorway Type	Total Number of lanes	Capacity limit (AADT)
M 3	4	109,688
M 2	6	157,500
M 1	8	210,938

The capacity limits have been calculated on the basis of the German Forschungsgesellschaft für Strassen- und Verkehrswesen [EWS-97, 1998]. With the help of standardised patterns over time, the maximum hourly traffic volumes have therefore been transformed into daily values. Using these capacity limits, 25 potential bottlenecks have been identified for the year 2010 on German motorways.

The future relevance of these capacity limits will be determined by the actual development. Concerning this, some experts expect the development of further flexibility in the diverse activities of daily life and therefore predict a continued decrease of the peak levels. Furthermore, by empirical research it was discovered that traffic growth in sections with high capacity utilisation rates is smaller than on less loaded roads. Therefore, it is not certain that capacity limits at the potential bottlenecks will be achieved.

The comparison between available capacity and the estimated traffic volumes enabled the identification of critical sections. The actual effects of a growing transport demand on the traffic situation depend on the capacity utilisation rate of roads. If the residual capacity is small, a further increase of demand will strongly affect the traffic flow. Where the maximum capacity of a road is exceeded, congestion occurs; as a consequence travel times on relevant routes rise. These effects have to be considered in the prediction of the future traffic situation.

Changes in traffic flow and travel times lead to changes in the costs of road usage. In particular, time costs have a strong impact on road users' behaviour. Therefore, the situation at bottlenecks in the network should be analysed in detail. The traffic situation is determined by traffic volume, average speed, travel time, route length, frequency of stops, quality of pavements, geography, travel costs, etc.

The reaction of road users primarily depends upon the individual personality of the drivers and their knowledge of the route conditions. A multitude of reactions is conceivable: route choice, time choice, mode choice and cancellation of trips. The simulation of these effects is difficult. The accuracy degree correlates positively with the extent of the data basis. It has therefore been found that origin-destination-models provide good results.

Within the determination of future traffic situations, the route choice behaviour at bottlenecks represents the interface between project and network level. At the network level, the available data basis is generally small. Nevertheless, it should be possible to provide information about the route choice in this framework, too. Therefore, a simplified methodology has been developed, which enables the provision of information about the traffic flow in critical sections. Shifts between two alternative roads can be determined. For the calculations a regression function, which is based on the Kirchhoff-rule

[PAV-ECO, WP2, 1999], has been used. With regard to length and average journey time, the routes are evaluated. This enables an estimation of the route choice behaviour of road users.

5.2.5 Traffic model at Project level

In many countries, much of the road network is loaded at traffic levels below the capacity of the road, and even a long-term traffic forecast will not raise traffic to the capacity limit. In those cases, capacity restraint assignment models are not necessary for the general distribution of traffic. However, in the case of road works, capacity restraints may occur.

For those cases, a simple route-based, capacity restraint traffic assignment model is proposed. A simple model of this type can also be used to manually correct the traffic database in the pavement management system, where the linear road section forecasts have indicated that some road sections have exceeded the traffic capacity.

In the following sections the development of a simple route-based model is described. The model is developed in a spreadsheet programme as a demonstration model for use in Work Package 1 of the PAV-ECO Project.

It should be stressed that the objective of the PAV-ECO Project is to describe models for use in PMSs [PAV-ECO, 1997]. The following, though not a fully developed model, demonstrates that a simple model can be used in combination with PMSs, particularly for planning road works.

5.2.5.1 Model structure

The model is route-based, contrary to the OD-model, which is zone-based. This means that the development and calibration processes are very different. The model is limited to an assignment model, which in this case is developed as a capacity restraint model.

The preconditions for the model are:

- the user-interface of the model should be easy to use
- the model can be run without any expert knowledge of traffic modelling
- forecasting can be done directly on the route loads
- simple calibration processes are used in the model.

The model is able to treat the situation shown in Figure 5.2.3., below. One road section on the project route is planned to have road works, and two deviation routes are identified.

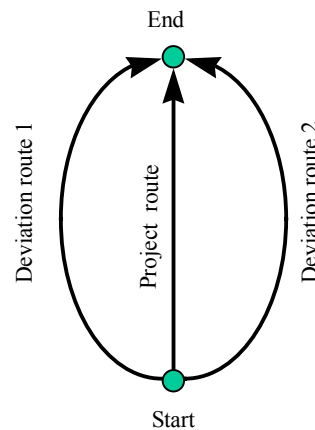


Figure 5.2.3 Routes treated in the simple model.

The model is built as a deterministic model with traffic dependant constraints. Due to this dependency - traffic is dependent on capacity constraint and capacity constraint is in turn dependent on the traffic load - it is most convenient to base the model on an iterative process. The iterations are performed as a series of all-or-nothing assignments with successive adjustments of the travel costs.

There are two principle ways in which the iterations can be undertaken:

- All the traffic is loaded in each iteration – i.e., applying the Smock algorithm.
- One percent of the traffic is loaded in each iteration - the incremental assignment.

For this model, the first method - the Smock algorithm - is the most convenient. The incremental assignment procedure is most powerful when used in an OD- model.

The cost function in the Smock algorithm is:

$$\text{Cost} = t * \exp (L/C - 1) \quad (5.2.1.)$$

where

t	travel time
L	mean load in the previous iteration
C	capacity.

The assignment procedure is as follows, from the initial situation of an unloaded network. (1) The cost function calculates the costs for the alternative routes and an all-or-nothing assignment is performed - all traffic from start-to-end is assigned to the route with the lowest travel cost. (2) With the values from the first iteration, new costs are calculated and another all-or-nothing assignment is performed. The traffic for each route is calculated as the mean value from the two iterations.

The subsequent iterations repeat the procedure from step (2).

With solution achieved within a finite number of iterations, the algorithm fulfils the first principle of Wardrop: “The journey time on all routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route” [Wardrop, 1952]. Or in other words that the traffic tends to settle down into an equilibrium situation in which no driver can reduce the journey time by choosing a new route.

This method distinguishes itself by converging to a state of equilibrium between supply and demand.

For use in the PAV-ECO Project work reported in Chapter 5.1, a demonstration model has been developed in a spreadsheet program. On the page following, Table 5.2.5 displays the user interface of the simple project level model. It is divided into three parts:

- An input Table, which together with the calibration factor is used for calibration of the model.
- A model results Table, which includes a Check Sum column to verify the modelled traffic against the counted traffic volumes.
- A modelled calculated speeds Table, which utilises the model results and the road type to calculate the resulting average daily speed at each road.

5.2.5.2 The user interface

The shaded areas are protected areas calculated by the model. The white areas are input areas. As can be seen from the column headings, the model can handle one project route and two deviation routes.

The fourth column heading is Distribution and refers further down the input Table to the distribution of the total AADT to different vehicle classes. In this example, the vehicles are divided into four classes, with a percentage distribution that is typical for the main roads in Denmark.

The last column is a combined Comments and Check sum column. In the comments area is written info for those parameters that are only used for information and that do not influence the outcome of the calculations. In the Check Sum area the input traffic data are shown for comparison with the subsequent model calculated data, for verification purposes.

Mean speeds are entered. Initially the best guess is entered, and thereafter the value entered is guided by the speeds calculated by the model. After calibration of the model to the normal situation, the speed (and capacity) of the project road can be altered to model the distribution due to maintenance works. In the demonstration model an example is considered in which a four-lane motorway is reduced to a two-lane carriageway. Many other different closure types are possible: narrow four-lane, shuttle working, etc, which have not been investigated, however, it is recommended to initiate such an analysis.

Table 5.2.5 The user interface of the simple project level model.

Route choice model for project level model

Input table	Project Road	Input – alternative routes		Distribution	Comments
		1	2		
Road type number	3	65	28		
Road name	Project Road	Dev. 1	Dev. 2		info
Road identification number					info
Road type	Motorway	Main road	Main road		info
Lanes	4	2	4		info
Mean speed [km/h]	105	55	68		
Speed restrictions [km/h]	110	60	70		info
Length of route/diversion [km]	14.2	14.5	14.4		
Capacity [veh/day]	26,000	9,000	16,000		
Mean travel time [min]	8.1	15.8	12.7		
Closure type					info
Length of maintenance [km]					Check Sum
AADT - all vehicles (vehs.)	26,000	7,000	15,000	100.0%	48,000
AADT – cars	20,800	5,600	12,000	80.0%	38,400
AADT - Light comm. vehs.	3,016	812	1,740	11.6%	5,568
AADT - Heavy CVs 2 axle	1,690	455	975	6.5%	3,120
AADT - Heavy CVs 3+ axle	494	133	285	1.9%	912

Model result	Project road	Dev. 1	Dev. 2	Check Sum	Calibration factor
			0		
AADT - all vehicles (vehs.)	26,006	7,195	14,799	48,000	1
AADT – cars	20,805	5,756	11,839	38,400	
AADT - Light CVs	3,017	835	1,717	5,568	
AADT – Heavy CVs 2 axle	1,690	468	962	3,120	
AADT – Heavy CVs 3+ axle	494	137	281	912	

Model calculated speeds	Project road	Dev. 1	Dev. 2
Estimated speed, Cars [km/h]	94.9	51.2	73.1
Estimated speed, CVs [km/h]	81.0	51.8	70.2

Key:

AADT = Average Annual Daily Traffic

CV = commercial vehicle

Dev. = route deviation / diversion

info = information

The lengths of the routes are given in km.
The capacity is given in vehicles per day.

5.2.4 Conclusions

There is a need for more accurate data on the distribution of traffic on road networks, particularly when determining future pavement management strategies. The linear projection of today's traffic twenty years ahead can lead to very biased traffic volumes, if the capacity of the road sections is not taken into account.

Three very different model types are described, which can be used at the project or network level and under different conditions with regard to the information levels available.

The OD-model is the most suitable for both project and network level as it includes the whole network as a coherent system of road sections. If one section is over-loaded, traffic will be redistributed. The model gives reliable results on all the road sections and the results can be treated as a traffic census database. The OD-model can also be used in other areas of a road administration, in particular in the planning department.

The network level model developed by the UoC is very useful when assessing long-term investment plans – not only road pavement maintenance management plans - and also for the case when an OD-model is not available. Examples based on data for Germany have been described in detail, but the model must be appropriately calibrated before it can be implemented in a different country.

The simple project level model is regarded as a tool for helping the planner to make a sensible redistribution of traffic in the case of reassignments due to road maintenance works. This is a demonstration model, only, as it is beyond the scope of this Project to produce computer models; the model requires further development before it can be used more generally.

References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.



5.3 Social Economic Evaluation

5.3.1 Introduction

This Chapter considers the social economic evaluation of alternative pavement management strategies. The following topics are considered:

- Society rate of return (investment costs, social costs) resulting from the use of alternative strategies under static conditions.
- Society rate of return (investment costs, social costs) resulting from use of alternative strategies under dynamic conditions.
- Preservation of road investment.

The most effective measure is generally one which achieves an objective with minimal costs. Hence, the most effective pavement maintenance strategy is one that requires minimum maintenance costs for preserving the investment in the road, or for maintaining the road structure at its initial condition, respectively. These costs consist of investment costs and social costs (time costs, vehicle operating costs, accident costs, costs of air pollution, and CO₂-emission costs) resulting from the hindrance to traffic caused by work sites.

Regarding long-term investment costs, the most effective maintenance strategy is one requiring minimal investment costs to maintain the road condition to a required standard. As road deterioration does not develop linearly with passage of time, but progressively, it is more cost-effective to carry out measures of low expenditure often, rather than higher expenditure measures less frequently during the analysis period. In Chapter 5.3.3, Preservation of Road Investment, a model is presented which makes it possible to determine the long-term costs of a maintenance strategy for maintaining the road condition to a required standard and for evaluating maintenance strategies with respect to their investment cost-effectiveness.

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

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 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. In this Chapter, this type of analysis, with respect to the overall economy, is carried out under static conditions and under dynamic conditions. In static analysis, only a single measure within a strategy is considered. In contrast, dynamic analysis considers the succession of measures (frequency of the measure, and interval between the measures) within a certain period for each strategy; in addition, traffic growth is assumed within the period considered. Carrying out both

forms of analysis together 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 within the project period.

5.3.2 Society Rate of Return

5.3.2.1 Structure of the analysis

For evaluation, three different types of maintenance strategy have been identified:

- **High-condition strategy:** The road is maintained by less-intensive measures, which are repeated at relatively short time intervals. Therefore the average serviceability (p_a) of the road is maintained at a relatively high standard throughout the road's life-cycle, hence this is termed the high-condition strategy. The typical maintenance profile of the high-condition strategy is shown in Figure 5.3.1.

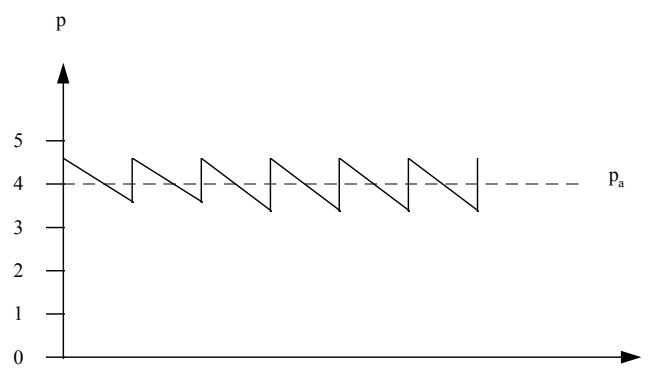


Figure 5.3.1 Maintenance profile of the high-condition strategy.

- **Medium-condition strategy:** The intensity of the maintenance measure is higher and the time interval between successive measures is longer than the minimum-condition strategy. The serviceability of the road is therefore maintained at a medium standard during its life-cycle. The typical maintenance profile of the medium-condition strategy is shown in Figure 5.3.2.

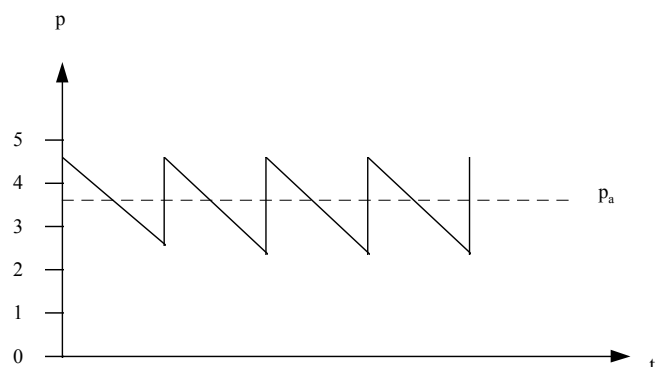


Figure 5.3.2 Maintenance profile of the medium-condition strategy.

- Low-condition strategy: The road is maintained by high intensity measures with relatively long intervals between successive measures. These are repeated over a relatively long time period. The road has an average serviceability standard that is relatively low throughout the road's the life-cycle, as a consequence. The typical maintenance profile of the low-condition strategy is shown in Figure 5.3.3.

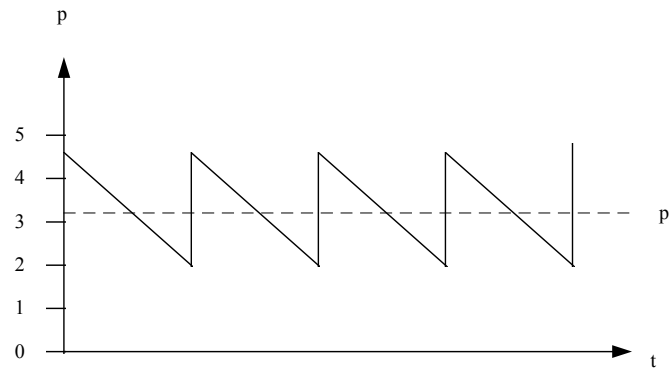
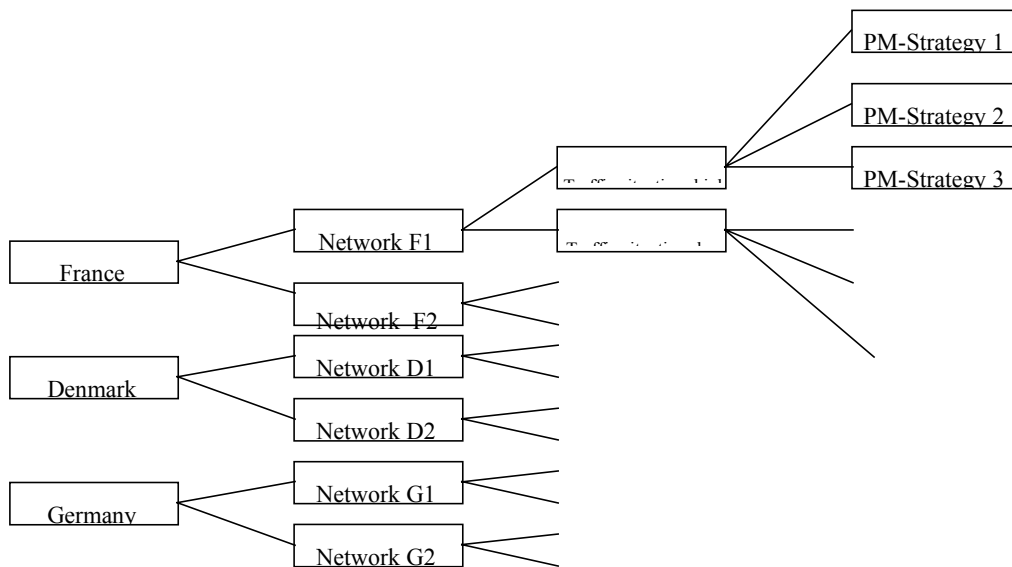


Figure 5.3.3 Maintenance profile of the low-condition strategy.

Economic evaluations of three maintenance strategies are presented for sample road networks from different European countries in order to identify international differences in the cost-efficiency of comparable strategies. For that purpose, Germany, France and Denmark were selected. For each of these three countries, two simplified networks (two-route networks or three-route networks) have been chosen. One of them is representative of a rural area, and the other is representative of a high-density area. Each of these six networks is analysed for the cases of high traffic and low traffic. In a further step, application of three defined pavement maintenance strategies at each of the twelve different cases is carried out. Finally, thirty-six case studies arise. Figure 5.3.4, following, shows the structure of the cost-benefit analyses carried out.



Total number of case studies: 36

Figure 5.3.4 Structure of the cost-benefit analyses.

DRI, LCPC and UoC provided the details and characteristics of the roads in the route-networks (i.e., the average daily traffic volume, road type, length, and share of freight transport) evaluated.

The parameters of the maintenance strategies (i.e., the type of maintenance measure, their investment costs and durations, intervals between the measures) have been provided by TRL.

5.3.2.2 Methodological procedure

The Cost-Benefit Analysis (CBA)

The traditional assessment tool for evaluating the cost-efficiency of a measure is the CBA procedure. CBA is structurally identical to commercial investment analysis procedures.

The CBA procedure is generally as follows. To determine the benefits of any proposed maintenance investment it is necessary to define two possible cases: the with-case, for which the appropriate maintenance measure will be undertaken, and the without-case (reference case), for which the measure will not be undertaken. The difference between the social costs of the without-case and the with-case is the benefit of the maintenance management strategy. This approach for determining the social benefits of a measure is known as the cost savings approach (benefits are equated to savings of social costs). In a further step, the benefits of the measure are related to the investment costs by a Cost-Benefit Ratio (CBR), given by Equation 5.3.1 on the following page.

Equation 5.3.1 Cost-benefit Ratio formula

$$CBR = \frac{C_{wc}^S - C_{woc}^S}{C_{wc}^I} = \frac{B_{wc}}{C_{wc}^I}$$

$C_{wc}^S = \text{Social costs for the with - case}$

$C_{woc}^S = \text{Social costs for the without - case}$

$C_{wc}^I = \text{Investment costs for the with - case}$

$B_{wc} = \text{Benefits of the measure (for the with - case)}$

If the CBR is larger than one (1.0), numerically, the measure is desirable from the point of view of the overall economy. Furthermore, the value this ratio for a number of candidate measures allows the measures to be ranked with respect to their cost-efficiency. A higher CBR indicates a more cost-effective measure.

The traffic simulation model (TSM)

The traffic simulation model 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 5.3.5, on the page following.

Initially, the input parameters, such as average daily traffic volume, share of freight transport, speed limits, road type, network length, investigation period are established. Thereafter, the types of costs described in the sections following, are quantified physical and monetarily. Various standardised EWS (1997) [EWS-97, 1998] unit costs are quoted in the following sections; these have been converted from DEM to euro for convenience (at the rate 2 DEM = 1 euro, November 1999).

Accident costs

EWS (1997) [EWS-97, 1998] accident quotas (accidents / 10⁶ heavy vehicle km) are used depending on the road type. Accidents can be separated into those affecting cars only and commercial vehicles only using these quotas, together with the input data of the model (traffic volume, road type, share of freight transport). The accidents are multiplied by the EWS (1997) cost rates per accident (e.g., commercial vehicle accident with personal injuries = 8,500 euro per accident, commercial vehicle accident with property damage = 8,100 euro per accident). Subcategories of accident costs are economic loss of earnings, loss of full health due to disablement, loss of spare time, medical treatment costs, repair costs, and the administration costs of insurance institutions, law institutions, and the fire, hospital and police services.

Noise costs

Exceeding legislated threshold sound levels (40 dB at night; 50 dB during the day), causes noise, which may be cost-equated. These threshold sound level exceedings (i.e., noise) are transformed into factors that are multiplied by the number of people (inhabitants) affected, to give Inhabitant coefficients (Ic). As each Inhabitant coefficient is valued at 42.5 euro, the social costs of noise per day are as follows.

$$\text{Total costs of noise per day} = I_c * 42.5 \text{ euro}$$

Where, $I_c = \text{noise intensity} * \text{number of people (inhabitants) affected by the noise}$

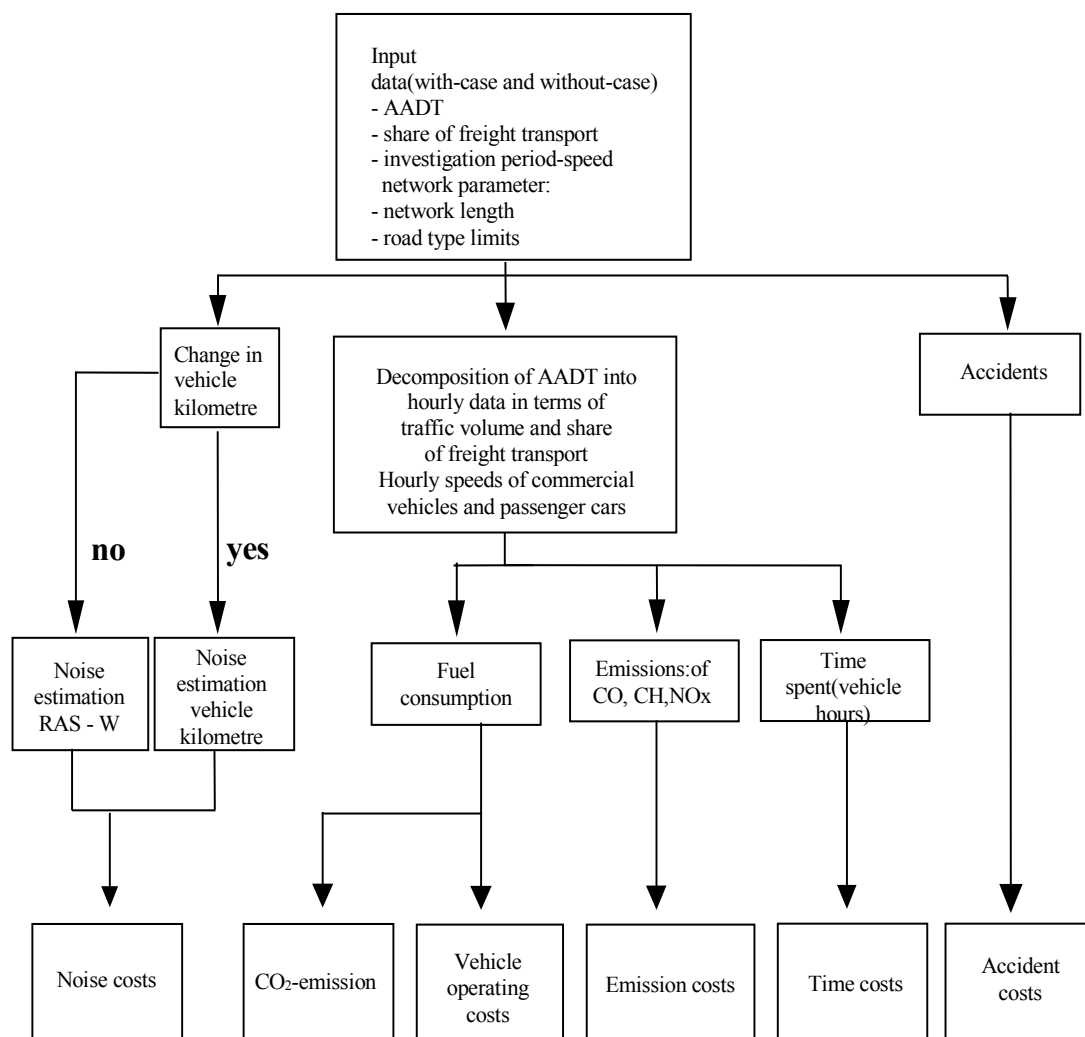


Figure 5.3.5 Structure of the traffic simulation model (TSM).

The social costs determined in this manner would have to be spent to avoid the damages, to buildings and to health, that are caused by the noise (for instance, by constructing noise bunds).

Determination of speed-related costs

The basis for the estimation of vehicle operating costs, time costs and CO₂-emissions costs are the EWS (1997) speed-volume functions. They specify the average speeds for cars and commercial vehicles, depending on average traffic volumes and share of freight transported on different types of road.

Determination of time costs

The road section length divided by the vehicle speed gives the travel time per vehicle on that road section. The travel time is multiplied by the EWS (1997) time costs for one hour, which are:

- Car: 5.5 euro
- Commercial vehicle: 21 euro
- Semi-trailer: 30 euro
- Bus: 62.5 euro

The time costs are separated into the following subcategories:

Freight transport:

- Labour costs and the drivers' expenses
- Provision costs (interest charges for loans and depreciation of the capital invested, garaging, and other general costs).

Passenger transport:

- Time costs for working hours
- Time costs for leisure hours
- Provision costs (commercially-used cars only).

The time costs per vehicle are multiplied by the number of vehicles of that type and by the number of days within the investigation period.

Determination of vehicle operating costs

Estimation of vehicle operating costs is based on two components. The first component is fixed for every vehicle type, and includes the basic costs of vehicle operation. This cost component is independent of vehicle kilometre travelled. The second term is the product of fuel consumption and fuel price. Fuel consumption is determined for different vehicle types by the EWS speed-fuel consumption functions (fuel consumption depends on average vehicle speed). The costs per vehicle are multiplied by the number of the relevant vehicle types and the number of days within the period of analysis.

Determination of CO₂-emission costs

CO₂-emissions are direct emissions. These disperse readily and spread widely in the atmosphere creating damage that is independent of the distance from the sources of the emissions. Therefore they have to be distinguished from indirect air pollution by NO_x, SO₂, CO, HC, PA (in which the distance between the source of the pollutant output and the place of its registration is a main determinant).

CO₂-emissions per vehicle km are determined by the EWS (1997) fuel consumption, CO₂-emission functions that are quantified separately for Diesel fuel and Petrol fuel.

CO₂-emission costs result from the product of the CO₂-emissions quantity by the costs per tonne (90 euro / tonne CO₂). These costs are multiplied by the number of the relevant vehicle types, the road length and the number of days within the analysis period. The total sum of these costs represents the investment necessary to avoid the damages resulting from CO₂-emissions. The values of these costs are estimated from the costs of those general measures that are necessary to cause a decrease of CO₂-emissions (e.g., by more economic use of limited energy resources, or by substitution of limited energy resources by non-limited energy resources).

