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Table of Contents

Executive summary iii
1. Introduction 1
2. Objectives of the project 3
3. Organisation of the project 5
4. Scientific and technical description of the results 7
5. Summary of research conducted on 'Road Condition Monitoring' 9
  5.1 Introduction 9
  5.2 Existing situation in pavement monitoring 9
  5.3 Optimisation of data collection procedures 11
  5.4 Assessment of equipment for monitoring pavement condition at traffic speed 16
  5.5 Application of high speed equipment 23
  5.6 Development of a monitoring strategy 28
  5.7 Future developments 31
  5.8 Conclusion 31
  5.9 References 32
6. Summary of research conducted on 'Technology' 35
  6.1 Introduction 35
  6.2 Selection of maintenance techniques and procedures for implementation 36
  6.3 Performance of innovative maintenance techniques in ALT facilities 41
  6.4 Practical implementation of procedures for road maintenance works 52
  6.5 References 59
7. Summary of research conducted on 'Safety at road works' 61
  7.1 Introduction 61
  7.2 Data Collection and Analysis 61
  7.3 Trials in Driving Simulators 66
  7.4 On-Site Data Collection 72
  7.5 Guidance on Traffic Management 74
  7.6 References 76
8. Summary of research conducted on 'Cost Benefit Analysis' 77
  8.1 Introduction 77
  8.2 The models 78
  8.3 Validation of delays model 84
  8.4 Agency and environmental cost assessment 92
  8.5 Extension to network level 95
9. List of Deliverables 97
10. Comparison of initially planned activities and work actually accomplished 101
  10.1 Work Package 1 'Management' 101
  10.2 Work Package 2 'Elaboration' 101
  10.3 Work Package 3 'Technology' 101
  10.4 Work Package 4 'Cost Benefit Analysis' 102
  10.5 Work Package 5 'Safety' 102
  10.6 Work Package 6 'Monitoring' 102
  10.7 Work Package 7 'Exploitation' 103
  10.8 Project co-ordination aspects 103
  10.9 Meetings 103

10.10 Conference attendance 103
10.11 Co-operation with other projects 103
10.12 Project scheduling and budget control 104
10.13 Performance of the consortium and individual partners 104
10.14 Contact details of the FORMAT team 105
11. References 107
Appendix 1: Deliverable Follow-up Sheet for Scientific Auditors 109
Appendix 2: FORMAT Project Steering Committee 111

Executive summary

The FORMAT project (Fully Optimised Road Maintenance) addressed Task 2.2.1/11 ‘Road infrastructure pavement maintenance management’ of the European Commission Key Action ‘Sustainable Mobility and Intermodality’. The project started on 1 February 2002 and ran for three years.

Twenty organisations contributed to this research project, nineteen from fourteen European countries and one from the United States of America. The funding of the project was shared between the European Commission and the Partner organisations or their funding agents. The Partners include national road owners, national highway research laboratories, universities, highway contractors and international trade associations.

The FORMAT project was designed to enhance the efficiency and safety of the European road network by providing the means to reduce the number, duration and size of road works for pavement maintenance activities. This has the potential to improve safety of both road workers and road users at road maintenance sites and to reduce disruption to road users

The project had the following technical and scientific objectives:

- To provide better performing, innovative pavement maintenance techniques and procedures that will reduce traffic disruption at the road works, in terms of congestion and improved safety;
- To develop an integrated cost-benefit analysis model that addresses key aspects of pavement maintenance, including road user costs;
- To produce safety strategies for road works that allow for arranging the work site lay-out and the timing of maintenance intervention in such a way that the safety of road users and road workers are optimised;
- To propose methods, procedures and equipment for monitoring the condition of road pavements at traffic speeds to minimise the number of disruptive road closures currently required for acquiring pavement condition data.

In order to achieve these wide ranging objectives, key aspects of the planning and execution of the pavement maintenance process were considered and the project was organised into seven integrated Work Packages comprising:

- four scientific Work Packages within which the research was conducted,
- one Work Package to develop the detailed methodology to conduct the research (WP2 ‘Elaboration’)
- one marketing Work Package to enable the research results to be implemented within Europe (WP7 ‘Exploitation’) and
- one management Work Package to control and direct the project to achieve the agreed objectives (WP1 ‘Management’)

The four scientific Work Packages addressed the following topics that were considered to be key to road pavement maintenance:

- pavement maintenance techniques and procedures (WP3 ‘Technology’)
- associated cost-benefit analysis methods (WP4 ‘Cost Benefit Analysis’)
- safety at work sites (WP5 ‘Safety’)
- high speed monitoring of pavement condition (WP6 ‘Monitoring’).

Work Package 3 **'Technology'** reviewed the developments in pavement maintenance technology throughout Europe and North America and identified the main innovations in this field concentrating on the most promising innovative maintenance techniques for both asphalt and concrete roads. Selected promising innovative treatment options were assessed and evaluated through accelerated testing in specialised full-scale road pavement test facilities. Pilot road trials were conducted on public roads to determine the efficiency of application of selected maintenance treatments, to provide data for the cost benefit models and to assess effective traffic management requirements.

Work Package 4 **'Cost Benefit Analysis' (CBA)** developed an integrated cost benefit spreadsheet model taking into account the costs due to pavement deterioration, additional user costs and safety at the work sites. In addition, environmental aspects such as benefits arising from recycling of road pavements and the reduction in noise from new innovative road surfaces were also modelled. The new models were assessed using data from in-service roads and from the pilot road trials of Work Package 3 'Technology' in order to determine their applicability in practical situations.

Work Package 5 **'Safety'** enabled the engineering requirements of road maintenance treatments to be carried out while optimising safety of both road workers and users. The safety implications of different traffic management options, including those necessary for new innovative maintenance treatments were assessed and proposals developed for appropriate traffic management layouts and associated signage. This was achieved by an analysis of accident data at sites with and without road works and through studies at specific sites. The effectiveness of new traffic management layouts was evaluated in driving simulators and through a detailed study of major works.

In Work Package 6 **'Monitoring'**, methods for measuring pavement condition at traffic speeds were assessed and procedures and methodologies were developed for applying such technologies. The main focus was on methods to measure the surface condition as well as the structural capacity of the pavement and other indicators required for optimum planning of pavement maintenance. The principal requirement was that the measurements should be carried out using equipment that is compatible with regular traffic flow. There have been significant developments both in Europe and the USA in equipment for assessing surface condition parameters such as cracking, fretting and ravelling and for structural condition assessment such as pavement thickness and deflection response. These types of equipment have been critically assessed and alternative monitoring strategies developed to make efficient and economic use of these and current routine equipment for monitoring condition.

An Inception Report was produced by Work Package 2 **'Elaboration'** shortly after the start of the project. It first reviewed the original proposals for research in the light of then current research developments in this subject area and any changing priorities of the European Commission and the Partner organisations. Then a detailed technical approach was developed together with a quality project plan to ensure that all the agreed research objectives of the project would be achieved. Finally, a methodology was proposed to enable the results of this research project to be exploited by European organisations and implemented by practising European engineers in order to improve the safety and efficiency of the European major highway network.

The objective of Work Package 7 '**Exploitation'** was to disseminate the results of the research in order that they can be exploited by European companies and implemented by European highway engineers to provide a more efficient, safe and cost effective highway system for the European residents. To achieve this objective, a programme of published reports from the project was designed, plans to participate in workshops conducted with other EC funded research projects were carried out and the results of the project were presented at international conferences for highway engineers. Finally, implementation plans were developed for each country participating in the project.

It was recognised that in order to achieve the objectives of this wide-ranging project, a comprehensive management approach was required. Work Package 1 **'Management'** fulfilled this requirement covering the activities of the Management Team and of the two Scientific Auditors. The Scientific Auditors were assigned to monitor the scientific quality of the research and report their observations to the Project Steering Committee. A Quality Assurance Plan was drawn up specifically for the project. and the management criteria were set up to ensure that the project achieved the objectives and that the research outputs were produced to the required standard, to the agreed timetable and within the allocated budget.

The scientific achievements include:

- Drawing up a comprehensive list of maintenance treatments and procedures used in individual European countries from which some innovative treatments were selected for assessment
- The construction and evaluation of the test pavements in four Accelerated Loading Test facilities. The treatments tested were a cement mortar grouted porous asphalt as an inlay; a binder course of steel slag asphalt concrete; two different high modulus binder courses as inlays under different thin asphalt surface layers; a high modulus binder course applied as an inlay to the wheeltracks alone under a thin asphalt surfacing; a thin asphalt overlay with geogrid over a cracked pavement.
- Three pilot trials on public roads were conducted to determine the ease of application of innovative maintenance treatments and any disruption to road users. The treatments assessed were the application of a new 0/6.3 porous asphalt on the ring road of Toulouse, France; the structural rehabilitation of a jointed concrete pavement on a motorway near Valencia, Spain involving injection grouting followed by either surface grinding or the application of two different asphalt surfaces with one incorporating a geotextile; the rehabilitation of a continuously reinforced concrete pavement near Baytown, Texas, in the USA that included various local repairs followed by the application of a bonded concrete overlay.
- Mathematical models for project level studies were implemented into spreadsheets to calculate probabilistically the additional road user costs due to delays at road works, the associated agency costs for the works, the environmental costs in terms of fuel emissions and noise, and the costs of pavement preservation. These individual models were integrated into a single spreadsheet model that contained default values for users without specific data inputs for all elements of the model.
- Data on accidents in general and those associated with road closures were collated from fifteen countries where data were available and analysed to provide indications on the effect of road closures on accident rates.
- Trials were conducted in driving simulators to explore the effects of innovative traffic management arrangements at work sites. These involved simulations on a two lane dual carriageway using narrow lanes in England to study their effect on speed and on a two way road in Sweden. Four different works arrangements were evaluated in each simulator.
- Safety data were collected and evaluated from two major road works sites on the E411 and E25 in Belgium where the works are being undertaken over a three year period and involve long-term operations on significant sections of two key routes.
- Equipment that is able to collect road pavement condition data at normal traffic speeds was assessed. These included devices that are in current routine use for measuring transverse profile, evenness, friction, texture, geometry, layer thickness and noise and also prototype devices that are still under development. The prototype devices were evaluated on public roads and included two for measuring cracking, two for measuring ravelling and fretting and two for measuring deflection response. In addition, some innovative applications of ground penetrating radar to measure layer thickness were assessed.

- The application of equipment for monitoring road condition at traffic speeds was considered including costs and benefits and guidance was drawn up to help road managers develop a strategy for monitoring the pavement condition.

The management achievements include:
- The project was held on schedule throughout its duration.
- All the eighteen planned Deliverables were submitted on time.
- The spending was in accordance with the progress during the project and hence with the original planning, both in terms of man months and in Euros.
- The dissemination efforts as detailed in the Inception Report at the start of the project have been implemented.

The dissemination of results has included the preparation of technical research papers for appropriate international conferences to disseminate the new knowledge. Also, specific national exploitation plans were drafted to evaluate the results with a view to implementing them into national road pavement management systems and specific procedures as appropriate.

This is the Final Technical Report of the FORMAT project as required under the ‘Guidelines for Reporting FP5 Growth Programme’. It also serves as the ‘Final Publishable Report’ as required by the same Guidelines. The main Report, however, for transferring the outputs of the project to the highway engineering community is FORMAT Deliverable D18 ‘Integrated Guide Fully Optimised Road Maintenance’ as specified in the Description of Work (Annex 1 to the FORMAT Contract), The Guide is available from the Project Secretariat.

This Report includes a section on the objectives of the project, a summary of the scientific and technical results, a description of how the results were disseminated and details on the management and co-ordination aspects of the project.

1. Introduction

The FORMAT project (Fully Optimised Road Maintenance) addressed Task 2.2.1/11 ‘Road infrastructure pavement maintenance management’ of the European Commission Key Action ‘Sustainable Mobility and Intermodality’. The proposal for the project was submitted for consideration for EC funding in March 2000. The contract was signed and the project started on 1 February 2002 and ran for three years finishing on 31 January 2005.

The FORMAT project was designed to conduct in-depth research into highway maintenance works in order to improve the efficiency, safety and cost of the maintenance works by appropriate planning, timing and execution of work zone operations. The research concentrated on four topics: maintenance technologies, minimising the cost of the complete maintenance operation, safety at work zones and surrounding areas and road pavement condition monitoring. These four topics were integrated in order to direct the research towards practical, implementable outputs that can be used by the European and North American highway community.

An Inception Report was the first output from the project in which:

- the proposals for research set out in the contract report entitled ‘Description of Work’ (2002) were reviewed in the light of on-going research developments in this subject area
- the scientific methodology was developed to ensure that the scientific/technical goals were achieved
- the integration of the different research topics forming this project was planned
- a detailed project plan was developed to ensure that all the agreed objectives of the project were achieved
- the management of the project was organised to meet the agreed deadlines of project deliverables and to ensure the quality of the research
- a programme was developed to enable the research results to be rapidly exploited by the European and North American highway engineering community through publications, workshops and conferences

Throughout the project the Inception Report was used as the blueprint to conduct the research in order to achieve the contracted objectives on time and to budget whilst maintaining the required technical standard. Two Scientific Advisors were appointed to the project both of whom were world renowned experts in the field of highway engineering. They worked independently of the technical research teams and their job was to critically assess what the technical teams were doing and to review the outputs before they were delivered to the European Commission. Their comments were taken into account and the outputs were revised as necessary to satisfy these experts before the contracted deliverables were given to the Commission. Allowance was made in the project plan for this stage in the internal review and approval of all technical outputs so that they were delivered on time.

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2. Objectives of the project

The FORMAT project was designed to produce a fully integrated approach to the optimisation of the key aspects of the planning and execution of road pavement maintenance, which would lead to a reduction in the number, size and duration of road closures. This in turn should lead to considerable savings for the road user, in terms of reductions in delays and accidents at road works and therefore to a reduction in the cost of these incidents for the community. Overall, the project aimed to provide practising engineers with the knowledge and means to improve the efficiency and safety of the European road infrastructure.

The project had the following technical and scientific objectives:

- To provide better performing, innovative pavement maintenance techniques, procedures and techniques that will reduce traffic disruption at the road works, in terms of congestion and improved safety.
- To develop an integrated cost-benefit analysis model that addresses key aspects of pavement maintenance.
- To produce safety strategies for road works that allow for arranging the work site lay-out and the timing of maintenance intervention in such a way that the safety of road users and road workers are optimised.
- To propose methods, procedures and equipment for monitoring the condition of road pavements at traffic speeds to minimise the number of disruptive road closures currently required for acquiring pavement condition data.

As the project proceeded specific shorter term objectives were set at approximately six monthly intervals so that the required progress towards the principal and technical objectives was achieved on time. These working objectives have been described in the three Progress Reports and two Management Reports produced during the project. (References 1-5)

3. Organisation of the project

The project was organised into seven integrated Work Packages comprising:

- four scientific Work Packages within which the research was conducted,
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4. Scientific and technical description of the results

In sections 5, 6, 7 and 8 a separate summary is given for each of the four technical Work Packages describing the work carried out throughout the project and highlighting the main results achieved.

The work is presented in the order that operations would be carried out in practice. Therefore the summary of research conducted in Work Package 6 concerned with monitoring the condition of the road is presented first. This is followed by the summary of research conducted in Work Package 3 concerned with road maintenance techniques and then the summary of the work conducted in Work Package 5 that concentrates on safety at road works sites. Finally the summary of research conducted in Work Package 4 concerned with the cost benefit analysis is presented.

5. Summary of research conducted on ‘Road Condition Monitoring’

5.1 Introduction

Optimisation of monitoring costs has never been a key issue, and therefore have never been the subject of advanced studies. Road network managers are usually planning systematically cyclic monitoring series, i.e. repeated with constant intervals without taking account neither of the needs according to the chosen maintenance strategy, nor of the specific behaviour of the road network. Although monitoring costs are usually small compared to the maintenance costs, substantial savings are possible by optimising the monitoring strategy on a network.

The use of traffic-speed equipment for monitoring pavement condition aims at reducing safety hazards and traffic disruption compared to stationary or slow moving survey equipment. In addition, attractive benefits can be achieved, including cost savings, by optimising the monitoring strategy on a road network taking into account the type and frequency of surveys.

Work Package 6 ‘Monitoring’ aims at optimising monitoring procedures for pavement maintenance purposes and at developing the procedure for use of high speed equipment for monitoring pavement condition in order to reduce traffic disruption and safety hazards due to stationary or slow moving survey equipment.

The Work Package has built on the results of COST Action 325 (1997): New road monitoring equipment and methods. Since the completion of COST Action 325 in 1997, high-speed monitoring prototypes have been developed or improved, notably in the domain of bearing capacity and surface distress. WP6 ‘Monitoring’ will critically assess some of these prototypes, select the most promising and develop schemes for the use of such monitoring equipment and for the application of the resulting data in pavement maintenance planning. WP6 is split into three tasks:

- Task 1: Optimisation of data collection procedures
- Task 2: Assessment of high speed monitoring prototype equipment
- Task 3: Application of high speed monitoring equipment in pavement maintenance planning

The first task provides appropriate monitoring procedures and schemes for the various types of networks, in term of data requirements, frequency and speed of data acquisition, in order to optimise data collection for pavement maintenance planning and design. Then, the second task presents an assessment of the capability of the state of the art prototype equipment to meet the specified data requirements. Finally, within the third task, procedures are developed for application of the data from selected prototype equipment in maintenance planning.

5.2 Existing situation in pavement monitoring

The reasons for monitoring pavement condition may range from legal reasons to practical, technical reasons. Among the reasons for monitoring at the network level are:

- Overview of budget needs
- Planning of maintenance

- Prioritisation of maintenance activities
- Determining condition indicators
- Asset valuation
- Securing a safe road network
- Providing a sustainable road network
- Providing a given level of service to the road users

Information on the surface (rut, cracking, bleeding, etc) and structural (layers thickness, characteristics, deflection, etc) condition of roads is an essential requirement for making efficient maintenance management of road networks. Indeed, valid, sufficient and reliable data, and good prediction models to be integrated in a PMS are needed. A lack of timely data or unsatisfactory/unreliable data thus makes it difficult to evaluate the road condition, to prioritise and optimise road maintenance actions (project level) and to determine the maintenance budget (network level). Improved monitoring systems are a key issue for good data on surface and structural property of the considered network.

Due to the size of the networks and the quantity of data that are usually necessary to collect for managing the maintenance in a professional way, and also for economical and safety reasons, the actual tendency is to develop and use high speed monitoring devices, especially for motorways and primary road networks monitoring, where the volume of traffic is very high. Thus, monitoring devices could be classified into two groups:

- Stationary or slow speed monitoring devices: the speed is considered to be lower than 25 km/h.
- High speed monitoring devices: the speed is considered to be the traffic speed or a little lower.

In order to reduce the monitoring costs, but also to reduce the impact of such operation on the traffic due to safety and delays issues, multifunctional devices have also been developed. However the inconvenience of such devices is that several parameters are monitored at the same time, consequently the same frequency, but the optimal frequency might be different for different parameters.

In European countries manual (visual) survey of surface distress data is still widely used in spite of many disadvantages (monitoring staff and road users safety issues, traffic disturbance, reliability of the data, time consuming and low survey capacity). Stationary and slow moving monitoring devices are also widely used and probably will be for a while. Many authorities use an image capturing/manual processing method in addition to the manual method. This method only solves problems of traffic disturbance and road safety. Concerning the structural condition survey, road authorities would like to increase the efficiency of monitoring. The use of traffic-speed devices would allow large networks to be surveyed, increasing the number and the quality of the data and optimising the monitoring process considering the maintenance management needs. Nevertheless it seems that Western European countries are in the middle of a transition to more automated processing method and Eastern European countries just beginning this transition. There is obviously a need to increase the speed and the daily capacity of data collection. This is especially true for large networks, where a reduction in time and personnel would significantly reduce the overall costs of data collection and traffic disruptions, and consequently improve the road safety.

A detailed inventory has shown that there is no publication referring to optimised management of pavement monitoring. Such policy exists for the maintenance of different equipment in general (road network included), but pavement monitoring seems to be treated as of less interesting operation and moreover of negligible cost, as there seems to be no willpower to optimise such business.

Actually we point out that pavement monitoring of a road network is usually performed at constant intervals. Pavement monitoring frequency is very different from one country to another. However it usually follows some rules, which depend on the objective of the monitoring operation as follows:

- To set up pavement performance models: short frequency (1 to 2 years)
- To collect data for a PMS database (simple survey): constant intervals (3 to 4 years)
- In case of any traffic modification or unexpected behaviour of a section: spot monitoring at variable frequency

Usually, the frequency between two surveys doesn't exceed 5 years, in order to avoid using "outdated" data. The necessity to monitor the entire network is also frequently discussed. Theoretically, it would be possible to monitor specific pavement sections that are representative of a portion of the network. This strategy consists in clustering the road network that is considered as identical road sections (same structure, same traffic, same climate, etc) and carrying out monitoring only on one or a sampling of sections per cluster. Some private motorway companies execute such strategy. However, such strategy is usually not applied on common road networks where pavement construction and maintenance has been performed in such way that no clustering is feasible.

5.3 Optimisation of data collection procedures

The state of the art shows that there is no publication illustrating that monitoring strategy based on the optimisation of the costs has yet been developed. Data collection is either random or periodic and cyclic. Intuitively it is presumed that such strategy is expensive, because most of the time, neither the condition of the monitored sections, nor the needs for information on the condition of the network according to a selected maintenance strategy are taken into account. However, such strategy still will be certainly commonly applied for some years for the following reasons:

- Methodology is simple.
- Monitoring campaigns at shorter cycles (intervals) makes it possible to work out or to verify pavement performance models.
- The monitoring budgets that are necessary are usually constant and are known in advance.
- The maintenance requirements are generally well defined, because of the large amount of information that is usually available.

Monitoring costs are relatively lower than maintenance costs, but they are not insignificant. Moreover, the tendency for total management of the road network maintenance is increasing. Such maintenance management does not only relate to the monitoring of the pavement, but also integrates the monitoring of additional parameters such as signing, safety elements, etc. Consequently, a general increase in monitoring spending can be expected in the future.

The purpose is thus to provide the manager of the road network with tools that make it possible to develop a monitoring strategy based on the optimisation of monitoring spending. Such optimisation aims at increasing monitoring effectiveness (no useless monitoring) and at reducing monitoring costs. A good knowledge of the road network performance constitutes the base of the future decisions for the manager who is also encouraged to define a monitoring strategy that cause a minimal charge and reduce if possible his budget.

5.3.1 Optimisation concept

The global optimisation concept is based on balancing the benefits of reducing monitoring costs with any extra maintenance costs or loss of asset value initiated by a lack of monitoring. Extra costs are associated with the risk of carrying out maintenance before it is needed and thus reducing the lifespan of the existing pavement or with the risk of having to apply a more expensive maintenance treatment if the pavement is allowed to deteriorate beyond the time when it should have been maintained.

The concept that is developed contains three aspects (or stages), namely:
1. Optimisation of monitoring procedure for one parameter in a given homogeneous section (scheme level). It is indeed advisable to define at which optimal time it is necessary to carry out a single monitoring campaign. The maintenance intervention according to the selected maintenance strategy is ensured.
2. Optimisation of the monitoring procedure for one parameter at network level (set of adjacent roads). It is assumed that the required monitoring device runs on the entire road network or part of the network considered.
3. Optimisation by combining the collection of more than one parameter at the same time. The current tendency is the development of new multifunctional monitoring devices, i.e. able to collect more than one parameter at the same time.

This optimised process for monitoring pavements (Monitoring Management) assumed that:
- Homogenous sections have been determined.
- Performance prediction models are known.
- Intervention thresholds are provided (which are maintenance strategy dependent).

Any other approach to monitoring was considered to be out of the context of FORMAT.
Definition: a section of road is defined as homogeneous when the coefficient of deviation of data for a given condition indicator on the considered section is lower than a given value.

5.3.1.1 Monitoring Scheduling (Scheme Level)

The best optimisation of data collection at scheme level would be to monitor the section only once, especially when the distress level is close to the threshold value that is given for the application of a maintenance treatment. Application time of such monitoring would then allow the definition with the best precision when the application of the maintenance treatment is optimal. For such policy, it is necessary to have pavement performance models available, that are accurate, or where a given confidence band is identified. The monitoring procedure that has to be applied is dependent on the maintenance policy or strategy which depends on the budgets allocated to the maintenance of the monitored road network. The general global alternative strategies are:

- Preventive maintenance strategy: localised treatments only
- Rehabilitation strategy: surface and strengthening treatments
- “Do nothing” strategy: until the structure has to be reconstructed

Various threshold levels can be applied depending on the selected maintenance strategy, like user sensitivity, serviceability, alert, and intervention threshold. Selection of the most efficient time for the application of a specific maintenance treatment can be carried out by assessing the condition or distress level of the considered homogeneous section and by forecasting its evolution with the use of a performance model.

Ideally, a pavement performance model should make it possible to define, without resorting to a monitoring survey, the adequate timing for a maintenance intervention. However, the large number of parameters which influence the pavement performance reduce the accuracy of such models. It is obvious that the performance models that are empirical or semi-empirical suffer from a certain inaccuracy, but the development of analytical models is extremely difficult. So, it is advisable to combine judicious pavement monitoring with pavement performance models in order to optimise the monitoring procedure and strategy.

By associating a confidence band to a given pavement performance model and by knowing the value of the indicator(s) that is (are) being considered in one homogeneous section at a given moment, it is possible to define the best time to carry out the next monitoring. The time required for the planning and the organisation of the maintenance is also taken into consideration.

Figure 5-1 provides a scheme of considered concept:

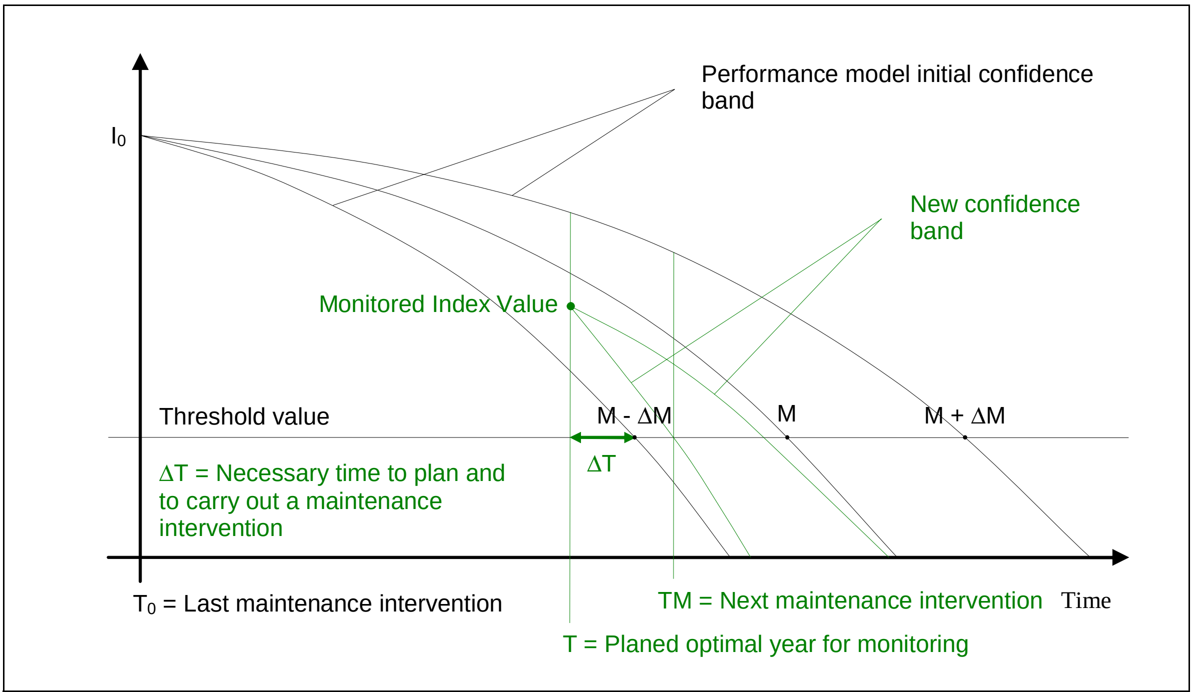

Figure 5-1: *Monitoring planning according to the indicator value, to the selected performance model, to the applicable confidence band, and to the threshold level.*

The confidence band associated to the theoretical performance model of a given indicator makes it possible to integrate uncertainties which are related to the evolution of the performance indicator. Setting up of a pavement performance model is relatively easy, but the estimation of the confidence interval is more complex. The proposed method for developing such confidence band is based on the assumption that for each indicator considered the average lifespan, an estimated lifespan variation and the risk in having the lifespan out of the lifespan variation, can be provided by the road manager.

By assuming a normal distribution of the performance variation on both sides of the performance model, the confidence band is associated to the risk assumed and is a function of the indicator previous monitored value, the residual estimated lifespan up to the maintenance level, and of the variation of the estimated average lifespan. The confidence band is expressed by the following considerations:

- Performance model: $I(I_0, M, t)$
- Indicator value at the previous monitoring survey : I_0
- Average lifespan[1]: M, or average residual lifespan: M_R

[1] Provided by the manager and depends on the maintenance strategy.

- Variation of the estimated average lifespan[1]: M
- ΔM estimated confidence interval[1]: %

The expected confidence interval (Δ%) corresponds to the confidence band accepted by the manager and provides the ΔM value (variation of the expected average lifespan).

The optimal monitoring time of a homogeneous section is when the indicator value reaches the threshold level reduced by the time ΔT that is necessary to plan and organise the maintenance intervention. The ultimate period to carry out the next monitoring campaign thus corresponds to T = M - ΔM - ΔT (Figure 5-1)).

5.3.1.2 Monitoring strategy (Network Level)

At network level the homogeneous sections that are to be monitored within a considered time are usually spread in a random order over the entire network. In addition those sections are not adjacent. Figure 5-2 illustrates an example of a portion of a network with various homogeneous sections x, y, z which are representing different calculated optimal monitoring times.

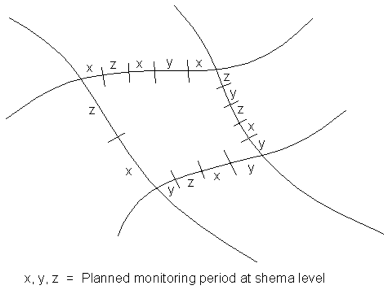

Figure 5-2: Example of various homogeneous sections on a portion of a network.

The concept aims at grouping sections from adjacent years (for example, sections that are planned to be monitored in year x with sections that are planned to be monitored in years x-1 and x+1) in a single monitoring campaign.

The benefit of grouping sections from adjacent years is the financial savings from monitoring. However, to postpone the monitoring time increases the risk of having to apply a more expensive maintenance treatment if the pavement is allowed to deteriorate beyond the time when it should have been maintained. To bring forward the monitoring time increases the risk of having to carry out an extra monitoring for planning the maintenance treatment with accuracy, or eventually, in case of no extra monitoring, increases the risk of carrying out maintenance before it is needed and thus reducing the lifespan of the existing network (asset loss). The advantages of shifting the monitoring time are (in case of advanced monitoring time) the possibility to detect sooner a fast propagation of the distress and (in case of delayed monitoring time) the possibility to better plan the maintenance treatment if the performance of the pavement is better than expected.

The next schema (Figure 5-3) shows the cost and benefit analysis procedure of the optimisation concept at network level:

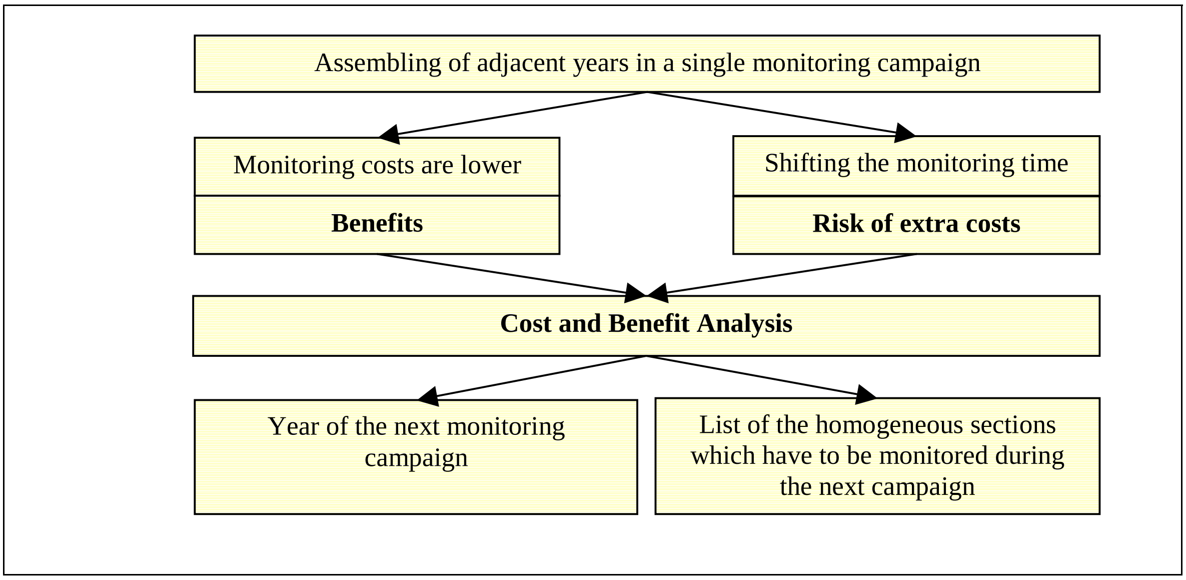

Figure 5-3: Optimisation Procedure at Network level.

The monitoring costs correspond to the device provision, the device movement, the data acquisition, the data treatment, the data analysis and the traffic management (signing, securing, etc). The extra cost (risk of extra maintenance cost) is calculated using a probabilistic approach which is based on a normal distribution representing the risk of missing the threshold value corresponding to the planned maintenance treatment.

5.3.1.3 Case for several indicators

In the previous chapter the optimisation concept for one indicator has been defined. It is obvious that the optimisation of the monitoring strategy integrating several indicators is much more complex. A monitoring optimisation process for several indicators remains similar to the one described previously, but the consideration of several indicators brings interactions that are linked to superposition phenomena. Combined data gathering of several indicators is usually linked to the use of multi-parameter data acquisition devices and depends on the needs of the road maintenance manager. Therefore, it is necessary that those devices meet the manager needs and that the finances can afford the potential of these monitoring systems offer.

The concept of risk (extra maintenance costs) can be adopted only for the indices dealing with the user comfort or with the structural performance. The hierarchical principle is to fix the priority on the indicators dealing with safety at the time when the monitoring program is set up and to combine or adapt monitoring of the other indicators considering the program of safety monitoring.

5.3.2 Monitoring schemes

Two models and spreadsheets have been developed, in order to show how to plan monitoring in a more optimised way according to the performance of the network and the selected maintenance strategy. One is a performance model containing a confidence interval that is based on statistical principles. The optimal year for a single monitoring campaign is calculated and then, according to the year of maintenance, benefits are calculated. This spreadsheet exactly illustrates the optimisation concept described before. The second model calculates and compares for an appropriate time span the annual discounted costs of implementing the maintenance at the optimal time intervals and performing the monitoring for selected time intervals. Both models are designed for use at the scheme level.

5.4 Assessment of equipment for monitoring pavement condition at traffic speed

Recent developments in high-speed road condition monitoring techniques are extremely encouraging. Many of the challenges set for the road monitoring community by previous European groups, e.g. COST 325, have been met and solutions found. Many of the prototype methods could be employed by highway administrations on a preliminary basis, with suitable safeguards.

Since FORMAT's proposal phase, some high speed monitoring equipment has passed from the stage of prototype to current routine use in pavement monitoring, for example equipment for measuring macrotexture and pavement thickness. However, the use of ground penetrating radar to measure pavement thickness has various limitations which has resulted in it remaining classified under the 'prototype' heading. In contrast, the measurement of macrotexture to supplement skid resistance measurements is well-established and is therefore classified as 'routine'. However, the measurement of macrotexture to provide a means of estimating ravelling and fretting is still considered to be in prototype and classified as such.

The next chapters provide the assessment of high-speed monitoring equipment and their capabilities in meeting the data needs (see chapter 5.5.1). In particular the equipment that are currently available as prototypes and can contribute to the desired high speed monitoring strategies (see chapter 5.5.2). In addition a description of practical site evaluations of selected equipment and results available to date is mentioned.

The characteristics and performance of high speed monitoring prototypes from Europe and the USA are evaluated considering the type of data being collected and its accuracy. The reliability, speed of monitoring, and method of referencing the location of the measurements is also evaluated. Based on this assessment, prototype equipment will be selected for the development of application procedures.

The test sections from Work Package 3 are in general too short (i.e. of the order of kilometres or less) for the on-site evaluation, so they are not well-suited to measurement by these prototypes. The assessments are therefore based mainly either on previous recent comparison studies on network lengths termed 'Non-FORMAT Network Trials' or on longer lengths of the network specially selected for the FORMAT project, termed 'FORMAT Network Trials'. An exception was for the measurement of layer thickness by ground penetrating radar where the equipment could be successfully deployed on some of the FORMAT pilot sites in France and Spain, termed 'FORMAT Pilot Study Trials'. Analysis of the resulting data has been completed and the findings are contained within this report.

The terms routine, prototype and research version are defined for the purposes of this report as follows:

Routine:	Equipment that is manufactured commercially and is in regular use on the road networks of several countries.
Prototype:	Equipment that is not yet manufactured commercially nor is it in regular commercial use.
Research version:	Equipment of which only one or two examples exist which are used only for research investigation measurements.

For all of the three classes of equipment, the capabilities of each equipment method used for measurement of a parameter were summarised in a separate table using classifications based broadly on the issues raised under monitoring requirements. These Tables of Capabilities each contain the following common information:

- Field of application
- Operational safety
- Measuring conditions
- Density, directness and quality of measurement
- Data processing and location referencing
- Present status of equipment and resources required

The current traffic-speed measuring capabilities are inventoried in the following chapters.

5.4.1 Routine equipment

5.4.1.1 Transverse profile

Traffic-speed transverse profilometers are basically of two different types. One type of transverse profilometer is based on a photographic or video technique where a plane of light is projected at an angle onto the road surface and a picture of the generated line is taken. The other type of transverse profilometers use contactless height sensors to sample the transverse profile across the pavement lane.

The normal way of evaluating transverse profile measurements is to calculate rut depths and/or theoretical water depths ignoring the effect of longitudinal road slope. Transverse profiles are interpreted using software to simulate the straight edge and wedge measurement and hence obtain the rut depth. Investigations of the measurement of rut depth with transverse profile measurement systems have shown that this method of measurement is directly comparable with the measurement taken by inspectors during visual condition surveys. Transverse profiles can also be used to derive theoretical water depths in combination with measures of crossfall of the pavement. A more rigorous but rather more complex approach also uses the longitudinal gradient of the pavement in this calculation. More recently, scanning lasers have become available that provide transverse profiles with much more detail and resolution. The various measuring capabilities and methods of interpretation currently available in Europe have recently been comprehensively evaluated in the project entitled FILTER (2002): FEHRL Investigation on Longitudinal and Transverse Evenness of Roads.