Determination of the costs of air pollution

The quantity of indirect air pollution is determined by applying the EWS (1997) speed-emission functions, which determine the quantity of air pollution caused by different kinds of vehicle emissions (NO_x, SO₂, CO, HC, PA), and which depend upon the different vehicle types and their vehicle km of travel. These different kinds of vehicle emissions are transformed by applying toxicity factors into standardised units of nitrogen x-oxide. The costs for one x-oxide unit is 850 euro / tonne. The estimated amounts of x-oxide emitted are multiplied by 850 euro to determine the total costs of air pollution resulting from vehicle exhaust emissions.

The TSM-compatible modelling of a pavement maintenance strategy

The social costs resulting from a pavement maintenance strategy are the difference between the social costs for the road network applying the with-case (wc) and the social costs for the same road network applying the without-case (woc):

$$C_{wc,f}^S = C_{wc}^S - C_{woc}^S,$$

$C_{wc,f}^S$ = Final social costs of the with – case

C_{wc}^S = Social Costs of the with – case

C_{woc}^S = Social Costs of the without – case

Social costs increase due to time losses and from increases in accidents due to the existence of work sites. For analysis, work sites must initially be transformed into TSM-compatible parameters, in order to determine the social costs on the road network considered when a maintenance management strategy is applied (in the with-case).

As previously mentioned, pavement maintenance strategies are differentiated by the type of maintenance measure and the time interval between the measures. For the static analysis of maintenance management strategies, the interval between the measures is neglected and only one application of the maintenance measure is assumed.

It is incorrect to assume that every kind of a maintenance measure requires the same type of work site, with respect to its layout, speed limit and length related to the road type. For economic analysis, however, a standardised length of the traffic hindrance (diversion) has been established based on the following assumptions: firstly, traffic safety costs are minimal per km, with a work site length of no more than about 5 km; secondly, the average length of a work site on German motorways is 3.2 km. Therefore work sites were assumed to have a fixed length of 3.2 km, as significant deviations from this value cannot be expected, due to minimisation of the costs of traffic safety meas

ures. In addition, a speed reduction section is assumed to exist before the work site section, with an assumed fixed length of 0.7 km.

Hence the assumed layout of a road section for undertaking any maintenance measure is as shown in Figure 5.3.7, on the following page.

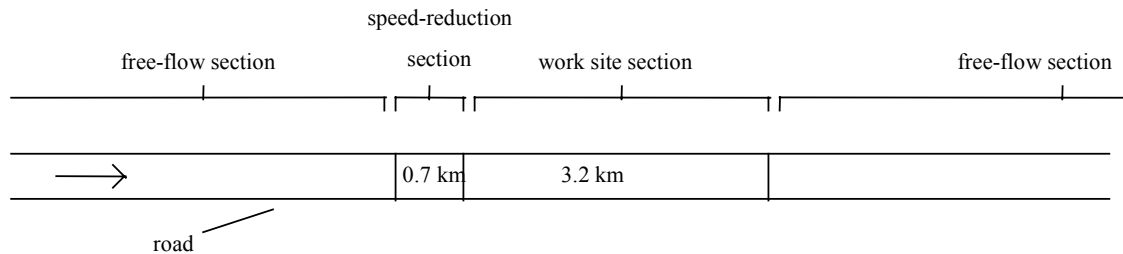


Figure 5.3.7 Layout of a work site on a four lane road.

The layout of the traffic diversion within the work site is also an important detail for determining the increase of social costs resulting from a work site. These details can also be assumed to be standardised and independent of the measure selected, and are only dependent on the road type. This is because it is necessary to minimise the reduction of the road’s capacity by the hindrance. Therefore it is assumed in the following that the original number of lanes are retained within the traffic diversion section.

For four-lane roads (i.e., two-lane dual carriageway roads), it is assumed that the two lanes on the side with the work site are diverted completely onto the counterflow carriageway, which then has to accommodate four lanes of traffic in opposing directions (a speed limit of 60 km/h is assumed), as shown in Figure 5.3.8, below.

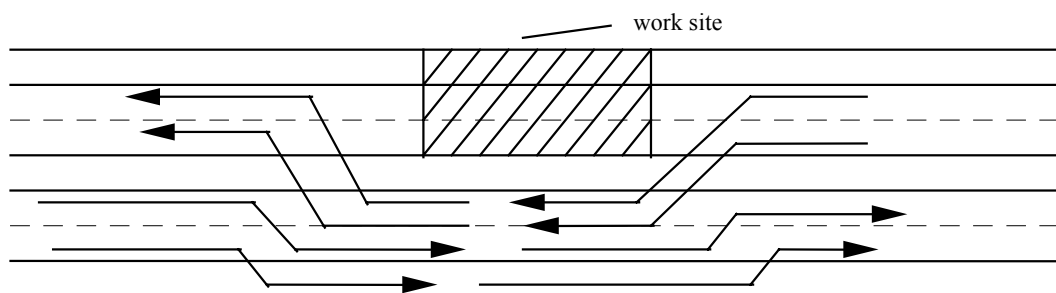


Figure 5.3.8 Layout of a work site on a four lane road.

For six-lane roads (i.e., three-lane dual carriageway roads), it is assumed that only two lanes on the side with the work site can be diverted onto the counterflow carriageway, which then has to accommodate the three original lanes and the two new lanes carrying counterflow traffic (a speed limit of 60 km/h is assumed), as shown in Figure 5.3.9, on the page following.

Definition of the layouts is necessary in order to identify the relevant functions that transform the quantified traffic data into physical data and social costs on these sections. This is because certain functions are valid for work site sections, and also because the resultant speed reduction sections are different from those that are valid for typical road types.

In order to determine the social costs for a road network for the case where a maintenance measure is applied, the social costs determined for the various separate sections must be summed. As a standardised work site is assumed, with respect to the road network considered, the differences between the social costs due to different maintenance measures arise due to the durations of the different measures. For that purpose, a proportional, increasing relationship of social costs to the duration of the measures is assumed. The duration of the measure is determined from the duration per kilometre multiplied by the length of the maintained road (the work site is moved along the road from the beginning to the end of the maintained road).

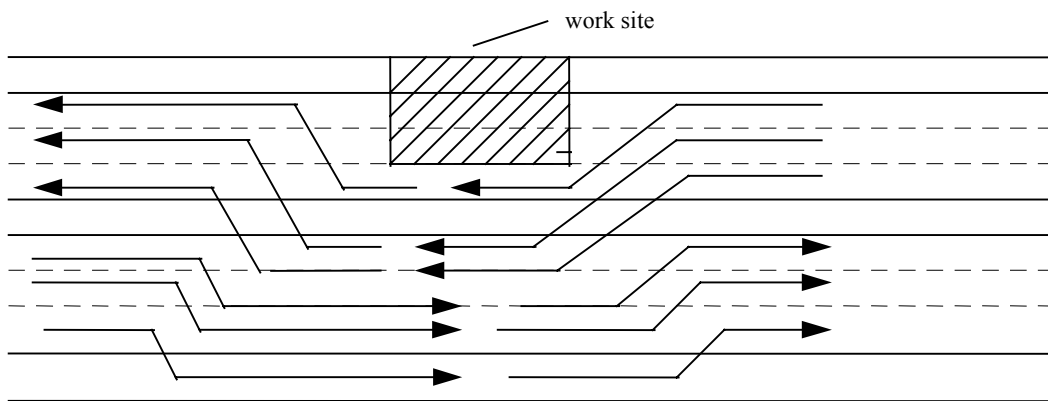


Figure 5.3.9 Layout of a work site on a six lane road

For determining the social costs on a road network for those cases with a maintenance work site, the original quantitative traffic parameters on the different roads do not apply because route-shift will occur due to the work site. Therefore firstly, the final route distribution has to be determined by a route-shift model.

The route-shift model

Due to frequently critical traffic conditions on the main road (and related higher user costs on this road), route-shift occurs.

The mode of operation of the model is as follows:

1. There is a certain ratio of road user costs (time costs + vehicle operating costs) on the main route to the road user costs on the alternative route.
2. The ratio is changed by the increase of the user costs on the main route resulting from the work site.
3. Precisely as many vehicles shift from the main route to the alternative route in order to maintain the initial cost ratio.

This is not a singlestage process, but a multistage process as the road user costs decrease on the main route due to the route-shift and increase on the alternative route. The initial ratio is consequently not maintained. Therefore traffic route-shift from the alternative route back to the main route occurs. This route-shift is of lesser extent than the first route-shift. The route-shifts between the two routes alternate with decreasing volume until the initial cost ratio is achieved. Figure 5.3.10, on the page following, demonstrates the mode of operation.



Both graphs show either the trend and the intensity (converging development) of operation of the route-shift, or the relation of the traffic volumes on both routes (traffic volume alternative route / traffic volume main route shows the same trend of operation, which is similar to the shift in different stages of a process). However, the graphs do not represent actual, specific data of route-shifts or traffic volumes.

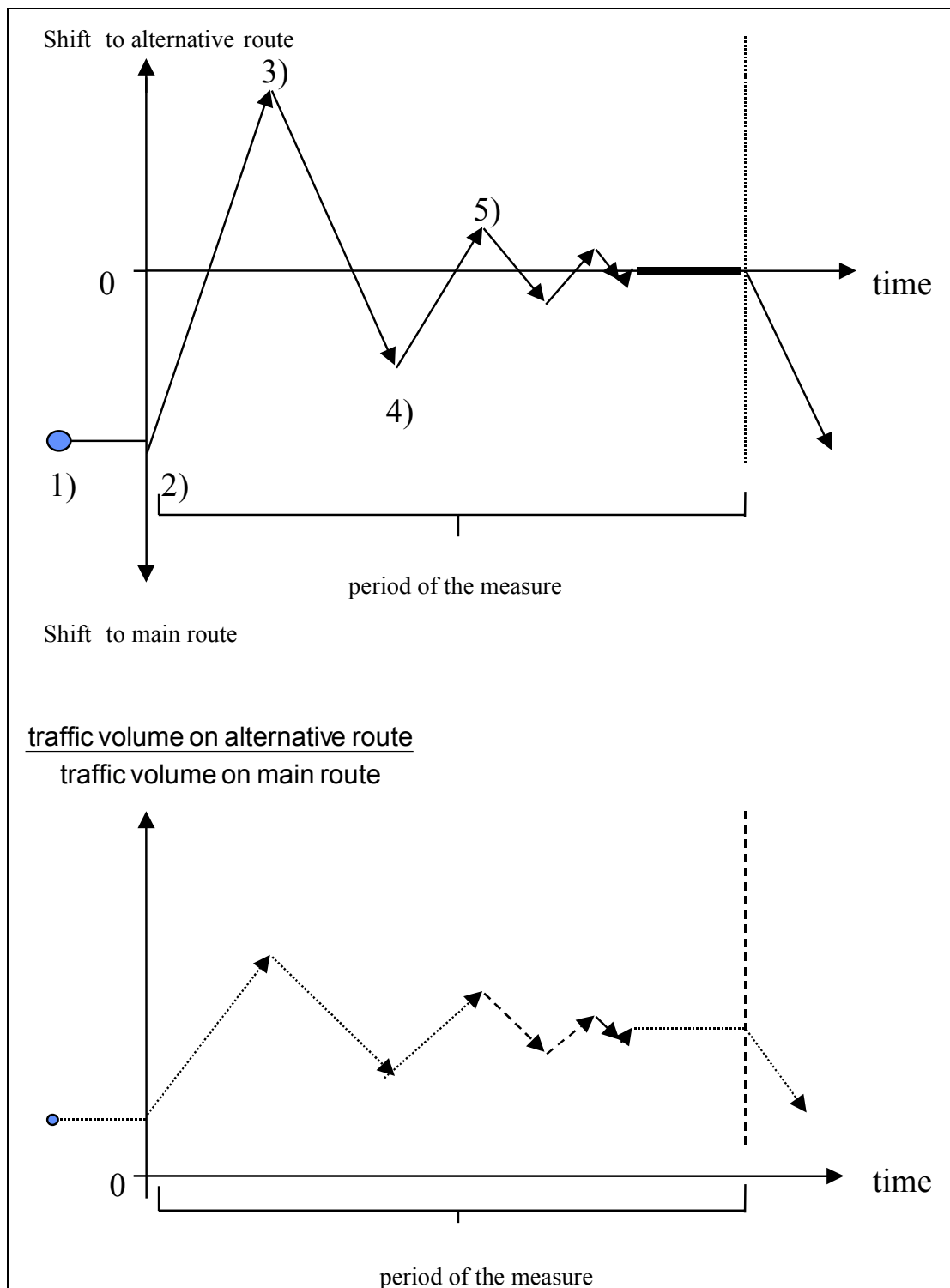


Figure 5.3.10 Mode of operation of the route-shift model.

Furthermore, the following rules are valid for the route-shift process:

- 1) The shifting traffic volume has the same share of freight transport (S_{st}) as the route from where it shifted (S_r).

$$S_{st} = S_r$$

- 2) Traffic always shifts onto the second-cheapest route (in case of three-route networks).

First shift: $r_m \Rightarrow r_{sc}$ $r_m = \text{main route}$ $r_{sc} = \text{second-cheapest route}$

- 3) Shifts (st) occur only if the road user costs increase (i_{uc}) to an extent of more than 0.005 euro, resulting from a work site or from the shift itself (in case of three-route networks). Lower increases are assumed to be negligible.

st, if $i_{uc} \geq 0.005$ euro

- 4) A route is only accepted as an alternative route if it is less than 40 % longer than the used route, as has been shown / determined from empirical studies.

$l_{r,a} / l_{r,u} < 1.4$ $l_{r,a} = \text{route length of alternative route;}$
 $l_{r,u} = \text{route length of used route}$

- 5) Only the main route (r_m) and the second-cheapest route (r_{sc}) are mutual alternatives, as also are the second-cheapest route and the third-cheapest route (r_{tc}). There is no alternative relationship between the third-cheapest route and the main route.

$r_m \Leftrightarrow r_{sc}$ $r_{sc} \Leftrightarrow r_{tc}$

After the final trip distribution is determined, the social costs resulting from a particular maintenance measure can be calculated.

5.3.2.3 Results of the CBA

Application of a maintenance strategy is assumed for the with-case. The without-case is the opposite: there is no application of any maintenance strategy.

Static analysis

Since the cost-efficiencies of the different pavement management strategies are to be regarded as the aggregate condition level for each of the countries, the investment costs and social costs for all four cases (2 networks x 2 traffic volumes) are added for each strategy and for each country. Weighting of the different cases per country, with respect to their share in the sum total of all cases per country, is not applied, because such data are not available; so all cases are therefore unweighted.

The social costs for the without-case are zero (0), as social costs cannot arise without the application of a maintenance strategy, and since only social costs from maintenance work sites are considered.

Normally, social costs savings resulting from better serviceability of a road due to the application of a maintenance strategy should also be taken into consideration. However, for the static estimation case, this aspect can be neglected as the investigation period is precisely related to the duration of the measure. The social costs savings resulting from

better serviceability of the road, or of the road section which has received maintenance treatment, are negligible in relation to the social costs resulting from the effect on traffic of work sites. Otherwise, the social costs of the without-case would not be zero (0), but have a positive value.

Table 5.3.1, following, shows the results of the static analysis (positive cost values are negative benefit values).

Table 5.3.1 Cost-benefit ratio of different maintenance strategies.

Strategy	Germany	Denmark	France
High-condition	-0.69	-0.04	-0.15
Medium-condition	-0.40	-0.04	-0.18
Low-condition	-0.51	-0.027	-0.18

Table 5.3.1, above, shows that if a measure continues for a longer period, the long-term average serviceability of the road reduces, and the social costs and investment costs (resulting from the intensity of the measure) consequently increase. This is valid for all the cases investigated.

The Danish case shows the special quality of very small absolute values, when the Danish results are compared with France and Germany. This is due to the much lower social costs in Denmark in comparison to the social costs in the other countries, although the Danish maintenance investment costs are similar to the German and the French costs. The relatively low social costs in the Danish case result from two facts:

Firstly, the speed on the Danish national road is limited by a very low speed limit for the free-flow section (i.e., 80 km/h on the 2 lane national road). In this case, the speed limit and not the traffic volume is the factor limiting the vehicle speeds (without a speed limit, vehicles could drive faster), and the resulting vehicle speed is 80 km/h. This means that a vehicle loses less time in the work site section (with a speed limit of 60 km/h) in respect to the free-flow section (with a speed reduction of 20 km/h), where the average speed is much higher. For instance, a vehicle on the main routes of the French network has an average speed of approximately 100 km/h, which is due to the higher speed limit of 110 km/h allowed by on French four-lane national roads (with a consequent speed reduction of 40 km/h occurring in the work site section). On German networks the time losses are even greater. As there is no speed limit, the real average speed is only limited by the traffic volume and is approximately 130 km/h (with a consequent speed reduction of 70 km/h occurring in the work site section). The time loss per vehicle when passing through the work site section is therefore approximately 100% higher on French networks and 350 % higher on German networks, than on the Danish high-density road network.

Secondly, work site sections on Danish two-lane national roads are assumed to be only 1.0 km long, in contrast to the 3.2 km long work site sections on the main routes of other national road networks (motorways or four-lane national roads). This is another reason for the low time losses per vehicle per passage through the work site section. These two reasons are the main contributors to the low time losses per vehicle.

In addition, another effect contributes to the low time losses in relation to the total traffic volume: the very low traffic volumes on both Danish road networks (in particular on the two-lane national roads). The time costs per vehicle are multiplied by a relatively low traffic volume and consequently low total time losses result. Regarding the results of all cases considered, the CBA clearly indicates negative benefits in all cases.

This is logical, as the without-case causes no social costs resulting from the work sites. These results could be ranked with respect to their cost-efficiency (with a lower value indicating a more cost-efficient strategy), but it is of no practical use to rank the results with respect to their efficiency, as all the ratios are not only below one (the cost-efficiency threshold value from the point of the overall economy), but even below zero. This would mean that each of the strategies considered would be inefficient when compared to carrying out no strategy at all. It is therefore clear that economic evaluation of the strategies in a static analysis does not give real information, since it does not allow integration of the other characteristic of a strategy, which is the intervals between the measures. Furthermore, another problem influencing static analysis is that social costs resulting from the changed serviceability of the road cannot be taken into account. Therefore evaluation of the economic efficiency by static analysis is not advisable. Nevertheless, presentation of these results is useful, in order to contrast static analysis with dynamic analysis.

Dynamic analysis

In contrast, with dynamic analysis, the change in the long-term serviceability of a road resulting from the different maintenance strategies is important.

The social costs of the with-case and the without-case consist of the costs resulting from the work site and of the costs resulting from a change in the serviceability of the road.

The Equation for the social cost benefit due to the maintenance measure is expressed as follows:

$$B_S = (C_{sa}^{S_{wc}} + C_{ws}^{S_{wc}}) - (C_{sa}^{S_{woc}} + C_{ws}^{S_{woc}})$$

B_S = *Benefit of the strategy considered*

$C_{sa}^{S_{wc}}$ = *Social costs resulting from the serviceability of the road for the with– case*

$C_{ws}^{S_{wc}}$ = *Social costs resulting from the work site for the with– case*

$C_{sa}^{S_{woc}}$ = *Social costs resulting from the serviceability of the road for the without– case*

$C_{ws}^{S_{woc}}$ = *Social costs from the work site for the without– case*

As $C_{ws}^{S_{woc}} = 0$ (no strategy means no work sites), the formula can then be simplified to:

$$B_S = C_{sa}^{S_{wc}} + C_{ws}^{S_{WC}} - C_{sa}^{S_{woc}}$$

The terms can then be regrouped in the following way:

$$B_S = C_{sa}^{S_{wc}} - C_{sa}^{S_{woc}} + C_{ws}^{S_{WC}}$$

Clearly the total benefits of applying a maintenance strategy, in relation to no maintenance strategy (the reference baseline), are the savings of social costs (negative cost values are positive benefit values) resulting from the improved long-term serviceability of the road $(C_{sa}^{S_{wc}} - C_{sa}^{S_{woc}})$, which are reduced by the social costs of the maintenance strategy resulting from the work site $(C_{ws}^{S_{WC}})$.

For this procedure, firstly the development of the serviceability of a road over time has to be known (a linear relationship is assumed). The average serviceability of the road at any time can be derived from the road's serviceability at the beginning of each interval (ideal serviceability $P = 4.5$) and that at the end of each interval, and by determining the mean of both values to give the average serviceability of the road.

As a result of the differences between the ideal serviceability and the average serviceability, a social costs (i.e., user costs and external costs) result. For the without-case (i.e., no strategy) an average theoretical serviceability of $P = 0.0$ (zero) is assumed. The cost-benefit ratio is the benefit of the measure (i.e., the benefit resulting from the improved serviceability of the road, reduced by the social costs resulting from work sites), divided by the investment costs.

Table 5.3.2, following, shows the results of the analysis for the German rural network with low traffic volumes. Note: the average traffic volumes and the average share of freight transport over the total period 1997-2011 are based on the calculated means of the corresponding values from 1999 and 2009.

Table 5.3.2 Efficiency of different strategies in relation to no strategy (German rural network, period 1997-2011).

	P at end of period	P_a	Additional user costs per year in relation to P_a=4.5 Mio. euro	Additional external costs per year in relation to P_a=4.5 Mio. euro	Total costs over entire 15 year period in relation to P_a=4.5 Mio. euro	Total costs over entire 15 year period of P_a=0 in relation to P_a=4.5 Mio. euro	CBR	R_E
Hcs	3.50	4.00	0.225	0.265	7.335	1166.7	84.2	3
Mcs	2.88	3.69	0.365	0.278	9.645	1166.7	105.3	2
Lcs	2.00	3.25	1.055	0.217	19.095	1166.7	123.1	1

Hcs = high-condition strategy; Mcs = Medium-condition strategy;
 Lcs = Low-condition strategy
 P_a = average serviceability; R_e = cost-efficiency Rank

Table 5.3.2, above, shows quite clearly that the benefits resulting from better serviceability of the road are higher if a higher average serviceability is guaranteed by the strategy considered (i.e., a high-condition strategy produces higher benefits). Furthermore, very high positive CBR values are achieved by all the strategies considered. This means that it is more efficient to carry out maintenance measures with some form of strategy rather than allowing the road to continue to function in an unserviceable condition with no strategy at all. In addition, it also becomes clear that the strategy with the lower frequency of application (i.e., longer intervals between maintenance interventions) is the more efficient. The main reason is that although the social costs of the different strategies differ only slightly from each other, the maintenance investment costs over the total period decrease, the longer the intervals are between the maintenance interventions (i.e., the relatively long periods between investments overcompensates for their high levels).

Consequently, although the benefits decrease as the intervals between the measures increase, they decrease inversely in relation to the investment costs. Therefore the low-condition strategy is the most efficient, and the high-condition strategy is the least efficient. The results show that the investment costs are the dominant factor for the economic efficiency of a strategy with respect to the social costs.

As the benefits of a strategy due to the improved serviceability of the road are generally not known in most cases, for the Danish and French road networks, which largely consist of national roads, a constant value of 100 Million euro has been assumed; the data for motorways cannot simply be adopted for national roads, as the materials used in their construction and the construction methods used are different. Table 5.3.3, following, shows the ranked position of the strategies considered, with respect to their efficiency.

Table 5.3.3 Ranked position of the strategies considered, with respect to their efficiency (differentiated into countries).

Strategy	Germany	Rank of strategy	Denmark	Rank of strategy	France	Rank of strategy
High-condition	2.29	3	5.81	3	3.24	3
Medium-condition	2.90	2	8.17	1	3.86	2
Low-condition	3.38	1	6.48	2	4.02	1

Table 5.3.3, above, shows the same ranking results for France and for Germany: The most efficient strategy is the low-condition strategy, and the least efficient is the high-condition strategy. However, for Denmark, although the high-condition strategy is the least efficient, in contrast to France and Germany, the medium-condition strategy is the most efficient strategy. The reason is that the medium-condition strategy has the

second-lowest social costs of all strategies in the Danish case, but it is combined with the dearest investment costs. This is due to the extraordinarily high investment costs/m² of the low-condition strategy measures applied in Denmark, in relation to the other strategy measures. For instance, one application of a low-condition strategy for the Danish rural network is 114 % more expensive per m², than for a medium-condition strategy measure. In Germany, the costs of low-condition strategy measures are 30.5 % higher than those of medium-condition strategy measures, whereas in France they are 28.6 % higher. As the investment costs of the medium-condition strategy are extraordinarily high, the cost-benefit ratio is correspondingly relatively low.

With regard to the overall economy, on the basis of the cost-benefit ratios determined, the procedure applied is not suitable for deriving the cost-efficiency of a maintenance management strategy. The economic efficiency rule that a strategy is always desirable from the point of the overall economy if the cost-benefit ratio is larger than one (1.0), numerically, is not valid with the procedure applied above. This is because the cost-benefit ratio is dependant on the numerical size of the assumed value which has been assumed to quantify the benefit of a strategy due to the improved road serviceability, in relation to the situation in which no strategy is applied. With a lower assumed value, all of the cost-benefit ratios would have been lower, but their ranking, for each of the countries considered, would not have changed. A positive CBR, however, will generally result if social costs resulting from improved serviceability of the road considered are included in economic efficiency analyses.

If the real benefits resulting from improved serviceability are not included, an international comparison of the efficiencies of the strategies is not possible (e.g., the reason for the high-condition strategy being more efficient in Denmark than in Germany). Nevertheless, the CBR-based procedure adopted is the best possible for evaluating the economic efficiency, with respect to the present knowledge of empirical data regarding the development and relationships between road condition and social costs. Further research is urgently needed into this aspect of road management economics.

5.3.3 Preservation of Road Investment

In this section, a submodel is proposed for estimating the costs of preservation of road investments, which may be used to evaluate different construction or maintenance strategies at network level.

The approach for estimating the costs of preservation of road investments at network level is consistent with that described for project level analyses, which are described in Chapter 5.1. The goals of project level and network level investment cost-efficiency analyses are different. Project level analysis focuses on technical analysis of the problem, and mainly delivers technical results. At network level, the analysis is concerned more with global budget estimation, which defines and allocates budgets in order to maintain a required standard of quality and serviceability of a road network.

Second only to maximisation of social benefits, the long-term preservation of capital investment in a road network is the essential aim of pavement maintenance strategies. The preservation of road capital at a manageable level can be seen as the minimum goal of highway authorities. Therefore, it is necessary to identify which strategy or budget

level will provide the best level of capital preservation, and will minimise the loss of capital value; and furthermore, to assess the loss of invested capital, if the maintenance work carried out is inadequate, inappropriate or late.

The residual life and the salvage value of the road pavement at the end of the analysis period depend on the condition of the pavement. The pavement condition may be determined with respect to its serviceability and to its structural capacity. In this context, pavement preservation has been regarded as the cost of the maintenance work necessary to restore the pavement to its initial condition with due regard to current design and construction procedures.

Importance of preserving road investment.

A detailed review of the economic aspects of preserving road investments has been carried out.

Road infrastructure capital is the foundation for road transportation services. In addition to transportation modes, organisational aspects and transport legislation, the standard of a country's road infrastructure defines the efficiency of road network. In particular, the steadily increasing importance of road traffic within the transport sector reinforces the importance of road infrastructure for the transport sector. During the last decades, passenger kilometre and ton kilometre of goods transported on roads have continuously increased to the detriment of alternative transportation modes, such as rail and inland waterways.

For highly developed industrial nations, it is quite correct to say that maintenance measures (routine maintenance, renovation and renewal) applied to road infrastructure are more important than new construction or extension measures. Moreover, those maintenance measures have an effect on the economic well-being and growth of an economy. The effect of failed investment in road infrastructure is that the growth-stimulating effects of traffic do not develop completely, and consequently, a country's economy suffers the loss of potential growth.

Methodology for estimating Road Investment costs

For evaluating the life-cycle costs of roads, two different methods can be used to determine the value of road investment costs. One method takes into account all of the investments made in the road from construction to the end of the analysis period (e.g., construction costs, routine and maintenance costs, structural maintenance costs); the other considers only the construction costs. Since periodic, routine and structural maintenance works are undertaken to preserve the serviceability of the road, the related costs are not considered as investments, but as preservation costs. Therefore in this study, road investment is determined using construction costs only.

Methodology for estimating the costs of Preservation of Road Investments

Two options must be defined in order to determine the costs of preservation of road investments. Firstly, the condition of each layer of the pavement structure is considered and an estimation is made of its residual value. The object is to assign the effects of the various types of deterioration to each pavement layer. Figure 5.3.11 shows the principle of operation of this method.

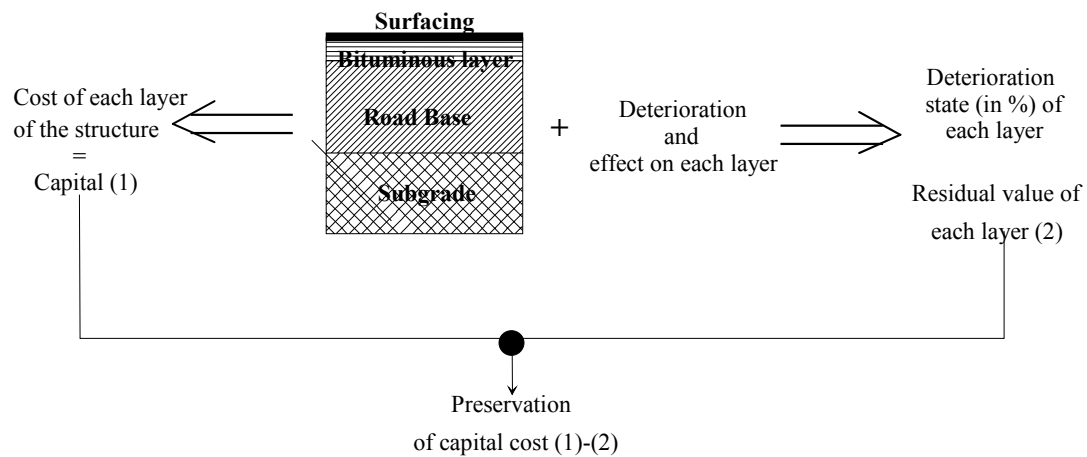


Figure 5.3.11 First method to determine the preservation of road investment.

The second approach, which has been chosen for the modelling in this study, is based on estimation of overall road condition. With this method, the state of deterioration of the whole road structure is determined using condition indicators. From the ranges and values of these condition indicators, a maintenance treatment is selected which will re-instate 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 5.3.12, shows the principle of this method and refers to the Chapters of the PAV-ECO Report [PAV-ECO, WP 3.3, 1999] in which the topics labelling the diagram boxes are described.

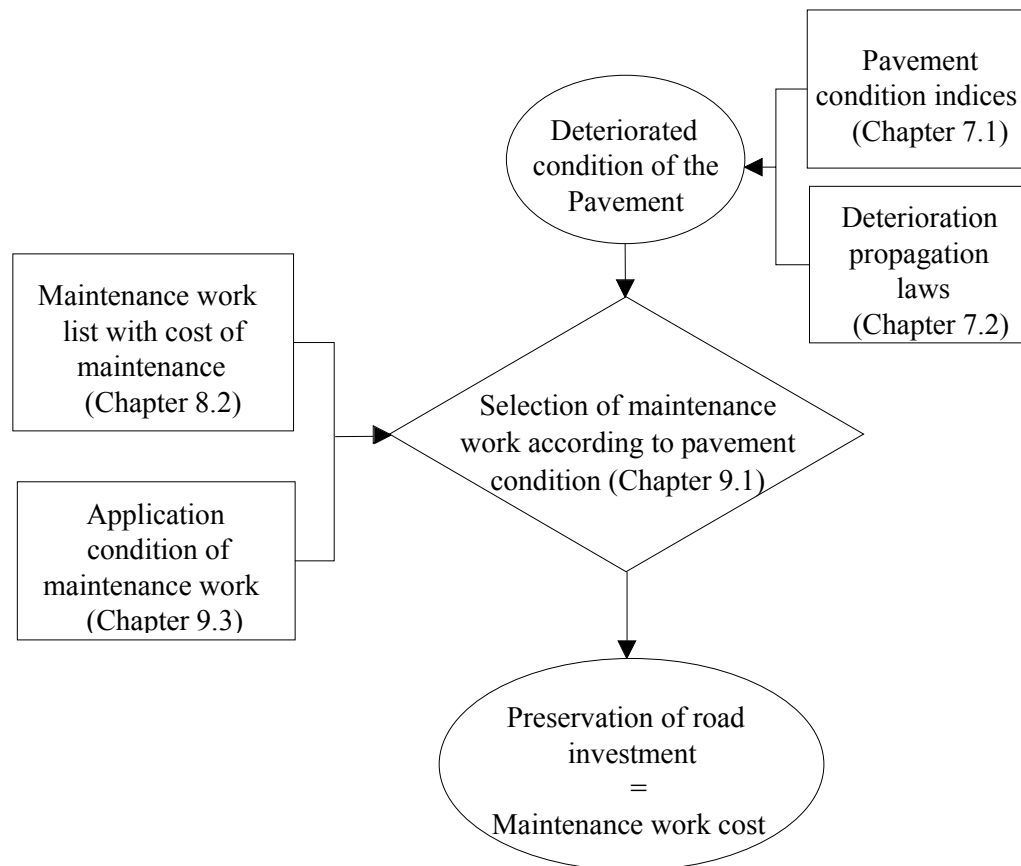


Figure 5.3.12 The second method to determine the preservation of road investment. The Chapter numbers in brackets refer to PAV-ECO WP 3.3 Report on the Preservation of Road Investment.

Indicators linking road pavement condition to deterioration

Empirical research was carried out to determine which indicators best link road network capacity, capital investment, and salvage value to road network condition.

Seven indicators which quantify a road’s physical condition are proposed, based on the results of the COST 324 action [COST 324, 1997]. These are: longitudinal profile, transverse profile, surface layer cracking, surface layer defects, surface texture, skid resistance and structural adequacy.

For these indicators, some countries have developed models that are presented in the COST 324 Report. However, it is still necessary to carry out studies using local performance models with regard to those indicators.

The PARIS Project [PARIS, 1998] proposed a set of coherent pavement performance models. The pavement performance models proposed should be applicable for European conditions, with respect to traffic loadings, climates and materials, and should also be suitable for modelling these distress types: cracking, rutting, longitudinal unevenness and ravelling. Before being applied in practice, these pavement performance models will need to be calibrated.

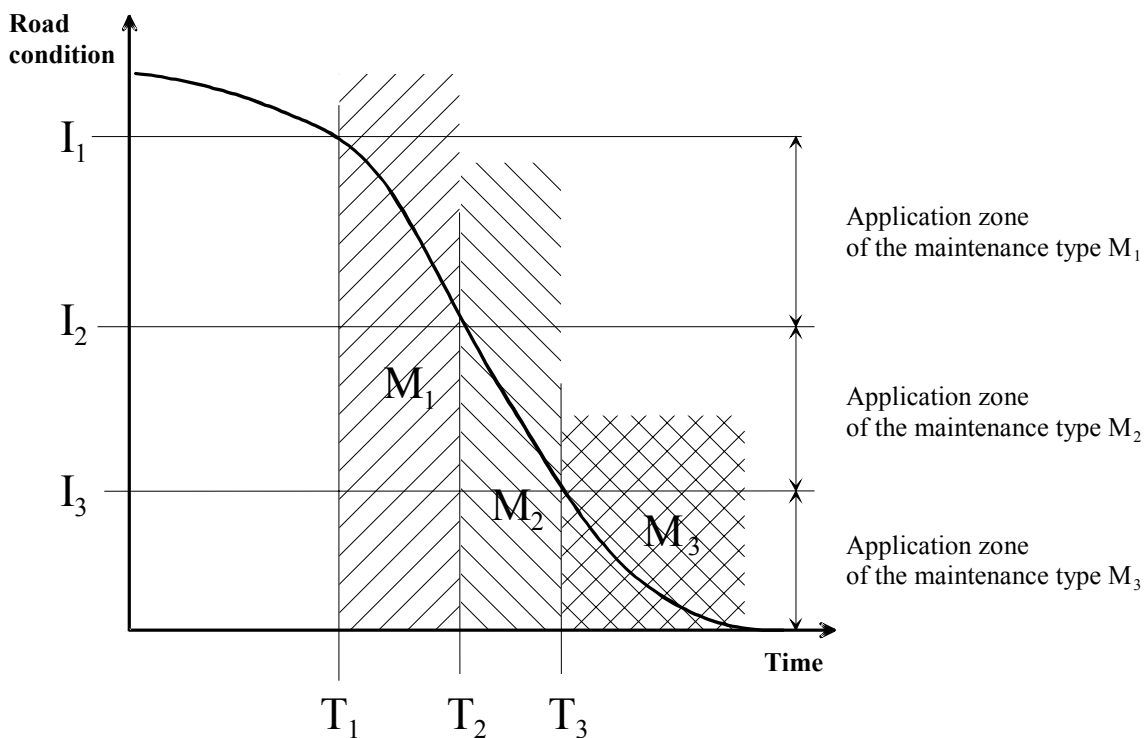
Common maintenance work types and their application conditions, in terms of the values of road condition indicators

Based on the results of the interviews described in Chapter 5.1 of this Report, a list of the most common types of maintenance treatments applied in Europe has been proposed. These are grouped by the type of maintenance work they represent (localised or periodic maintenance, routine maintenance, and structural maintenance). For each, an explanation of their effect on the deterioration types (visual condition, longitudinal unevenness, rutting, skid resistance, bearing capacity) is given.

Modelling the costs of Preservation of Road Investment

The model proposed for estimating the costs of preservation of road investment is based on the costs of maintenance treatments.

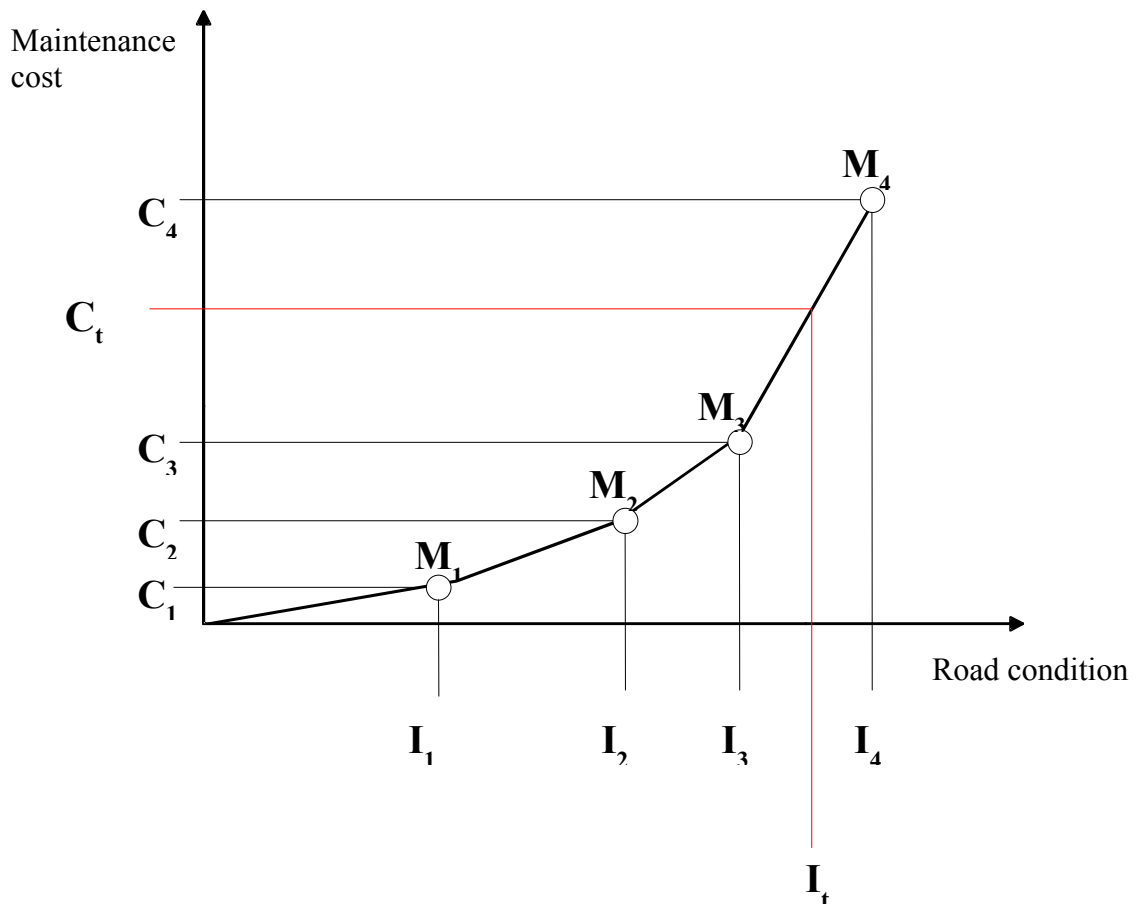
Road condition indicators evolve with time. At the end of the analysis period, with respect to the values of the indices, an appropriate maintenance treatment can be identified to restore the road pavement to its initial structural condition. The maintenance work implemented may be valid for a range of condition indicator values (and not only for one index value), as shown in Figure 5.3.13, following.



M_i = maintenance type proposed for the rehabilitation as soon as the indicator value I_i
 T_i = time when the road condition reach the I_i value

Figure 5.3.13 Determination of maintenance treatments with respect to the pavement condition.

The model calculates the cost of the appropriate maintenance treatment required at the end of the analysis period to restore the pavement to its initial condition. When an analysis period terminates between two interventions, the maintenance cost curve is drawn by linear interpolation between the costs of the two adjacent maintenance interventions, as shown in Figure 5.3.14.



M_i = Maintenance work, type i
 I_i = Trigger limit for the maintenance work, type i
 C_i = Cost of the maintenance work, type i

I_t = Road condition at evaluation time (t)
 C_t = Preservation of capital cost at evaluation time (t)

Figure 5.3.14 Principles for estimating the costs of preservation of road investment.

The cost of preservation of road investment is expressed by the following Equation:

$$\text{For } I_n \leq I_t \leq I_{n+1} \quad C_t = C_n + ((I_t - I_n) / (I_{n+1} - I_n)) * (C_{n+1} - C_n)$$

Further details of the study are given in the literature [PAV-ECO, WP3.3, 1999].

5.3.4 Conclusions

Resulting from various political conditions (e.g., growing environmental sensitivity, budgetary constraints), establishing cost-effective pavement maintenance strategies has become increasingly important for the decision-making processes in road network maintenance management. Pavement management strategies will probably become even more important in the future, as economic evaluation methods are becoming established as management tools for estimating the economic efficiency of maintenance decisions.

Traditional road network maintenance management procedures have been inadequate, as they have considered the long-term investment costs (selection of construction methods and road construction materials) only. Social costs (time costs, vehicle operating costs, costs of air pollution, costs of the greenhouse-effect, accident costs and noise costs) resulting from different pavement management strategies, however, have been neglected.

The objectives of the work described in this Chapter, was to determine the social costs resulting from the hindrances caused to traffic by roadwork sites and to evaluate the cost-efficiency of different strategies which account for these social costs and investment costs. Three strategies were selected for evaluation: (1) a high-condition strategy (low-intensity measures which are repeated at short intervals), (2) a medium-condition strategy (medium-intensity measures repeated at medium-period intervals) and (3) a low-condition strategy (high-intensity measures repeated at long intervals).

A traffic simulation model (TSM) was presented which makes it possible to simulate traffic situations mathematically and to evaluate these situations financially (i.e., to determine the social costs). Additionally, a method for TSM-compatible modelling of the strategies was also presented. It was found that work sites mainly affect the social costs by increasing time costs and accident costs (the effects on other types of social costs are negligible). The cost-efficiencies of selected maintenance strategies were analysed for representative road networks from three European countries (Germany, France and Denmark).

The maintenance management strategies considered have each been evaluated by static analysis (one maintenance measure only) and by dynamic analysis (appropriate maintenance measures at relevant intervals within a fifteen year period). It has been established that the static analysis method does not give realistic information, as it neglects the time intervals between maintenance measures, which are an important characteristic of any strategy. Dynamic strategy analysis is the proposed economic analysis tool, in which the efficiency of the maintenance strategies is expressed by cost-benefit ratios (i.e., benefits = savings of social costs).

This study has shown that maintenance strategies with more intensive measures and longer intervals are the most cost-efficient in the long-term. This is because the social costs of the different maintenance strategies differ only slightly from each other, whereas the investment costs essentially decrease as the intervals between the maintenance interventions become longer. For cost-efficiency, maintenance investment costs are seen to be the dominant factors in economic analyses of road maintenance investment strategies.

Social costs resulting from the altered serviceability level of roads, as a result of different maintenance strategies, should also be considered in economic analyses of road maintenance strategies. Unfortunately, the value of social costs resulting from different serviceability levels have not been quantified and are not known, in particular for national road networks. However, despite the lack of knowledge in this area, only minor differences have been determined in comparative analyses in which social costs with and without changes in road serviceability levels were considered.

Research in this area of road management economics is urgently needed into the performance and long-term serviceability of national road networks.

References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.

5.4 Allocation of Funds

5.4.1 Introduction

The PAV-ECO Project aims to establish models for the evaluation of pavement maintenance on the basis of life-cycle cost. 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.

An essential part of an effective highway management system is the ability to assess the size of maintenance budgets. In this 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.

A literature survey and a review of current practice have shown suitable tools for this type of allocation are not yet available. The work carried out in this Project and described here, 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.

5.4.2 Literature Review

A literature survey of more than 100 articles 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 prioritisation 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 reason for the lack of information on fund allocation has been acknowledged in various reports and can be summarised by the following:

- There has been a strong tradition of funding maintenance work based on previous levels of funding with prioritisation and allocation techniques being developed to make best use of the available budget.

- Allocation between different parts of a road network has often been on a political basis rather than a full technical analysis of the consequences of alternative levels of funding. In particular, the long-term cost-effectiveness of fund allocation has been considered less important than more easily visible short-term benefits.
- In the past, maintenance budgets were often adequate to fund all ‘desired’ maintenance (i.e., the need for fund allocation procedures has only been required since budgets have fallen to below the level seen necessary for an acceptable level of serviceability).
- The greatly increased level of commercial and passenger traffic in the past decade has raised the amount of maintenance funding required and, therefore, the importance of the issues to the public, politicians and administrators.

A summary of general approaches adopted has been prepared by the OECD (1994) and the World Bank (Heggie 1995). Typically, the Government of a country plays the key role in the overall allocation of funds between different Departments, and possibly Regions, considering alternative investment strategies to achieve national or regional goals.

At the next level of fund allocation, the Government Department responsible for highways requires similar techniques for the allocation of funds between Regions. Further tiers of local government may then be involved as the allocations are devolved down to different road types.

In 1995, Heggie described three basic methods used for fund allocation, and emphasised the need for them to be simple, transparent and consistent:

- **Simple allocation formulae**

Funds are assigned on the basis of pre-determined percentages to different parts of the network. The advantage of this procedure is that it is simple and direct, but the disadvantage is that allocation is based on past experience and this may bear little relation to future condition and usage.

- **Indirect assessment of need**

Where there is no reliable data for assessing needs directly and/or where the cost of collecting the required information would be prohibitively expensive, this approach is often used with the following criteria for the assessment:

- Land area
- Population
- Road density
- Agricultural production or potential

The factors may be weighted according to perceived importance, judged on political as well as technical and financial grounds.

This approach has merit as it is pragmatic and, through weighting, takes into account a mixture of technical and socio/political needs. The suitability of this approach relies, of course, on the weighting of the different factors.

- **Direct assessment of need**

This approach can be at different levels of sophistication and may take into account the results of detailed condition surveys, and costing of alternative pavement and bridge maintenance treatments. Whereas this is the most comprehensive of the approaches listed, there are many difficulties that may occur. For instance, the level of complexity of surveys needs to be chosen, and must be linked to a system that can make proper use of the data. Weighting the results of the condition survey is normally necessary to ensure that both essential and preventative maintenance is carried out with optimal effect. Decisions will have to be made as to how the budget requirements are weighted, as there may be significant differences in allocations depending on whether a short-term or long-term strategy for maintenance is used.

The OECD Report (1994) reviews current approaches and breaks down fund distribution into two categories: Government and type of road improvement.

Where funds are distributed by the Government, an apparent correlation has been noticed between the size and homogeneity of the country or region and the method of distribution. For smaller and more homogenous countries or regions, allocation appears to be carried out on a 'needs' basis using data from evaluations and established methods and formulae, whereas larger and more varied countries or regions place greater emphasis on 'equity'. This results in all regions getting some share of funds, regardless of need.

It is also noted that a combination of these two strategies is typically the norm and a balance between efficiency and equity has to be found to take into account the implications of different demographic, topographic and economic factors, as well as road types, on funding.

Distribution of funds by type of road improvement requires rigorous engineering and economic appraisal to take into account *inter alia* traffic, pavement or bridge condition and safety. Among western countries, there is still a considerable range in approaches to this appraisal and the parameters and properties included in the analysis.

Various attempts to optimise maintenance funding using mathematical modelling have been carried out. An example of a model developed in Finland is given by Tapio et al (1992). The model is designed to optimise pavement rehabilitation policy and fund allocation at a network level. The Markov model used represents deterioration by the probability of a pavement condition changing over a year, and includes 135 possible condition categories and 8 treatment options. The model attempts to find levels of rehabilitation treatments that balance the higher user costs incurred with poorer maintenance. At the time the reference was published, the model had only been used at a network level and was considered difficult to use on a regional level.

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 standardised 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.

5.4.3 Literature Review

In addition to the literature review, a brief examination was undertaken of current approaches adopted in England, Switzerland and France for the allocation of road maintenance funds.

5.4.3.1 England

Road maintenance funds are provided by Central and Local Government for the national road and bridge network. The processes for allocating budgets are completely separate for the national and local roads. For Motorways and Trunk Roads, funds are allocated annually to the Highways Agency which in turn divides the funds for bridges and pavements through the assessment of maintenance bids from each Region. These maintenance bids are based on information submitted by the Maintenance Agents responsible for areas of the network and are provided separately for capital and routine maintenance.

No firm rules exist for the division of funds between pavement and bridge maintenance. All of the bids are prioritised as part of a Value Management process, by consideration of various factors such as safety, preservation of the asset, and the environmental implications of the work. For routine maintenance, the requirements are described fully in the Trunk Road Maintenance Manual (Department of Transport, 1992) but individual parts of the work are categorised in the same way as capital maintenance, using unavoidable, highly desirable and desirable to indicate the priority of the work. The introduction of life-cycle costs is part of the business objective of the Highways Agency derived from the 1998 Government white paper 'A New Deal for Trunk Roads in England' (Department of Environment Transport and the Regions, 1999) which described the Government approach to road maintenance in the future:

“Our fundamental principle is that roads should be maintained on a minimum whole life cost basis. This means carrying out maintenance in a way that minimises costs over time to the Government taking into account the disruption to traffic”.

For routine maintenance, a study commissioned by the Highways Agency has related the level of spending on routine maintenance for different parts of the road network. This is to enable the funding to be transferred if responsibility for a road, or part of the network, is assumed by others. In this study, the cost of routine maintenance was explained in terms of four factors: road environment, traffic level, road type and number of lanes.

As for pavements, funds for bridge maintenance are allocated following assessment of maintenance bids and compiled by Regional offices of the Highways Agency. Allocation of funds to each Region is carried out through negotiation and prioritisation of schemes, with safety being considered as the highest priority (i.e., classed as 'Essential'). Other works receiving a high priority are those committed in previous years, and those classed as 'Preventative' (i.e., maintenance work to arrest the deterioration of a structure before it reaches the minimum acceptable level). Before implementation, schemes have to be justified on economic grounds with more than one option being costed. Following this initial prioritisation, bids are then assessed according to work

categories (e.g., pier strengthening and parapet replacement) and the maintenance options giving the lowest values for each structure are selected (Haneef and Chaplin, 1998).

Funds for Local Government road and bridge networks are provided from Central and Local Government. Local Authorities raise funds from local taxes using various methods for justification and allocation. Additional road maintenance funds are provided by Central Government through the Standard Spending Assessment (SSA) system (Dubock et al, 1997) and Transport Supplementary Grants (TSG). The SSA takes into account demographic, geographic, social and economic characteristics of each area, including education, social services and police, in addition to highways. For highways funds, the SSA funding is to contribute to the overall maintenance of Local Roads, but the Local Government is not obliged to spend the money on highways. The TSG on the other hand is 'additional' Government funding for Principal Roads, which is bid for on the basis of the condition of these roads. The allocated money is then 'ring-fenced' for the maintenance of Principal Roads. The approach to TSG funding is currently under review, to take account of recent improvements in condition data available for the Principal Roads.

5.4.3.2 *Switzerland*

As part of the review, Viagroup undertook a review of the management of highway maintenance in Switzerland. Switzerland is a Federal State composed of 26 Cantons and around 2900 municipalities. Roads are owned and managed at both of these levels.

National highways are in the ownership of the Cantons but funding for construction, maintenance and the operation of these roads is regulated by Federal Laws (Hussain, 1999) and supported by the Federal Government.

Together, the Cantonal roads form the national main road network, and are eligible for Federal funding for major construction and improvements. At the Federal level, part of the fuel taxes for road transport use has, by law, to be used for road-related expenditures.

For National Highways, the costs of new construction are subsidised by the Federal Government, by between 58 and 97%, taking into account:

- road type (two- and three-lane dual carriageways, or single carriageway express roads)
- environment (urban or non-urban).

Non-technical aspects taken into account include the financial condition of the Canton and national interest.

Federal subsidies for maintenance, rehabilitation, and renewal range between 50 and 80%, according to the ratio of National to Cantonal highways, their importance and the current financial condition of the Canton. The proportion of the costs of operations and operational maintenance financed by the Federal Government varies between 40 and 95%.

Among the different contributions from the Federal Government to the Cantons, the general distribution of non-object related funds for the costs of public roads is dependent on:

- length of public roads in the Canton
- costs for construction, maintenance and operation of roads
- financial condition of the Canton
- taxation of motorised traffic in the Canton.

The distribution of maintenance funds for Cantonal roads depends on the size of the Canton. Some Cantons use a ‘distribution formula’ which takes network length as one of the most important factors. Funding regulations for roads differ between Cantons (Hussain, 1999) and municipalities may be required to contribute to the costs for the construction of these roads in their area. However, a major factor in determining the funds for each Canton is the financial condition of each of the municipalities. Similar regulations are also applicable for maintenance works carried out on Cantonal roads.

One method for the allocation of maintenance funds is the ranking method used by the Canton of Neuchâtel. The method determines a combined index for each road section (or maintenance job unit) that takes into account the weighted contribution of different parameters. The higher the number of points, the higher the priority. Table 5.4.1 shows the factors and allocation of points used.

Table 5.4.1 Criteria and weighting.