5.4.1.2 Evenness

Routine network level monitoring of pavement evenness is undertaken using profilometers that can operate at traffic speeds. A profilometer is any device capable of producing a representation of the true pavement profile without systematically introducing distortion. All profilometers are limited by the vertical precision to which individual profile points can be measured, the accuracy to which the datum can be determined and the range of longitudinal wavelengths over which they produce a valid profile. Currently two types of high speed profilometer are in common use:

- Non-contact Profilometers: these devices use non-contact sensors, normally laser or infrared, to measure the relative distance between the vehicle frame and the surface of the pavement.
- Profilometers: as far as is known, the only example of this form of device is the French Analyseur de Profil en Long (APL).

5.4.1.3 Friction

Two important parameters are assessed routinely in order to verify safety conditions with respect to tyre-pavement friction: friction coefficient and texture depth. Several types of testing equipment have been developed for the assessment of friction coefficient at traffic speeds, both at network and at project level.

Although friction measuring devices operate routinely in a number of European countries it is difficult to compare results between different countries because of the large number of devices and friction indices. Therefore, several international initiatives have taken place, or are underway, in an attempt to harmonise and/or correlate the friction parameters (for example, as reported by PIARC, 1995; Bennis and de Wit, 2003; and Descornet, 2003).

5.4.1.4 Texture

Traditionally, the texture has been assessed by measuring the area that a given volume of fine material covers when spread over the surface and expressing this as a texture depth value; the volumetric patch technique. More recently, high-frequency laser measurement devices have been used to record the profile (usually in the nearside wheelpath) at a high sampling rate. Suitable algorithms can then be used to analyse the measured profiles to derive a measure of texture depth that relates closely to the value derived from the patch method. Such laser-based techniques can be used at a wide range of test speeds including normal traffic speed. Trials to compare the various methods of texture measurement have been reported by PIARC (1995).

5.4.1.5 Geometry

Most multi-function survey vehicles are provided with instrumentation that enables the data acquisition at traffic speed. The technique generally uses accurate gyros that measure the roll, yaw and pitch of the vehicle from which the geometric parameters can easily be derived. These can operate at normal traffic speed and are unaffected by usual operating conditions.

5.4.2 Prototype equipment

The current status of the prototype condition monitoring equipment for operation at traffic speed is summarised for the measurement of cracking, ravelling and fretting, bearing capacity, layer thickness and noise.

5.4.2.1 Cracking

In the evaluation of crack monitoring methods it is the end use and the requirements of the user that dictate the necessary outputs. This implies that different crack monitoring techniques can be used depending on whether the data are for PMS purposes, performance control or maintenance and operations. The first automatic image collection systems used film that had to be developed, but today three types of technique are mainly used:

1. Standard video (analogue or digital)
2. Line scan video (analogue or digital)
3. Distance measuring laser cameras (point or line scan)

Standard video/film creates frames/images that cover a certain area. The frames are generated at a constant rate, usually 25 frames per second, which means that the coverage of the pavement will depend on the speed of the survey vehicle. A line scan camera is an image acquisition tool whose sensor consists of one line of photo elements. The image is therefore acquired line by line. The scanning of lines is controlled by the speed of the measuring vehicle. As with the standard video, this technique is considered to be a two dimensional method with a third pseudo dimension of greyscale levels. The final method that uses lasers is considered to be a true three-dimensional technique. The principle used is that of “laser triangulation”: the measurement of the distance from a reference plane with as many and closely spaced measuring points as necessary to give true three-dimensional distance information. Examples of the three different techniques include (1) PAVUE and WiseCrax (2003), (2) HARRIS (2003) and (3) G.I.E. Laser Vision and Laser RST (2003). A recent review of current available systems is provided by PIARC (2003) and a review of the remaining challenges for such systems is described by Offrell (2003).

Trials of survey contractors offering automatic crack detection systems are being carried out by TRL during 2003 and 2004 on behalf of the UK Department of Transport with some publicity support from the FORMAT study. Over 50km of the English Principal Road Network was selected as test sites. Each of the sites was surveyed by the HARRIS vehicle to provide high-quality vertical digital reference images of the road surface. These were analysed manually for the presence of cracking using a well established and standardised process. This has provided the reference results against which the surveys of a number of contractors, including two using the PAVUE system, are being compared. This work is still ongoing and therefore cannot now be reported within this report.

Trials of the PAVUE system for the Highways Agency in the year 2000 must be mentioned also. These non-FORMAT Network level trials were carried out on two 80km urban and rural test routes. Summary assessment of the performance of PAVUE in the measurement of cracking has been complicated by the differences in sensitivity found between PAVUE and the reference that do not necessarily reflect poor performance by PAVUE, or make the system unsuitable for carrying out Network surveys. In general, the PAVUE system identified the same areas of cracking as the reference system, HARRIS. However, if the high levels of deterioration over isolated lengths, observed by PAVUE and not by HARRIS, arise from “real” defects for which HARRIS is less sensitive, then these differences can be considered acceptable. However, it is felt that the general level of deterioration observed by PAVUE on the rural route that was not observed by HARRIS, and which is also linked to the inherent difference in sensitivity of the two systems, requires further monitoring to ensure that this will not complicate the use of the PAVUE crack data when applied to Network assessment of pavement surface condition.

In conclusion, automatic crack measurement devices mounted on vehicles that travel within the normal traffic stream are now widely available. Some are in regular use on the road network. Although the results are fairly consistent between machines using the same systems, correlation between different machines and with manual assessment is more problematical. Relative levels of crack density can be very similar but absolute levels very different, particularly between automatic machine surveys and manual inspections. The systems can also show very different sensitivities on different types of surfacing which may only be overcome with very accurate records of construction type or real-time identification of surface type. Therefore, further work is needed to improve the robustness of such measurements and the comparability of the different types of equipment if such equipment is going to be fully useful to the highway engineer. Part of this process will probably include comparability tests on a wide range of representative road surfaces in various stages of distress.

5.4.2.2 Ravelling and fretting

DWW in the Netherlands have, in the past few years, developed a high-speed method to assess the amount of ravelling on porous asphalt surfaces based on texture profiles. Other texture-based methods are being developed by CROW in the Netherlands and TRL in the UK.

During 2002, extensive validation (non-FORMAT trials) of the **Stoneway model** (based on the texture measurements of the ARAN) took place in the Netherlands. Although the Stoneway method had been compared successfully to the visual condition survey ravelling classification, this classification used by DWW does not assess the actual amount of ravelling; rather it estimates the intervention year directly during the survey. During the validation tests of the method the modelling was required because it allowed the intervention year and matching dispersion to be estimated and compared to the visual condition survey results. The validation exercise showed that the variability of the Stoneway measurements in combination with the SHRP-NL model produces acceptable results, which are more objective and accurate than the visual condition survey estimation currently used by DWW. It was also shown that the SHRP-NL modelling could probably be improved by tuning the model to match the visual condition survey results. This means that the future emphasis will be on improving the propagation model rather the repeatability of the measurements. Overall it was concluded that the results showed promise for the future replacement of the visual condition survey at a network level with the measurement of the Stoneway parameters combined with the SHRP-NL ravelling model. Before doing so, DWW have decided to monitor its network for one year using visual condition survey and the Stoneway method in parallel. The differences will be analysed at the network level and tuning of the SHRP-NL model will be considered if it still shows a systematic deviation in the estimated intervention years. It is likely the following visual condition survey monitoring cycle of ravelling will be replaced by the Stoneway observations.

The **Multiple linear regression analyses** method (CROW) is comparable to the DWW Stoneway method. The findings of the research project (non-FORMAT trials) were presented by Nagelhout et al (2004). Intermediate results show that the quality of the estimated models for the various surfaces is comparable to the quality of the Stoneway model.

In the UK, the routine network level surveys of crack density have been shown to be excessively sensitive to the presence of fretting or ravelling, but particularly on the hot rolled asphalt (HRA) wearing course materials. TRL Limited was therefore commissioned to develop a means of identifying the degree of ravelling that would aid engineers in the interpretation of the cracking results. Rather than develop a totally new approach, TRL adapted the existing Stoneway method for UK conditions (**Modified Stoneway**). Again the correlation was very encouraging (non-FORMAT trials).

In conclusion, the Dutch approach to the detection of ravelling based on the analyses of the texture signal appears promising. In particular, the independence of the methods from ambient light levels and the use of the third dimension (depth) positively discriminates them from image processing techniques. It is therefore not surprising that, as a result of the positive findings of the DWW research, other researchers, such as CROW and TRL, have started to investigate the use of texture-based techniques to assess surface distress. One drawback of this approach is the fact that a maximum of three longitudinal lines are scanned, from which the condition of the entire surface is extrapolated. However, as the DWW research has shown, this does not prohibit the use of the technique at a network level. This limitation could be overcome with the use of additional longitudinal texture lasers or lateral scanners. The use of these techniques in combination with image processing techniques is also promising. The combination of complementary techniques should improve the quality of the results by removing the drawbacks of the individual techniques.

5.4.2.3 Bearing capacity

Two European traffic-speed prototype devices were selected for further evaluation by the FORMAT consortium: the Swedish Road Deflection Tester (RDT) and the Danish High Speed Deflectograph (HSD). The Rolling Wheel Deflectometer developed in the USA, which has been developed with FHWA funding, is also briefly reviewed.

As part of a wide-ranging programme of work for the UK Highways Agency, reviewing developments in this area, the Swedish Road Deflection (RDT) equipment was brought to the UK for an evaluation of its performance on major roads (non-FORMAT trials). Falling Weight Deflectometer (FWD) and/or Deflectograph deflection surveys of the same sites were used as references for comparison with the RDT measurements. The data analysis showed that the RDT deflections have a poor correlation with those from either the FWD or Deflectograph and are very much poorer between the FWD and Deflectograph. In addition, the RDT deflections also have a poor level of consistency between repeat runs on the same site both in terms of deflection level and deflection variability, and the RDT deflections are generally more variable than those of the FWD or Deflectograph. Based on these results, the report concluded that the measurements from the RDT, in its state of development at that time, were not sufficiently accurate or repeatable for use in assessing the bearing capacity of major roads in the UK. An investigation into the possible sources of error was made in order to apply a correction and to allow a revised evaluation of the repeatability. It was found that the (manual) triggering of the test section start point was not accurate enough and the lateral alignment of the front and rear arrays was not optimum. A project to correct these possible problems is thus planned to run during 2004, but no results have been published yet.

LCPC assessed the performance of the Danish High Speed Deflectograph (HSD) during October 2003 on selected lengths of the road network comprising over 50 lane kilometres of motorway, national and regional roads. The data provided by the HSD, within the framework of the assessment, were repeatable and showed a good correlation with those carried out by the FWD. However the duration of pre-heating of the Doppler sensors is rather long and the electronics of the acquisition chain showed signs of weakness. The equipment was found to be sensitive to climatic conditions and the required calibration procedures were long and delicate. Further work is thus necessary to resolve these issues and an improved procedure for the interpretation of measurements should be developed.

Field tests carried out in Texas in 2003 (non-FORMAT trials) provided the most comprehensive study to date of the Rolling Wheel Deflectometer's (RWD, USA) capabilities, in terms of data quality, usefulness of results, correlation to other devices, and practical considerations. Overall, it is believed that the RWD has demonstrated its usefulness as a network-level structural evaluation tool for highway pavements, although several aspects, such as the influence of thermal effects, need to be investigated further so that improvements can be made to the RWD's accuracy and repeatability. The performance of the RWD was compared to that of the FWD and RDD over 38 test sections. In all cases, the correlations between devices showed similar trends in the sense that as deflections increased according to one device, the other device also showed an increase in deflection. However, the magnitude and rate of change in deflection varied.

5.4.2.4 Layer thickness

The Ground Penetrating Radar (GPR) is an electromagnetic sounding method which uses radio frequencies for subsurface investigation. Although the use of GPR for pavement evaluation is relatively recent (Maser, 1993; Scullion, 1994; Saarenketo, 1992; Van Leest, 1998) the GPR has the potential to be a useful tool, both at project and at network level, as it allows for measurements at high speed. From the existing methods for measurement of layer thickness, three systems were selected for study: GPR with dipole antennas, GPR with air coupled horn antennas, and Step frequency radar.

GPR using close air coupled dipole antennas or horn antennas is nowadays a routine testing method, which can operate at traffic speed, for detection of pavement structure variations and determination of layer thickness. However, the resolution or minimum thickness obtained with these devices is limited to 25 mm in the surface layer for the higher frequency antennas and, therefore, they are not suitable for detection of thin surface layer thickness. A new step frequency radar prototype is presently being developed in France which aims to overcome this limitation. FORMAT pilot study trials in Toulouse, France in 2003 showed the potential of the method on the old construction but the ingress of water into the upper layers of the new structure prevented fully satisfactory results being obtained in this case.

The FORMAT pilot study trials in Valencia Spain in 2004 showed for GPR, in general, that the quality of the results obtained from concrete pavements was not as good as those from flexible pavements. Layer thickness trials (non-FORMAT trials) had taken place in 2003 in the UK in order to assess the performance of UK GPR contractors. The performance trial has shown that, in general, UK GPR contractors can carry out high-speed measurements of layer thickness to a high level of accuracy.

Although GPR is already at a routine stage, the interpretation of radar data is complex and should only be carried out by experienced engineers. Special care is required during the filtering process and noise cleaning in order to avoid losing valuable data. The propagation velocity of the GPR signal is highly dependent on the material characteristics. It is sensitive to several factors, such as degree of compaction, cracking, moisture etc. During automatic interpretation of the data some ‘typical’ values are assumed for the parameters involved in the process. The calibration of radar results using cores is always required. To confirm the accuracy of a survey, the results obtained with GPR could be compared with additional cores, taken at locations different to those used previously to calibrate the radar system. In general GPR will not detect adjacent layers of similar materials. For that reason the consideration of several layers within the same material should be made with caution. Improvements are therefore required for the efficient applicability of GPR.

5.4.2.5 Noise

External or environmental noise can be estimated at traffic-speed by a proxy method. However, the Close ProXimity (CPX) method and the proxy method using texture measurement are still in development.

The close proximity method (ISO/DIS 11819-2: 1997) allows noise to be measured at arbitrary locations and continuously along a road but the repeatability and the reproducibility have not yet been proved, and the influence of the test vehicle and the background noise may not be completely controlled. Moreover, only noise generation is measured; propagation properties are not estimated. Many devices are currently under development in Europe and research is being conducted to optimise the positioning of the microphones and the processing of the measurements.

Research has been conducted to estimate noise levels by proxy. Some relations between noise spectrum and texture profile spectrum were derived during the 1970s and these have been confirmed in the last 5 years. However there is currently no generally accepted formula for predicting noise level from a texture spectrum. Furthermore, other parameters must be taken into account, such as acoustic absorption which depends on porosity and permeability, and the effect of road surface stiffness.

In conclusion these new methods, with potential for use at a network level, are under development, but the measurement methods and the data processing procedures have not yet been finalised. The SILVIA European project (2005): Sustainable Road Surfaces for Traffic Noise Control, will provide more information about these methods.

5.4.2.6 Summary

In summary, much still needs to be done to ensure that all these new methods can be routinely used on highway networks and that they will provide robust and meaningful outputs that can be reliably used as inputs to pavement management systems thus enabling more efficient and economic management of these very valuable assets. However, some of the methods may be applied immediately, especially if any measurements are compared with those obtained using the slower conventional approaches before significant maintenance decisions are made. The table below (Table *5-1*) summaries the global current status of prototype equipment.

Table 5-1: Status of prototype equipment

Measured Parameter	Status of prototype condition monitoring equipment able to operate at traffic speed
Cracking	Pre-production devices exist and some could be considered to be production devices
Ravelling and fretting	Pre-production devices are now available and will shortly be in routine use
Bearing capacity	Prototypes are showing the potential to measure deflection directly or a suitable proxy
Layer thickness	Devices exist and are used as routine equipment in many countries
Noise	Direct noise-measuring equipment exists for network application. In addition texture-based methods may soon be feasible with suitable safeguards

5.4.3 Research equipment

Monitoring equipment in the domain of research (e.g. assessment of the in-depth distress), do not run at traffic-speed, however the initial field measurements at low speed have been very encouraging and the results showed a good correlation between the crack depths determined from the specialist GPR results and coring.

5.5 Application of high speed equipment

Applying high speed equipment in the monitoring strategy depends on the needs of the road network manager. For that reason two questionnaires were sent to the FORMAT members in order to find which pavement properties highway authorities monitor today and what they would like to monitor in the future. The gap between practice and desire permits to define the needs in improving the high speed monitoring equipment and in implementing them into the monitoring strategy or a global maintenance & monitoring strategy. Then a thorough cost and benefit analysis compares, with a simple and methodic approach, the traditional static/slow monitoring techniques to high/traffic speed testing. Due to the already routine use of high-speed monitoring equipment for parameters as transverse profile, evenness, friction, and texture, this cost and benefit analysis especially illustrates the savings in case of using high speed equipment for the following parameters: bearing capacity, layer thickness and surface condition (cracking, raveling and fretting).

5.5.1 Current status of condition monitoring

In order to characterise the current practice among the participating countries with respect to monitoring activities, a questionnaire was prepared and distributed among FORMAT members. This questionnaire dealt with 20 selected pavement condition properties and its aim was to assess the current monitoring practice for maintenance planning purposes, both at network and at project level. Fifteen countries answered the questionnaire.

The methodology adopted for the analysis of the questionnaire is as follows:

1. For each condition property: Percentage of countries that measure and use it, for each level.
2. Percentage of countries where that measurement is performed with traffic disturbance, for each level.
3. For each condition property: general status as follows:

Wide usage (75% ≤ Measure and use ≤ 100%)
Moderate usage (25% ≤ Measure and use < 75%)
Limited usage (Measure and use < 25%)

The next table (Table 5-2) is as a result of step 3 (% corresponds to the percentage of the countries):

Table 5-2: Distribution per intervals of measured (M) and used (U) properties.

Usage	Network level	Project level
Wide Usage 75% M&U 100%	• Longitudinal unevenness • Transverse unevenness • Crack information • Friction	• Longitudinal unevenness • Transverse unevenness • Crack information • Pavement structure • Bearing capacity • Pothole • Cross fall
Moderate Usage 25% M&U < 75%	• Macrotexture • Curvature • Road marking condition • Megatexture • Other surface defects • Gradient or hilliness • Pothole • Cross fall • Bearing capacity • Pavement structure	• Macrotexture • Curvature • Road marking condition • Megatexture • Other surface defects • Gradient or hilliness • Friction • Noise (outside vehicles) • Stepping, Faulting
Low Usage M&U < 25%	• Vibration (unevenness induced comfort) • Pavement reflectance • Noise (inside vehicles) • Rolling resistance • Stepping, Faulting • Noise (outside vehicles)	• Vibration (unevenness induced comfort) • Pavement reflectance • Noise (inside vehicles) • Rolling resistance

At network level, only longitudinal and transverse unevenness, crack information and friction are measured and used by more than 75% of the countries. The properties which are related with the pavement structural condition have more attention at project level than at network level. Such is the case for pothole, bearing capacity or pavement structure. Cross fall is also highly ranked at project level. There are a wide range of surface condition parameters that are considered of moderate importance, e.g. macrotexture, curvature, road marking condition, megatexture, other surface defects and gradient. However, some of these parameters are considered of high importance just at the project level. These are mainly related to structural condition with the addition of crossfall. Although friction was considered of high importance by many of the respondents at network level, interestingly it is only considered of moderate importance at project level. Two properties introduced at this level of importance, but only at project level, are noise (outside the vehicle) and stepping or faulting of rigid pavements.

5.5.2 Desired condition monitoring

The structure of the second questionnaire permitted to the respondent, for both network and project levels, to assign priorities to each property previously identified. The following scale was proposed:

- Level 3 (score = 3): High priority
- Level 2 (score = 2): Medium priority
- Level 1 (score = 1): Low priority
- Level 0 (score = 0): Not relevant

The next table (*Table 5-3*) is as a result of the enquiry (score = 45: it is a high priority for all the 15 countries that answered to the questionnaire):

Table 5-3: Properties distribution per intervals of score.