Criteria / Parameter	Range	Weight	Maximum Score
<i>Safety</i>			
Accident rate	1 – 4	3	12
Skid properties	1 – 5	2	10
Rutting	1 – 5	4	20
<i>Durability</i>			
Surface distress	1 - 5	3	15
Bearing capacity	1 – 5	4	20
<i>Other</i>			
Roughness	1 – 5	2	10
Traffic volume	1 – 6	2	12
Maximum priority score:			99

Pavement management systems used in Switzerland incorporate an optimisation process based on life-cycle cost analyses in which pavement condition is the primary criterion. User costs have not yet been included. The pavement condition indicator is usually a combined index taking into account visual distress, unevenness (roughness) and rutting of the pavement. In addition, skid resistance and bearing capacity are used to trigger maintenance treatments.

A general approach adopted is to divide the budget into two parts and distribute one part according to traditional (objective) procedures (e.g., length) and the other part according to the output from the pavement management analysis.

Following preliminary research work and trial applications in a few Cantons, a "standard method" for the functional evaluation of roads or road sections is currently being developed by the technical committee on road maintenance management. This method is for use in conjunction with simplified maintenance planning procedures such as a ranking method, but consideration of the influence of the functional evaluation in life-cycle cost analysis and optimisation is also possible.

The functional evaluation of roads takes the following parameters into consideration:

- geographical factor
- importance to tourism
- special uses (e.g., routes for exceptional loads)
- network function
- traffic volume
- heavy goods traffic volume
- maximum speed limit
- public transport use
- design speed
- existence of alternate routes
- number of lanes
- asset value (reconstruction value)
- user groups
- climatic zone
- utilities
- annex infrastructures
- presence of structures
- altitude
- grade

For practical applications, each parameter is weighted so the sum of the weights equals 100. Each parameter can be subdivided into 2 to 5 classes or ranges, associated with a given number of points. The result of this functional evaluation is the sum of the product of (weight * score), which can be expressed directly as the overall weight of a specific road category.

Switzerland currently has about 9 % of the national highway network in tunnels and the maintenance and rehabilitation of these can be considered in 3 ways:

- operational capacity of the tunnel including all safety-related installations
- capacity of the road network and the role of tunnels as a possible bottleneck
- structural maintenance of the tunnels

Special factors affect the costs of maintenance of road tunnels:

- Side access for maintenance work in a tunnel is not possible. Therefore, a major proportion of the carriageway in a tunnel, if not the entire width, has to be closed to traffic during maintenance operations.
- Road tunnels are very often situated where alternative routes are not available (or maybe only seasonally) and a detour will mean a much longer journey.
- Although most structural components of a tunnel generally deteriorate gradually (similar to road pavements), thus giving options for the type and timing of interventions, electro-mechanical components are different. These may require maintenance at regular intervals, or alternatively, complete replacement at the end of the service life. This maintenance may cost more than 50 per cent of the total maintenance budget for tunnels. The costs of maintenance work and the disruption to road users are now so high that consideration is given to building an extra parallel tunnel to reduce the effects of maintenance for major tunnels.

5.4.3.3 France

In France, the review by the LCPC has shown funds for highway maintenance in each Region are allocated in proportion to the surface area of the pavements. The main drawback to this approach is that condition or traffic volume is not explicitly taken into account, and with time, Regions in ‘Good’ condition will tend to improve, and Regions in a poorer condition to deteriorate.

The allocation of pavement maintenance budgets is carried out for different road types:

- VRU (Voies Rapides Urbaines - fast urban roads)
- VCA (Voies a Caractere Autoroutier - roads with motorway characteristics)
- GLAT (Grandes Liaisons d’Amenagement du Territoire - main national links)
- RNL (Routes Nationales de Liaison - connecting highways)
- RNO (Routes Nationales Ordinaires - ordinary highways)

Part of the budget is allocated as a monetary sum per kilometre to each road type. The remainder of the Department budget allocation, B , for pavement maintenance is calculated using Equation 5.4.1

$$B = 10 * S_{VRU} + 6 * S_{VCA} + 4 * S_{GLAT} + 3.5 * S_{RNL} + 2 * S_{RNO} \quad (5.4.1)$$

Where S signifies the surface area of pavements of the given category (e.g., VRU)

For routine and winter maintenance, the funding per kilometre is allocated to each road type, taking into account the width of the pavement.

5.4.4 Methodology for fund allocation

The influence of the factors on maintenance costs for national or regional networks vary, and cannot be taken into account by a simple factor or ‘lump sum’. Furthermore, when the variations between countries and regions in treatment types, costs, and their relative priorities are considered, the situation is made more complex. Also, in addition to the above, pavements and bridges deteriorate at different rates, making ‘simple’ (but reliable) strategies for fund allocation difficult to find. The implication is, therefore, that assessment of maintenance funding requirements for a network should be carried out taking into account the characteristics of each road and pavement type individually. Then, once the structures have been assessed, maintenance requirements need to be prioritised (weighted) for effective fund allocation to obtain the appropriate network funding.

In addition to the above, the following points need to be addressed in a fund allocation procedure:

- Effective fund allocation for national or regional highway networks should take into account traffic and user costs in addition to direct works costs.

- Pavements and bridges are typically designed for around 20 to 40 years and 120, years respectively. Fund allocation should therefore take into account long- and short-term costs and benefits for both types of structures.
- To allocate funds between different types of structures (e.g., pavements and bridges), the financial worth of different options for bridges and pavements must be compared using a common base. This is especially important as maintenance procedures for these structures are different, incurring differing costs at different times in the life of the structure.

Life-cycle costs take account of the factors identified as being important for fund allocation and this work has established an approach in which life-cycle costing can be applied. Four alternative approaches were assessed using data appropriate to Motorways and Trunk Roads in England. The advantages and disadvantages of each method are discussed. In the description of the approaches, a road network is used, but the same approach can be applied to bridges, or a combination of pavements and bridges. To examine the approaches, an example road network, categorised by road type, traffic level and level of condition has been used. The proportion of the network in each category is given in Table 5.4.2. The same terms are used to describe the traffic levels and condition for all road types, but the values for each road type are particular to the road type (i.e., high traffic on a Motorway is more than high traffic on the Dual carriageway, etc.). For this analysis, all of the pavements have been assumed to be of flexible construction, but other categories could be introduced to represent other forms of construction.

All of the methods use a categorisation of the network. The categorisation should be made on the basis of information available and each category represented by a length of road that is typical of the roads in that category. To take account of the long-term maintenance costs for the road network, the life-cycle cost of the road length representing each category is calculated using the maintenance policy appropriate to that category of the network.

Table 5.4.2 Data for the example road network.

Road type	Traffic			Condition			Region	
	High (%)	Medium (%)	Low (%)	Good (%)	Average (%)	Poor (%)	North (km)	South (km)
Motorway (2x3 lanes)	79	16	5	34	34	32	1038	963
Dual carriageway (2x2 lanes)	20	20	60	34	34	32	1848	932
Single carriageway (1x2 lanes)	25	71	4	34	34	32	755	429

5.4.4.1 Method 1: Life-cycle cost ratios

For Method 1, the life-cycle cost of each road is calculated assuming the present maintenance policy continues to be applied in the future and sufficient maintenance funds are available. The life-cycle cost for each category is determined from the life-cycle cost of the road representing that category, multiplied by the length of road in the category. The sum of the life-cycle costs for all categories represents the life-cycle cost of the whole network. The ratio of the life-cycle cost of a category of the network to the life-cycle

cost of the whole network, represents the proportion of the maintenance budget to allocate to that category of the network.

The advantages of this Method are:

- The method is relatively simple to apply and can be used to distribute funds using the ratio of life-cycle costs calculated for each combination of pavement or bridge type. This may include level of condition, traffic flow and desired level of serviceability. In this way, all aspects of maintenance can be included in the assessment allowing, for example, the funding needs of a structural repair of a bridge and a pavement in a ‘Poor’ condition carrying a high traffic volume to be weighted fairly.
- The approach is flexible allowing a user to select an appropriate level of serviceability to be applied to different parts of the network. For example, the method takes into account values of life-cycle cost corresponding to a level of serviceability for single carriageway roads with low traffic and an alternative level of serviceability chosen for a Motorway.
- The approach can be applied for use with local, regional or national networks.

The principal disadvantage of this method is that the calculation of life-cycle cost for a given category uses a single measure of the level of serviceability. No explicit account is therefore taken of the existing condition relative to the level of acceptable serviceability specified in the maintenance policy for the category.

5.4.4.2 Method 2: Condition Targets

This improves Method 1 by incorporating the difference between the existing condition and the ‘target’ condition for the category. This enables categories of the network in a condition away from the target condition, to be given a higher priority for funding than categories which are close to the target condition.

The approach uses both the life-cycle cost of keeping each category of the network in the existing condition and the life-cycle cost of maintaining the same network at another target condition. The difference in these life-cycle costs represents the priority to be given to reaching the target condition. The differences are normalised to give the relative priority of all categories of the network as shown in Equation 5.4.2.

$$W = \frac{(WLC_{\text{target1}} - WLC_{\text{existing}})}{\sum (WLC_{\text{target1}} - WLC_{\text{existing}})} \quad (5.4.2)$$

Where WLC_{target1} = the life-cycle cost associated with maintaining the target condition
and WLC_{existing} = the life-cycle cost associated with maintaining the existing condition

The results from the analysis of the existing network showed that there were inconsistencies in the calculation of the weights. For example, negative values were present and

a Motorway with high traffic and in ‘Poor’ condition had a smaller weight than the same road type in ‘Good’ condition.

With this approach, negative values are obtained when the existing condition is better than the target condition, and the life-cycle cost for the existing pavement is thus higher than that for the target condition. To remove the negative values and so avoid distorting the calculated weights, all values were ‘rebased’. However, the effect of this, where one weight has a large negative value, is to make the other weights very similar in value and therefore reduce the relative priorities of the different categories.

The advantages of this Method are:

- Account is taken explicitly of two levels of condition and, hence, the difference between the existing condition and a ‘target’ condition can be included in the weighting.
- The method is relatively simple to apply.

The disadvantages of this Method are:

- A target condition and the existing condition are taken into account, but not a ‘minimum acceptable’ condition. A ‘minimum acceptable’ condition would give an indication of the effect of the difference between the existing condition and the minimum condition.
- Where ratios are calculated using the difference between target conditions, the relative magnitude of costs associated with different pavement types can be distorted. This, for example, can lead to a single carriageway road obtaining similar or greater funding than a highly trafficked Motorway.

5.4.4.3 Method 3: Minimum acceptable condition

This method takes into account three states of serviceability. In addition to the target condition and the existing condition used in Method 2, the minimum acceptable condition is also used. This approach allows for the increase in life-cycle cost associated with conditions lower than the target condition, if insufficient funds are available to carry out the required maintenance. The aim of Method 3 is therefore to give a higher priority to a category of the network where the target condition is only slightly better than the minimum acceptable condition, than to another category where the target condition is much better than the minimum acceptable condition. Where there are insufficient funds for all categories, a higher priority will be given to the category with a condition near to the minimum acceptable condition for that category.

The weights for Method 3 can be calculated using Equation 5.4.3.

$$W = \frac{WLC_{\text{target1}} - WLC_{\text{existing}}}{WLC_{\text{existing}} - WLC_{\text{target2}}}$$

$$W' = \frac{W}{\sum W} \quad (5.4.3)$$

Where WLC_{target1} = the life-cycle cost associated with maintaining the desired condition

WLC_{target2} = the life-cycle cost associated with maintaining the minimum acceptable condition

WLC_{existing} = the life-cycle cost associated with maintaining the existing condition

and W' = normalised weight

Similarly to Method 2, this Method again results in some negative values, where the existing condition is better than the target condition. Using the same rebasing technique used in Method 2, produced the same type of inconsistencies in the allocation. For example, a Motorway with high traffic and in 'Poor' condition had a smaller weight than a pavement on the same road type and with the same traffic level but with the pavement in 'Good' condition.

Method 3 can, however, produce a very different allocation between categories. The categories in poor condition do get higher weightings than the categories on the same road type in good condition, but the effects between road types can be misleading. This is due to a combination of the ratios of differences in target condition, and of rebasing. When the difference in life-cycle cost resulting from the existing and minimum acceptable conditions is small, the weights become large. The weights obtained therefore bear no relation to the absolute values for the category (i.e., a single carriageway road can have a larger weight than a motorway, if the existing condition is close to the 'target 2' condition). A means of differentiating between road classes in addition to states of condition is also required.

The advantage of this Method is:

- Explicit account is taken of the existing condition relative to the range of acceptable conditions (i.e., a minimum acceptable condition and a higher target condition).

The disadvantages of this Method are:

- As for Method 2, when rebasing is required to avoid negative values, if large negative values are present, there is little differentiation between the weights for each of the other categories.
- Calculating ratios of differences in life-cycle costs can lead to unrealistic funding allocations.
- The Method takes no account of the absolute values of the life-cycle costs for the category.

5.4.4.4 Method 4: Life-cycle cost multiplier

Method 4 overcomes the disadvantages seen in Methods 1, 2 and 3, to take into account two target levels of condition and enhance the difference in weights between categories by using the life-cycle cost associated with the target condition as a multiplier in the calculation of the weights. In addition, the present condition relative to the two target conditions is taken into account through the denominator shown in Equation 5.4.4.

$$W = \left[\frac{WLC_{target1}}{(WLC_{target1} - WLC_{target2})} \right] * WLC_{target1} \quad (5.4.4)$$

Where $WLC_{target1}$ = the life-cycle cost associated with maintaining the desired condition
 and $WLC_{target2}$ = the life-cycle cost associated with maintaining the minimum acceptable condition

Application of this Method can be described as a series of steps:

1. Calculate values of the life-cycle cost associated with the desired and minimum acceptable levels of condition for each category of the network requiring funds for maintenance
2. Calculate the weight for each category of network
3. Multiply each weight by the length of road in each category
4. Sum the multiples of weight times length
5. Calculate the ratios for each category, i , to determine the allocation as shown in Equation 5.4.5.

$$\text{Allocation} = \frac{W_i * km_i}{\sum (W_i * km_i)} * F \quad (5.4.5)$$

Where F = funds to be allocated.

To demonstrate the approach described in Method 4, for the network shown in Table 5.4.2, the life-cycle costs were calculated using the COMPARE Whole Life Cost Model developed by the Transport Research Laboratory on behalf of the Highways Agency (Abell, 1994 and Bowskill and Abell, 1994). The analysis was undertaken using works costs and maintenance policy typical of England. It should be noted that use of a different technique for calculating the life-cycle cost may give different values to those from COMPARE, but the overall approach is still valid.

Life-cycle costs include the costs to the road user incurred at maintenance works sites, in addition to the works costs incurred by the road authority. However, in some countries only the works costs are considered in assessing the difference between construction and maintenance options. The approach described in this study is applicable including, or excluding, the costs to the road user incurred at roadworks.

Figures 5.4.1 and 5.4.2, respectively, show the weights, as a percentage, to be used in the allocation of budget resulting from the analysis using life-cycle costs based on works and user costs and on works costs only.

In addition to the benefits gained from a life-cycle cost approach and the advantages listed for Methods 1, 2 and 3, the results show consistency between the weights for each category. For example, Motorways have a higher weight than single carriageway roads, and a pavement in ‘Poor’ condition and carrying ‘High’ traffic has a bigger weight than the category in ‘Good’ condition with ‘Low’ traffic on the same road type.

The general shapes of the plots in Figures 5.4.1 and 5.4.2 are similar, but not the same. This is due to the nature of the costs calculated and gives an indication of the effect of including user costs in life-cycle cost calculations. In particular, user costs are significant on pavements that have high traffic flows and these increase the weights on the heavily trafficked roads.

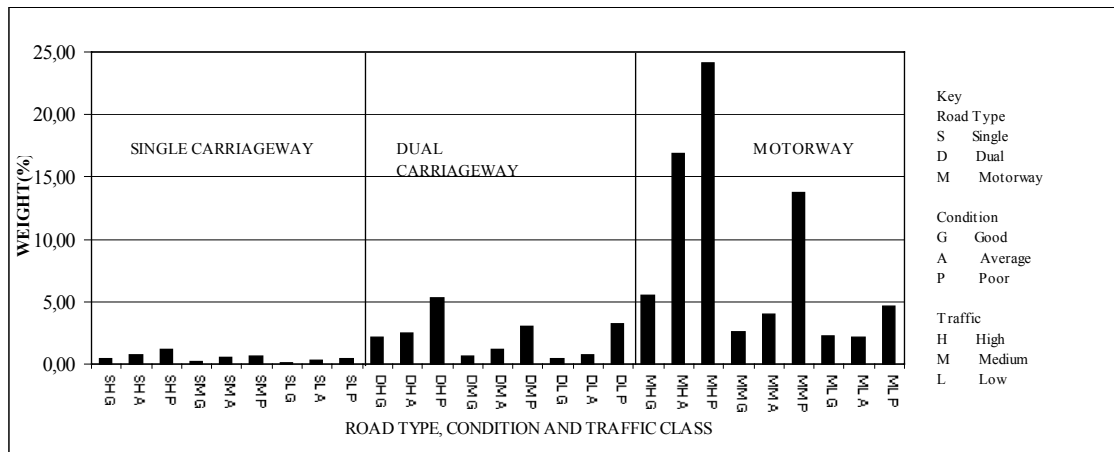


Figure 5.4.1 Weights for each road category based on the total works and user costs.

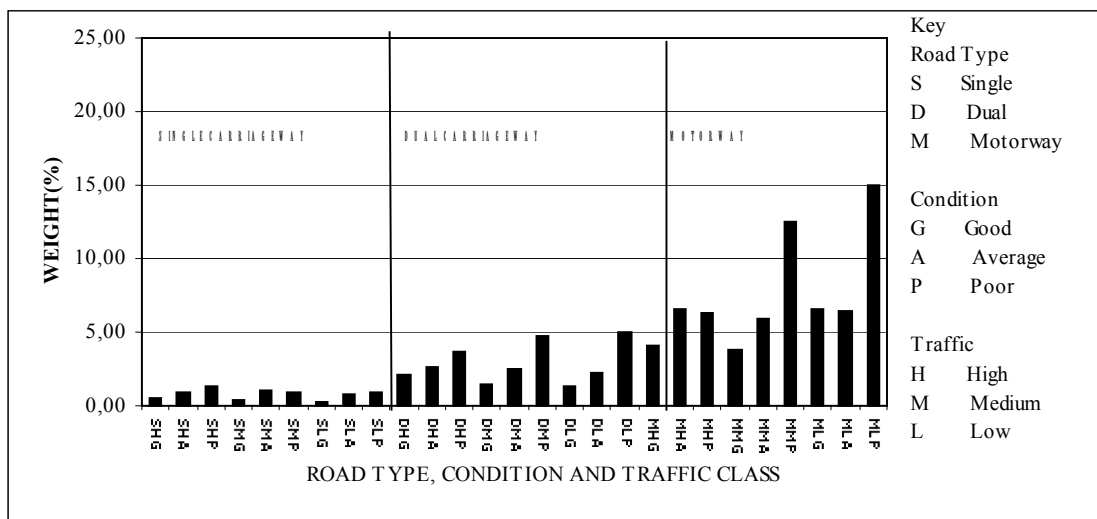


Figure 5.4.2 Weights for each road category based only on the total works costs.

5.4.5 Bridges

The approach described in Method 4 can be applied to any asset for which the life-cycle costs can be calculated. For funding of bridge maintenance, the same approach can therefore be adopted and, further, budgets for bridges and pavements can be combined and the shares of the budgets investigated. The principal advantage of this approach is that costs are ‘normalised’ by bringing values of all ‘items’ to a common time base.

The allocation of funds between pavements and bridges can be carried out in exactly the same way as described for pavements. In the description of Method 4, the budget was allocated between different categories of pavements in the network. To include bridges in the allocation, additional categories can be included to represent the different bridges in the network. These categories may represent different bridge types, different bridge types on different road types, or whatever categorisation is appropriate for the analysis and for which life-cycle costs can be calculated. The fund allocation procedure is therefore as follows:

1. Select representative categories of pavement and bridge types, conditions and traffic bands that are best suited to represent the network.
2. Calculate the life-cycle costs for each bridge type and length of pavement in each of the categories and compute values for weights using the ‘Method 4’ approach.
3. Scale-up the life-cycle costs to represent the network by multiplying the costs by the number of bridges or kilometre of pavement in the respective categories in the network.
4. Allocate funds to bridges and pavements using the ratios of the scaled-up life-cycle costs.

5.4.6 Public versus Private Finance

In recent years there has been an increase in the use of private finance to fund the addition of roads to the network and to provide the required level of service on parts of the existing network. There are various ways of undertaking this approach and, in some cases, the road authority may pay the private road operator directly, rather than introduce user tolls on the roads. When the payments are made by the road authority, this reduces the funds available for the other parts of the network. There is, therefore, a need to judge the value-for-money from the use of privatisation in this way.

In assessing the level of payment to make to the road operator, Method 4 can be used to help examine the level of funding required from the road authority. In moving part of the network to a private operator, the length of road in one or more of the categories is changed. This then affects the distribution of funds to the other categories in the network.

The overall procedure, using Method 4 in this way can be summarised as:

- Using Method 4, calculate the expenditure for the current network.
- The length of road to be privatised is removed and the maintenance budget for the remaining network reduced by the payment to be made to the private road operator.
- Using Method 4, calculate the new expenditure for the remaining network.

If the new allocation for maintenance is less than the allocation prior to transfer of the road, then privatisation of the road is not warranted for the level of payment to be made to the private road operator. The application of Method 4 is shown below:

	Original Network	Reduced network
Motorways	$km * W_m = A$	$km * W_m = E$
Dual Carriageways	$km * W_d = B$	$km * W_d = F$
Single Carriageways	$km * W_s = C$	$km * W_s = G$
Sum	$\sum km * W = D$	$\sum km * W = H$

The allocation is as follows:

Motorways	$(A/D) * M_{original} = AA$	$(E/H) * M = EE$
Dual Carriageways	$(B/D) * M_{original} = BB$	$(F/H) * M = FF$
Single Carriageways	$(C/D) * M_{original} = CC$	$(G/H) * M = GG$

Where $M_{original}$ and M represent the budget available for the network before and after transfer of the road to the private operator, respectively.

If AA , BB or CC is less than EE , FF or GG respectively, then the cost of the transfer is penalising the remaining part of the network.

5.4.7 Example Applications

The fund allocation technique developed as Method 4 has been used to demonstrate the approach using data from England, Denmark and Finland. Data from England has been used to illustrate the sensitivity of the allocation to changes in the categories of levels of condition. Data from Denmark has been used to show the effect of the proposed method on the complete Danish network, and, to illustrate the procedure for fund allocation between three Regions, data from Finland has been used. A full description of the sensitivity testing and budget analysis undertaken as part of this study is given in the full report on the work (PAV-ECO Work Package 4, 1999)

5.4.7.1 Sensitivity Analysis - England

The categories used to represent the Trunk Road network in England are given in Table 5.4.2.

To represent the pavement condition categories, the conditions of pavements near the beginning, at the middle and towards the end of their lives on each of the road types

were used. Representative traffic flows were used for each road type and the COM-PARE Whole Life Cost Model was used to calculate the life-cycle costs for each category.

The weights calculated for the 3 road types, 3 condition, and 3 traffic levels using data for two Regions from the English road network are shown in Figure 5.4.1.

To investigate the effect on the allocation caused by different regional characteristics, a selection of conditions were simulated using data from two other Regions in England, with changing pavement lengths, conditions and traffic flows. The categories and carriageway lengths used in the initial allocation are given in Tables 5.4.3 and 5.4.4. Figure 5.4.3 shows the weights for budget allocation between the two Regions using the total life-cycle cost.

Table 5.4.3 Condition and Traffic Distribution: North.

Road Type	Traffic (% of length)			Condition (% length)			Carriageway length (km)
	High	Me- di- um	Low	Good	Aver- age	Poor	
Motorways (2 x 3 lanes)	79	16	5	34	34	32	2077
Dual carriageway (2 x 2 lanes)	20	20	60	34	34	32	1695
Single carriageway (1 x 2 lanes)	25	72	3	34	34	32	1510

Table 5.4.4 Condition and Traffic Distribution: South.

Road Type	Traffic (% of length)			Condition (% length)			Carriage- way length (km)
	High	Medium	Low	Good	Average	Poor	
Motorways (2 x 3 lanes)	85	8	7	38	38	24	1925
Dual carriageway (2 x 2 lanes)	15	30	55	38	38	24	1865
Single carriageway (1 x 2 lanes)	100	0	0	38	38	24	859

Variation in the number of categories

The effect of using two, rather than three categories of condition was investigated by using an equal distribution between ‘Good’ and ‘Poor’ categories of condition, rather than the ‘Good’, ‘Average’ and ‘Poor’ categories used in the initial analysis.

Figure 5.4.4 shows the weights calculated for each category of pavement using total life-cycle costs. A comparison with Figure 5.4.3 shows the effect of using too few categories, when more complete information is available. In this example, the overall change in the allocation between the two Regions is small, but the graphs clearly show the change in the allocation for each road type.

Variation in traffic flow

Figure 5.4.5(a) shows the allocation between the two Regions for the initial distribution of traffic and condition. Figure 5.4.5(b) shows the distribution of funding between the two Regions when the traffic categories in North are amended to be 15%, 25% and 65% in the high, medium and low categories, respectively. There is no change in the categories for South. The chart shows clearly the reduction in the proportion of funding to North with the lighter traffic flows.

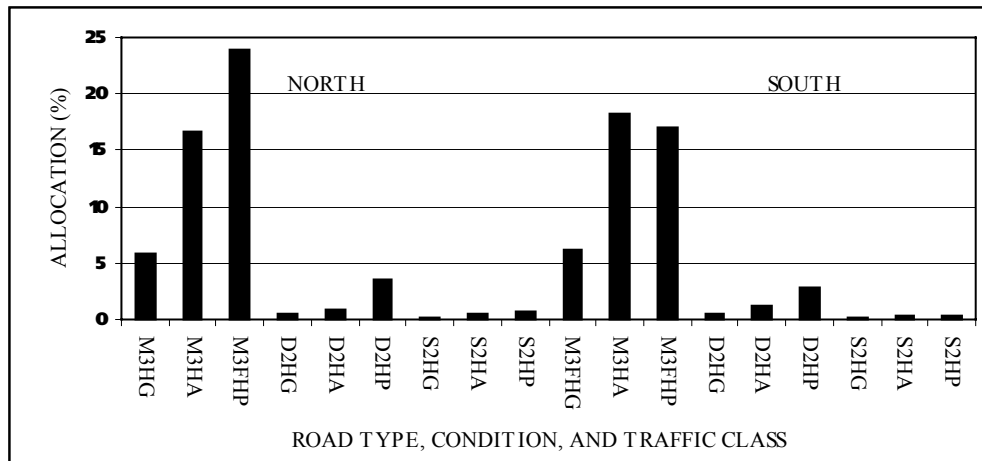


Figure 5.4.3 Weights for allocating budgets between North and South using 3 categories of condition (Good, Average and Poor).