Priority	Network level	Project level
Top priority 30 Score 45	• Longitudinal unevenness • Transverse unevenness • Crack information • Friction	• Longitudinal unevenness • Transverse unevenness • Crack information • Friction • Bearing capacity • Pavement structure • Pothole
Medium priority 15 Score < 30	• Macrotexture • Road marking condition • Megatexture • Other surface defects • Noise (outside vehicles) • Bearing capacity • Pothole • Pavement structure	• Macrotexture • Road marking condition • Megatexture • Other surface defects • Noise (outside vehicles) • Cross fall • Curvature • Stepping, Faulting • Gradient or hilliness
Low priority Score < 15	• Vibration (unevenness induced comfort) • Pavement reflectance • Noise (inside vehicles) • Rolling resistance • Cross fall • Curvature • Stepping, Faulting • Gradient or hilliness	• Vibration (unevenness induced comfort) • Pavement reflectance • Noise (inside vehicles) • Rolling resistance

The results showed that transverse unevenness, crack information, friction, and longitudinal unevenness are considered important both at network and project level. Bearing capacity, pavement structure and pothole are also seen as very important at project level, but less important at network level. It should be emphasised that the replies are influenced by the type of pavements most widely used in each country. For example, the fact that step faulting is only occurring in rigid pavements, will result in few countries assigning a high priority to this parameter. A more detailed analysis was performed concerning the most important parameters. Information like rut shape, number and size of potholes, and type and position of cracks is desired during the monitoring.

5.5.3 Is there a gap between practice and desire?

The questionnaires give some indication of what highway engineers in general regard as in need of development. In other words which parameters can now be measured at traffic speed and hence, because of potentially high survey rate can be considered to be of relatively low cost. Three of the top four parameters given top priority at network level, i.e. longitudinal evenness, transverse evenness and friction, are currently widely carried out at traffic speed. The fourth parameter, cracking, has been shown to be feasible at traffic speed with appropriate safeguards.

With respect to the medium priority parameters for network level surveys, several can already be measured fully or partially at traffic speed. Again the work of this group has shown that most of the outstanding parameters, e.g. Other surface defects (in particular ravelling and fretting), Noise (outside vehicles), Bearing Capacity and Pavement structure (layer thickness) can either be measured at traffic speed or there are existing prototypes that show the potential for such measurements. The outstanding parameters at this level of priority appear to be the measurement of potholes and some aspects of road marking condition.

For the project level parameters it is clearly better if they can be carried out at traffic speed but it is often considered acceptable to cause traffic disruption in order the collect the detailed information needed. Many of the parameters can already be measured at traffic speed or there are developments in hand to achieve this. However it should be realised that often the measurement capability of traffic-speed systems in their early stages of development cannot provide the level of detail required for project level investigations. As developments continue then this limitation is often overcome.

5.5.4 High speed monitoring devices: Cost and benefit analysis

Replacing of static/low speed monitoring methods by traffic speed monitoring devices has an impact on the users delay. In order to assess the benefit due to the reduction of the users cost the integrated spreadsheet (CBA model) developed by FORMAT WP4 has been utilised. This cost and benefit analysis especially deals with monitoring costs (operating costs and traffic management costs) and associated user costs. Safety cost (extra-risk of accident), cost for data analysis and cost due to the quality of the inspection (risk of missing the threshold value associated with a maintenance intervention) are not taken into account.
The selected monitoring methods depend on the type of test to be carried out. The tests are listed as follows and the selected testing methods for slow and high monitoring are mentioned in the *Table 5-3*.

- Deflection (bearing capacity)
- Structure (thickness of the layers)
- Cracking / ravelling / fretting (surface condition)

5.5.4.1 Monitoring cost

The monitoring cost includes the operating (survey) and the traffic management (safety signals, moveable lane closure, work zone protecting) costs. Survey costs are very complex to identify because they depend on many parameters (road network length, type of road, number of carriageways, type of monitoring equipment, age of the monitoring equipment, etc). Monitoring speed and required personnel are also two influential parameters. Moreover, it is necessary to differentiate the fixed costs (preparation, rental of the equipment) and the variable costs (length/number of points to be monitored). The costs are also different if the equipment belongs to a state-owner or a private-owner.

The costs mentioned in the next table (*Table 5-4*) are a compromise between all the costs provided by the WP6 members; however for a similar test the selected costs come from a same road network.

Table 5-4: Selected monitoring costs for Cost Benefit Analysis

Type of test	Static/low speed method	High speed method	Comments
Deflection	FWD: 105 [EUR/km/cw] speed: 5 [km/h]	High speed deflection device: 30 [EUR/km/cw] traffic speed	Slow speed method: Traffic management included (55 EUR/km/cw if not).
Structure	Coring: 725 [EUR/km/cw] speed: 5 [km/h]	650 [EUR/km/cw] traffic speed	Slow speed method: Traffic management included (675 EUR/km/cw if not).
Surface condition	Walking visual survey: 400 [EUR/km/cw] speed: 25 [km/day]	60 [EUR/km/cw] traffic speed	Slow speed method: Traffic management included (200 EUR/km/cw if not).

5.5.4.2 Users cost

The users delay model is based on the estimation of coefficients determining the distribution of traffic (sum of three Gaussian functions). The delay prediction is very sensitive to the traffic considered (traffic level and traffic flow) and the value of road residual capacity during maintenance. The road is considered as a 2x2 carriageways and the monitoring site as follows:

- 2 open lanes in one direction, 1 open lane in the other direction (along the work zone)
- No contra-flow
- No diversion
- Monitoring is scheduled for daytime (9h-12h and 13h-16h)

A sensitive analysis was made on the traffic level (AADT = 10’000, 25’000, 50’000 and 75’000), the traffic flow (interurban, rural, urban bypass) and the road residual capacity during maintenance (1’100 and 1’350 PCU/h). Figure 5-4 shows the users cost resulted from the model.

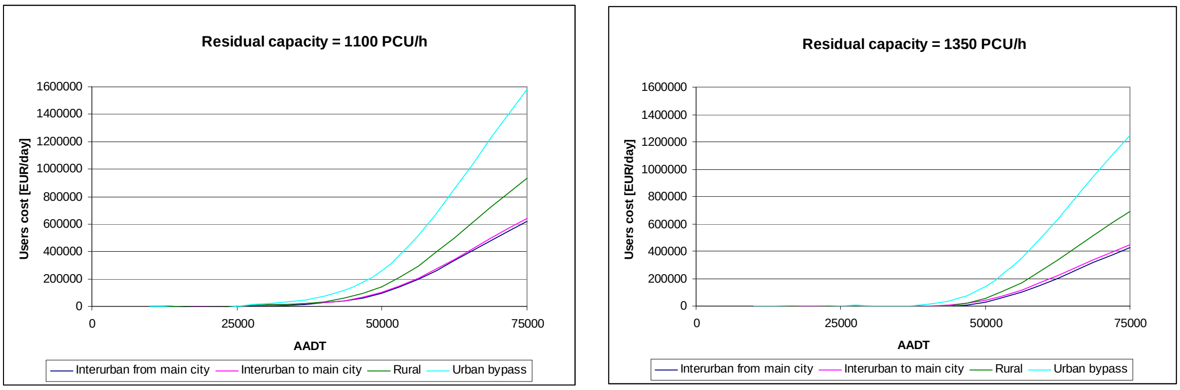

Figure 5-4: Users cost for Cost Benefit Analysis

A residual capacity of 1100 instead of 1350 PCU/h would triple the users cost for an Average Annual Daily Total (AADT) of 50’000 and would increase it by 50% for an AADT of 75’000. No significant changes would be observed with lower AADT.

5.5.4.3 Cost and Benefit Analysis

The length of the road network considered in this Cost Benefit Analysis (CBA) was 1000 km (road 2x2 lanes, one lane monitored) and the total traffic management cost was fixed at 2000 EUR/day. The considered residual capacity for the analysis was 1350 PCU/h and traffic flow "interurban".

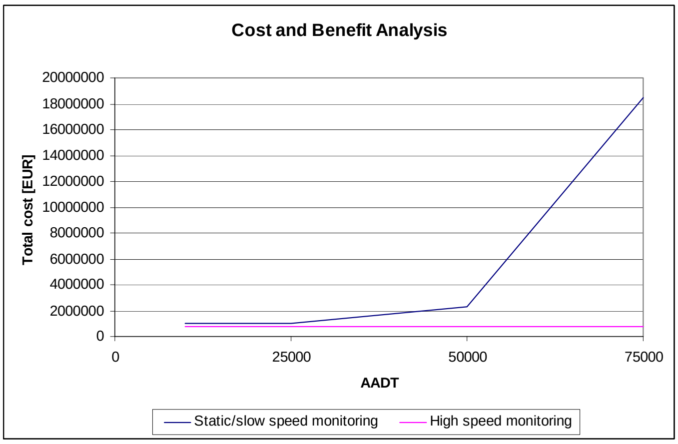

Figure 5-5: Cost and Benefit analysis

Figure 5-5 above presents the results of the cost and benefit analysis. The extra users cost had a huge influence on the total cost if a queue was initiated, so the AADT level had a drastic influence on total cost.

This analysis showed that in terms of monitoring cost and extra users cost, traffic speed monitoring is more beneficial than static/slow speed monitoring but the benefits are even larger with a high value of AADT. The cost and benefit analysis did not only permit quantification of this likely benefit but also showed that the initiation of queues should be avoided. It was also observed that the residual capacity of the road is a dominant factor in the calculation of the extra users cost. Due to the large number of required parameters the results are extremely complex to validate. Among other things knowledge of the traffic management cost and the survey cost is very important. In addition some high speed monitoring devices are still considered as prototypes (they are not used as routine equipments) and so it is not possible, as yet, to provide reliable survey costs for such equipment.

5.6 Development of a monitoring strategy

For most highway authorities first of all it is too expensive uncritically to monitor all possible pavement condition parameters, secondly it is impractical due to availability of equipment, and thirdly only a limited number of pavement condition parameters play a role in pavement maintenance planning in a given country. Hence, often just a few parameters are monitored at regular intervals or at a defined time. For example a 5-year criterion (residual life < 5 years) regarding bearing capacity is considered in Denmark and in the UK for.

The UK Highways Agency design manual HD 30/99 (1999) gives an example of pavement condition monitoring on for the network level and it also provides guidance for subsequent investigations/reviews at project level following the network surveys. The intention with the procedure is to identify the parts of the road network showing signs of potential surface or structural deterioration. Sections identified with problems go on to further scrutiny according to a second phase procedure.

5.6.1 Example of development of a monitoring strategy for one parameter

DWW monitors the Stoneway-parameter on a two-yearly basis at traffic speed. The estimated intervention time should be accurate within a standard deviation of one year up to three years after the last monitoring observation (one year is required for planning).

Figure 5-6 shows the typical progress of ravelling with time. The curved drawn line depicts the best fit 50% probability model of ravelling behaviour on the test sites, the dashed lines respectively the 5% and 95% models. The normal distributions associated with these curves are drawn as well, at specified times. The horizontal black line depicts the intervention level. The asymptote Theta is probably the result of the intervention that takes place before the distress reaches the level Theta. This model has been derived based on 10 years of yearly monitoring of test sections varying in age and traffic load in the Netherlands, and could represent the model of the optimisation concept defined in section 5.3.1.1.

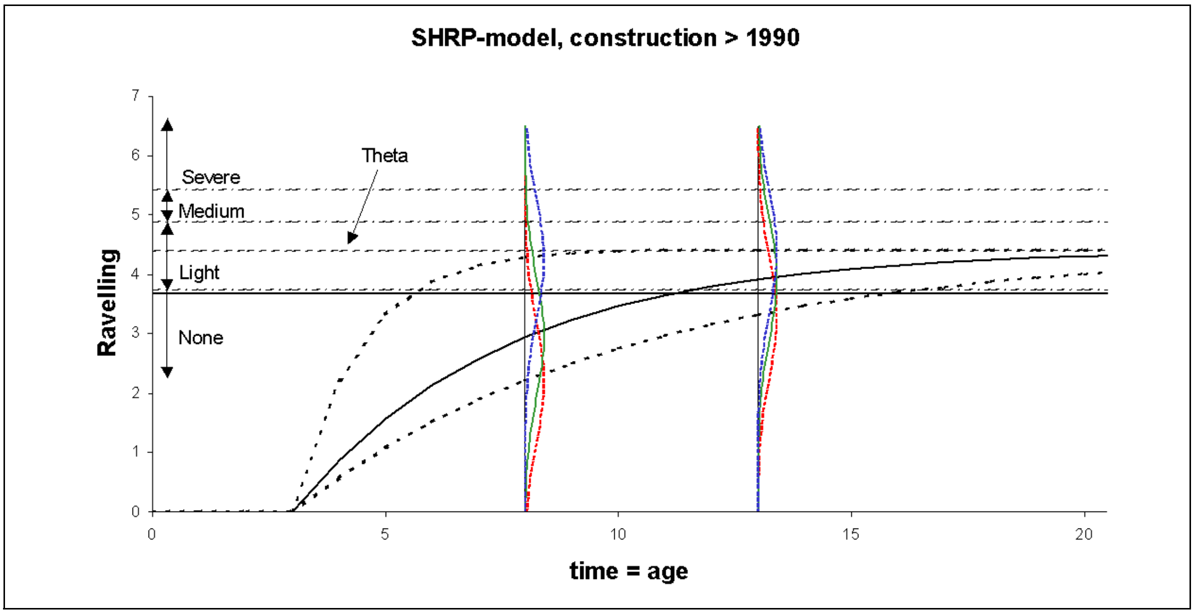

Figure 5-6: SHRP-NL deterioration model for ravelling on porous asphalt

From Figure 5-6 it can easily be seen that there is a substantial spread in the rate of ravelling deterioration. In addition it was observed that the standard deviation resulted in a mean standard deviation of 1,1 year in intervention time, corresponding with a 2,2 years 95% confidence interval. The first observation, after a surface age of three years can give an indication of the ravelling behaviour of a section. However the associated inaccuracy of the observation and the inaccuracy of the model make a second observation necessary to be more secure about the actual ravelling behaviour. This second observation should be not to close to the first because, in this case, it would not strengthen the estimated behaviour model very much. On the other hand, one should not wait too long because one might be in risk of not applying appropriate treatment in time. Two years after the first survey, in line with the mean 95% confidence intervention interval, seems to be a sensible choice.

In conclusion, regarding the dependency of the model on the accuracy and actual value of the observation, a two year monitoring cycle seems to be an appropriate choice for the monitoring of ravelling in this particular case.

5.6.2 Elements to consider when establishing a monitoring strategy

The elements of a road monitoring strategy depend on the objectives of the monitoring process. The layout of a monitoring strategy also depends on available equipment and the experiences with specific types of equipment. A third element which is important is the economy involved in different types of strategies, and finally the highway authority also needs to consider practical aspects of monitoring like testing frequency for the different types of equipment. The objectives that should be achieved by the monitoring process may differ from one highway authority to another. Obviously, many strategies look similar, though, because highway authorities have similar needs and – not to forget – because come from the same tradition. Most countries will probably agree with the UK Highways Agency in its six key objectives for maintaining its road network (Highways Agency, 2002):

- Maintaining safety
- Minimising expenditure over time
- Minimising disruption to users
- Minimising the impact on the environment
- Setting maintenance priorities
- Management of maintenance

These objectives can be implemented in the monitoring strategy using three headings (Highways Agency, 2002):

- Safety
- Serviceability
- Sustainability (minimising costs over time as well as the environmental effects)

On this basis, a number of specific pavement condition parameters can be identified, which need to be measured. Examples of these parameters were mentioned in Chapters 5.5.1 and 5.5.2.

Monitoring strategies are often dependent on tradition with regard to the equipment which is available as suppliers of pavement condition information. There is a close relationship between the input needs of Pavement Management Systems and the equipment available at the time the Pavement Management System was developed. With the increased emphasis in Europe on one common market the traditional acquisition of road monitoring services is rapidly changing and highway agencies are expected to look beyond their own borders to find the equipment that suit their specific needs.

One aspect to acknowledge with regard to length of network to be monitored is that it is more cost effective to test an entire network instead of only monitoring selected parts of the network which may be scattered around. Savings can be made, however, in the analysis of data, where only the selected, scattered parts are analysed. One other aspect to consider, when setting up a monitoring strategy, is the frequency of testing. The frequency must be totally in phase with the performance characteristics of the data required in a Pavement Management System, and with the reliability of their associated model. Pavement parameters closely connected to safety issues should be predominantly followed.

A modern monitoring strategy should focus on safety, serviceability and sustainability. Concerning the safety issue, the monitoring should be conducted as often as needed to make sure that no safety risks occur on the roads. The monitoring of the pavement condition should be made with traffic speed equipment. The serviceability issue implies that the monitoring should allow the highway authority to evaluate the comfort level of the road network. The monitoring should also be made at traffic speed. The sustainability aspects imply that the monitoring strategy should include measurements of parameters that allow an evaluation of the environmental impact due to road maintenance. The monitoring should be conducted with the optimum frequency.

Based on the above comments, a monitoring strategy could be established which looks like this: the road network is divided into a number of classes based on traffic level and importance. When deciding on the road lengths in each class the highway authority should also be realistic regarding the level and extent of monitoring measurements. The following classes could be imagined:
Class A: 10 percent of the network (most important roads)
Class B: 25 percent of the network (important roads)
Class C: 50 percent of the network (other roads)
Class D: 15 percent of the network (lower class)

For each of the classes monitoring measurements could be suggested (type of test, measurement speed, frequency of monitoring, etc).

5.7 Future developments

The use of existing databases and the creation of combined condition indices have to be further developed. Common standards and definitions have to be established. The promotion and opportunities for joint ventures and European wide projects have to increase. To develop high technology equipment to monitor new desires is expensive. The need and desire seems to be common in many countries. Some of the desired pavement properties for maintenance planning do not need to be monitored as frequently as others meaning that single items of equipment can serve more than one road network. This implies that the optimal solution must be joint development projects between two or more countries. Finally the necessary accuracy in all aspects has to be examined. This will be a good base for further creative developments.

5.8 Conclusion

The ideal monitoring strategy, especially at network level, must be in accordance with the needs of the stakeholders of a road network, the level of knowledge of the performance of the road network, and the allocated budget and resources. In addition, the procedures for maintenance monitoring are highly dependant on the purpose of the monitoring process, which in turn is dependent on the Pavement Management System used by a specific organisation. The development of strategies is therefore extremely complex. However, in order to improve the current monitoring strategies some key elements and tools have been given through the work of FORMAT WP6.

After identifying the monitoring strategy in practice, an essential item was to define the current and the desired status of monitoring condition. It was demonstrated that the existing techniques and equipment (routine or prototype) could measure at traffic-speed most of the traditional data required.

One key finding of this report is that monitoring should take place at traffic speed since this optimises safety on the road during testing and since it disturbs traffic the least. A cost benefit analysis has shown that traffic speed monitoring is more beneficial than static or slow speed monitoring, and that the benefits of traffic speed testing increase with an increasing traffic level. Although a few or the prototype assessment trials have not been completed, nevertheless, it is possible to say that recent developments in traffic-speed road condition monitoring techniques are extremely encouraging and promising.

Another key element is the frequency of monitoring. A concept of monitoring procedure was developed and showed that financial savings are possible.