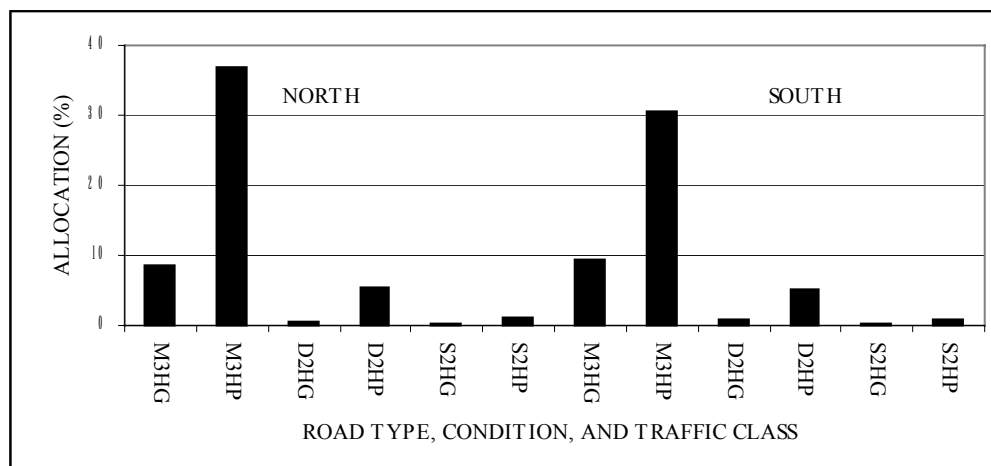


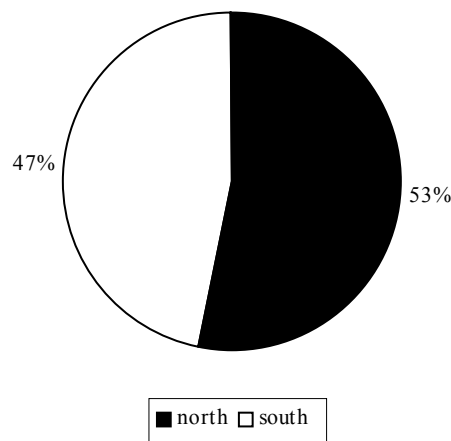
Figure 5.4.4 Weights for allocating budgets between North and South using 2 categories of condition (Good and Poor).

The following notation has been used for Figures 5.4.3 and 5.4.4:

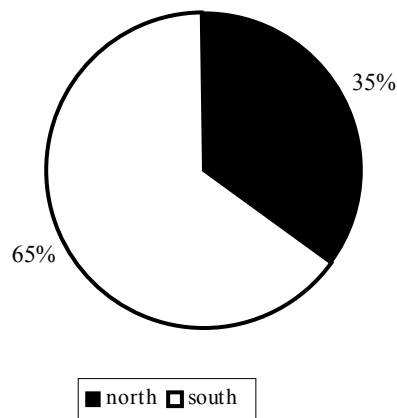
Road type:	S2 Single	D2 Dual	M3 Motorway
Condition:	G Good	A Average	P Poor
Traffic:	H High	M Medium	L Low

5.4.7.2 Fund allocation for pavements within a single region using Danish data

The road network in Denmark is managed as a single region. However, using information provided by the DRI for the Danish road network, the potential allocation of the maintenance budget between the different categories in the network was examined. The same number of categories as for England was used but the definitions of the categories reflected the road types, traffic flows and pavement condition in Denmark. A method for calculating the life-cycle costs using deterioration rates, cost relationships and other factors appropriate to Denmark was not available so the COMPARE Whole Life Cost Model was used with the data for the Danish road network, but with the deterioration relationships and maintenance treatments developed in England. With the lighter traffic flows and different climatic



(a) Original traffic categories



(b) Amended traffic categories

Figure 5.4.5 Effect of changes in traffic categories on the allocation between regions.

conditions, the predictions from COMPARE will not be accurate for Denmark, but the analysis indicated how the overall approach can be applied in Denmark.

Life-cycle costs were used to obtain the weights for ‘Average’ condition (for the three traffic classes) for Denmark. Using the results from these calculations, values for

‘Good’ and ‘Poor’ conditions for Danish roads were found using the ratios between ‘Good’, ‘Poor’ and ‘Average’ conditions derived for the UK data.

The procedure used was as follows:

For medium traffic flows and data from Denmark, life-cycle cost weights were calculated using the Method 4 approach with ‘Average’ condition.

For medium traffic flows, ratios between ‘Good’ and ‘Average’, and ‘Good’ and ‘Poor’ conditions, derived from the analysis of English data, were then applied to obtain weights for ‘Good’ and ‘Poor’ conditions for Denmark, as shown in Equations 5.4.6 and 5.4.7.

$$A_{Dm} * \left[\frac{G}{A} \right]_{Em} = G_{Dm} \quad (5.4.6)$$

$$A_{Dm} * \left[\frac{P}{A} \right]_{Em} = P_{Dm} \quad (5.4.7)$$

Where A represents the life-cycle cost weight for ‘Average’ conditions,
 P represents the life-cycle cost weight for ‘Poor’ conditions,
 G represents the life-cycle cost weight for ‘Good’ conditions,
 D represents Danish values,
 E represents English values, and
 m represents ‘Medium’ traffic level.

For high traffic conditions, the life-cycle cost weights for high traffic flow and ‘Average’ conditions were used with the ratio between ‘Good’ and ‘Average’ conditions calculated for Danish data in step 2, as shown in Equation 5.4.8.

$$A_{Dh} * \left[\frac{G_{Dm}}{A_{Dm}} \right] = G_{Dh} \quad (5.4.8)$$

Where h represents ‘High’ traffic level

Similarly for ‘Poor’ condition, the life-cycle cost weight for high traffic flow was calculated using Equation 5.4.9.

$$A_{Dh} * \left[\frac{P_{Dm}}{A_{Dm}} \right] = P_{Dh} \quad (5.4.9)$$

The same procedure was then used for low traffic flows with the appropriate life-cycle cost weights. The distribution of weights obtained is shown in Figure 5.4.6.

To obtain values appropriate for use with the categories used for fund allocation, weights for lengths of pavement in three categories of condition and with different traffic levels were calculated using the data supplied by Denmark, as shown in Table 5.4.5. The allocation derived from the life-cycle cost weights and the network information is shown in Table 5.4.6.

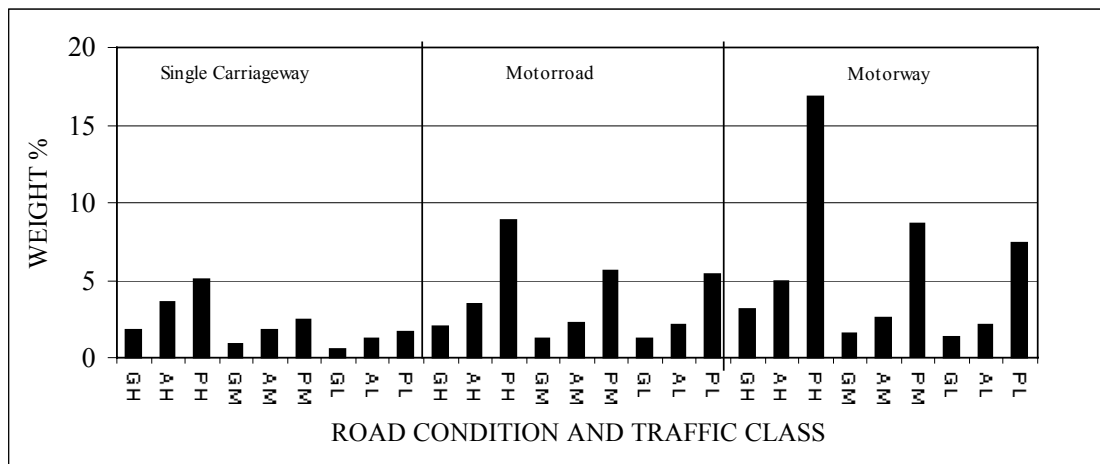


Figure 5.4.6 Weights (in %) for roads in Denmark based on road type, condition and traffic class.

Table 5.4.5 Danish road network information.

Road Type	Length (km)	Condition		Traffic Flow		
				High (%)	Medium (%)	Low (%)
Motorway	861	Good	77%	65	34	1
		Average	12%			
		Poor	11%			
Motorroad	147	Good	77%	3	73	24
		Average	12%			
		Poor	11%			
Single Carriageway	611	Good	77%	1	86	13
		Average	12%			
		Poor	11%			

Table 5.4.6 Fund allocation for the Danish road network.

Road Type	Allocation (%)
Motorway	84
Motorroad	7
Single carriageway	9

The allocation shown in Table 5.4.6 is similar to that currently used in Denmark, where 75% of the structural budget is allocated to Motorways, which form a large proportion of the total network. Further analyses undertaken into the effects of changes in road lengths and traffic levels showed the method continued to produce consistent results.

5.4.7.3 Analysis of Regions in Finland

Road network, pavement condition and traffic information for Finland, supplied by VTT, was used to calculate funding allocation ratios for three of the thirteen Regions. The Regions were Uusimaa, Turku and Kaakois-Suomi. These Regions were selected to show how changes in pavement condition and traffic in one Region can affect the budget allocation in the two other Regions. A summary of the network information is shown in Tables 5.4.7 and 5.4.8 for the three Regions. The pavement condition provided was described by unevenness (i.e., roughness, IRI value), strength (Bearing Ratio), surface condition (total area affected) and rut depth (mm).

To obtain appropriate values for the life-cycle cost weights, the method developed for data from Denmark was used. The resulting weights are shown in Figure 5.4.7, and show a consistent pattern between condition and traffic level.

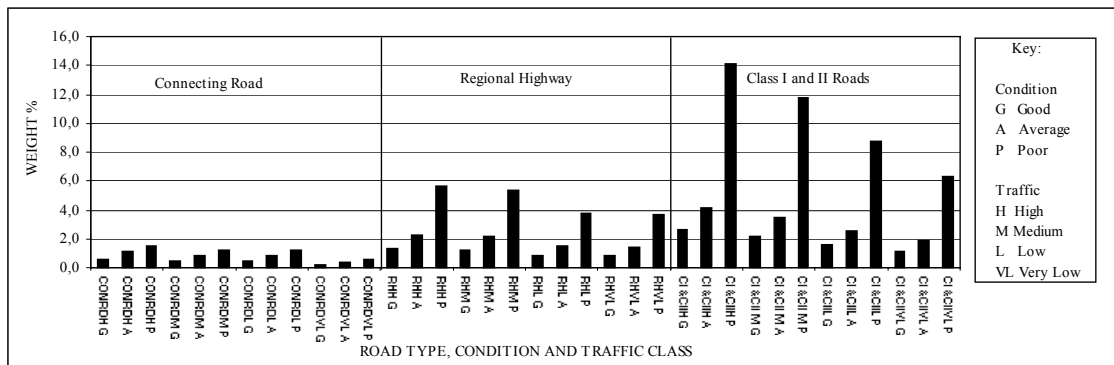


Figure 5.4.7 Weights (in %) for roads in three Regions in Finland based on road type, condition and traffic class.

Table 5.4.7 Pavement lengths and condition details for three Regions in Finland.

Road Type and Condition	Region		
	Uusimaa	Turku	Kaakois-Suomi
Class I: Total lengths	709	771	112
Good %	62	43	51
Average %	35	55	46
Poor %	3	2	3
Class II: Total lengths	292	359	288
Good %	58	33	70
Average %	39	59	26
Poor %	3	8	4
Connecting Roads: Total lengths	2120	3047	2175
Good %	41	44	48
Average %	41	39	34
Poor %	18	17	18
Regional Highways: Total lengths	764	1007	1483
Good %	52	56	56
Average %	43	37	32
Poor %	5	7	12

Table 5.4.8 Pavement lengths and traffic details for three Regions in Finland.

Road Type and Traffic	Region		
	Uusimaa	Turku	Kaakois-Suomi
Class I: Total lengths	709	771	112
High %	73	39	28
Medium %	27	60	71
Low %	0	1	1
Very Low %	0	0	0
Class II: Total lengths	292	359	288
High %	72	1	0
Medium %	28	65	45
Low %	0	23	55
Very Low %	0	0	0
Connecting Roads: Total lengths	2120	3047	2175
High %	3	1	0
Medium %	20	10	4
Low %	50	56	39
Very Low %	27	33	57
Regional Highways: Total lengths	764	1007	1483
High %	18	5	0
Medium %	45	39	11
Low %	37	54	75
Very Low %	0	2	14

The COMPARE Whole Life Cost Model was not designed to analyse all of these measures of condition, so a representative set of condition values were adapted from condition profiles generated by a COMPARE analysis. The fund allocations were cal

culated for the base data and the sensitivity to changes in network condition was examined by modifying the distribution of pavement condition for the three Regions. The three cases investigated were:

- (i) The base data (Case 1).
- (ii) Exchanging lengths of pavement in ‘Good’ condition with those in ‘Poor’ condition for the Uusimaa Region (Case 2).
- (iii) Exchanging lengths of pavement carrying ‘High’ traffic with lengths carrying ‘Low’ traffic in the Uusimaa Region (Case 3).

The resulting fund allocations between Regions are shown in Table 5.4.9. Exchanging lengths of ‘Good’ and ‘Poor’ condition and ‘High’ and ‘Low’ traffic in one Region did not involve a large change to the network picture and the changes have limited effects on the overall allocation between Regions. Nevertheless, those small changes still resulted in a change in the funding for the Uusimaa Region from 27% to 34%. With budget levels set very tightly, this change could have a significant effect on the way the network is managed.

Table 5.4.9 Fund allocation between three Regions in Finland.

Region	Case 1	Case 2	Case 3
	Original Data	Lengths of pavement in ‘Good’ and ‘Poor’ condition reversed	Lengths of pavement carrying ‘High’ and ‘Low’ traffic reversed
Uusimaa	29	34	26
Turku	35	32	36
Kaakois-Suomi	36	34	38

The fund allocation method has been applied to only three Regions but the same approach could be taken with all of the Regions. The importance of taking traffic and condition into consideration during the allocation procedure was illustrated by the change in allocated budgets when condition or traffic categories were amended. Use of three classes of condition and four classes of traffic appeared to work well, and highlights the need for the number of categories used to classify traffic and condition, to suit the network under consideration.

5.4.8 Discussion

Fund allocation methods for highway networks have been investigated using a literature survey and the development of an approach which takes the long-term performance of the network into consideration by basing the allocation on weights derived from the life-cycle costs of the network. The application of the new method has been demonstrated using data from England, Denmark and Finland.

The following points have been considered during the development of the fund allocation procedure:

- (a) Sufficient funds for the maintenance needs of the highway network are usually not available.

- (b) Maintenance requirements need to be prioritised if funding is to be applied in a cost-effective manner.
- (c) Highways are large, long-term assets and the funding of maintenance for these assets should be considered over a long time period, rather than simply examining the current condition.
- (d) Highway networks include roads and bridges and to make efficient use of available maintenance funding, a technique that can combine both of the maintenance requirements is essential. The technique needs to take into consideration different types of bridges and pavements as well as a variety of possible maintenance measures, and the times at which they are applied.
- (e) A technique that can take into account all of the requirements is life-cycle costing. To use life-cycle costs for pavements and bridges, relationships between condition, traffic, traffic delay costs and other factors affecting maintenance strategies and costs are required. It follows that for networks in significantly different areas or Regions (e.g., mountainous or flat terrain, or urban or rural environments) different cost models may be used.
- (f) It is clear that the various 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 approaches using life-cycle costs have been examined, with Method 4 (i.e., Life-cycle cost multiplier) being shown to meet the requirements to take into account 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.

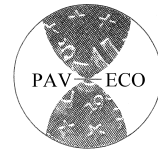
The two target conditions may be considered as representing a desirable condition and a minimum acceptable condition. The weights devised take into account the margin of deterioration (i.e., the worsening in condition that can be tolerated if there are insufficient funds for the full allocation).

- (g) Using the weights based on life-cycle costs, a general technique has been developed for fund allocation between Regions. The general approach is suitable for allocating funds between any assets and for investigating the long-term costs of changes to network size and budget level.

5.4.9 Conclusions

A method of fund allocation has been developed that takes account of long-term performance in current allocations and can be applied to pavements and bridges on local, regional or national highway networks.

The approach is not limited to pavements and bridges, and can be used with any item that can be 'valued' using life-cycle costs, whether they simply include works costs or they also take user costs into account.



The proposed fund allocation technique can be used to model the effects of privatising parts of a network on the remaining publicly-funded highways.

The proposed method depends on appropriate values of life-cycle cost being calculated for the network, or networks, under consideration. Accordingly, the techniques used to calculate the life-cycle costs must be appropriate to the situation to be modelled and the best available models should be used that include appropriate pavement and bridge deterioration models, works procedures and user costs.

References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.

5.5. EU VOC models

5.5.1 Introduction

Vehicle operating costs are all costs generated during the operational life of a vehicle which are at the expense of the user.

VOC form a significant component of the life-cycle costs associated with each link in a road network. The level of costs depends upon the condition of the pavement, the physical characteristics of the road link and the traffic flow on the road. It is not the amount of the rising costs which is interesting to determine, but its variation with regard to the deterioration of the network. It is therefore necessary to know the determining parameters in the different models and to study their sensitivity.

Vehicle operating 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 load of the vehicle, etc. A distinction must be made between running costs, which are caused by the use of the vehicle, and the fixed costs (licence, insurance, etc.). Even though fixed costs may be estimated exactly in most cases, this is not the case for running costs, which are rather difficult to determine.

Four main factors make up that part of the VOC which referred to as the running costs. These are fuel consumption, tyre costs, engine oil consumption, and maintenance and repair costs.

Fuel costs are an important component of VOC. For some vehicle classes in some countries, they represent more than fifty percent (>50%) of the total costs. The parameters affecting fuel consumption are the vehicle characteristics, the climatic conditions, the driving technique, the speed, the vehicle conditions, the load, the geometric characteristic of the road (unevenness, slope). It is important to note in this regard that fuel consumption leads directly to emission costs. Savings in fuel consumption equate directly to savings in the external costs.

Tyre costs are an important element of vehicle operating costs and they are sensitive to road conditions. Tyre costs depend on the driving technique, the climate, tyre quality, vehicle condition, load factors, road surface conditions, gradients and curvatures, and vehicle speed.

Vehicle lubricant costs, which include costs associated with the consumption of engine oils, other oils and grease, are a minor element of VOC. They typically constitute less than 3 percent of the total costs. The parameters that affect lubricant costs are road and traffic characteristics, operating policy and vehicle condition.

Vehicle maintenance costs are crucially important in the calculation of benefits to road condition improvements. They are a large component of VOC; they are sensitive to road conditions and accurately estimating their increase, as vehicles age, is essential in determining vehicle replacement expenditures, and thus depreciation and interest costs.

Vehicle maintenance costs depend on the type of vehicles, how they are used and on the geometric characteristics of the roads on which they are used.

5.5.2 Description of the HDM-4 model

At the beginning of 1969, the World Bank initiated a study with the aim of developing new quantitative bases for decision makers responsible for road design construction and maintenance. This study, called the Highway Design and Maintenance Standards (HDM), has become a major research programme in collaboration with institutions from many countries. It has led to the development of a model which permits the prediction of the total life-cycle costs of a road (construction cost, maintenance cost, user costs) as a function of road design, maintenance type and various political options that may be considered.

The development of models for Vehicle Operating Costs was carried out on the basis of research done in Kenya (1971-75), in the Caribbean (1977-82), in Brazil (1975-84) and in India (1977-83) and was finished in 1987. These models, grouped under the term HDM-III model, are essentially applicable to economies in transition [Watanatada et. al, 1987a, Watanatada et. al, 1987b, Chesher et. al., 1987].

Based on the HDM-III model, a new version named HDM-4 has recently been developed. In the new HDM-4, relationships for a total of 16 representative vehicles have been incorporated and updated using results from recent research conducted in New Zealand, South Africa and Australia. The vehicle speed models in the new HDM-4 are calculated separately under free-flow and congested traffic flow conditions. Revised free speed models have been developed based on the constrained speed model used in HDM-III.

Based largely on mechanical considerations, the various proposed models must, at some stage, be calibrated in a detailed way with a view to future use in countries of the European Union and central Europe. Table 5.5.1 presents the HDM-4 models which are related to User costs [University of Birmingham, 1999].

Table 5.5.1 HDM-4 user costs models.

Vehicle-related costs	Time-related costs
Fuel consumption	Crew hours
Oil consumption	Overhead costs
Tyre consumption	Passenger travel time
Vehicle utilisation and service life	Cargo transit time
Parts consumption	Road impassability costs
Labour hours	
Capital costs (depreciation)	

5.5.3 Sensitivity analysis of the HDM-4 models

The sensitivity analysis carried out on the global HDM-4 model was limited to the vehicle related components (as listed in Table 5.5.1, above).

For all the VOC models that have been selected, the constitutive parameters were grouped in three categories. The first, on which the analysis is based, is composed of variable parameters dependent on the geometric condition of the road. The second category includes parameters dependent on the type of vehicle used, while the third is related to parameters defined by default in the HDM-4 program.

Almost one hundred parameters were necessary to run simulations with the models. Their distribution according to the categories described above is: variable parameters (12), parameters related to vehicle type (61), parameters defined by default in the models (24).

The sensitivity analysis was carried on the variable parameters (12) using the characteristics for the medium passenger car vehicle type. For each of the parameters, the upper and lower variation bounds relative to conditions found on the national Swiss road network were determined. Table 5.5.2 presents these values.

Table 5.5.2 Upper and lower bounds relative to Switzerland for the variable parameters of the sensitivity analysis.

Variable	Description	MIN	MAX
PLIMIT(km/h)	Posted speed limit	30	120
WIDTH (m)	Carriageway width	7	10
RI (m/km)	Average unevenness (roughness) of road	1	5
GR	Average gradient of the road section in decimal form	0	0.08
dFUEL	Proportional increase in fuel consumption due to congestion	0	0.24
PCTDS (%)	Percentage of time driving on snow covered roads	0	1
PCTDW (%)	Percentage of time driving on water covered roads	0	10
TD (mm)	Average sand patch texture depth	0	2
R (m)	The average radius of curvature (note: ∞ = infinite)	75	∞
e (m/m)	Superelevation	0	0.07
a (m/s ²)	Vehicle acceleration	0	0.8

The first analysis consisted in determining the effect of an individual variation of each parameter on the VOC components (fuel, oil, tyres, labour hours, parts, service life). This approach allows one to define the determinant parameters which influence the VOC.

The following summary gives a global and rapid overview of the effect of each parameter of the HDM-4 model on the components of the VOC. The values given in Table 5.5.3 represent the percent variation of VOC when the value of each parameter varies between a minimum and a maximum which is common on the primary road network in Switzerland.

Table 5.5.3 Summary table showing the influence of the variation of the parameters on the components of VOC.

		Consumption of			Parts	Labour hours	Service life
		Fuel	Oil	Tyre			
Parameters to consider in a free-flow traffic condition (no congestion)	PLIMIT	10%	4%	30%	0%	0%	0%
	Gradient	39%	20%	37%	0%	0%	0%
	Width	2%	1%	3%	0%	0%	0%
	Unevenness	2%	1%	12%	17%	10%	5%
	Snow	0%	0%	0%	0%	0%	0%
	Water	1%	0%	1%	0%	0%	0%
	TD	1%	0%	1%	0%	0%	0%
	Curvature	2%	1%	0%	0%	0%	0%
	Elevation	0%	0%	0%	0%	0%	0%
Parameters to add in a congested situation	Accel-eration	0%	0%	68%	0%	0%	0%
	dFUEL	11%	4%	1%	0%	0%	0%

Where

- PLIMIT = posted speed limit
- TD = average sand patch texture depth
- DFUEL = proportional increase in fuel consumption due to congestion

It may be observed in Table 5.5.3, above, that only three parameters mainly influence VOC (grey cells) in a free-flow traffic condition. These parameters are the speed limitation (PLIMIT), the gradient (GR) and the unevenness (roughness, RI).

The congested situation has not been taken into account in the comparison of models.

5.5.4 Description of other VOC models

Based on a bibliographic study [PAV-ECO, WP 5, 1999], as well as on a report prepared by the Partners of the RIMES Project, 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.

Table 5.5.4, following, presents a summary of the characteristics of the various models and permits a rapid evaluation.

Table 5.5.4 Summary of the characteristics of the various models.

Feature	HDM-4	HEN 2	VETO	FIN-VOC	NOR-WAY	BEL-MAN	Hungary	ARI-ANNE	Germany
Basis									
Statistical	X	X	X	X	X	X	X	X	X
Mechanistic	X	-	X	-	-	-	-	-	-
Vehicle operation									
Free-flow speed	X	X	X	X	X	X	X	X	X
Congested speed	X	X	X	X			-	X	X
Typical vehicles									
Default	X	X	X	X	X	X	X	X	X
User specified	X	-	X	-	-	-	-	-	-
Road variables									
Gradient	X	X	X	X	X	X	X	X	X
Curvature	X	-	X	X	X	X	-	X	X
Superelevation	X	-	X	-	-	-	-	-	-
Unevenness	X	-	X	-	X	X	-	-	-
Pavement type	X	-	X	-	-	-	-	-	-
Texture	X	-	X	-	-	-	-	-	-
Snow, water, ice	X	-	X	-	X	-	-	-	-
Wind, temperature	X	-	X	-	-	-	-	-	-
Absolute elevation	X	-	X	-	-	-	-	-	-
VOC components									
Fuel	X	X	X	X	X	X	X	X	X
Non-fuel detailed	X	-	X	-	X	X	-	-	-
Non-fuel global	-	X	-	X	-	-	X	X	X

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 FIN-VOC, 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.

5.5.5 Comparison between HDM-4 and the German model

The objective of these investigations is to determine what between a complex as HDM-4 VOC model and a simple model as the German model is the most fitting, according to the characteristics of the European networks.

In the German model, the same cost components as in the HDM-4 model are considered, but in a more simplified way. They are grouped in two components: fuel consumption, which is calculated, and the cost unit rates, which are defined for each type of vehicle and include all of the other (depreciation, tyre wear, maintenance, servicing, lubricants).

Table 5.5.5 represents a sort of characteristic form for both models in order to compare them and to be aware of the parameters used in each model.

Table 5.5.5 Table comparing the HDM-4 and the German models.

	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)

Comparison of the results has been undertaken in two parts which consider the operation of a vehicle of the medium passenger car type in a free-flow traffic situation. The first part only considers fuel consumption, while the second part considers all of the other operating costs of the vehicle.

Regarding the fuel consumption comparison, the results show the same trend for each model. Figure 5.5.1 shows fuel consumption as a function of speed determined by the HDM-4 and the German models for identical road characteristics.

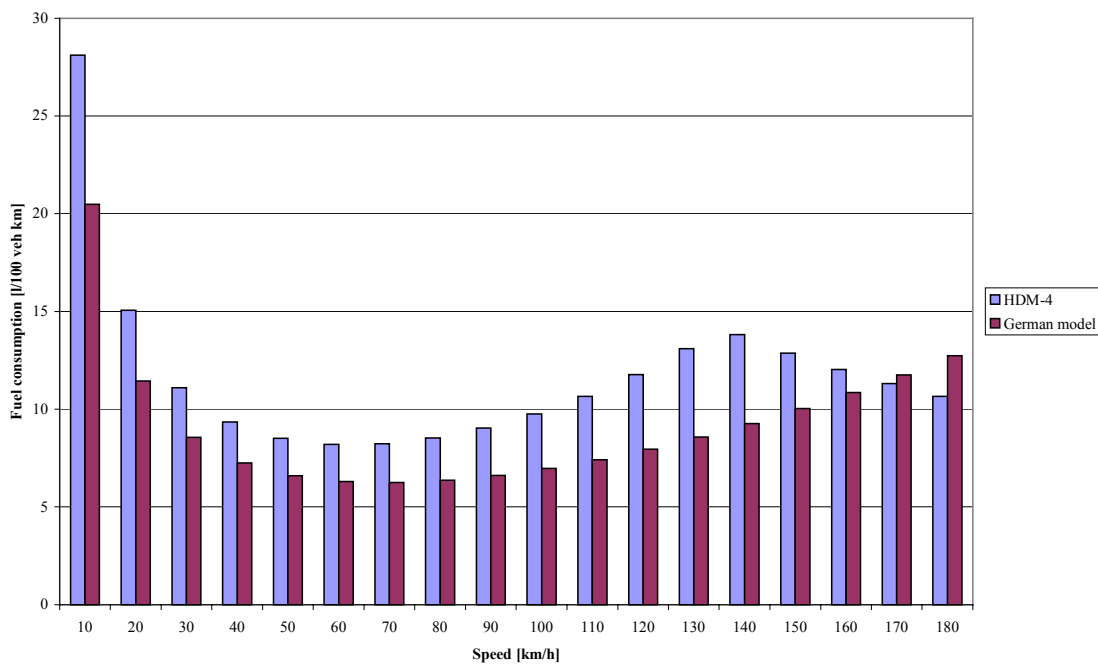


Figure 5.5.1 Comparison of fuel consumption as a function of speed for the HDM-4 and the German models.