Based on the findings of WP6, the highway authorities are recommended to consider the following items when dealing with road maintenance monitoring:
- Consider and define aims of maintenance monitoring

5.8.1.1 Decide on a monitoring strategy

- Consider monitoring frequency of different types of testing equipment
- Use high speed equipment for monitoring, especially at roads with high traffic volumes
- Continue the development of high speed monitoring equipment as well the development of new types of monitoring methods such as instrumented vehicles and instrumented (Smart) roads

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6. Summary of research conducted on ‘Technology’

6.1 Introduction

The objective of WP3 ‘Technology’ was to assess innovative maintenance techniques and procedures for maintaining both bituminous and concrete roads, aiming at reducing user delays and safety hazards at road works. This aim was achieved by selecting innovative maintenance techniques that perform better by lasting longer and/or by taking less time to apply. In this way, the number of road closures and their duration will be reduced. The innovative techniques and procedures developed under Work Package 3 focused on reducing the number and the duration of road closures for pavement maintenance purposes.

WP3 ‘Technology’ comprised three Tasks. :

- Task 1 ‘Selection of maintenance treatments’ to be studied in subsequent tasks;
- Task 2 ‘Performance evaluation’ of selected maintenance techniques in Accelerated Loading Tests;
- Task 3 ‘Pilot studies’ for practical implementation of selected maintenance techniques on actual road sites.

The objective of Task 1 was to provide a selection of the most promising innovative maintenance techniques for evaluation and practical implementation as appropriate. These are the techniques and procedures that are considered best suited to treat the main types of pavement distress occurring in European countries.

In Task 2 the performance of selected maintenance techniques was evaluated by independent testing in full-scale Accelerated Loading Testing (ALT) facilities. The selected maintenance treatments were applied to worn pavements that have been constructed within the facilities. The condition of the test pavements was assessed before and after the application of the maintenance treatments and during the tests. The analysis of the results obtained provided an assessment of the efficiency and the improvement in pavement durability achieved by each individual maintenance treatment.

Task 3 dealt with the implementation of selected innovative treatments on three road sites. The selected treatments were applied with close monitoring of their application, in terms of duration of the work, conditions for application, improvement in pavement condition, etc. The aim was to collect information concerning the practical application of the maintenance techniques, not only in relation with the technological aspects, but also in relation with traffic management and user costs during maintenance activities.

The following sections summarise the work performed in each of these tasks and present the main results achieved with these activities.

6.2 Selection of maintenance techniques and procedures for implementation

6.2.1 Identification of pavement maintenance activities

The condition of the pavement during its life will deteriorate due to the effect of traffic loads, climate, ageing, etc. Maintenance treatments are generally applied because, at a certain point in time, the condition of the pavement has become unsatisfactory in respect of the structural condition or the safety of the road users.

Different types of pavements will have different predominant deterioration mechanisms and therefore, different distress types. Two main groups of pavement structures were considered in this project:

- Flexible pavements and composite pavements;
- Rigid pavements.

The following condition indicators were used to assess the need to perform maintenance activities:

Flexible and composite pavements	Rigid pavements
• Cracking - Surface cracking; - Reflective cracking; - Fatigue cracking ("bottom up" cracking). • Rutting - Permanent deformation of pavement layers - Wear from studded tyres • Longitudinal unevenness • Bearing capacity • Surface defects • Skid resistance • Tyre/road noise.	• Cracking • Longitudinal unevenness • Faulting • Punchouts • Spalling • Surface defects • Skid resistance • Tyre/road noise

Pavement maintenance activities can be performed in different contexts, having different objectives. The final selection of a specific maintenance treatment for a certain project will depend on the scope of the maintenance activity and on a number of factors related to the specific site under study, such as the pavement design, pavement condition and distress type, traffic and climate. Maintenance treatments can be organised in 4 main categories:

<u>Localised treatments</u> include isolated repairs aiming at solving or minimising specific functional or structural problems in localised areas.

<u>Surface treatments</u> include all treatments which are applied to the whole pavement surface, up to a depth of 40 mm.

Strengthening treatments are aimed at rehabilitating a pavement to improve its structure with additional mechanical strength to withstand traffic loads. This group of treatments will include overlays of more than 40 mm thickness.

Reconstruction treatments include the work undertaken to restore the serviceability of an existing pavement when its remaining structural life is insufficient.

Using the COST 343 database on pavement maintenance treatments, complemented with further input from WP3 team members, a list of maintenance techniques and procedures that are considered best suited to treat the main types of pavement distress occurring in European roads was prepared.

The maintenance activities considered in this list, which included maintenance options for flexible, composite and rigid pavements, were organised into the above four main categories.

The following two sub-groups were considered for strengthening treatments:

- Strengthening treatments for flexible pavements;
- Strengthening treatments for rigid pavements

Similarly, the following two sub-groups were considered for reconstruction:

- Reconstruction of flexible pavements;
- Reconstruction of rigid pavements.

Many of the strengthening treatments for flexible pavements are also applicable to composite pavements. Strengthening or reconstruction treatments which are specifically designed for composite pavements (pavements which have a cement-treated main structural layer, with a bituminous surface layer) were included in the same groups as those for rigid pavements.

In addition to the simple list of maintenance treatments, detailed information was collated about the suitability of the treatment to correct certain defects in the pavements. Information about the procedures for application of each of the listed maintenance treatments was also gathered. An extract of the list of treatments and procedures for application, concerning strengthening treatments for flexible pavements, is shown in Table 6.1.

Table 6.1 – Example of list of maintenance treatments and procedures for application: strengthening treatments for flexible pavements

NAME OF TREATMENT	PROCEDURE FOR APPLICATION
Bituminous overlay (>40mm)	Apply one or more hot mix bituminous layers to improve the bearing capacity of the pavement. The additional thickness depends on the future traffic expectation
Bituminous overlay with geotextiles or samis > 40 mm	Install a geotextile or SAMI on existing pavement and apply one or more layers of hot mix bituminous material to improve the bearing capacity. The treatment is to reduce the risk of reflective cracking
Bituminous overlay with geogrids > 40 mm	Install a geogrid on existing pavement and apply one or more layers of hot mix bituminous material to improve the bearing capacity. The treatment is to reduce the risk of reflective cracking
White-topping	Apply a Portland Cement Concrete overlay to asphalt pavement to improve the bearing capacity. The existing pavement might require milling to make level before applying the overlay
Ultrathin white-topping (UTW)	Apply a thin (approx 100mm) Portland Cement Concrete (PCC) overlay to a milled asphalt pavement. Joints are cut in the PCC at a spacing according to the thickness
High modulus asphalt binder course + thin asphalt wearing course	Apply a binder course of high modulus asphalt concrete followed by a new wearing course. This technique may be used as an overlay or as an inlay
Stone skeleton binder course + new overlay	Apply a binder course with gap-graded aggregate skeleton and fill it with mortar and compact. Apply a new wearing course
Steel slag asphalt concrete binder course + new overlay	Apply an asphalt concrete binder course with steel slag aggregate for better interlock and reduction of peak temperatures of asphalt. Apply a new wearing course
Asphalt overlay with plastic waste (> 40 mm)	Apply an asphalt overlay containing plastic waste as aggregate or containing bitumen modified with plastic waste in one or more layers. This material should improve crack resistance and deterioration rate
Fiber reinforced asphalt overlay (> 40 mm)	Apply an asphalt overlay reinforced with steel, glass or synthetic fibres

6.2.2 Approach for selection of maintenance techniques

The efficiency of maintenance treatments to correct problems associated with the condition indicators listed in section 6.2.1 was identified according to the following (see example in Table 6.2):

X – The treatment is suitable for improving the condition indicator;
S – The treatment is not specifically designed to correct the given condition indicator, but it may improve it, as a secondary[2] positive effect with that respect.

[2] An example of a "secondary effect" is the application of a thick bituminous overlay (> 40mm), which may improve the skid resistance of the wearing course, although it is not specifically designed to improve skid resistance.

Table 6.2 – Example of classification of efficiency of maintenance treatments: strengthening treatments for flexible pavements

NAME OF TREATMENT	Surface cracking	Reflective cracking	Fatigue cracking	Rutting	Long. Unevenn	Surface defects	Spalling of JCP	Punchouts of CRCP	Skid resistance	Bear cap. flexible	Faulting of JCP	Tyre noise
Bituminous overlay (>40mm)	S	X	X	X	X	S			S	X		S
Bituminous overlay with geotextiles or samis > 40 mm	S	X	S	S	S	S			S	X		S
Bituminous overlay with geogrids > 40 mm	S	X	S	X	S	S			S	X		S
White-topping	S		X	S		S				X		
Ultrathin white-topping (UTW)	S		X	S		S				X		
High modulus asphalt binder course + thin asphalt wearing course	S			X	S	S			S	X		S
Stone skeleton binder course + new overlay	S	S	S	X	S	S			S	X		S
Steel slag asphalt concrete binder course + new overlay	S	S	S	X	S	S			S	X		S
Asphalt overlay with plastic waste (> 40 mm)	X	X	X	X	S	S			S	X		S
Fiber reinforced asphalt overlay (> 40 mm)	X	X	X	X	S	S			S	X		S

From the list produced as described above, some of the most “promising” maintenance treatments and procedures for application were selected for evaluation in Accelerated Loading Tests (ALT) and in pilot studies. The selected treatments were those that are most effective in correcting the main deficiencies in the principal European road network, and that were considered as “innovative” by members of WP3 team. In this context “innovative” meant that they are still in an experimental phase, or have just recently started to be used in certain European countries.

The selection of treatments for implementation was also based on the consideration of the type of assessment to be performed and on its feasibility.

6.2.3 Selection of treatments for evaluation by Accelerated Loading Testing

Accelerated Loading Testing (ALT) facilities are full-scale pieces of equipment that are capable of applying wheel loads as heavy as, or greater than those permitted on public roads, onto road pavement structures that are constructed with conventional road construction equipment. They are able to apply these wheel loads quickly, under controlled conditions of loading and, in some facilities, under controlled environmental conditions.

This means that ALT research primarily investigates the effect of heavy traffic loads. Time dependent effects, like ageing, cannot be simulated in ALT. Surface defects, where ageing and tyre friction have a large influence, cannot be investigated over a short time-scale in ALT. Therefore, the ALT research was orientated towards structural effects.

There were no suitable rigid pavement structures in the existing ALT facilities, and the time and budget allocated to the FORMAT project did not allow for the construction of a dedicated full-scale rigid pavement in these facilities. Therefore, the ALT focussed on flexible pavements, which represents around 90% of the European main road network.

Rutting in the bituminous layers has been identified in previous projects as one of the most relevant deterioration mechanisms for flexible pavements in the European main road network. Therefore, greater emphasis was given to rutting experiments in ALT. Cracking is also an important deterioration mechanism in European flexible pavements and therefore, one of the ALT experiments addressed this issue In this case, preference was given to the selection of a surface treatment (less than 40 mm thick), since there is less information regarding the application of this type of treatment on cracked pavements. However, it was acknowledged that this option would involve an added risk of failure.

Taking into account the above considerations, and the criteria for selection set in the previous sections, the following innovations were selected for ALT experiments in the FORMAT project:

Rutting	Cracking
- Cement grouted porous asphalt inlay; - Steel slag asphalt binder course + Stone Mastic Asphalt (SMA) surface; - High modulus bituminous binder course inlay + thin asphalt surface; - High modulus bituminous binder course wheel track inlay + thin asphalt surface.	- Geogrid + Thin asphalt concrete

6.2.4 Selection of treatments for practical implementation in pilot trials

Pilot tests on in-service pavements allow the assessment of the efficiency, the procedures for application of the maintenance treatments and for the traffic management on real maintenance sites. In general, pilot tests are also used to assess the effect of ageing and climate on the durability of maintenance techniques. However, due to the limited time frame of the FORMAT project, it was not possible to evaluate the longevity of maintenance treatments in the pilot tests.

The candidate treatments for application in the pilot tests were selected in order to complement the ALT experiments. These treatments were drawn from the list of “most promising” maintenance treatments and they aim at the following maintenance needs which were not addressed in the ALT:

- Improvement of surface condition through the use of a new porous asphalt surface (finer aggregate);
- Structural rehabilitation of Jointed Concrete Pavements (JCP) through injection of cement grout under the concrete slabs + asphalt overlay with or without anti-crack system (geotextile), or with grinding just for restoring the surface profile;
- Structural rehabilitation of Continuously Reinforced Concrete Pavement (CRCP) through localised full-depth repair + thin bonded concrete overlay.

6.3 Performance of innovative maintenance techniques in ALT facilities

6.3.1 Objectives

The objectives of ALT on the selected maintenance treatments were to:
- assess the performance of the deteriorated pavement after application of innovative and conventional maintenance treatments;
- assess if the treatment has any side effects;
- provide experience with the application of the treatments that could contribute to best practice guidelines;
- give some relative indication of the cost of the innovative treatment.

The following ALT facilities were selected for the performance assessment of innovative maintenance techniques:
- The Halle-Fosse at LAVOC, Switzerland;
- The Lintrack at DWW, Netherlands;
- The Pavement Testing Facility at TRL, UK
- The Manège de Fatigue at LCPC, France.

The facilities of LAVOC, DWW (LinTrack) and TRL have linear test tracks, with provisions for temperature control; the LCPC facility has circular test tracks in the open air and is capable of applying many heavy wheel loads at high speeds.
Taking into account the ALT facilities characteristics, as well as the results concerning selection of maintenance treatments, the following experiments were conducted:
- DWW: Two treatments. The first concerns use of a cement mortar grouted porous asphalt as an inlay in pavements with rutting problems. The procedure is to first apply a porous asphalt layer and then fill the voids with a cementitious grout. The second treatment concerns use of a binder course of steel slag asphalt concrete.

- LAVOC: Use of a high modulus asphalt binder course as an inlay plus a thin asphalt surface layer, also for pavements with rutting problems. The procedure is to first apply a binder course of high modulus asphalt concrete followed by a new surface layer.

- TRL: Use of a high modulus asphalt binder course, applied as an inlay to the wheel path alone, plus a thin asphalt surface layer over the complete lane. This will have the advantage of resulting in a higher rate of application, associated with considerable savings in materials, since it is restricted to the wheel track areas. This experiment addresses both surface cracking and rutting.

- LCPC: Use of a thin bituminous overlay (< 40 mm) with geogrid. The procedure is to first install a geogrid on the existing pavement and apply a thin layer of hot mix bituminous material. The treatment is expected to reduce the risk of reflective cracking.

The selected maintenance treatments were applied to worn pavements that had been constructed within the facilities.

6.3.2 Design of the experiments

Each of the ALT experiments concerned the performance assessment of the selected innovative maintenance treatment in direct comparison with a conventional maintenance treatment. The condition of the test pavements was assessed before and after the application of the maintenance treatments. The analysis of the results obtained in the tests provides an assessment of the efficiency and the improvement in pavement durability achieved by each individual maintenance treatments.

In the experiment at LCPC a thin bituminous overlay with geogrid reinforcement has been tested, which was applied on a cracked pavement, without removing the cracked layers. Therefore the design of the experiment included sufficient loading of the pavement to induce cracking before application of the innovative and reference treatments. Furthermore, the thickness of the original structure was specifically chosen to be relatively thin to ensure that cracking occurred.

Also, in this experiment it was vital to record the moment of reappearance of cracks and their subsequent development, which meant that frequent inspection for possible cracking detection was a key element in the setup of the experiment. During the ALT after application of the treatments, frequent inspections were performed on each section to detect new cracks and to record their development and severity as a function of number of load applications.

The performance of the innovative treatment was based on a comparison of the rate and severity with which the cracks reappeared and grew for the innovative and for the conventional treatment.

The rutting experiments at LAVOC, TRL and DWW were designed to be as comparable as possible. In principle the design of the experiment involved the following steps:

- loading the pavement to induce rutting in two wheel tracks;
- applying the innovative treatment in one wheel track;
- applying the reference treatment in the other wheel track;
- loading wheel tracks again under the same condition;
- comparing the development of rutting in the selected innovative treatment with the rutting in the conventional treatment to assess the relative performance of the innovative treatment.

For these tests, a constant pavement temperature of 40^{o}C at 40 mm depth was maintained. This was achieved by heating the test pavements as necessary, using specially dedicated heating systems, bearing in mind that all three test facilities are sheltered by a building or a cover.

The loading conditions within the three testing facilities were also chosen to be as similar as possible, as indicated in Table 6.3. The lateral wander of the wheel, which is very important for the development of rutting, was also as similar as possible between the facilities. For the lateral wander profile a Laplace distribution was chosen according to recent research at the Technical University of Vienna (Blab 2001), as shown in Figure 6.1. The speeds had to show some variation, between 10 and 20 km/h, due to differences in the ALT facilities.

Table6.3 - Loading conditions at the rutting experiments

Characteristics	DWW	LAVOC	TRL
Temperature (°C)	40	40	40
Wheel	385/65 R22.5	385/65 R22.5	385/65 R22.5
Load (kN)	45	45	40
Pressure (MPa)	0.9	0.8	0.8
Speed (km/h)	18	15	20
Wander (m)	± 0.30 (1)	± 0.35	± 0.36

(1) Truncated

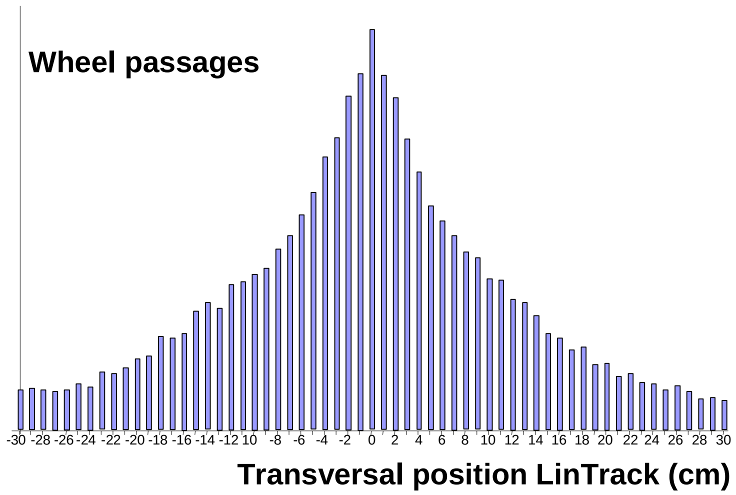


Figure 6.1 - Lateral distribution of wheel loads used in the LinTrack ALT

In all experiments, the development of rut depth with load was followed in several cross profiles by means of a profilometer (see Figure 6.2).

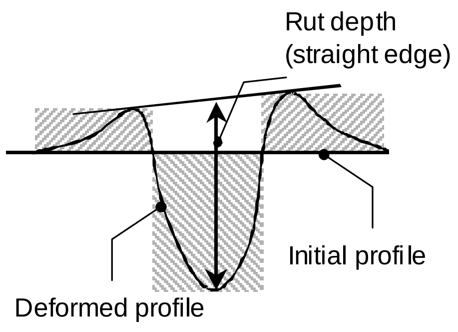


Figure 6.2 - Rut depth

From this, the rut depth relative to the level of a straight edge over the wheel path was derived. The development of rut depth in the innovative treatment was plotted together with the development of rut depth in the reference conventional treatment. The ratio of both curves directly gave a value for the relative performance.

6.3.3 Cement grouted porous asphalt inlay

Figure 6.3 shows the pavement section after application of the cement grouted porous asphalt (CGPA) wearing course. Basically this consists of a porous asphalt with a high void ratio of 25-30%, of which the voids are filled with a cement grout mortar. Several producers offer this material. The selected type uses standard porous asphalt with 4.5% of bitumen, 3% of limestone filler with hydroxide, 0.25% of cellulose fibre, 87% of coarse aggregate and 10% of breaker sand.
To construct the test section, the top layers of the existing structure were planed off over a width of 3.75 m (i.e. half of the total width of the test pavement) and over a depth of 120 mm. Then, the 80 mm thick porous asphalt was placed. Details of the construction procedures are given in FORMAT Deliverable D9.