Concerning the non-fuel components comparison, the results shows that the German type model gives no variation between the best/worst cases whereas the HDM-4 model is sensitive to the variations, as shown in Table 5.5.6.

Table 5.5.6 HDM-4 sensitivity of non-fuel components with respect to total VOC.

	HDM-4		
	Variation between worst and best situations	Proportion of component cost to total non-fuel cost	Effect of variation of component to total non-fuel cost
Oil consumption [l/1000 km]	26%	3%	1%
Tyre consumption [% of new tyre price/1000 km]	69%	10%	7%
Labour hours [number of hours/1000 km]	10%	45%	5%
Parts consumption [proportion of new vehicle price/1000 km]	0%	21%	0%
Depreciation [proportion of new vehicle price/1000 km]	0%	21%	0%

A sensitivity analysis of the two VOC models (fuel + non-fuel components) based on extreme road conditions on the primary road network in Switzerland shows a bigger sensitivity of the HDM-4 model, as shown in Table 5.5.7.

Table 5.5.7 Comparison of the sensitivity of the HDM-4 and the German models to the total VOC.

	HDM-4		German Model	
	Worst situation	Best situation	Worst situation	Best situation
<i>Variation of total VOC</i>	30%		7%	

Referring to the results of Column in grey of Table 5.5.8, and considering that the fuel component represents approximately 40% of the total VOC, the effect of the variation of the various non-fuel components on the total VOC are shown in Table 5.5.8, following.

Table 5.5.8 Effects of variation of a component on total VOC determined by HDM-4.

	Effect of variation of a component on total non-fuel cost %	Effect of variation of a component on total VOC %
Oil consumption [l/1000 km]	1	0.6
Tyre consumption [% of new tyre price/1000 km]	7	4.2
Labour hours [number of hours/1000 km]	5	3.0
Parts consumption [proportion of new vehicle price/1000 km]	0	0
Depreciation [proportion of new vehicle price/1000 km]	0	0

A study carried out by Viagroup [Scazziga, 1990] has quantified the relative proportions of the various types of user costs (VOC, accidents, time) of the yearly expenditures set aside for maintenance of the Swiss primary road network. The results, given in Table 5.5.9, show that a only minor proportion (< 2%) is due to vehicle operating costs.

Table 5.5.9 Proportion of the three main user cost types relative to the total expenditure in the national Swiss road network.

Type of cost	Proportion of the total expenditure
Vehicle operation	< 2%
Accidents	approx. 10%
Time loss	approx. 25%

Considering the condition of the Swiss primary road network, based on the IRI Index distribution (see Figure 5.5.2), the whole network is clearly in good condition, and thus the variation of VOC between worst and best situation will be very small.

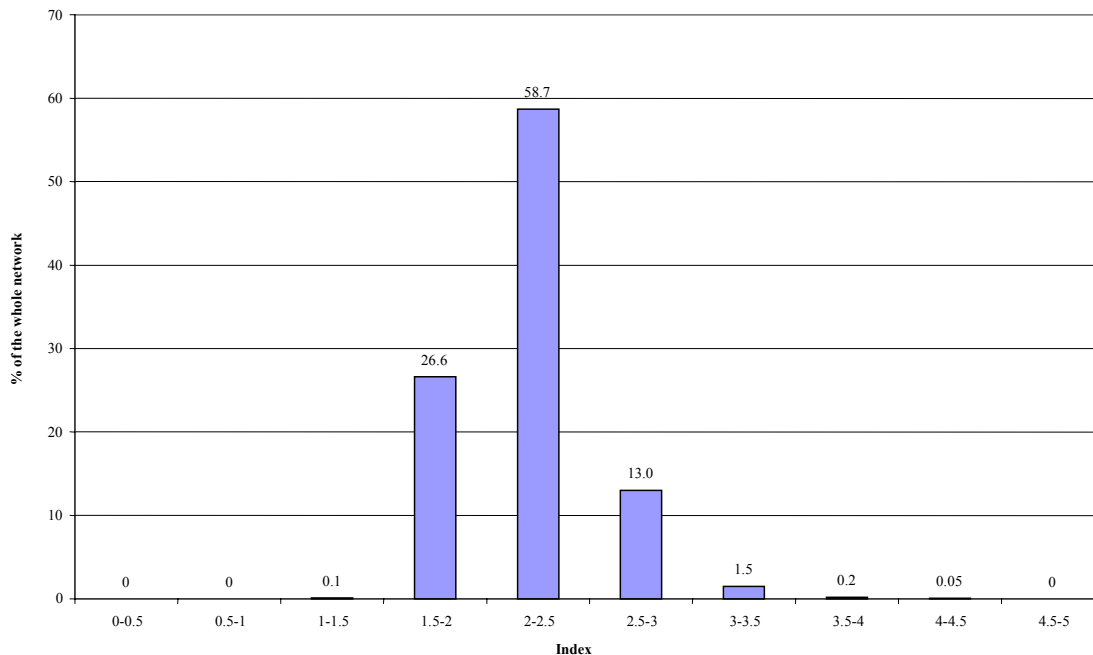


Figure 5.5.2 Distribution of the Swiss network as a function of the IRI index.

Given these results, it may be concluded that the assessment of VOC, for a road network comparable to that in Switzerland (i.e., European conditions), is not worth considering.

5.5.6 Conclusions

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 which shows the greatest sensitivity in its results with respect to 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%) present 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 HDM-4, is not useful and therefore a more simple model, which includes the vehicle speeds and the gradients as parameters, such as the German model, is more suitable for European conditions.

Consequently the German model was selected for use in the calculations of VOC in the work reported in Chapters 5 and 7.



References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.



6. Dissemination and Exploitation of Results

Beyond the technical and scientific deliverables from the five operational Work Packages, the PAV-ECO Project produced identified the need for a Work Package to cover the dissemination and exploitation of results from the Project.

This chapter does not present any model, method or scientific results, but it describes all the actions that were undertaken by the Project team to disseminate the results from the Project. The chapter further outlines the exploitation plan of the Project.

6.1 Intellectual Property Rights

The PAV-ECO consortium had no aims for the commercial exploitation of the results from the Project. The consortium was made up mainly of national highway research laboratories and universities, whose research results are in the public domain. The two private consultants who contributed to the Project do not claim ownership of any property rights to the results of the PAV-ECO Project.

The results of the Project are therefore in the public domain, and the consortium will pursue the implementation of these results without seeking commercial revenues.

6.2 Dissemination

6.2.1 General Dissemination Activities

Apart from special events like conferences and seminars, the PAV-ECO consortium provided the European public with up-to-date information on the Project in two ways: by a Newsletter and via the Internet.

The PAV-ECO Newsletter

The Newsletter, published in both English and French, regularly provided an update on the Project. The first edition, which was issued on August 1998, presented the objectives and the organisation of PAV-ECO. It also covered the research work carried out from October 1997, when the Project started, until July 1998. The second edition, which was issued in May 1999, covered the period following, ending at April 1999. The current status of the Project at this date was described. The opportunity was also taken to present the workshop to be held in Brussels in June 1999, during the pre-opening day of the 2nd European Road Research Conference. In December 1999, the third edition of the Newsletter was issued, presenting the final results of the Project.

The PAV-ECO Newsletter was widely distributed, especially to the European Road Directorates and Road Network Management Authorities, and also to the European Experts, such as the FEHRL Members.



The PAV-ECO website

The website [<http://lavocwww.epfl.ch/ProjetsEuropeens/pav-eco/>] was created by LAVOC from the Project commencement, and will be maintained at least until the end of 2000. It consists of two separate parts: the internal mail box and the public site. The internal mailbox was exclusively used by the Partners, to exchange information such as meeting programmes and dates. The minutes of meetings were also available to the Partners, as well as monthly reports. The public part aims at making available, to all those interested, the major documents and Deliverables from the Project. As a general rule, any relevant Project document was made available on the site shortly after it was delivered to the European Commission. For convenience, only the Executive Summary of the Final Reports of each Task and work-package were accessible on the website. The Newsletters could also be read on the website. A direct link was made between the PAV-ECO website and others, such as CORDIS (the European Commission), FEHRL, PARIS (another European Project closely related with PAV-ECO), and the homepages of the various Project Partners.

6.2.2 Dissemination of the results during the Project

The PAV-ECO Partners took the opportunity offered by the 2nd European Road Research Conference to present the main Deliverables of the PAV-ECO Project. Other presentations were prepared, depending on the opportunities offered by international conferences.

2nd European Road Research Conference

The 2nd European Road Research Conference was held in Brussels between the 7th and 9th of June, 1999. Although the Project was not completed at this time, the opportunity was taken to present its first results. Thus, a general paper entitled Development of models for the economic evaluation of maintenance: the PAV-ECO Project [Lepert Ph., Hildebrand G., 1999], was presented during the session on Pavement Management Systems. Its main objective was to explain the Project. In the first part, the context in which road management systems are developed and used in European countries was addressed. This presentation was based on the literature review, and on the interviews of Road Directorates conducted during the Project. In the second part, the Project programme was explained. Emphasis was placed on the impact of changes in traffic flow on maintenance needs, social economic effects from maintenance works, allocation of funds for different infrastructure components, and vehicle operating costs.

A joint workshop was organised by the PAV-ECO/RIMES teams in connection with the conference; at this workshop four papers authored by members of the PAV-ECO consortium were presented [PAV-ECO, 1999].

The first presentation entitled The PAV-ECO Project provided an overview of the Project, while the second presentation, entitled Pavement Maintenance Measures Evaluation, mainly reported on the work done, and the results obtained, within Work Package 1. After a general description of the framework of life-cycle cost analysis on individual road projects, the paper addressed the comparison of the financial costs to the road agency, economic costs to road users during the service life of the road, and the additional costs to road users caused by maintenance works, associated with alternative

maintenance strategies. This paper also addressed the concepts of residual life and salvage value of the pavement, as it was developed in Work Package 1.

A third paper was presented, describing the results of Work Package 2. It was entitled: Impact and Integration of Traffic Change in Pavement Management. The paper described the way in which the impact of traffic change has been managed in the Project.

The fourth presentation was entitled: Social Economic Evaluation of Pavement Maintenance. This paper stated that the aim of a global pavement management approach must be an essential improvement of the road maintenance and rehabilitation policy. Therefore, the objective of the PAV-ECO Project, and especially of Work Package 3, was to strengthen the social economic evaluation models used in current maintenance management procedures. The basic idea was to develop an analytical framework, based on a traffic simulation model that allows a consistent cost-benefit analysis for all kinds of pavement management strategies. The paper gave an overview of the PAV-ECO research results on this topic, and also included a ranking of these various pavement strategies by benefit-cost ratios.

About thirty people were present at the Workshop. The discussion addressed the different aspects covered by the presentations, and enabled more in-depth discussions of some points, such as the influence of maintenance on VOC, on accidents, and on pollution.

Other dissemination activities during the Project

In order to promote the results of the Project, the Technical Committee of PAV-ECO encouraged all Partners to prepare papers and presentations displaying the results of PAV-ECO.

By the beginning of May 1999, a paper was presented by the LCPC at the Joint Congress of the Canadian Institute of Traffic Engineers (CITE) and the Association Québécoise des Transports et des Routes (AQTR). This paper, entitled: Towards a better evaluation of the profitability of road maintenance, in Europe [Lepert et. al., 1999], provided an excellent opportunity to inform North American pavement engineers about the PAV-ECO Project. It gave an overview of the pavement maintenance situation for a large number of European countries.

In September 1999 the PAV-ECO Project was presented in Helsinki at the annual seminar of The Finnish Road Structures Research Programme 1994-2001 (TPPT). The presentation was made in Finnish and focused on life-cycle costs at project level.

6.2.3 Dissemination of the results after the conclusion of the Project

Dissemination of the Project results will continue after the conclusion of the Project; this section describes the plans currently in action to achieve this.

International Conferences

The 1st European Pavement Management Systems Conference will be held in Budapest in September 2000. This was recognised as an excellent opportunity to disseminate the

results of the Project, which were still not available at the 2nd European Road Research Conference. Therefore the Partners, and particularly the leaders of Work Packages 1, 4 and 5, prepared four abstracts which were submitted to this Conference secretariat. In June 2000, a presentation of the PAV-ECO Project will be given at the Nordic Road Association Conference, which will be held in Malmö, Sweden.

Organisation of regional and national seminars

The PAV-ECO Partners also tried to promote the results from the PAV-ECO Project at national or regional level, at least in each participating country. To achieve this goal, the Partners decided to prepare different conferences, at national or local level, in which they would present the Project and its results. Naturally, these meetings could not be held before the end of the Project, and only after submission of the complete set of results to the European Commission. However, such events have to be prepared well in advance and advertised early. The Partners consequently decided to commence planning the various events as soon as the last quarter of the Project was reached.

From the beginning of this action, it was recognised that PAV-ECO Project could not be presented alone, since it addresses only part of the complete infrastructure management process. Therefore, in most cases, the meetings combined a presentation of PAV-ECO results with a presentation of some other Projects or research work, which clearly completed and complemented the work done in PAV-ECO. Typical examples are joint presentations of the PARIS and PAV-ECO results by LAVOC (in the autumn of 1999), or LCPC + LAVOC + Viagroup + BRRC of Belgium (at the beginning of 2000). Other meetings are proposed to be held in spring 2000 when DRI, TRL and UoC, respectively, will participate in regional or national arrangements with the aim of disseminating the final results of PAV-ECO.

In many cases, language is a barrier to the dissemination of results. Having recognised this difficulty, LCPC together with LAVOC, Viagroup and BRRC planned a common French speaking meeting dealing with both PAV-ECO and PARIS Projects. This meeting will be held in Strasbourg, which is a suitable central location for the Belgian, French and Swiss administrators and experts concerned.

6.3 Exploitation

The primary implementation of the Project's results lies with road authorities across Europe, at all levels of pavement management - national, provincial and municipal. The people involved with pavement management at road authorities can be reached in two ways.

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 (see Appendix 6). Five FEHRL member institutes were represented in the consortium undertaking the PAV-ECO Project and these are in close relationship with the other 18 members. By sharing the results with their fellow member institutes and by making the models from the Project freely avail

able to the practitioners of road pavement management, direct implementation of the Project results at national level will be attained. Once implemented at that level, 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. These firms offer complete software packages to their clients, who normally do not investigate in detail the technical management planning engine of the software. In other words, 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.

References

Fuller details for the references quoted in this Chapter can be found in the References section immediately following Chapter 7, Summary, Conclusions and Recommendations, and in Appendix 1: List of Deliverables.



7. Summary, Conclusions and Recommendations

7.1 Summary

Interviews of representatives from road directorates in fifteen European countries and a literature review established a basis for the work on 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.

A framework was developed for comparison of 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.

Maintenance work zones cause additional costs to the road users, mainly in terms of increased travel time. Maintenance works also affect vehicle operating costs by 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.

A method based on the pavement condition at the end of the analysis period was developed to estimate pavement preservation as the relative proportion of the cost of rehabilitation to restore the road pavement to its initial structural condition.

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 and simple linear traffic forecasts lead to the traffic level exceeding the capacity on some road sections. If the over-capacity traffic is diverted to other routes, the maintenance requirements for those routes will increase, whereas the road section with less traffic will require less maintenance. Thus it is important to base the maintenance strategy on reliable traffic forecasts and traffic assignment models.

The impact of change in traffic was examined in terms of traffic forecasts and traffic simulation models. Forecasts involve the descriptions of determinants for the supply and demand of traffic; determinants for European road networks have been identified and were used as a guideline for establishing traffic forecasts. The use of traffic simulation models, both at the network level and at the project level, was investigated. At the network level, a traffic simulation model for the consistent analysis of alternative maintenance strategies was described. At the project level, traffic models for a complex road network, as well as for a simple road network were assessed. For the simple network at the project level, a prototype traffic assignment model was developed to demonstrate the approach.

The most effective pavement maintenance strategy can be considered as one which requires the minimum costs for the preservation of the road investment, or to maintain the road condition at its initial condition. The costs involved consist of investment costs and the social costs (time, vehicle operation, accidents, air pollution, CO₂-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; and social costs arising from the traffic at work sites should also be considered.

The evaluation of the social economic effects from maintenance of the road infrastructure considers the society rate of return (based on investment costs and social costs) resulting from the use of three alternative maintenance strategies. Situations where a single measure or a succession of measures, within the strategy, are considered. This type of analysis illustrates how maintenance measures of limited expenditure carried out at high frequency can be compared with measures of larger expenditure carried out at a lower frequency. Furthermore, the preservation of investment costs at the network level is discussed and a model is presented which 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.

Current fund allocation methods for road networks were investigated using the results from a literature survey. This found little information on methods available that took into account anything other than size of network, current traffic levels and climatic zones. A new approach was developed using 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. 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.

Vehicle operating costs comprise all the ownership costs occurring 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. To study the variation of vehicle operating costs with regard to the deterioration of the road network, various vehicle operating cost models were evaluated and the sensitivities of the model parameters were examined.

The major objective of the evaluation of vehicle operating costs models appropriate to European conditions involved a review of the HDM-4 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 vehicle operating cost model, like that developed in Germany. Based on the results of this work, a simple model is proposed for use in life-cycle analyses in European countries.

Beyond the technical and scientific Deliverables of PAV-ECO, attention was given to the dissemination and exploitation of the findings from the Project. The PAV-ECO



Partners had no ambitions for commercial exploitation of the results from the Project, so all findings from the Project are available, in the public domain.

Dissemination of the results from PAV-ECO took place during the Project and will continue after completion of the work. Two major sources of information on the Project were the PAV-ECO Newsletter and the PAV-ECO Internet website. The Newsletter was published three times; at the start of the Project, at midway, and after its termination. The PAV-ECO website was created at the start of the Project and will be maintained until the end of 2000. The aim of the website was to provide all interested parties easy access to major documents and to the Deliverables from the Project.

On several occasions during the Project, the PAV-ECO Partners presented the Project work. The major event for dissemination was the 2nd European Road Research Conference held in Brussels in June 1999; another dissemination activity during the Project was presentation of the Project at a conference in Canada in May 1999.

A number of dissemination activities have been planned for the first year following the conclusion of the Project. Four abstracts have been submitted for the 1st European Pavement Management Systems Conference to be held in Budapest in September 2000, and a planned presentation at the Nordic Road Association Conference in June 2000. In parallel, some of the Partners also have made national or regional arrangements to promote the PAV-ECO Project results in the spring of 2000.

The primary route for implementation of the Project's findings is with road authorities in Europe. People involved with highways management at these agencies will be approached, both at the national level through the Forum of European Highway Research Laboratories and at local level through private consulting firms. While the national highway authorities can benefit from implementing the PAV-ECO results at the national level, local road authorities often implement pavement management technologies with the assistance of private consultants.

7.2 Conclusions

Based on the five technical Work Packages of PAV-ECO, the following conclusions can be drawn from the research work:

A framework has been developed for the comparison of life-cycle costs of different maintenance strategies and treatments at the project level. Its use involves the calculation of road owner and user costs over a selected analysis period. The difference in costs between the alternatives are examined, with costs occurring in future years of the analysis period discounted back to the beginning of the period. A method based on the pavement condition at the end of the analysis period has been developed to estimate the pavement preservation value as the relative proportion of the cost of rehabilitation to restore the road pavement to its initial structural condition.

Annual user costs are calculated in a number of European countries using a modified HDM-III model or a national model. At the high level of maintenance applied in those countries on motorway and primary road networks, the VOC do not vary with the levels of road pavement condition. In the case of work zones, the VOC are affected by fuel

consumption, speed and lengthier diversion routes. However, where maintenance is deferred, additional user costs due to high unevenness levels, can be calculated from the changes in VOC due to road condition.

The need for development of models to estimate additional user costs due to maintenance work zones and to calculate the costs of preserving pavement condition is recognised by most road authorities, even though such models are in use only in a few countries. Very few literature references were found for models developed to estimate additional user costs due to maintenance work zones.

A model is proposed to estimate the additional time costs and the additional VOC due to maintenance work zones in terms of the difference in costs between a with-maintenance case and a without-maintenance case.

Without roadworks, the accident rate depends upon factors including road geometry, surface condition, climatic condition and traffic volume; the accident rate increases at roadworks sites, but reliable models for the estimation of the additional accident costs could not be established as the existing data is diverse and too limited in quantity.

There is a need for more accurate data regarding the distribution of traffic on road networks, particularly when determining future pavement maintenance strategies. The linear projection of current traffic flows into the future can lead to a very biased distribution of traffic around the network if the capacity of the road sections is not taken into account.

The origin-destination model was found to be the most suitable for both project and network level, as it includes the whole network as a coherent system of road sections; if one section is over-loaded, traffic will be redistributed. The results from the model give traffic flows on all the road sections and the results can be treated as a traffic census database. For cases when an origin-destination model is not available, an alternative network level model is presented, which is very useful when assessing long-term investment plans – not only road pavement rehabilitation plans.

A simple, prototype, project level, traffic assignment model has been developed as a tool for the planner to carry out a sensible redistribution of traffic in the case of reassignments due to road maintenance works.

It is not only the investment costs that should be considered in life-cycle cost analyses of road projects, but also the social costs, consisting of user costs (costs of time, vehicle operation, accidents covered by insurance) and third party costs (costs of air pollution, CO₂-emissions, accidents not covered by insurance). The effects of three different maintenance strategies (good, medium and poor condition) were compared. It was found that the effect of work sites is mainly to affect social costs, by increasing the time costs and accident costs, while the effect on other social cost components is negligible.

A case study examined the efficiency of three different maintenance strategies for road networks in Denmark, France and Germany under either static (one maintenance measure within a fifteen year period) or dynamic (suitable maintenance measures at relevant intervals within a fifteen year period) conditions. While the static evaluation provided

little information, the dynamic evaluation enabled the efficiency of the strategies to be expressed by benefit-cost ratios.

A number of European VOC models have been evaluated to assess their suitability for inclusion in life-cycle cost models for roads in Europe. Among the models investigated, the HDM-4 model was found to be the most detailed. A sensitivity study of the HDM-4 model showed that only the parameters of vehicle speed, road gradient and unevenness of the road surface had a significant influence on the VOC. Furthermore, for a high-standard European network with a narrow band of unevenness values, the contribution of the unevenness component to VOC is negligible. Hence, only vehicle speed and road gradient need to be considered when determining VOC.

A comparison between the HDM-4 model and a simpler VOC model developed in Germany, which mainly depends on fuel consumption and vehicle speed, confirmed that a simple VOC model, which takes vehicle speeds and road gradients into account, is suitable for European road conditions.

7.3 Recommendations

The conclusions stated in the previous section lead to a number of recommendations for application of the PAV-ECO findings, as well as for further research activities within the field of life-cycle cost analyses of pavement maintenance strategies:

The suggested framework for the comparison of life-cycle costs of different maintenance strategies and treatments should be applied at network level, as well as at project level. Similarly, the concept of preservation of capital investment should be applied at network level, as well as at project level.

There is a need in Europe for models addressing additional user costs due to maintenance work zones. Furthermore, the development of models for quantifying the social costs of accidents at road maintenance work zones should be initiated.

Models for traffic distribution and vehicle speed due to road maintenance work zones should be developed and implemented in life-cycle cost analyses.

Traffic forecast models used in pavement maintenance life-cycle analyses should be improved to take capacity limits into account.

Social costs should be included in the analysis of the cost-efficiency of alternative road maintenance strategies.

In the social economic evaluation of alternative pavement maintenance strategies, a dynamic approach, which evaluates suitable maintenance measures at relevant intervals within a given time period, should be applied.

The relation between (long-term) pavement serviceability and social costs is not well known and should be explored.

Pavement management systems can be used to prioritise maintenance works funded from a specified budget. The budget to use for a particular part of the network should be based on an analysis of the long-term costs for each part of the network, using a life-cycle cost approach. This will enable the future impact of current funding levels to be taken into account in deciding the current budgets.

A simple model, which considers vehicle speeds and road gradients, should be used for determining vehicle operating costs for the European road user context.

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Appendix 1:

PAV-ECO ECONOMIC EVALUATION OF PAVEMENT MAINTENANCE





Appendix 1

PAV-ECO: ECONOMIC EVALUATION OF PAVEMENT MAINTENANCE

LIST OF DELIVERABLES

Each Work Package comprised a set of Tasks and the documentation of these topics formed the milestones in the Project.

Other deliverables from the Project are:

- Four progress/management reports summarising the progress of the Project and describing achieved milestones and their content
- A Final Report encompassing the entire Project results and describing the achieved innovations and benefits
- General publication of the Project results through the presentation of peer-reviewed papers at international conferences addressing specific parts of the Project. A list of papers presented at conferences and workshops is given in Appendix 3.

PAV-ECO Project Inception Report

PAV-ECO Project Inception Report. Pavement Structure Management System: Economic Evaluation of Pavement Maintenance. Project for EU DG VII, RTD-Programme, ref. RO-97-SC 1085/1189, Brussels, Belgium, November 1997. Prepared by the Danish Road Institute, Roskilde, Denmark, 5 December 1997.

Work Package 1: Maintenance Measures Evaluation

Task 1: Optimal maintenance strategies – Final Report. Laboratoire Central des Ponts et Chaussées, Paris, France, March 1999.

Task 1: Optimal maintenance strategies - Annex to the Final Report. Laboratoire Central des Ponts et Chaussées, Paris, France, March 1999.

Task 2: Financial and economic costs – Final Report. Viagroup SA, Winterthur, Switzerland, April 1999.

Task 2: Financial and economic costs - Annex 1: Impact of User Costs Prioritisation on Long Term Pavement Performance. Viagroup SA, Winterthur, Switzerland, October 1999.

Task 3: Work zone effects on road user costs and task 4: Pavement preservation – Report, VTT, Technical Research Centre of Finland, April 1999.

Task 3: Cost to road users at maintenance - Technical Annex. CETE de Sud-Ouest, France, March 1999.



Work Package 2: Impact of Traffic Change

Task 1: Traffic flow patterns, and Task 2: Adding of new roads – Final Report. Anders Nyvig A/S, Copenhagen, Denmark, May 1999.

Annex: Traffic forecast. University of Cologne, Germany, June 1999.

Work Package 3: Social Economic Evaluation

Task 1: Complementary costs at maintenance sites, and Task 2: Society rate of return - Final Report. University of Cologne, Germany, October 1999.

Appendix to the WP3 task 1 & 2 Report. University of Cologne, Germany, October 1999.

Task 3: Preservation of road investment – Final Report. École Polytechnique Fédérale de Lausanne, LAVOC, Switzerland, March 1999.

Work Package 4: Allocation of Funds

Task 1: Public Roads, Bridges and Private Financed Roads, and Task 2: Regional Distribution of Funds – Draft Final Report. Transport Research Laboratory (TRL), UK, September 1999.

Work Package 5: EU VOC Model

EU VOC models - Final Report. École Polytechnique Fédérale de Lausanne, LAVOC, Switzerland, March 1999.

Appendix 1: Technical User Guide. September 1998. École Polytechnique Fédérale de Lausanne, LAVOC, Switzerland, March 1999.

Appendix 2: Technical information. École Polytechnique Fédérale de Lausanne, LAVOC, Switzerland, March 1999.

Appendix 3: Vehicle operating cost models. École Polytechnique Fédérale de Lausanne, LAVOC, Switzerland, March 1999.

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 – Final Report. Laboratoire Central des Ponts et Chaussées, Paris, France, September 1999.



PAV-ECO / RIMES Workshops

Report, Paris, 8-9 October, 1998. Road Directorate, Copenhagen, July 1999.

Report, Brussels, 6 June, 1999. Road Directorate, Copenhagen, July 1999.

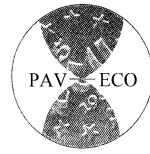
PAV-ECO Management and Progress Reports

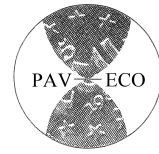
Management and Progress Report no. 1, for the period 1 October 1997 to 31 March 1998, Road Directorate, Copenhagen, Denmark, April 1998.

Management and Progress Report no. 2, for the period 1 April 1998 to 31 September 1998, Road Directorate, Copenhagen, Denmark, October 1998.

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Management and Progress Report no. 4, for the period 1 April 1999 to 31 September 1999, Road Directorate, Copenhagen, Denmark, October 1999.





Appendix 2:

PAV-ECO Newsletters

The two Newsletters that were published during the Project are included in this Appendix. The third Newsletter will be published after termination of the Project.



Economic Evaluation of Pavement Maintenance

Introduction

This newsletter provides an update on the PAV-ECO project. PAV-ECO is a part of the project "Pavement and Structure Management System", which covers two separate, but related, research projects under the EC Transport RTD Programme. The two projects are PAV-ECO (Economic Evaluation of Pavement Maintenance) and RIMES (Road Infrastructure Maintenance Evaluation Study). This first edition of the newsletter covers the research work carried out from October 1997 when the project started until October 1998.

Objectives

The PAV-ECO project aims to meet the objectives of the EC Transport RTD Programme by developing performance cost models for evaluation of the life cycle costs of existing pavements, their interrelationships with the maintenance needs of structures, and the effects on road infrastructure maintenance when new roads are added to the network. The proposed cost maintenance models will improve the efficiency of the decision making process by bringing together scientific and technical excellence and inventiveness from leading countries developing pavement management systems and pavement maintenance performance models.

The objectives of the project are to establish financial and economic models for the evaluation based on life cycle costs for :

- * optional application of different maintenance measures
- * impact of changed traffic flow on maintenance needs
- * allocation of funds for different components of the road infrastructure
- * social economic effects from maintenance of the infrastructure

- * vehicle operating costs appropriate to European conditions

The PAV-ECO partners are either part of national road agencies or closely related to road authorities, and as such they represent the end users in the partners' home countries. This will ensure the dissemination and exploitation of the project results. The partners will have the necessary influence on research and development in the area of road infrastructure management both nationally and internationally (through FEHRL, Forum of European National Highway Research Laboratories). As a consequence hereof the PAV-ECO members will be able to promote the results as policy and methodology proposals in future implementations of management systems in European countries.

Organisation of project

In combination with the issue of dissemination of results from the project, the five areas listed above in which models for financial and economic evaluation should be established constitute the six work packages of PAV-ECO. Danish Road Institute is responsible for overall management and co-ordination of the project, while six different partners manage the six work packages. With only eight partners in the project, all partners in practice take part in all work packages.

A quality assurance system has been established. Each work package has a monitoring person who is responsible for evaluation of the results from a work package both with regard to the technical contents and observance of existing plans.

Current Status for PAV-ECO

The PAV-ECO project officially started on 14 October 1997 and it will end on 13 October 1999. One year into the project status is that



all six work packages have started their work, and one package has finalised its work.

A total of 15 European road authorities have been interviewed this spring and summer as part of a review of maintenance and rehabilitation methods currently used in Europe.

The work package concerned with the impact of changed traffic flow on maintenance needs was finalised in June 1998, and the results of this work is expected to be published later this year on the PAV-ECO homepage.

PAV-ECO on the Internet

The PAV-ECO project has established a homepage on the Internet. At the address <http://dgcwww.epfl.ch/LAVOC/ProjetsEuropeens/Pav-eco/> updated information about the project can be found. The homepage consists of two parts: one part which is accessible for everyone, and one part which can only be accessed by the PAV-ECO partners.

The open part of the web site consists of a general description of the project and its partners (with direct links to the latter) as well as access to reports produced by the PAV-ECO group.

The internal part of the homepage consists of minutes of meetings, time and activity schedules, activity reports, and draft versions of documents to be published. Once the EU Commission has approved a draft document, it is transferred from the internal part of the homepage to the open part. This procedure has recently been used for the first time, when a technical glossary, which is to be used by both the PAV-ECO and RIMES groups, was moved to the public part of the homepage.

Dissemination of PAV-ECO Results

As dissemination and exploitation of results are very important issues for the PAV-ECO group, significant effort has been put into identifying a suitable venue for the presentation of the PAV-ECO findings. The venue chosen is the 2nd European Road Research Conference, which is to be held in Brussels on 7-9 June 1999. The conference is jointly or-

ganised by the European Commission, FEHRL, and FERSI (Forum of European Road Safety Research Institutes).

PAV-ECO has submitted four abstracts for acceptance by the organising committee. The subjects of the papers cover PAV-ECO in general, pavement maintenance measures evaluation, impact and integration of traffic change in pavement management and social economic evaluation of pavement maintenance.

Next issue of the Newsletter

The PAV-ECO newsletter will be issued at irregular intervals whenever the project has news to present to the public. The intention is to publish a newsletter every six months.

Editorial Note

The newsletter is published by the Danish Road Directorate, Danish Road Institute. Inquiries about PAV-ECO or the contents of this newsletter should be directed to:

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Evaluation Economique de l'Entretien des Chaussées

Introduction

Cette lettre d'information présente l'état du projet PAV-ECO. PAV-ECO est une composante de l'action « Système de Gestion des Chaussées et des Ouvrages » qui comprend deux projets de recherche distincts mais coordonnés, et qui est supportée par le programme R&D de la Direction Transport de la CE. Ces deux actions de recherche sont PAV-ECO (Évaluation Economique de l'Entretien des Chaussées) et RIMES (Etude d'Évaluation de l'Entretien des Infrastructures Routières). Le premier numéro de cette lettre couvre les travaux de recherche menés d'Octobre 1997, lorsque le projet démarra, à Octobre 1998.

Objectifs

Le projet PAV-ECO vise à atteindre les objectifs de la Direction Transport de la CE en développant des modèles financiers pour évaluer le coût global des chaussées sur l'ensemble de leur durée de vie, les relations entre ce coût et les besoins d'entretien des chaussées, et l'impact de la création de nouvelles liaisons dans un réseau sur l'entretien des infrastructures routières. Les modèles financiers proposés amélioreront l'efficacité des procédures de prise de décision en associant les qualités scientifiques et techniques et le caractère innovant des systèmes d'aide à la gestion des routes des pays développés et les modèles d'entretien des chaussées.

Les objectifs du projet sont d'établir des modèles financiers et économiques s'appliquant sur toute la durée de vie de la structure pour :

- * l'application optionnelle de différentes mesures d'entretien

- * l'impact des changements dans le trafic sur les besoins d'entretien
- * la répartition des fonds entre les différentes composantes de l'infrastructure routière
- * les effets sociaux économiques de l'entretien des infrastructures
- * le coût d'exploitation des véhicules en Europe

Les partenaires du projet sont des services des Directions des Routes ou sont en étroite relation avec ces Directions, et en tant que tel, représentent l'utilisateur final de leur pays. Ceci favorisera la diffusion et l'exploitation des productions du projet. Les partenaires auront l'influence nécessaire sur les recherches et développement conduits dans le domaine de la gestion des infrastructures routières tant au plan national qu'international (à travers le Forum des Laboratoires Européens de Recherche Routière, FLERR). En conséquence, les partenaires du projet seront à même de promouvoir les résultats sous forme de propositions politiques et méthodologiques lors de la mise en œuvre de systèmes de gestion dans les pays européens.

Organisation du projet

Avec l'action de diffusion des productions du projet, les cinq domaines listés ci-dessus, et dans le cadre desquelles seront établis les modèles économiques et financiers, forment les six sujets de recherche de PAV-ECO.

Le Danish Road Institute est responsable de la gestion d'ensemble et de la coordination du projet, alors que les six autres partenaires gèrent les six sujets. Avec seulement huit partenaires dans le projet, pratiquement chaque partenaire contribue aux différents sujets.



Un système d'Assurance Qualité a été instauré. Chaque sujet est suivi par un partenaire qui est chargé d'évaluer les résultats du sujet en considérant à la fois le contenu technique et la conformité au programme de travail.

Etat d'avancement de PAV-ECO

Le projet PAV-ECO a officiellement démarré le 14 Octobre 1997, et s'achèvera le 13 Octobre 1999. Après douze mois de travail, les six sujets de recherche ont entamé leur travaux, et l'un d'eux est d'ores et déjà achevé.

Au total 15 Direction des Routes européennes ont été interviewées au cours du printemps et de l'été dans le cadre d'une analyse des méthodes d'entretien et de réhabilitation en usage en Europe.

Le sujet portant sur l'impact des changements dans le trafic sur les besoins d'entretien s'est achevé en Juin 1998, et les résultats de ce sujet seront publiés cette année sur la page d'accueil PAV-ECO.

PAV-ECO sur Internet

Le projet PAV-ECO a créé une page d'accueil sur Internet. A l'adresse <http://dgcwww.epfl.ch/LAVOC/ProjetsEuropeens/pav-eco/>, on peut trouver des informations récentes sur le projet. La page d'accueil comprend deux parties, l'une en accès libre, l'autre en accès réservé aux partenaires de PAV-ECO.

La page ouverte en accès libre sur le site web propose une présentation générale du projet et de ses partenaires (avec un lien direct vers ceux-ci) et donne accès aux rapports produit par le groupe PAV-ECO.

La partie de la page d'accueil réservée à un usage interne donne accès aux comptes-rendus des réunions, aux programmes d'actions, aux rapports d'activité, et aux versions provisoires des documents prévus en publication. Ce n'est que lorsque la Commission Européenne a approuvé une version provisoire que celle-ci est transférée de la partie interne du site à la partie en accès libre. Cette procédure a récemment été mise en œuvre pour la première fois quand un glossaire

technique, utilisé par les groupes PAV-ECO et RIMES, a été installé en accès libre.

Diffusion des résultats de PAV-ECO

Parce que la diffusion et l'exploitation de ses productions sont des points jugés essentiels par le groupe PAV-ECO, un effort significatif a été fait pour identifier la meilleure opportunité pour présenter les résultats de PAV-ECO. La manifestation retenue est la 2^{ème} Conférence Européenne de Recherche Routière, qui se tiendra à Bruxelles, du 7 au 9 Juin 1999. Cette conférence est organisée par la Commission Européenne, le FLERR et le FERST (Forum Européens des Instituts de Recherche en Sécurité Routière).

PAV-ECO a soumis quatre résumés au comité d'organisation. Ces articles recouvrent une présentation générale de PAV-ECO, l'évaluation des mesures d'entretien des chaussées, l'impact et la prise en compte des changements dans la distribution du trafic et l'évaluation socio-économique de l'entretien de chaussées.

Prochain numéro de la Lettre d'information

La lettre d'information PAV-ECO sera publiée à intervalles réguliers, et chaque fois que le projet aura des informations nouvelles à faire connaître. Il est prévu de publier une lettre chaque semestre.

Note éditoriale

La lettre d'information est publiée par l'Institut des Routes du Danemark, Direction des Routes du Danemark. Les renseignements sur PAV-ECO ou le contenu de cette lettre peuvent être obtenus auprès de:

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Economic Evaluation of Pavement Maintenance

Second Issue May 1999

Introduction

This newsletter provides an update on the PAV-ECO project. PAV-ECO is a part of the project "Pavement and Structure Management System", which covers two separate, but related, research projects under the EC Transport RTD Programme. The two projects are PAV-ECO (Economic Evaluation of Pavement Maintenance) and RIMES (Road Infrastructure Maintenance Evaluation Study). This second edition of the newsletter covers the research work carried out from October 1998 until April 1999.

Objectives and Project Organisation

A brief description of the objectives and the organisation of the PAV-ECO project can be found in the first edition of this newsletter. A more detailed description can be found on the PAV-ECO homepage on the Internet. Since the first edition of this newsletter the homepage has moved to a new address: <http://lavocwww.epfl.ch/ProjectsEuropeens/pav-eco/>.

PAV-ECO uses the Internet in two ways, partly for dissemination of intentions and results and partly as internal "project archive". The open part of the homepage consists of a general description of the project and it will also provide access to the released PAV-ECO deliverables.

Current Status for PAV-ECO

The PAV-ECO project officially started on 14 October 1997 and it will end on 13 October 1999. One and a half year into the project status is that all six work packages have started their work, and two packages (1 and 5) have by now been finalised.

Work Package 1 regarding maintenance measures evaluation consists of four tasks.

The objective of Task 1 was to review maintenance and rehabilitation techniques and strategies currently used in Europe and to develop models for optimal maintenance strategies at the project level based on predicted pavement performance. Infor-

mation on actual European practice was collected via both literature survey and interviews of 15 European road authorities. Work in Task 1 is reported in "Economic Evaluation of Pavement Maintenance, Package no 1: Maintenance Measures evaluation, Task no 1: Optimal maintenance strategies".

The objective of Task 2 was to provide the data and models needed to fulfill the overall objective of WP1: The development of an analysis system for the economic evaluation of alternative pavement maintenance and rehabilitation strategies on individual road projects. To complete these objectives the work was based on an information gathering exercise that comprised interviews of European road directorates and a literature review. The outcome of Task 2 is reported in "Maintenance Measures Evaluation, Task no 2: Financial and Economic Costs, Costs of Maintenance Measures, User Costs, Costs of Deferred Maintenance".

The outcome of Task 3 and Task 4 is jointly presented in one report: "Work Zone Effects on Road User Costs, Pavement Preservation. Report for Tasks 3 and 4 of Work Package 1 of Economic Evaluation of Pavement Maintenance". The objective of Task 3 was to establish relationships between maintenance works and additional road user costs due to higher travel time costs, vehicle operator costs and accident costs, and the objective of Task 4 was to develop a methodology to determine the salvage value of the investment in pavement.

Work package 5 on a EU Vehicle Operating Cost (VOC) Model has also been finalised. The latter report provides a review of the different VOC models used in Europe and sets up further requirements for their use in life cycle cost models in Europe.

All reports have been delivered to the EU Commission and executive summaries can be accessed via the PAV-ECO homepage.

Next issue of the Newsletter

The PAV-ECO newsletter will be issued at irregular intervals whenever the project has news to present to the public. The intention is to publish a newsletter every six months.

Editorial Note

The newsletter is published by the Danish Road Directorate, Danish Road Institute. Inquiries about PAV-ECO or the contents of this newsletter should be directed to:

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E-mail: HJE@VD.DK

Announcement of the PAV-ECO Joint Workshop

From the 7 to 9 June 1999, the Second European Road Research Conference (ERRC) will be held in Brussels, Belgium. The objective of the conference is to bring together results of high quality road transport research programmes and projects carried out within Europe and bring them to the attention of politicians, policy makers, road operators, local authorities and industry, thereby encouraging their implementation.

Although there will be a primary focus on road transport research, a key objective will be to establish clearly those areas where broader issues of inter-modality and intermodal trip-making affects policies for road investment and land use. Further information on the Conference can be found on the CORDIS system at the following address: <http://www.cordis.lu/transport/home.html>

In addition to the main technical sessions the PAV-ECO and RIMES research consortiums will be hosting a joint workshop. The Workshop will be held at the conference venue from 9:00 to 13:00 on Sunday 6 of June. Registration for the Conference will cover attendance at the Workshop, and enrolment for the Workshop must accompany the registration form for the Conference, as space will be limited.

Scope

The scope of the PAV-ECO/RIMES Workshop is to give participants an update of the objectives and the progress of the project : Pavement and Structure Management System, which covers two separate, but related research projects. They are the PAV-ECO project and the RIMES (Road Infrastructure Maintenance Evaluation Study) project.

Preliminary Programme

The Workshop will take the form of presentations from each research consortium followed by discussions. The presentations are scheduled to be as followed:

The RIMES project presentations

- The development of project and programme level models
- The needs of road administrations and the development of a network level model

The PAV-ECO project presentations

- The PAV-ECO project
- Road User Costs and Pavement Preservation in Life Cycle Cost Analysis
- Modelling of the Impact of Traffic Change
- Development of Models for Economic Evaluation of Pavement Maintenance

Further Information

For further information about the joint PAV-ECO/RIMES Workshop contact can be made with the following:

Hans Jørgen ERTMAN LARSEN
E-mail: hje@vd.dk
OR Henry KERALI
E-mail: rimes@bham.ac.uk



Evaluation Economique de l'Entretien des Chaussées

Second numéro Mai 1999

Introduction

Cette lettre d'information présente l'état du projet PAV-ECO. PAV-ECO est une composante de l'action « Système de Gestion des Chaussées et des Ouvrages » qui comprend deux projets de recherche distincts mais coordonnés, et qui est supportée par le programme R&D de la Direction Transport de la CE. Ces deux actions de recherche sont PAV-ECO (Evaluation Economique de l'Entretien des Chaussées) et RIMES (Etude d'Evaluation de l'Entretien des Infrastructures Routières). Ce second numéro de la lettre couvre les travaux de recherche menés d'Octobre 1998, à Avril 1999.

Objectifs et organisation du projet

On trouvera dans la première édition de cette lettre une brève description des objectifs et de l'organisation du projet PAV-ECO. Une description plus détaillée est disponible sur le site Internet PAVECO. Depuis la première édition de la lettre, ce site a changé d'adresse :

<http://lavocwww.epfl.ch/ProjetsEuropeens/pav-eco/>

PAVECO utilise l'Internet de deux façons : d'une part pour diffuser ses perspectives et ses résultats, d'autre part en tant qu'archivage interne du projet. La partie publique du site contient une description générale du projet et donne également accès à ses productions diffusables.

Etat d'avancement du projet

Le projet PAV-ECO a débuté officiellement le 14 Octobre 1997 et s'achèvera le 13 Octobre 1999. Un an et demi après ce démarrage, les six sujets ont commencé leur travaux, et deux d'entre eux (1 et 5) sont maintenant terminés.

Le sujet 1, qui porte sur l'évaluation des mesures d'entretien, comprend quatre axes.

L'objectif de l'axe 1 était de procéder à une revue des techniques et des stratégies d'entretien et de réhabilitation couramment utilisées en Europe et de développer des modèles de stratégies d'entretien

optimales, au niveau projet, basées sur la prévision du comportement des chaussées. Les informations sur les pratiques européennes furent recueillies par le biais d'une étude bibliographique et d'entrevues avec 15 directions des routes européennes. Les travaux de l'axe 1 sont rapportés dans « Evaluation Economique de l'Entretien des Chaussées, Sujet n° 1 : Evaluation des Mesures d'Entretien, Axe n° 1 : Stratégies d'Entretien Optimales ».

L'axe 2 visait à fournir les données et les modèles nécessaires pour atteindre les objectifs généraux du sujet : le développement d'un système d'analyse pour l'évaluation économique des stratégies alternatives d'entretien et de réhabilitation au niveau des routes individuelles. Pour atteindre ces objectifs, le travail s'appuya sur un recueil d'information associant des entrevues avec des Directions des Routes européennes et une analyse bibliographique. Les résultats de l'axe 2 font l'objet du rapport « Evaluation des Mesures d'Entretien, Axe 2 : Coûts Economiques et Financiers, Coûts des Mesures d'Entretien, Coûts d'Entretien Différé ».

Les résultats des axes 3 et 4 sont présentés ensemble dans un même rapport « Rapport des axes 3 et 4 du sujet 1 de l'Evaluation Economique de l'Entretien des Chaussées ». Le but de l'axe 3 était d'établir des relations entre les travaux d'entretien et les coûts additionnels supportés par les usagers en raison des temps de trajet plus longs, des coûts de fonctionnement des véhicules et d'accidents. L'objectif de l'axe 4 était de développer une méthode pour déterminer la valeur résiduelle de l'investissement routier.

Dans le sujet 5, un modèle de coût de fonctionnement des véhicules a été développé. Le rapport de ce sujet propose une revue des différents modèles de coût de fonctionnement utilisés en Europe et définit des conditions supplémentaires pour qu'ils puissent être utilisés dans les modèles de coût sur la durée de vie des chaussées en Europe.

Tous ces rapports ont été remis à la Commission Européenne et leurs résumés sont consultables sur le site internet de PAV-ECO.

Prochaine publication de la lettre

La lettre PAV-ECO est publiée à intervalle régulier (si possible chaque semestre) et chaque fois que le projet dispose d'information à porter à la connaissance du public.

Note éditoriale

La lettre d'information est publiée par l'Institut des Routes du Danemark, Direction des Routes du Danemark. Les renseignements sur PAV-ECO ou

le contenu de cette lettre peuvent être obtenus auprès de:

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Annnonce de l'atelier commun PAV-ECO

Du 7 au 9 Juin 1999, la seconde conférence européenne sur la recherche routière se tiendra à Bruxelles, en Belgique. Les objectifs de cette conférence sont de rassembler les résultats des programmes et des projets de haut niveau en recherche routière, et de les porter à l'attention des responsables politiques, des décideurs, des gestionnaires routiers, des autorités locales et des industriels et, par là même, d'encourager leur exploitation. Bien que l'accent soit mis sur la recherche concernant les transports routiers, un objectif clé est d'identifier clairement les domaines dans lesquels les résultats portant sur l'intermodalité et les transports multimodaux peuvent influencer les politiques d'investissements routiers et d'aménagement du territoire. Pour plus d'information, consultez le site CORDIS, à l'adresse suivante : <http://www.cordis.lu/transport/home.html>

En marge des sessions techniques principales, les groupements de recherche PAV-ECO et RIMES organiseront un atelier en commun. L'atelier se tiendra sur le site de la conférence, le Dimanche 6 Juin (9:00 - 13:00). L'inscription à la conférence inclut la participation à cet atelier, et la fiche d'inscription à l'atelier doit être jointe à celle de la conférence, car le nombre de place est limité.

Contenu

L'objet de l'atelier PAV-ECO/RIMES est de donner aux participants une vision actualisée des objectifs et de l'avancement du projet « Système de Gestion des Chaussées et des Ouvrages », qui regroupe deux projets distincts mais associés, les projets PAV-ECO et RIMES (Etude d'Evaluation de l'Entretien des Infrastructures Routières).

Programme préliminaire

L'atelier comprendra une suite de présentations de chaque groupement de recherche, suivies de discussion. Le programme des présentations est le suivant.

Les présentations du projets RIMES

- The development of project and programme level models
- The needs of road administrations and the development of a network level model

Les présentations du projet PAVECO :

- The PAV-ECO project
- Road User Costs and Pavement Preservation in Life Cycle Cost Analysis
- Modelling of the Impact of Traffic Change
- Development of Models for Economic Evaluation of Pavement Maintenance

Pour plus d'information sur l'atelier commun PAV-ECO/RIMES, contacter :

Hans Jørgen ERTMAN LARSEN (E-mail : hje@vd.dk)

OU Henry KERALY (E-mail : rimes@bham.ac.uk)



Appendix 3:

CONFERENCES AND WORKSHOPS





Appendix 3

CONFERENCES AND WORKSHOPS

AQTR / CITE Congress, Montréal, Canada, 3 May 1999.

- **Towards a better evaluation of the profitability of road maintenance, in Europe**, by Ph. Lepert and R. Abadie (LCPC)

2nd European Road Research Conference, Brussels, Belgium, 7 - 9 June 1999.

- **Development of models for the economic evaluation of maintenance : the PAV-ECO Project**, by Ph. Lepert (LCPC) and G. Hildebrand (DRI)

PAV-ECO / RIMES Joint Meeting and Workshop, Paris, France, 8 - 9 October 1998.

Report, Road Directorate, Copenhagen, Denmark, January 1999.

- **Traffic assignment models in PMS - the impact from capacity restraint on the management strategy**, by S. Hansen (Anders Nyvig A/S)
- **The future of PMS: Technical or socio-economic approach**, by Dr. W. H. Schulz (UoC)

PAV-ECO / RIMES Workshop, Brussels, Belgium, 6 June 1999.

Report, Road Directorate, Copenhagen, Denmark, July 1999.

- **The PAV-ECO Project**, by H. J. Ertman Larsen (DRI)
- **Pavement Maintenance Measures Evaluation**, by A. Ruotoistenmäki and H. Spoof (VTT)
- **Impact and Integration of Traffic Change in Pavement Management**, by S. Hansen (Anders Nyvig A/S)
- **Social Economic Evaluation of Pavement Maintenance**, by Professor Dr. H. Baum, Dr. W. H. Schulz and R V. Schott (UoC)



Appendix 4:

LIST OF TECHNICAL COMMITTEE MEETINGS





Appendix 4

LIST OF TECHNICAL COMMITTEE MEETINGS

During the period October 1997 to September 1999, nine Technical Committee meetings were held, one approximately every three months.

The PAV-ECO Technical Committee met as follows:

- Meeting no. 1 was hosted by DRI on 21 October, 1997, in Copenhagen.
- Meeting no. 2 was hosted by LAVOC on 6 March, 1998, in Lausanne.
- Meeting no. 3 was hosted by VTT on 5 June, 1998, in Espoo.
- Meeting no. 4 was hosted by UoC on 11 September, 1998, in Cologne.
- Meeting no. 5 was hosted by TRL on 4 December, 1998, in London.
- Meeting no. 6 was hosted by LCPC on 5 March, 1999, in Paris.
- Meeting no. 7 was hosted by DRI, on 6 June, 1999, in Brussels.
- Meeting no. 8 was hosted by Viagroup S.A., on 26-27 July, 1999, in Winterthur.
- Meeting no. 9 was hosted by DRI on 3 September, 1999, in Copenhagen.

Meeting no. 7 was held in conjunction with the 2nd European Road Research Conference, which was held in Brussels, Belgium, between 7 – 9 June, 1999.

In addition to the Technical Committee meetings, ad hoc Working Package meetings were held, as necessary.





Appendix 5:

PARTICIPANTS IN THE RESEARCH PROJECT



Appendix 5

PARTICIPANTS IN THE RESEARCH PROJECT

During the period of October 1997 to September 1999, nine Technical Committee meetings were held at approximately three month intervals.