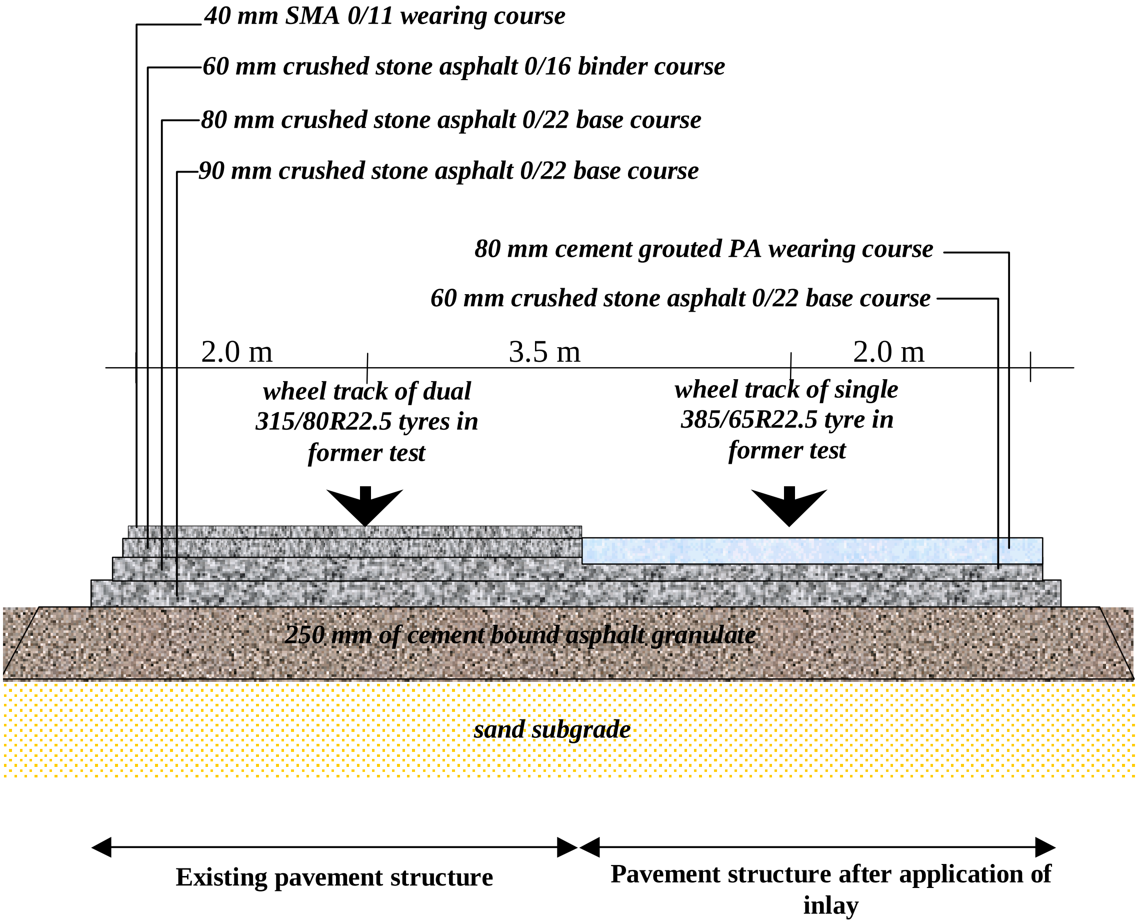


Figure 6.3 - Cross section of test pavement pavement after applying cement grouted porous asphalt wearing course

The cement grouted porous asphalt test section was tested under the same conditions as used in the former rutting programme, which provided the reference for the FORMAT test.

During the rutting test the development of the rutting in the wheel track was periodically measured by means of a transverse profilometer. Figure 6.4 shows the development of rutting in the pavement section with CGPA, in comparison with the selected conventional treatment - a well-performing conventional dense asphalt wearing course with 45/60 bitumen.

Figure 6.4 - Comparison of rutting behaviour of cement grouted porous asphalt wearing course (CGPA) with results from the conventional dense asphalt wearing course (DAC) with 45/60 bitumen - DWW

From the results obtained in this ALT experiment, Cement Grouted Porous Asphalt was considered promising from the point of view of rutting resistance. The main conclusions from the test were as follows:

- The innovative treatment is suitable for improving the pavement condition with respect to rutting or surface defects. Other characteristics such as skid resistance are not necessarily improved by this treatment.
- The cement grouted porous asphalt has shown a potential for good rutting resistance under normal traffic. However, the potential for withstanding severe traffic conditions was not demonstrated.
- The application of this maintenance treatment is time-consuming, when compared to conventional asphalt overlays or inlays. High quality of work and therefore, enhanced quality control procedures are necessary to exploit the rutting resistance potential of the treatment. Furthermore, special attention must be paid to the climatic conditions during and immediately after application of the treatment, since rainfall may compromise the final quality of the pavement.
- The cost for the cement grouted porous asphalt is around 1.5 times higher than that of conventional asphalt materials.

6.3.4 Steel slag asphalt concrete binder course + SMA surface course

This treatment was considered promising from the point of view of rutting resistance. It was also tested in the Lintrack facility (DWW), where it was applied as a 90 mm thick binder course inlay under a 35 mm thick Stone Mastic Asphalt (SMA) surfacing. The Steel Slag Asphalt Concrete (SSAC) binder course was placed on the existing structure shown in Figure 6.3, after milling part of the existing asphalt layers, leaving the lower 90 mm crushed stone asphalt 0/22 (STAC 0/22), plus 30 mm of the next STAC 0/22 layer.

The binder course mixture was produced using a special electro-oven slag quality, which is insensitive to the swelling process, as part of the coarse aggregate fraction. Both the steel slag asphalt concrete and the SMA were manufactured using a polymer-modified binder.

The reference treatment used for this experiment was the same as that used in the previous experiment. The SSAC section was tested under the same conditions as used in the previous experiment and the development of rutting in the wheel track was periodically measured by means of a transverse profilometer. Figure 6.5 shows the development of rutting in the SSAC section, in comparison with the conventional dense asphalt wearing course with 45/60 bitumen.

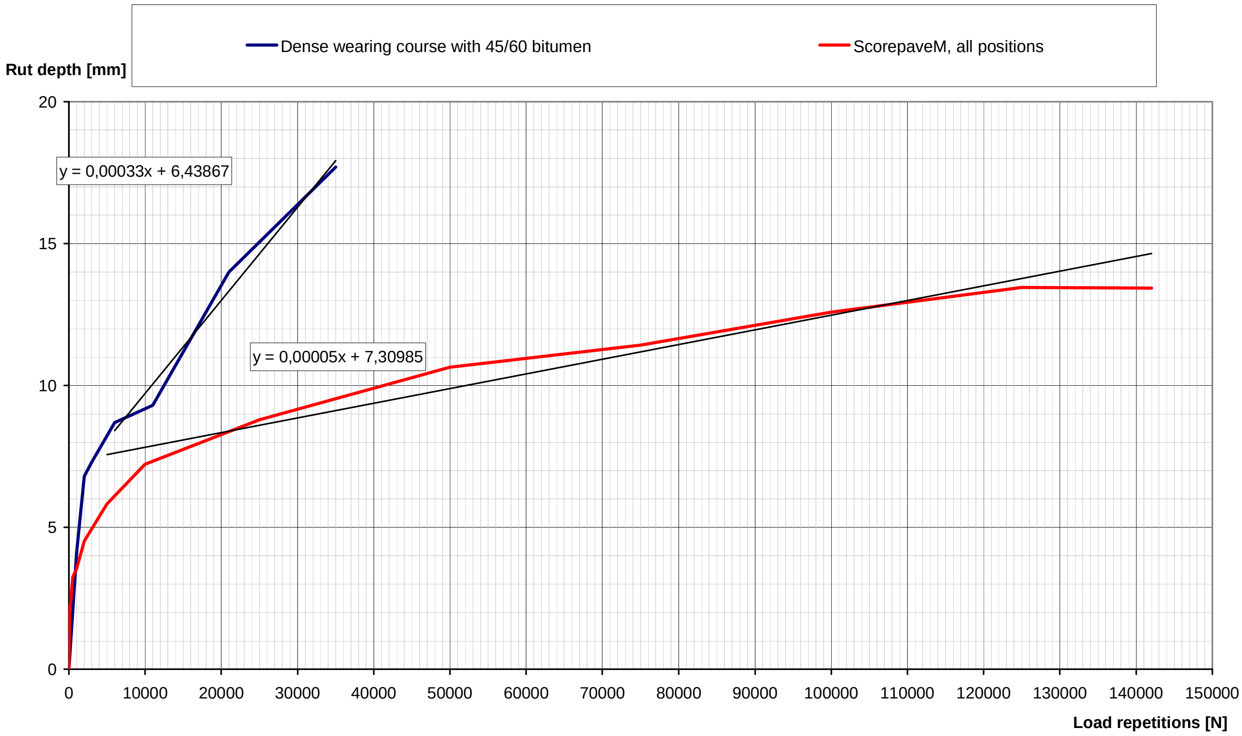


Figure 6.5 - Comparison of rutting behaviour of Steel Slag Asphalt Concrete (SSAC) binder course + SMA surface with results from the conventional dense asphalt wearing course (DAC) with 45/60 bitumen - DWW

The main conclusions from the test were as follows:

- The innovative treatment is suitable for improving the pavement condition with respect to rutting, cracking and general surface defects. Other characteristics such as skid resistance are not necessarily improved by this treatment. These depend on the SMA surface course.
- Through the ALT experiment, the innovative treatment showed a remarkable rutting resistance, thus potentially increasing the pavement life with respect to this mode of deterioration.
- The construction procedures are similar to those used for placing a conventional asphalt layer. However, special care should be taken at joints between adjacent layers, which should be saw cut. The construction time is also similar to that for conventional materials, however, the material is workable for longer, and it also cools down more slowly.
- The cost of the treatment is estimated as being 25% higher than that of the conventional treatment.

6.3.5 **High modulus binder course + thin surface**

This treatment was considered promising because it is claimed to have a good resistance to rutting and surface cracking, when it is applied as an inlay. Two separate tests were performed on this treatment.

The first test was carried out in the ALT facility at LAVOC, where a 60 mm thick EME ("Enrobé a module Elevé") binder course with a 20 mm surface was applied after milling 60 mm off the existing asphalt layers. This solution was tested side by side with a conventional 90 mm binder course with a 40 mm surface course, applied as an inlay, after milling 30 mm of the existing asphalt layers. Figure 6.6 shows the deformed cross-section monitored at different stages of the tests. Figure 6.7 presents the development of rutting in the EME section, in comparison with the conventional asphalt inlay.

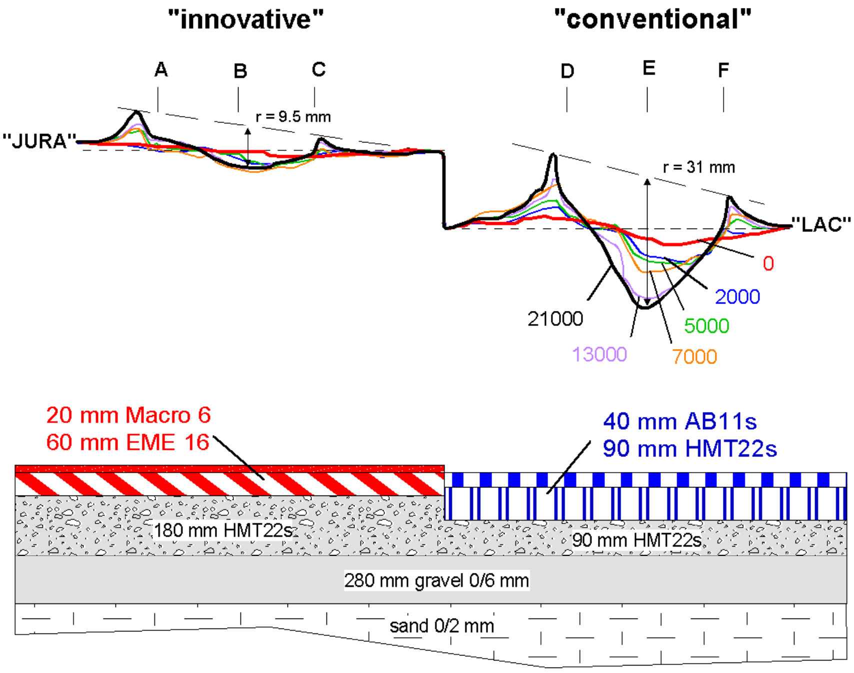


Figure 6.6 - Deformed cross-section monitored in section 2 at different stages of the test performed at LAVOC

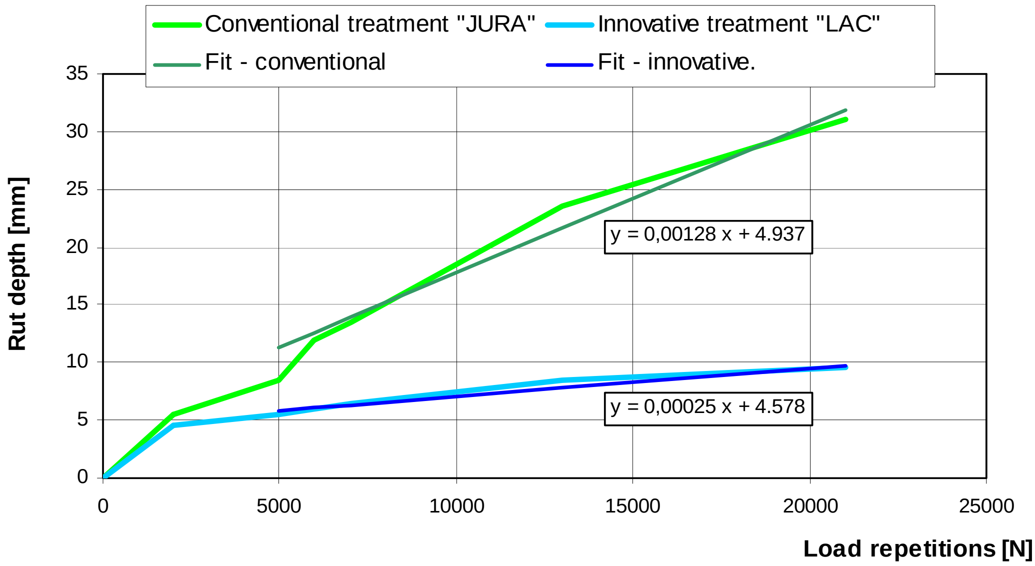


Figure 6.7 - Comparison of rutting behaviour of EME + thin surface with results from a conventional asphalt inlay tested at LAVOC

The second test was performed at TRL, where a 60 mm thick High Modulus Binder course using a 15 penetration grade bitumen (HMB15) with a 30 mm thick surfacing was tested side by side with a conventional Heavy Duty Macadam binder course (HDM50) with the same surfacing. The TRL test also included another section where the inlay was only applied along a 1 m width trench in the wheel-track, which would be a very interesting solution when the deterioration of the pavement is concentrated in this area. Figure 6.8 shows the cross section of the test pavement and Figure 6.9 illustrates the application of the tack coat before placing the wheel track HMB15 inlay.

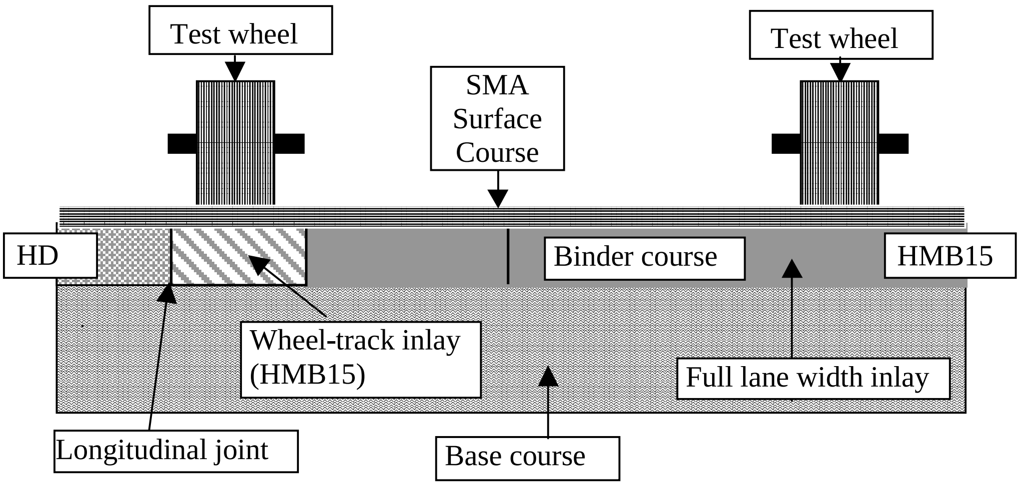


Figure 6.8 – Cross section of the test pavement at TRL

Figure 6.9 - Placing the wheel track HMB15 inlay at TRL

The main conclusions from the tests performed at LAVOC and at TRL concerning High Modulus binder course inlays are the following:

- This innovative treatment is suitable for improving the pavement condition with respect to rutting or surface defects. Other characteristics such as skid resistance are not necessarily improved by this treatment because they depend on the surface layer to be used. For the specific case of the wheel-track inlay tested at TRL, it will be ideally suited if the deterioration is limited to the wheel-track.

- Through the two ALT experiments, the innovative treatment showed a very good rutting resistance, thus increasing the pavement life with respect to this mode of deterioration. However, this potential for increased rutting resistance could only be demonstrated for the full-width inlays.

- The construction procedures are similar to those used for manufacturing and placing conventional asphalt layers. The experiment at TRL also showed that wheel-track inlays using High Modulus asphalt mixtures is a viable technique: the asphalt was easy to place by hand and compact and a good bond was achieved at the vertical interfaces with the existing layers, for both a planed interface and a saw-cut interface.

- The comparison between the estimated construction costs of the innovative treatment and a reference treatment will depend on the reference which is used. However, for the wheel-track inlays, a considerable reduction of material costs will be achieved.

6.3.6 Very Thin Asphalt Concrete (VTAC) with geogrid

This treatment was considered promising from the point of view of resistance to surface cracking. It was tested at the LCPC ALT facility, in Nantes, where it was applied as an overlay 25 mm thick, over a cracked surface. Due to the deformation of the tested surface, it had to be superficially milled before application of the maintenance treatment. The performance of the Very Thin Asphalt Concrete (VTAC) with geogrid was compared to that of VTAC without geogrid and a conventional Thin Asphalt Concrete (TAC), 40mm thick, placed under similar conditions. Figure 6.10 shows the three pavement sections tested.

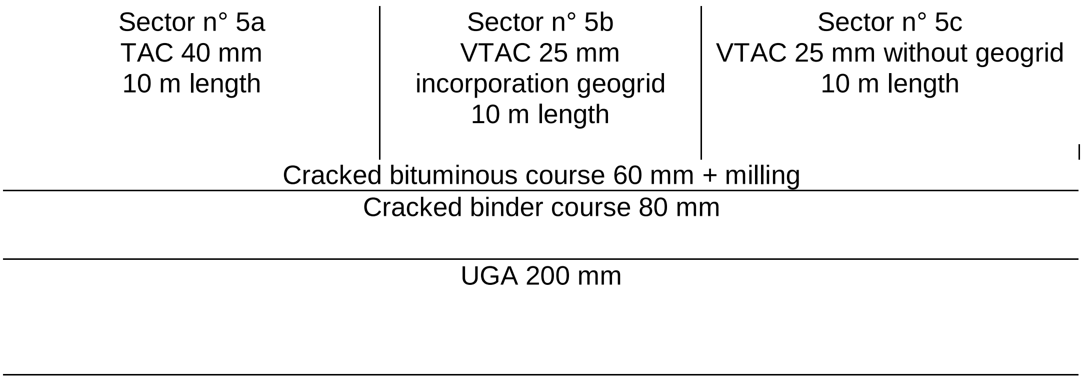


Figure 6.10 – Pavement structure 5 after application of the maintenance treatment at LCPC

The pavement condition at the end of the experiment (after 1 million 2x32.5 kN wheel loads) is shown in Figure 6.11. The total crack length was measured before application of the maintenance treatments and after the end of the ALT. If we take the total crack length in each section before application of the treatment as a reference, we get the percentages of crack length after ALT for the three sections (Table 6.4).