The PAV-ECO Technical Committee attendees were:

- | | |
|----------------|---|
| Denmark | Mr. Hans Jørgen Ertman Larsen, Danish Road Institute
Mr. Gregers Hildebrand, Danish Road Institute
Mr. Robin Macdonald, Danish Road Institute

Mr. Søren Hansen, Anders Nyvig A/S |
| Finland | Mr. Antti Ruotoistenmäki, Technical Research Centre of Finland
Mr. Harri Spoo, Technical Research Centre of Finland |
| France | Mr. Philippe Lepert, Laboratoire Central des Ponts et Chaussées |
| Germany | Professor Dr. Herbert Baum, University of Cologne
Dr. Wolfgang H. Schulz, University of Cologne
Mr. Oliver Althoff, University of Cologne
Mr. Andreas Schneider, University of Cologne
Mr. Volker Schott, University of Cologne |
| Switzerland | Mr. Jean-Claude Turtshy, Laboratoire des Voies de Circulation LAVOC - EPFL
Mr. Marc Fontana, Laboratoire des Voies de Circulation LAVOC - EPFL

Mr. Ivan Scazziga, Viagroup SA |
| United Kingdom | Mr. Richard Abell, Transportation Research Laboratory
Mrs. Vijay Ramdas, Transportation Research Laboratory |

In the accomplishment of the Project, several people outside the Technical Committee provided valuable assistance to the management of the Project:

- | | |
|---------|---|
| Denmark | Ms. Susanne Baltzer, Danish Road Institute
Mrs. Lise Bjulf, Danish Road Institute
Mrs. Helen Hasz-Singh, Danish Road Institute
Mrs. Anna-Marie Ørnstrup, Danish Road Institute
Mr. Charles Lykke Hansen, Danish Road Institute
Mr. Bent Lund, Danish Road Institute
Mr. Svenning Olm, Danish Road Institute
Ms. Rikke Rysgaard, Danish Road Directorate
Mr. Niels Peter Albrechtsen, Danish Road Directorate
Mr. Jørgen Sand Kirk, Danish Road Directorate |
|---------|---|



PARTICIPANTS IN THE RESEARCH PROJECT (continued)

Denmark Dr. Wei Zhang, Technical University of Denmark

France	Mr. Robert	Abadie, CETE Ouest	(Nantes)
	Mr. Jean Louis	Girard, CETE Ouest	(Nantes)
	Mr. Michel	Sauvestre, CETE Sud Ouest	(Bordeaux)
	Mr. Ludovic	Alibert, CETE Sud-Ouest	(Bordeaux)
	Mr. Pierre	Lachaud, CETE Sud-Ouest	(Bordeaux)



Appendix 6:

FEHRL *FORUM OF EUROPEAN NATIONAL HIGHWAY RESEARCH LABORATORIES*





Appendix 6

FEHRL FORUM OF EUROPEAN NATIONAL HIGHWAY RESEARCH LABORATORIES

Address: c/o Transport Research Laboratory
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Tel: +44 1344 77 02 41
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E-mail: raddis@trl.co.uk.

Secretary General Mr. Rod ADDIS

Status Established in 1989 for EU and EFTA countries, based on the application of a Memorandum of Understanding.

AIMS AND OBJECTIVES OF FEHRL

The Forum of European National Highway Research Laboratories (FEHRL) was formed in 1989 by the national highway research laboratories in EU and EFTA countries. At present, the Forum comprise, as full Members, 18 national laboratories in all member states of the Union, and in EFTA countries. Laboratories in Croatia, the Czech Republic, Hungary, Poland, Romania and the Republic of Slovenia have been admitted as Associate Members.

The purpose of FEHRL is to encourage collaborative research between European laboratories and organisations in the field of highway engineering infrastructure, leading to the provision of relevant knowledge and advice to governments, the European Commission, the road industry and road users.

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

THE PROFESSIONAL FIELDS COVERED BY MEMBERS ARE :

- Geotechnics
- Pavement Engineering
- Bridge Engineering
- Construction Materials
- Maintenance Management
- Environmental Issues
- Traffic loading
- Safety at roadworks



ORGANISATION OF FEHRL

The operation of the Forum is based on the application of a Memorandum of Understanding that all Members are required to sign. The Memorandum specifies the rights and responsibilities of Members and Associates, and describes the organisational arrangements.

Together, the Members of FEHRL constitute the Board, from whom a President is elected to serve for a half-year term. The Board meets twice per year to conduct the business of FEHRL, and to ensure that the objectives are being vigorously pursued.

The day-to-day business of FEHRL is carried out by the FEHRL Executive Committee (FEC), under a Chairman elected by the members of the Board. The FEC is responsible for ensuring that the decisions of the Board are carried out, that any information required by the Board is made available, that all possibilities for pursuing FEHRL objectives are identified and exploited, and that contacts with other appropriate organisations are encouraged and maintained.

The Board and the FEC are both served by a Secretariat, and funded by contributions from the Members.

FEHRL MEMBERS

Austria	ÖFPZ	Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.g.H.
Belgium	CRR OCW	Centre de Recherches Routières Opzoekingscentrum voor de Wegenbouw
Denmark	DRI	Danish Road Institute
Finland	VTT	Technical Research Centre of Finland
France	LCPC	Laboratoire Central des Ponts et Chaussées
Germany	BASt	Bundesanstalt für Straßenwesen
Greece	KEDE	Central Public Works Laboratory
Iceland	PRA	Public Roads Administration
Ireland	NRA	National Roads Authority
Italy	ANAS	Centro Sperimentale Stradale
Luxembourg	INRR	Institut National de Recherche Routière
Netherlands	DWW	Dienst Weg- en Waterbouwkunde, Rijkswaterstaat
Norway	NRRL	Norwegian Road Research Laboratory Norway
Portugal	LNEC	Laboratório Nacional de Engenharia Civil
Spain	CEDEX	Centro de Estudios y Experimentación de Obras Públicas
Sweden	VTI	Swedish Road and Transport Research Institute
Switzerland	LAVOC	Laboratoire des Voies de Circulation – EPFL, Lausanne
United Kingdom	TRL	Transport Research Laboratory

ASSOCIATE MEMBERS

Croatia	IGH	Institut Gradevinarstva Hrvatske
Czech Republic	CDV	Centrum Dortavníno Výzkumu
Hungary	KTI Rt	Közlekedéstudományi Intézet Rt.
Poland	RBI	Road and Bridge Institute
Romania	CESTRIN	Centre for Road Engineering Studies and Informatics
Republic of Slovenia	ZAG	ZAG Slovenije, National Building and Civil Engineering Institute.



Appendix 7:

GLOSSARY OF GENERAL PROJECT PARAMETERS, AND ECONOMIC AND TECHNICAL TERMS



Appendix 7

GLOSSARY OF GENERAL PROJECT PARAMETERS, AND ECONOMIC AND TECHNICAL TERMS

General Project Parameters

Table A7.1. General parameter options / descriptions for analysis models in PAV-ECO

Parameter	Options / descriptions
Project Level	Road length treated - may comprise more than one treatment length
Network size	To be specified within the Project
Environment	Rural (Urban problems excluded)
Road Types	Motorways - 2 x 4 lanes, 2 x 3 lanes, 2 x 2 lanes all with hardshoulders Dual carriageways - 2 x 3 lanes, 2 x 2 lanes Single carriageways - 4 lanes, 3 lanes, 2 lanes (2 directions)
Road hierarchy (classes of road type within each hierarchy)	Motorway, National Roads, Local Roads
Road width	Linked to road type, but no specific widths
Pavement type (All paved)	Flexible, Flexible/Rigid Rigid-jointed, Rigid-continuous Rigid/Flexible
Vehicle categories	As HDM-4 and COST 323
Traffic levels	Limited by road type - to be identified in the study
Vehicle wear factors	No restrictions
Climate	All climates in EU countries
Maintenance works	Treatments identified from the review. Works parameters linked to treatment type and road type (e.g. closures for maintenance works). Lane restrictions at maintenance will include road closures.
Condition measures (roads and bridges)	To be identified from the review.
User costs	To be specified within the Project for the categories included in the Inception Report.

To enable the Work Package leaders develop the work in a common direction it was necessary to specify some general parameters for which the analysis and prototype models would apply. Similarly, for interaction between PAV-ECO and RIMES, a common set of general parameters was required.

For PAV-ECO, the parameters identified and the options to be included for each parameter are shown in Table 1, above. Parameter descriptions will tend to vary between countries, but the descriptions used are those generally adopted throughout the EU.

Some parameters were fixed at the start of the Project, while for others the dependent factors were as given (e.g., road type for traffic levels), though actual values were defined during the study.

Life-cycle cost models for bridges have not been considered by the PAV-ECO Project.

General Technical Terms

This is a list of definitions of general terms which are mainly (as far as possible) taken from a synthesis of the PIARC dictionary (CD-Routes), the French Dictionnaire de l'entretien routier, and OECD reports.

1 Road Network Management

This covers two main activities: the management of works on roads (construction rehabilitation, maintenance) and the use of the roads (usability, traffic management, route guidance). Good road management implies consistency between these two activities.

2 Road domains

Roadworks apply to different components of the network, called 'road domains'. These are the pavements, the environment (shoulders, ditches, etc.), signs and bridges. In some countries, attempts are made to ensure some consistency between the maintenance levels applied to these different domains.

3 Objectives of road management

Road management aims at achieving one or several of the following objectives:

- for the road users, reduction in travel time, improved safety, improved comfort and predictable travel time.
- for the agency, the preservation of the asset
- nearby residents, respect for the environment.

Highway authorities can pay more attention to these objectives through their choice of works and maintenance strategies (see network classification, following).

4 Network classification

Classification of the roads of the network into several categories, in which the manager gives different weights to the management objectives.

5 Construction

Construction of a road may have objectives in terms of service life, serviceability and functional characteristics.

Construction to meet these objectives can be in one stage or in several stages (staged investment strategy).

6 Improvement

Improvement of an existing road can provide new service life, serviceability and functional characteristics (geometry improvement, number and width of the lanes, etc.). As for construction, improvement can be done in one or several stages.

7 Rehabilitation

Application of maintenance works to restore the structural condition of a deteriorated pavement, and improve some of its functional characteristics (but not, for example, the number of lanes). Rehabilitation strategies are generally similar to construction strategies.

Synonym : reconstruction, reinforcement

8 Maintenance

Periodic application of maintenance works to preserve or restore all or some of the serviceability characteristics (safety, comfort, structure) of a pavement, without any increase in service life or functional characteristic (geometry, traffic, etc.)

9 Condition Indicators

Parameters which describe the condition of a pavement, derived from measurements or surveys of the road pavement. It has been agreed by the Project Technical Committee to take advantage of the list and definitions of condition indicators already established by the PARIS Project (PARIS is an EU funded project to examine pavement deterioration). The definitions are:

a) Wearing course distresses

- **Rutting** : Deformation shown by the transverse profile.
- **Deflection** : Value of the deflection measured in standard methods.
- **Unevenness** : Deformation shown by the longitudinal profile.
- **Ravelling** : Loss of particles from the pavement surface.
- **Bleeding** : Excess bituminous binder occurring on the pavement surface.
- **Skid resistance** : In different countries, skid resistance is characterised by the texture, as measured by the sand patch method, or the transverse friction coefficient, or the longitudinal friction coefficient, or combinations of these.

b) Structural distresses on non-concrete pavement

- **Reflective cracks on semi-rigid** : a crack predominantly at right angles to the pavement centre line.
- **Transverse crack not specifically in the wheelpath** : a crack predominantly at right angles to the pavement centre line; thermal cracking on some asphalt wearing courses.
- **Transverse crack in wheelpath** : a crack in the wheelpath, predominantly at right angles to the pavement centre line; fatigue cracking on flexible pavements.
- **Longitudinal crack in wheelpath** : crack in the wheelpath, predominantly parallel to the pavement centre line; fatigue cracking.
- **Longitudinal crack not specifically in the wheelpath** : crack predominantly parallel to the pavement centre line; environmental cracking.
- **Alligator cracking** : series of interconnected cracks in the wheelpath; fatigue cracking.
- **Crazing** : A pattern of interconnected cracks over the whole road surface.
- **Block cracking** : a pattern of cracks that divide the surface into approximately rectangular pieces ; combination of fatigue and thermal cracking, on semi-rigid pavements.
- **Joint cracking (transverse and longitudinal)** : crack at transverse or longitudinal construction joint ; construction defect.
- **Edge deterioration** : Cracking, ravelling or potholes within about half a metre of the edge of the carriageway, or damage to the verge due to over-riding; construction defect.

c) Structural distresses specific to concrete pavements

- **Biased crack** : Breaking line of a slab linking adjacent sides, and at more than 0.5 metre from the corner of the slab.
- **Corner break** : Breaking line of a slab linking two adjacent sides, and at less than 0.5 metre from the corner of the slab.
- **Block cracking** : Longitudinal and transverse cracks combining in regular square patterns.
- **Joint shift** : Step between the two edges of a joint or a crack.

10 Maintenance and Rehabilitation works

Spreading, according to proper procedures and with appropriate pieces of equipment, of materials in order to maintain, rehabilitate or strengthen an existing pavement. The main types of maintenance works are as follow :

a) Localised or (routine) maintenance

- **Crack sealing** : Process to fill cracks using a sealing compound.
- **Piece of surface dressing** : Local application of surface dressing (a few square metre) to seal localised alligator cracking.
- **Pothole repairs** : Repair of potholes with available and, when possible, appropriate materials.
- **Patching** : Removal of localised areas of failed or unsatisfactory materials from a road pavement and replacement with selected compacted materials.
- **Reshaping** : Operation aimed (either by grading or backfilling) at restoring the initial profile of a pavement (either longitudinal or transverse), or at improving the profile.
- **Chipping** : Treatment of areas of bituminous pavements with excess binder by rolling pre-coated chippings into the pre-heated surface.

b) Periodic maintenance

- **Surface dressing** : Spreading of bitumen binder and covering with aggregates, on the surface of a pavement.
- **Slurry surfacing** : On-site preparation and spreading of a thin layer of bituminous material consisting of bitumen coated aggregates.
- **Thin overlay** : Maintenance which consists of spreading and compacting bituminous materials on an existing pavement in a layer up to 4 cm thick.
- **Milling** : Process consisting of scarifying the pavement surface and removing the material.
- **Repaving** : Process consisting of heating and scarifying a pavement, shaping if necessary, adding new material and compacting. Depending on the technique, this may be described as thermo-reshaping, thermo-regeneration, or on site recycling.

c) Structural maintenance

- **Single overlay** : Maintenance which consists of spreading and compacting bituminous materials on an existing pavement in a layer between 4 cm and 14 cm thick.
- **Thick overlays** : Maintenance which consists of spreading and compacting bituminous materials on an existing pavement in layers, the total thickness of which is more than 14 centimetre.
- **Partial reconstruction** : Removal of the surfacing and roadbase and replacement with new layers.

11 Threshold

Value of one or more condition indicators which trigger(s) maintenance.

synonym : severity level

- **User sensitivity threshold**

Threshold beyond which users are expected to feel the distresses when driving under normal conditions on the road pavement.

- **Serviceability threshold**

Threshold beyond which a road pavement can no longer carry traffic appropriate to that road type. (e.g. serviceability threshold is higher for motorways than local roads).

- **Alert threshold**

Threshold beyond which no maintenance is done, in a maintenance strategy. The alert threshold indicates that the road is approaching the intervention threshold.

- **Intervention threshold**

Threshold which, in a maintenance strategy, actually triggers the maintenance operations

12 Maintenance strategy

A strategy is a set of decision rules which makes it possible, from the values of pavement condition indicators, to identify the sections which require maintenance, to define the works to be undertaken, and the appropriate order for these maintenance operations.

Three major types of maintenance strategies are, for example:

- Strategy for preventive maintenance,
- Strategy for curative maintenance,
- Strategy for no maintenance.

Example 1 : Preventive maintenance

Maintenance strategy which programmes works before the distresses reach a level which could affect the structure, safety or comfort of users, although the associated distresses



may not be perceptible by the users. The intervention threshold is above the user sensitivity threshold.

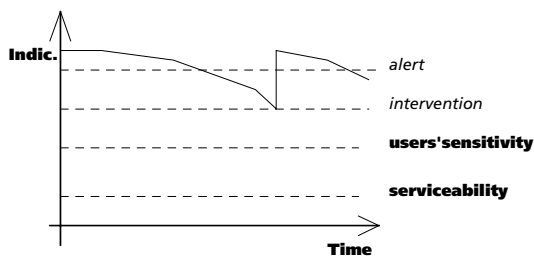
Example 2 : Curative maintenance

Maintenance strategy which programmes works only when the distresses reach a level which affect user safety, and thus the highway authority's liability. The type of maintenance work is then aimed to meet these objectives and, in most cases, has no effect other than delaying the deterioration. (*The Intervention threshold is similar to the User Sensitivity threshold*).

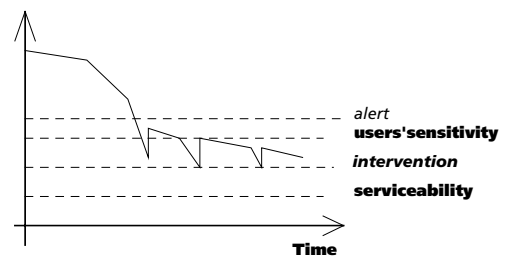
Example 3 : Minimum maintenance

Strategy which consists of performing no maintenance at all on the road, until the serviceability is almost zero, and then to perform rehabilitation. (*The Intervention threshold is similar to the Serviceability threshold*).

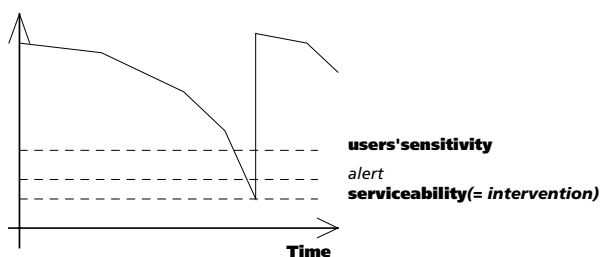
Example of different types of maintenance strategies



Ex. n° 1 : Preventive maintenance



Ex. n° 2 : Curative maintenance



Ex. n° 3 : 100% rehabilitation strategy

13 Life-cycle

The life-cycle of a road structure comprises design, construction, maintenance, rehabilitation, and possible removal of the structure.

14 Analysis period

The period of time, for which the various effects and costs are determined.

15 Life-cycle cost analysis

Life-cycle cost analysis comprises the analysis of a series of construction and maintenance actions on a pavement, and costs to road users which occur during the analysis period.

16 Total discounted cost

The total cost during the analysis period discounted to the value at a specified date.

17 Pavement life

The duration, quantified by the number of load applications of a standard axle or of years, to reach the serviceability threshold.

Synonym : life span

18 Residual life

Difference between the actual age of the pavement (in number of load cycles or years) and its theoretical life.

19 Salvage value

Residual life converted into monetary units.

Synonym : residual value

20 Discount rate

The internal rate used in cost accounting to convert the costs of various maintenance actions carried out at different points to a common point in time (to the year of reference).

Economic Terms

1 Social costs

In contrast to investment costs of a maintenance measure, the social costs are the costs borne by the road users (time costs, vehicle operating costs, accident costs covered by insurance premiums) and third persons (costs of air pollution, CO₂-emission costs, noise costs, accident costs not covered by the vehicle insurers).

2 Benefits

The benefit of a maintenance measure is equivalent to the savings of social costs resulting from the maintenance measure.

3 Cost Benefit Analysis (CBA)

This is the traditional assessment tool for evaluation of the efficiency of a maintenance measure. It is structurally identical with the common calculation for business invest

ments. The benefits of a maintenance measure are confronted with its investment costs. As benefits are regarded as savings of social costs (resulting from a maintenance measure) this method is a cost-savings approach.

4 Cost savings approach

This approach regards benefits as savings of social costs (resulting from a maintenance measure). One example of a cost-savings approach is Cost-Benefit Analysis.

5 Cost Benefit Ratio (CBR)

It is the result of a Cost-Benefit-Analysis. The benefits are divided by the investment costs. As an indicator of cost-efficiency of a maintenance measure, it provides two types of information: firstly: the economic legitimacy for carrying out a maintenance measure. If the ratio is larger than 1 (benefits are higher than costs) the maintenance measure is desirable from the point of the overall economy; if it is lower than 1, it is not desirable. Secondly, going beyond this information, the CBR allows a ranking of alternative maintenance measures regarding their efficiency. The higher the ratio, the more efficient is the maintenance measure.

6 With-case / without case

The with-case represents the case of carrying out the regarded maintenance measure. In the without case, no maintenance measure is carried out. The social costs of the with-case reduced by the social costs of the without-case are the benefit of the regarded maintenance measure. Negative cost values resulting from the reduction have to be regarded as positive benefit values.

7 Traffic simulation model

The model transforms quantitative traffic parameters (traffic volume, share of freight transport) into social costs as monetary data, depending on certain input parameters (share of freight transport, average daily traffic volume, investigation period, speed limits, length of the road network considered and distribution of road types). By empirical based functions, these data are transformed into further physical data, such as speed, fuel consumption, noise, emissions, accidents. In a further step, these physical data are assessed by monetary values. The quantified amounts of the different categories of social costs result from that assessment.

8 Road type

Road type is an input parameter of the traffic simulation model. Roads are separated into different categories depending on their capacity. The capacity depends on speed limits, number of lanes and carriageway widths. Therefore, a separation of roads into all real existing combinations of these characteristics is used for the traffic simulation model. The categories are derived from the EWS (Empfehlungen für Wirtschaftlichkeitsuntersuchungen an Straßen).

9 EWS (Empfehlungen für Wirtschaftlichkeitsuntersuchungen an Straßen)

This document (recommendations for economy investigations at roads) has been prepared by the society entitled the Research Society for Roads and Traffic, which consists of a large number of road engineers and transport economists. It provides the empirical based functions which link the physical data (traffic volume, share of freight transport, speed, noise, fuel consumption, emissions, accidents) with each other and provides the monetary assessments of them.

10 Accident costs

The EWS-accident quotas (accidents/ 10^6 heavy vehicle km) are used, depending on the road type. In relation to the traffic volume, a certain amount of accidents result. Accident costs result from economic losses of production, losses of welfare by disablement, losses of spare time, medical treatment costs, repair costs as well as from the administration costs of insurance institutions, law institutions, hospitals, fire and the police.

11 Noise costs

Noise costs are the costs which have to be spent on avoiding (for instance by installation of noise bunds) of noise emissions which cause damage of some sort (damages to buildings, damages to health). Only noise levels exceeding certain threshold sound values (40 dB for night; 50 dB for day) are considered. These noise threshold level exceedings are transformed into coefficients which are multiplied by the number of people concerned. Inhabitant coefficients (I_c) result from that. One inhabitant coefficient is evaluated with 42.5 euro per day:

12 Time costs

The time spent per vehicle equals the road length, divided by the vehicle speed. This time spent is multiplied by the EWS-time costs for one hour (passenger cars: 5.5 euro; Truck: 21 euro; Semi-trailer: 30 euro; Bus: 62.5 euro). Components of the time costs of freight transport are the labour costs and expenses of the drivers, as well as provision costs (interest charges of the capital investment, depreciation of the capital investment, garage, general costs). Components of the time costs of passenger transport are time costs for labour hours, time costs for leisure hours, as well as provision costs (for commercially used passenger cars only).

13 Vehicle operating costs

The estimation of vehicle operating costs is based on two terms. The first term is fixed for every vehicle type, and describes the basic costs for vehicle operation. This cost-component is independent from vehicle kilometre. The second term is the product of fuel consumption and fuel price. The fuel consumption is determined for different vehicle types by the EWS-speed fuel consumption functions (fuel consumption depends on vehicle speed).

14 CO₂-emission costs

CO₂-emissions are direct emissions. They spread widely in the atmosphere and thus damage independently of the distance to the source of emission. Therefore they have to



be distinguished from the indirect air pollution (distance between the source of the pollutant output and the place of the admission is important) by NO_x , SO_2 , CO, HC, PA.

The CO_2 -emission per vehicle km is determined by the EWS-fuel consumption CO_2 -emission functions separated for Diesel and Petrol. The CO_2 -emission costs result from multiplication of the CO_2 quantity by the costs per tonne (90 euro / t CO_2). The amount of the costs represents the costs which would have to be spent in order to avoid the damages resulting from CO_2 -emission. These costs are derived from general maintenance measures for a decrease of CO_2 -emission (by more economic usage of limited energy resources or by substitution of limited energy resources by non-limited energy resources).

15 Costs of air pollution

The quantity of indirect air pollution that results from the EWS-speed emission functions that determine the quantity of air pollution separated into different kinds of emissions (NO_x , SO_2 , CO, HC, PA) and that depend on different vehicle types and their vehicle km travelled. These different kinds of emissions are transformed by toxic factors to a standardised unity of nitrogen x-oxide. The costs for one x-oxide-unit is 850 euro / tonne. The amount of x-oxide is multiplied by 850 euro for determination of the total costs of air pollution.



Appendix 8:

ACRONYMS



Appendix 8

ACRONYMS

Acronym	Meaning of acronym
AADT	Average annual daily traffic
ANAS	Anders Nyvig A/S, Hørsholm, Denmark
AQTR	Association Québécoise des Transport et des Routes
ARIANNE	French model for vehicle operating costs
BELMAN	Danish pavement management system
BMS	Bridge management system
BRRC	Belgian Road Research Centre, Brussels, Belgium
CBA	Cost-benefit analysis
CBR	Cost-benefit ratio
CETE	Centres d'Études Techniques de l'Équipement, France
CITE	Canadian Institute of Traffic Engineers, Canada
CO	Carbon monoxide
CO ₂	Carbon dioxide
CORDIS	Community Research and Development Information Service
COST	European Cooperation in the Field of Scientific and Technical Research
dB	Sound (noise) level – decibel
DG VII	Directorate General VII (Now Directorate General Transport)
DRI	Danish Road Institute, Roskilde, Denmark
EFTA	European Free Trade Area
EPFL	École Polytechnique Fédérale de Lausanne, Switzerland
EU	European Union
euro	European currency unit (approximate value in November 1999: 1 euro = 2.00 DM = 6.60 FRF = 0.64 GBP)
EWS	Empfehlungen für Wirtschaftlichkeitsuntersuchungen an Straßen (German document with recommendations for economic investigations of cost-efficiency of roads)
FEC	FEHRL Executive Committee
FEHRL	Forum of European Highway Research Laboratories
FINVOC	Finnish model for vehicle operating costs
GNP	Gross National Product
GDP	Gross Domestic Product
h	hour
HC	Hydrocarbons
HCM	Highway Capacity Manual (a TRB publication)
HDM-III	Highway Design and Maintenance Standards, version 3, World Bank
HDM-4	Highway Design and Maintenance Standards, version 4, PIARC
HEN2	United Kingdom model for vehicle operating costs
IRF	International Road Federation
IRI	International Roughness Index (an index of road surface unevenness)
IRRD	International Road Research Documentation
km	kilometre
LAVOC	Laboratoire des Voies de Circulation - EPFL, Lausanne, Switzerland



LCC	Life-cycle costs (also known as whole life costs)
	Meaning of acronym
Acronym	
LCPC	Laboratoire Central des Ponts et Chaussées, France
m	metre
M/R	Maintenance and rehabilitation
NO _x	Nitrogen oxides
NPV	Net present value
OD	Origin-destination
OECD	Organisation for Economic Cooperation and Development, Paris
PA	Particles (minute fully/partially burnt hydrocarbon particles, primarily from diesel engine exhausts).
PARIS	Performance Analysis of Road Infrastructure
PAV-ECO	Economic Evaluation of Pavement Maintenance - Life Cycle Cost at Project and Network Level
PIARC	World Road Association
PMS	Pavement management system
PSC	Project Steering Committee
PV	Present value
NDLI	N.D. Lea International Ltd.
NPV	Net Present value
NRC	National Research Council, U.S.A.
RIMES	Road Infrastructure Maintenance Evaluation Study
RTD	Research and Technological Development
SSA	Standard Spending Assessment (U.K.)
SMS	Structure Management System
SO ₂	Sulphur dioxide
TPPT	Road Structures Research Programme (FinnRA and VTT, Finland)
TRR	Transportation Research Record
TRB	Transportation Research Board, U.S.A.
TRL	Transport Research Laboratory, Crowthorne, UK
TSG	Transport Supplementary Grants (U.K.)
TSM	Traffic simulation model
UK	United Kingdom
UoC	University of Cologne
VETO	Swedish model for vehicle operating costs
VIAGERENDA	Belgian pavement management system
Viagroup	Viagroup SA, Winterthur, Switzerland
VOC	Vehicle operating costs
VTI	Swedish Road and Transport Research Institute
VTT	Technical Research Centre of Finland, Espoo, Finland
WP3.3	PAV-ECO Work Package 3, Task 3
WP1.3 Annex	PAV-ECO Work Package 1, Task 3, Technical Annex