Table 6.4: Comparison between crack length for the three tested solutions

	CONVENTIONAL TREATMENT 40 MM TAC	**Innovative treatment 25 mm VTAC with geogrid**	**25 mm VTAC without geogrid**
%of cracked length	23%	21%	30 %
Ratio	1	0,91	1,34

Section 5a (TAC 40 mm)

Section 5b (VTAC 25 mm + geogrid)
Section 5c (VTAC 25 mm)

Figure 6.11 – Surface condition of the pavement at the end of the test

The main conclusions from the test were as follows:

- The innovative treatment is suitable for improving the pavement condition with respect to surface defects, for example surface cracking.
- The results of the experiment did not demonstrate that the VTAC with geogrid performed better than the conventional TAC. However, the presence of the geogrid delayed the initiation of cracking in comparison to the sections without geogrid. In all three sections, there were problems with bonding between the overlay and the existing surface in the trafficked areas.
- For the reason presented above, these thin or very thin overlays are not recommended in situations where the existing surface has to be milled. An increase in the tack coat applied is also recommended, especially when the surface is cracked. The application of the VTAC with geogrid is more time-consuming, when compared to applying conventional asphalt overlays.
- The cost for VTAC with geogrid was around 10% higher than that of the conventional 40 mm thick TAC overlay.

6.3.7 Summary conclusions from the ALT experiments

In summary, the ALT showed that in terms of performance the innovative maintenance treatments trialed gave promising results. Some of the treatments tested also showed considerable benefits in terms of material consumption and environmental impact. However, the success of these techniques relies strongly on good construction practices and enhanced quality control procedures.
Finally, it should be borne in mind that the results from ALT will only describe the performance of pavement structures with respect to load associated deterioration mechanisms. Moreover, they refer

to a situation that is better "controlled" in terms of traffic loads and climatic conditions than the real situation in road pavements. The conclusions from this type of experiment must always be supported by results obtained in Real Load Tests (RLT) on road pavements, which are subjected to the effects of time and climatic variations, and where the variability of materials and construction procedures can play an important role in the pavement performance.

6.4 Practical implementation of procedures for road maintenance works

6.4.1 Objectives

The main objectives of the pilot trials performed under the FORMAT project were to:

- assess the efficiency of the selected maintenance techniques in improving the pavement condition.
- gain experience with the application of the treatments that could contribute to best practice guidelines;

Three pilot trials were performed for testing the innovations selected in task 1:

- The application of a new porous asphalt surface on a flexible pavement situated on a motorway in France. This treatment aimed at restoring the skid resistance of the existing surface. A new mix design, using a finer aggregate and a highly modified binder was used for this application. This treatment is expected to have a better durability with respect to the conventional porous asphalt mixtures used in France.
- The structural rehabilitation of a jointed concrete pavement in a motorway located in the vicinity of Valencia, in Spain. The maintenance works were performed in two phases: during the first phase, the pavement foundation was injected with cement grout, in order to restore the slab support; during the second phase, three different solutions for the restoration of surface evenness were trialed: a conventional bituminous overlay, a bituminous overlay with a geotextile to inhibit reflection cracking, and grinding of the concrete surface.
- The rehabilitation of a continuously reinforced concrete pavement (CRCP) near Baytown, Texas, in the USA. The maintenance works comprised a number of local interventions concerning areas in worse condition, followed by the application of a bonded concrete overlay.

The application of the maintenance treatments was closely monitored, in all aspects related to the issues studied in the FORMAT project: the procedures for application, the materials characteristics and the procedures for traffic management during application. The user delays during application of the maintenance treatment were also monitored, in order to provide input for cost-benefit analysis.

6.4.2 Application of a new porous asphalt surface in Toulouse

Due to the traffic, the East part of the ring road of Toulouse (South of France) needed a new wearing course. This toll free section whose owner is Autoroute du Sud de la France (ASF) links A 62 (Bordeaux Toulouse) to A 61 (Toulouse Narbonne). It is 2x3 lanes with emergency lane, with an average daily traffic of 110,000 vehicles for both directions. The existing wearing course was an old 0/10 porous asphalt and a thin asphalt concrete with the same grading for bridges. The entire wearing course surface is roughly 360,000 m².

Porous asphalt 0/6.3 and 20 % in situ void content was chosen due to the fact that it is the best compromise between skid resistance and rolling noise. The work consisted of the following:

- Milling of the old porous asphalt 0/10 up to a nominal depth of40 mm;
- Laying of a clean tack coat with a minimum application rate of 350 g/m² of bitumen (either 500 to 600 g/m² of emulsion)
- Implementation of anti-cracking system with geogrid over an area of 13,000 m² from kilometre 236.400 to 237.250 after laying a clean tack coat with a minimum application rate of 900 g/m² of bitumen (about 1.4 kg/m² of emulsion)
- Laying of a new 0/6.3 porous asphalt in a nominally 30 mm thick layer across the entire width of the ring carriageway (3 driving lanes and 1 emergency lane)
- Laying of a new thin asphalt concrete in a 40 mm thick layer on bridge decks.

Figure 6.12 illustrates the works performed:

Figure 6.12 – Application of the porous asphalt

The clean tack coat is a special and patented process whose trademark is COLNET for Europe. The Colnet tack coat is a special emulsion in which an additive is introduced during spreading. Thanks to this clean tack coat, trucks can drive on it without getting the existing roads dirty.

Other works were performed like grit blasting between kilometre 228.900 and 230.700 in the Narbonne Bordeaux direction in order to restore a good micro texture on the existing pavement.

The works were carried out at night, and the traffic was diverted between two successive exits during the execution of the work. There was a one-day gap between milling and laying of the new wearing course, so the milled surface bore traffic for one day before being covered with the porous asphalt.

- Special organisation was required for the night work:
- Installation of traffic signing and diversions from 10 pm,
- Pavers and rollers transfer from 10 pm to 11 pm,
- Cut joint from 11 pm to midnight,
- Porous asphalt laying from midnight to 4.30 am,
- Road marking from 4.30 am to 6 am,
- Opening back up at 6 am.

Skid resistance was the main indicator to be improved by the maintenance treatment. Other surface characteristics, such as evenness, were not assessed, since the type of treatment applied (thin wearing course) was not designed for this purpose. Skid resistance was measured with the French equipment ADHERA, which gives the “Coefficient de Frottement Longitudinal” (CFL) (Longitudinal Friction Coefficient) using the “blocked wheel” system, which means that the sliding ratio is 100%. During the test, a 1 mm film of water was sprayed under the tyre.

Tests were done at different speeds (40, 80 and 110 km/h) in order to establish the relation between speed and skid resistance. The results were expressed in terms of average value for each 20 m of road.

Generally speaking, the CFL coefficient decreases when speed increases. Slow speed (40 km/h) tests allow to assess the effect of micro texture and high speed tests (> 90 km/h) the effect of macro texture. With this type of device, one can evaluate both micro and macro texture for the wearing course.

The results obtained on the new wearing course were very homogeneous with low standard deviations. When compared to the French envelope for all wearing courses, these results showed an average skid resistance at low speed and a very good performance at high speed. When compared to other porous asphalt surfaces, the results are in the upper side of the envelope, both at low and at high speed.

6.4.3 Structural rehabilitation of a jointed concrete pavement in Valencia

A 3 km long motorway stretch under the responsibility of AUMAR (Autopistas del Mare Nostrum), in Spain, was selected as a pilot test section. The pavement is 25 years old and consists of 0.25 m thick jointed unreinforced concrete slabs, with no dowel bars, placed over a 0.15 m lean concrete base and a 0,50 m gravel layer. A significant percentage of the pavement slabs were severely cracked, which was attributed to poor foundation support.

The maintenance technique selected for this pavement consisted of the following steps:

- to improve the slab support, therefore eliminating the cause of cracking, making the best possible use of the existing pavement structure;
- to place an overlay that will increase, to a certain extent, the pavement’s bearing capacity and will restore the riding condition.

Within a 3 km section, 3 sub-sections were defined, for application of each of the three maintenance options summarised in Table 6.5.

Table 6.5: Maintenance options to be trialed in the Valência pilot study

Option Nº	Description	
	Phase 1	Phase 2
1	Crack and joint sealing + Foundation stabilisation by grouting	Diamond grinding + Joint sealing ; no overlay
2		Bituminous overlay using modified binder (60 mm thick)
3		Anti-crack system (geotextile) + Bituminous overlay using modified binder (50 mm thick)

The first phase of application of maintenance treatments to the pilot test section took place between April and June 2003 and consisted of the following operations:

- Joint and crack sealing, in order to prevent the cement grout from "escaping" during injection;
- Hole drilling, either in the slabs of the slow lane or in the shoulder, followed by cleaning operations;
- Cement grout injection at controlled pressure (Figure 6.13)
- Cleaning.

Figure 6.13 – Injection of cement grout

The second phase took place in September - October 2003 and consisted of the conclusion of the treatments for sealing and improving pavement evenness, combined with some degree of strengthening, in the case of sections 1 and 2. The following activities were performed:

Section 1:

- Application of a regulating layer directly on the concrete slab with varying thickness, typically 20 to 30 mm, using conventional asphalt concrete;
- Application of a 60 mm thick asphalt overlay using polymer modified binder for the asphalt mixture.

Section 2:

- Application of a regulating layer directly on the concrete slab with varying thickness, typically 20 to 30 mm, using conventional asphalt concrete;
- Application of an anti-crack system consisting of a geotextile impregnated with bitumen at 1200g/m^2;
- Application of a 50 mm thick asphalt overlay using polymer modified binder for the asphalt mixture.

Section 3

- Surface grinding of the concrete slabs, in order to restore longitudinal evenness.

Only the slow lane was closed during the road works in phase 1 and a “lane closed” signalling was used for that purpose. “Lane closed” signalling was also used in phase 2, this time involving the diversion of all the traffic along the opposite carriageway, in such a way that the latter (North direction lane) was temporarily used as a two-way road.

The assessment of the different solutions was performed by visual inspection and crack mapping, longitudinal unevenness and FWD testing before and after each of the construction phases. Skid resistance was also measured.

The results from the FWD tests performed before and after the injection works clearly demonstrated the benefits induced by this operation in terms of the structural integrity of the pavement. The severity of the surface deterioration was also reduced in this operation, due to the closure of cracks.

Surface evenness, texture depth and skid resistance significantly improved with the application of the asphalt overlays in sections 1 and 2. For section 3, although there was an improvement in surface evenness and skid resistance with the grinding operation, texture depth decreased with the operation.

6.4.4 Application of a bonded concrete overlay to a CRCP in Texas

The pilot site consisted of a 250 mm thick CRCP located on SH-146 in the Houston District near Baytown, Texas. Before rehabilitation, the pavement was experiencing spalling and cluster cracking at different severity levels. The main steps of the rehabilitation programme included:

- Full Depth Repair (FDR) at selected sections experiencing cracking and spalling at medium and high severity level prior to placement of the overlay,
- Milling the pavement lanes to a depth of 50 mm to remove spalled and delaminated concrete,
- Cleaning the surface of milled lanes, and
- Applying 50 mm bonded concrete overlay (BCO) on a 330 m pavement length over a period of a weekend.

Relative to work zone considerations, FDR is typically a short-term method of repair. The work zone was delineated by use of advance warning and blocker trucks with flashing lights. Traffic cones were set at specified spacing to channelise the traffic lanes. Construction of the BCO was done phase by phase over several weekends after the FDR work was completed. The work zone was again delineated similarly as the FDR work zone, where instead of traffic cones, directional I-beam barricades were used to enhance visibility during night time. A detour signal was also used during paving operations.

The efficiency of the Full Depth Repair in restoring the structural integrity of the pavement was assessed through visual inspection and Falling Weight Deflectometer (FWD) testing before and after performing the FDR work. In this method of repair, FDR was used to repair local distresses as preparation of the pavement for the overlay. Comparing the pavement condition before and after FDR, it was obvious that FDR addressed deteriorated transverse and longitudinal cracks, joint spalling, blowup and punchouts. The results from the FWD tests performed before and after FDR showed an increase of the Load Transfer Efficiency in joints or cracks and also an increase of the Relative Radius of Stiffness of the concrete slabs. This indicated that FDR effectively restored the rideability and structural integrity of deteriorated pavement.

Repairs of concrete pavement surfaces requiring bonding between old and new concrete have been considered to be somewhat experimental. Hence construction time and post-construction testing was conducted to evaluate the improvement of the techniques.

The potential of delamination between the BCO and the original concrete pavement at an early age is critical to the success of the overlay and is significantly affected by climatic factors at the time of construction. Therefore, a weather station was used to collect climatic data during placing and curing of the overlay. Aspects such as the variation in time of maturity, effective curing thickness or concrete modulus were closely monitored through the curing period.

Shear strength testing was also conducted to evaluate the bond between the overlay and the existing concrete. A torsional test device (torque wrench) was applied to debond the new concrete from the existing concrete (shown in Figure 6.14) and measure the shear strength at the interface.

(a)………………………………………………..….(b)

Figure 6.14– Shear Strength Testing

The shear stress and strength with respect to the time were depicted in Figure 6.15, which shows the shear strength increases greatly with the increase of the time. The shear stress also varies with the time but, at any time it didn't reach the shear strength, which indicates that there was no delamination at the interface.

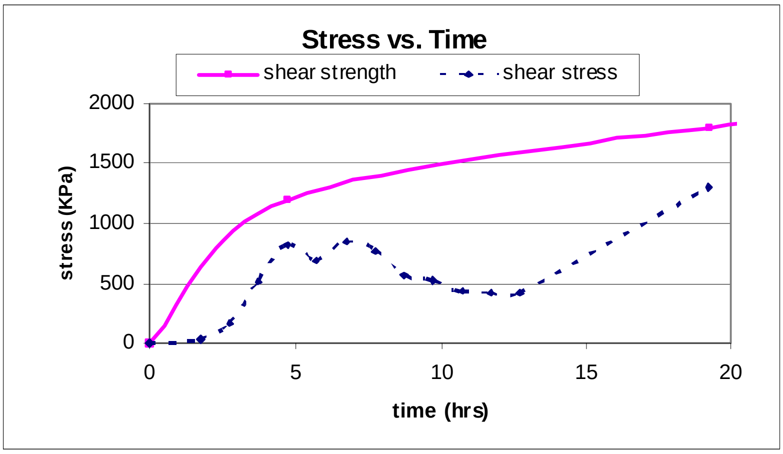


Figure 6.15– Interfacial Shear Stress and Strength

In conclusion, the application provided a monolithic structure of increased load-carrying capacity for the need of current traffic loadings with reduced user delay and improved safety control, and it is an innovative and effective method of repair for CRCPs. With adequate pre-overlay repair, it is recommended as a feasible and innovative repair strategy for CRCPs.

6.5 References

Blab, R. Analytical methods for modelling deformation behaviour of flexible pavements. (In German). Publication No. 11, Institute for Road Construction and Maintenance, TU Vienna, 2001

7. Summary of research conducted on ‘Safety at road works’

7.1 Introduction

The FORMAT project (Fully Optimised Road Maintenance) addresses Task 2.2.1/11 ‘Road infrastructure pavement maintenance management’ of the European Commission Key Action ‘Sustainable Mobility and Intermodality’. The FORMAT project is designed to conduct in-depth research into highway maintenance works in order to improve the efficiency, safety and cost of the maintenance works by appropriate planning, timing and execution of work zone operations. This section summarises the work of Work Package 5 (WP5: “Safety”).

One of the major aims of FORMAT is considering differences between maintenance techniques and the associated traffic management in terms of a comprehensive Cost Benefit Assessment Framework (primarily the work of WP4). This assessment takes into account road owner/operator costs in carrying out maintenance work, and road user costs in terms of delays and accidents. More specifically, one of the tasks of WP5 is to explore the effects of these variations in traffic management arrangements on safety.

Work Package 5 has been active throughout all 3 years of the FORMAT project. The title of the Work Package is “Safety” and that has formed the main thrust of the work, but other more general traffic management issues have also been looked at. The work has been mainly focussed in 3 areas:

- Collation and analysis of accident data collected outside of FORMAT
- Trials of alternative traffic management arrangements in driving simulators
- Analysis of data specifically collected by FORMAT from works sites.

This section summarises the work in each of these strands. The work is reported in detail in FORMAT WP5 Deliverables:
D5: Report on Collection of Accident Data from across Europe
D11: Analysis of General and Specific Accident Data
D13: Results from On-road Trials
D16: Assessment of Innovative Traffic Management in Driving Simulators

Within the overall FORMAT programme, Work Package 4 is looking at the differences between maintenance techniques and the associated traffic management in terms of a comprehensive Cost Benefit Analysis Framework. This Framework takes into account road owner/operator costs in carrying out maintenance work, and road user costs including delays and accidents. One of the key tasks of WP5 has been to explore the effects of variations in traffic management on safety.

7.2 Data Collection and Analysis

The first activity within FORMAT WP5 was the collection and analysis of data. This work is reported in detail in Deliverables D5 and D11. The primary interest was data which could be used to develop methods of comparing the safety of different works regimes. This would then become input for the Cost Benefit Framework being developed under WP4. The initial step was therefore to assess the amount, nature and quality of data available.

There are many levels of detail of information which could be used within the WP4 Cost Benefit Framework. For instance the anticipated accident levels could be expected to vary with traffic flow, number and width of lanes open, signing and marking, etc. In addition, the number of accidents might be expected to vary from country-to-country. Although the main thrust of the wider FORMAT project was the assessment of innovative maintenance techniques it was not felt likely that these would, in themselves, affect the accident rate. However employing different maintenance techniques could affect accident rates through factors such as the width of carriageway made unavailable to traffic, the duration of the works, whether work was carried out overnight, etc.

WP5 sought data from across Europe and the United States of America. Information was obtained from 15 different countries. It should be noted that funding for FORMAT did not include the resources necessary to carry out any large-scale data collection. Therefore WP5 concentrated on gathering and interpreting data which already existed. The level of detail of information available varied greatly between countries.

Deliverable D11 contains many tabulations of numbers of injury accidents and accident rates (number of accidents per vehicle-kilometre) including tabulations of all accidents and tabulations specifically covering those associated with works. The tabulations include information covering the whole road network and sub-sets, most cover all personal injury accidents but some are for serious or fatal accidents only. A selection of the tabulations from Deliverable D11 is reproduced here.

For example Table 7.1 shows the number of personal injury accidents in the year 2000 and the percentage of these accidents which occur at works.

Table 7.1: Number of personal injury accidents in 2000 and percentage at works

Country	Scope	Number of accidents		Percentage at works
		Total	At works	
Austria	Motorways	2 466	122	4.9
Austria	All roads	42 126	515	1.2
Denmark	Motorways	341	12	3.5
Denmark	All roads	7 346	113	1.5
Finland	Motorways	161	2	1.2
Finland	Major roads	2 336	33	1.4
Finland	All roads	3 084	42	1.4
France	Motorways	6 624	81	1.2
France	Major roads	24 515	135	0.6
France	All roads	121 223	245	0.2
Netherlands	Motorways	4 184	149	3.6
Portugal	Motorways	1 918	63	3.3
Portugal	Major roads	10 585	328	3.1
Portugal	All roads	44 159	1152	2.6
Slovenia**	Motorways	338	11	3.3
Slovenia**	Major national roads	1846	21	1.1
Slovenia**	Other national roads	2629	34	1.3
Spain	Motorways	3 041	62	2.0
Spain	Major roads	19 861	469	2.4
Spain	All roads	44 720	1 133	2.5
Sweden	All roads	9 226	106	1.1
Switzerland	Motorways	45 359*	648*	1.4
Switzerland	All roads	238 946*	1 109*	0.5
UK	Motorways	9 394	439	4.7
UK	Major roads	116 938	1 796	1.5
UK	All roads	233 729	2602	1.1

* includes damage only accidents
** data for year 2002

Great care must be taken when trying to draw conclusions from these figures. Firstly there are likely to be differences in definition, for instance whether an accident is reported to be associated with works could be limited to being within the area restricted by works, or could include accidents occurring in queues on the approach to works. Often these decisions will rest with individuals (for instance police officers, who may work to different guidelines in different countries). Secondly, differences in the percentage of accidents occurring at works will not be simply related to differences in the safety of works in a particular country. Other factors which affect this proportion are concerned with the level of works activity such as number of works, length of works, duration of works; the type of traffic management employed, particularly whether it is necessary to close lanes; and the traffic flow past the works.

The figures are useful in demonstrating that while over the whole road network accidents at works generally account for less than 2% of the total, it is often much higher at motorways (typically 3-5%). This may be due to a combination of low non-works accident rates on such roads, and the need to carry out major works while maintaining high flows by means such as the use of contra-flow. However, for the reasons outlined above, it is not felt that these data provide suitable information on the risk associated with works for use within the Cost Benefit Framework being developed in WP4. For that purpose it is necessary to make direct comparisons between the accident costs incurred when works are in place with the corresponding accident cost when no works are present.

To take account of the effect of works on safety within a cost-benefit analysis it is necessary to develop a means of estimating the change in costs due to the presence of the works. It was therefore the aim of WP5 to develop estimates of the change in accident cost rate defined as the product of multiplying accident rates by the cost of accidents:

ACR = AR * C

Where ACR is the accident cost rate (euros/thousand vehicle-kilometres)
AR is the accident rate (accidents/thousand vehicle-kilometre)
And C is the accident cost (euros/accident)

The change in accident cost rate is most appropriately expressed as the ratio of Personal Injury Accident Costs with and without roadworks (RATIO) where:

RATIO = ACR_W / ACR_N

And ACR_W is the accident cost rate with works
ACR_N is the accident cost rate without works

It is recognised that different countries have different accident records and use different maintenance techniques. It was therefore intended that different values of the accident cost ratio should be developed for each country and for variations in layout. In practice very few studies have been identified which allow direct calculation of the change in accident cost rate or simply of change in accident rate.

The only examples identified of estimation of changes in accident cost rate came from Germany where two studies of motorways in Hessen are reported by Grebe and Hanke (1991) and Durth, Stöckert and Klotz (1999). These results are summarised in Table 7.2.

Table 7.2: Summary of data on accident cost ratios

Country	Situation	Period	Accident Cost Ratio
Germany (Hessen)	Short term works on motorways	1986-1989	5.6
Germany (Hessen)	Short term works on motorways	1991-1996	7.0
Germany (Hessen)	Long term works on motorways	1991-1996	1.2

Although no other studies have been found which directly compare accident costs with and without works, it is possible to derive estimates for some countries from the information that is available. For example, if it is assumed that the accident costs are the same for accidents in works as for the equivalent national average, then the comparison of accident costs can be reduced to a comparison of accident rates with and without works. The German data from the studies mentioned above can be analysed in this way. In addition a series of studies has been carried out in the UK at various times from 1982 until 2003. In these studies data on numbers of accidents, flows and traffic management arrangements have been collected at each site and for the equivalent periods for other years when no works were in place. The accidents and flow information were used to estimate the accident rate with and without works. These accident rates were then compared to estimate the increased accident rate with works.

An alternative approach, is to seek to develop the equivalent information from more aggregated data. Exercises of this sort usually involve making assumptions about important factors such as traffic flow, and in practice can be complicated by incompatibilities between data sources. Nevertheless, if carried out carefully, they can develop useful information. Within WP5, anlyses of this type have been carried out on data from Finland and Slovenia (more information on this process is contained in Deliverable D11). The results, in terms of the ratio between accident rates with and without works, are shown in Table 7.3, together with the results from the German and UK studies mentioned above.

Table 7.3: Personal injury accident rates - ratio between values with and without works

Country	Scope	Year	Ratio
Finland	Class I main roads *	2001	4.9
Finland	Class II main roads	2001	3.9
Finland	Regional Highways	2001	4.8
Finland	Connecting Roads	2001	3.9
Germany	Motorways in Hessen (short-term works)	1986-1989	3.2
Germany	Motorways in Hessen (short-term works)	1991-1996	9.8
Germany	Motorways in Hessen (long-term works)	1986-1989	1.5
Germany	Motorways in Hessen (long-term works)	1991-1996	1.9
Slovenia	Motorways	2002	1.6
Slovenia	Other national roads	2002	2.9
UK	Selected motorways in England	1982	1.5
UK	Selected motorways in England	1987	1.6
UK	Selected dual carriageways in England	1991	1.1
UK	Selected motorways in England	1993	2.3
UK	Selected motorways in England	2002	1.0

* includes motorways but most (greater than 90%) of the roads are single carriageway

Although not a major part of the work of WP5 information was collected on accident costs as shown in Table 7.4. Some countries have supplied data in the form of costs per accident, others as costs per casualty. It is to be expected that for the same severity the cost per accident would be higher than the cost per casualty since an accident may injure more than one casualty.

Table 7.4: Costs of accidents and casualties (in Euros)

Country	Accident (A) or Casualty (C) costs	Severity (of most severely injured person)		
		Slight	Serious	Fatal
Belgium	A	25 000	370 000	1 470 000
Finland #	A	50 456	250 000	1 934 161
Slovenia †	A	6 516	14 989	19 101
UK	A	24 755	248 053	2 130 895
Austria	C	43 605	73 695	805 223
Denmark	C	31 088	113 900	1 101 882
France	C	22 665	154 534	1 030 224
Germany	C	3 835	86 920	1 227 100
Slovenia	C	9 873	79 422	950 300
Spain *	C	497	28 679	217 266
Sweden	C	38 700	666 700	1 538 000
Switzerland	C	13 333	200 000	1 200 000
UK	C	15 967	207 073	1 842 795
USA	C	23 350	827 300	2 457 400

The factors taken into account in calculating these costs vary between countries, known differences are noted below.

* excludes cost of damage to vehicle or road

† these are figures only for physical damage, they do not include hospital costs or an allowance for "pain, grief and suffering"

these figures include an allowance for the under-reporting of accidents

This work revealed how little detailed information exists about the change in accident risk and costs associated with works activities. Whilst many countries routinely collect information on the number of accidents at works these do not in general allow an estimation of the increased risk/cost because they do not include any measure of exposure (number of works, length of works, duration of works, flow through works).

One very direct way of addressing this lack of information is to carry out specific studies such as those carried out in Germany and the UK. These studies are quite expensive since they involve major data collection exercises, but they do produce a clear comparison between accident rates (and, in the case of the German study, accident cost rates) with and without works. By matching the accident figures for the same stretch of road taking account of issues such as flow levels, length of works, etc, these studies provide a much better indication of the true change in risk and costs. However, to keep costs within reasonable bounds, these studies usually have to be limited in either type of road, geographical area, or time period.

A second approach is to use information from existing databases as has been done in Finland and Slovenia. This approach has the advantage of using data which is routinely collected and therefore avoids the high costs of the more detailed studies. However, the extraction of the information is time consuming and there are concerns over the compatibility of data from different sources.

It is recommended that at least one of these two approaches should be adopted in all countries. Perhaps a combination of using the second approach to carry out an annual review using routinely collected data and regular (say once every 5 years) studies of particular stretches of road as in the first approach. In time this would provide a source of national data which could be incorporated into the Cost Benefit Framework developed in WP4.

In the meantime it is necessary to fill in the gaps in the information. The best advice which can be given at this stage is for missing data to be replaced with that from a study for similar countries and/or road types. It is recognised that this is not the ideal solution since there is a limited number of studies to select from. It may be possible to supplement this approach with very small scale studies of a few roads in a country to seek to establish some provisional values until more comprehensive data can be developed.

7.3 Trials in Driving Simulators

This strand of the work involved trials using driving simulators to explore the effects of innovative traffic management arrangements at works. It is fully reported in FORMAT Deliverable D16. Work in FORMAT has identified some variation in practice between countries (and sometimes within countries) in terms of traffic management arrangements at road works. Information was gathered on the additional accident risk associated with the presence of works. It had originally been planned to explore some of the implications from this data through the on-road trials being conducted by Work Package 3. However, partly due to the nature of the works, and partly due to liability concerns, it has not been possible to use those trials in this way. It was therefore decided to make more extensive use of driving simulators than had originally been planned.

Driving simulators provide a safe environment in which to study the safety implications of changes to traffic management. They also allow trials to be closely controlled in ways which are not possible on the public road, for instance in terms of the traffic flow. The WP5 Team have access to two driving simulators: at VTI in Sweden and at TRL in the UK. The original planning for WP5 had only included one set of simulator trials but, to compensate for the reduced usefulness to WP5 of the on-road trials mentioned above, the programme was extended to include trials on both simulators.

Lengthy consideration was given to the development of the trials. A web-based literature review was undertaken to help establish what similar work had been carried out in the past. Many interesting options could have been explored, but time and funding restraints meant that only one basic scenario could be developed for each simulator which meant that some difficult choices had to be made. The first decision was that the trials should concentrate on traffic management at works sites which were representative of significant parts of the main European road network. There were two main types of major road network within the countries represented in WP5: those where the majority of roads were dual carriageways with restricted access, and grade-separated junctions, and those where the majority of roads were single carriageway roads carrying two-way traffic. It was therefore decided to cover both these situations by representing a high quality dual carriageway in the trial at TRL and a good standard single carriageway at VTI.

Having decided on the type of roads to be represented, the next stage was to decide on the type of works. To seek to make the trials as relevant as possible to road authorities, opinions were sought on the most interesting options from the countries represented within WP5. There was a clear consensus that the point of greatest interest was the effect of lane width on speed. This therefore became an important aspect of the simulator trials. Other areas of particular interest were the effect of road markings (particularly on speed), the level of traffic flow and the effect of weather. It was felt that the latter was not easily explored within the simulator environment, and in any case was not a factor which could be controlled by the designer of the traffic management. It was therefore decided that the main aspects of the trial should be the effect of using narrow lanes, and the effect of using different road markings to delineate the lanes.

Narrow lanes are used in some countries since they are seen to have potentially beneficial effects on both capacity and safety. At high flows, the use of narrow lanes can remove the necessity to close a lane to traffic thus maintaining much higher throughput. In many situations this can prevent, or at least greatly reduce, the development of queues and so significantly reduce delays. However at lower flows, when traffic is moving freely, the more constricted feel brought about by the presence of narrower lanes can reduce speeds and so contribute to improved safety.

Two trials have been undertaken: at VTI a two lane single carriageway was modelled, at TRL a two lane dual carriageway was used. In each trial four different works arrangements were presented to each driver with stretches of unaffected road before the first works, between the works and after the last works sections.

In the VTI (single carriageway) trial sufficient road space was retained to allow two-way operation but with very limited width. The main variations in layout studied concerned the separation between lanes on the narrow two-way carriageway through the works as illustrated below in Figures 7.1 – 7.4:

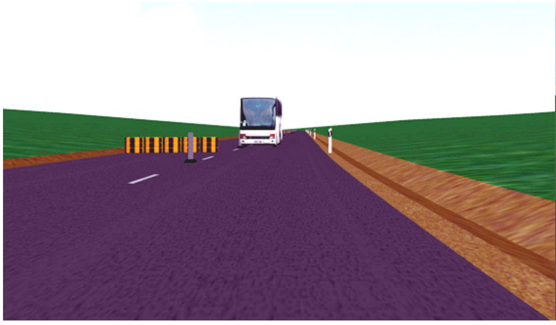


Figure 7.1: No lane marking

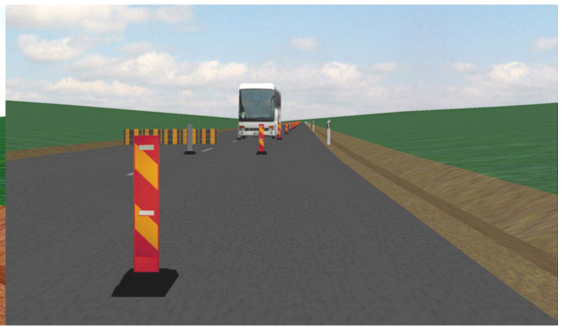


Figure 7.2: Guiding vertical markers

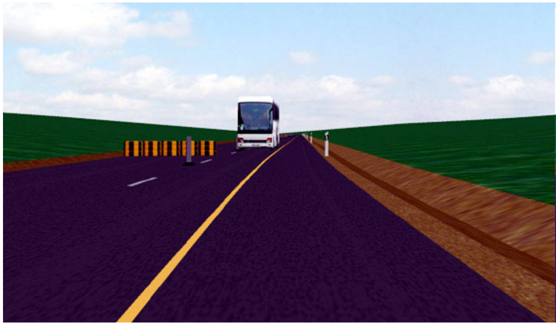


Figure 7.3: Orange line

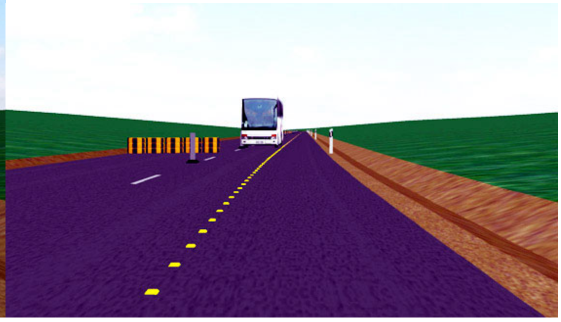
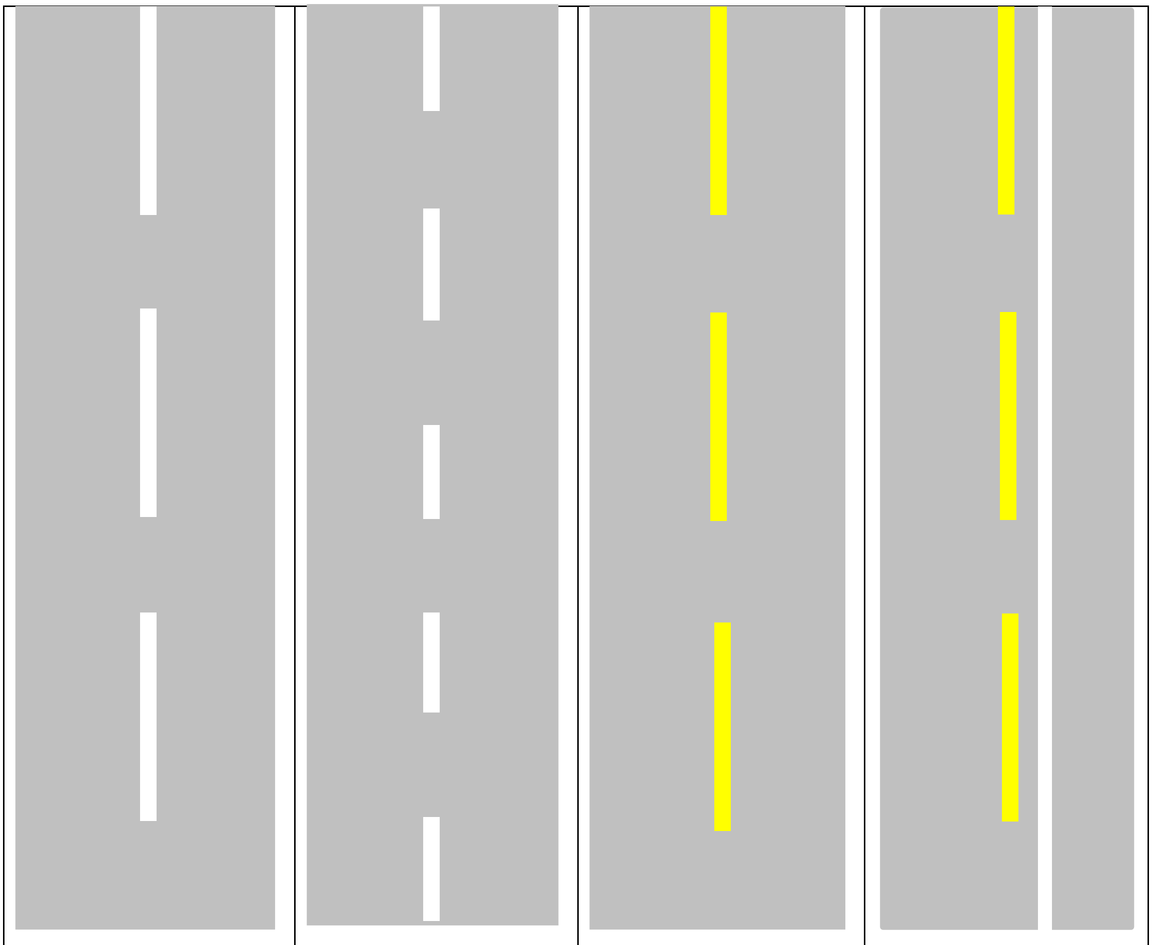


Figure 7.4: Studs

In the TRL (dual carriageway) trial one lane was closed in one direction. This allowed either the use of a single standard lane or, by employing the hard shoulder, the use of two narrower lanes. The use of the single standard lane (layout 1) retained the normal lane markings. For the layouts involving the use of two narrow lanes three different types of lane marking were included in the trial as illustrated below in Figure 7.5:



Layout 2	Layout 3	Layout 4	Layout 4 with yellow lines in addition to existing markings
White mark = 6000mm Gap = 3000mm	White mark = 3000mm Gap = 3000mm	Yellow mark = 6000mm Gap = 3000mm	Yellow mark = 6000mm Gap = 3000mm Continuous white line

Figure 7.5: Narrow lanes (Layouts 2, 3 and 4) – nb UK driving on the left

Since the new maintenance techniques assessed under WP3 did not require innovative traffic management arrangements, the layouts considered here have not been directly linked to specific techniques. The extent to which they are "innovative" will also vary from country to country. It is inevitable that particular approaches may be relatively well-established in one country, but seen as innovative in another. This can be true of both maintenance techniques and traffic management arrangements. In particular the use of narrow lanes (on single or dual carriageways) whilst widespread in countries with extensive heavily used road networks, is not common throughout Europe. Within that the range of different lane delineation methods considered here (studs, different coloured lines, vertical delineators, or no markings at all) will include something innovative for most countries.

The two trials were developed in consultation but run as separate studies. The two sets of results have been pulled together to establish some overall view of the study. These conclusions are presented in three parts:
The effect of using narrower lanes
The effect of signing
The effect of lane delineators and markings

7.3.1 Narrow Lanes

The VTI study involved a single carriageway and therefore involved interactions with on-coming traffic. No other traffic travelled in the same direction as the test vehicle and therefore drivers were completely free to choose their own speed. Speeds were significantly reduced in all the layouts (by around 30 to 40 km/h). Since all the layouts had the same width there was no information on the effect of lane width.

The TRL study involved a dual carriageway and (since it was not a contra-flow system) there was no interaction with on-coming traffic. In this case there was traffic travelling in the same direction, in the case where one lane was closed (layout 1) this meant that there could be no overtaking and the test car speed could be constrained by other vehicles. In the other cases where two lanes were kept open, overtaking was possible although the narrowness of the lanes may have dissuaded some drivers from doing so. In practice, there was little difference between the layouts at the mid-point of the works, but speeds were much lower through the works than between works.

A reduction in speed is usually regarded as an important contributor to reduced accident risk. In addition, in circumstances where narrow lanes allow provision of an additional lane they maintain much higher capacity and allow overtaking opportunities which, if used sensibly, may help to reduce frustration through the works and thus poor driving behaviour. Furthermore, in the TRL trial the majority of participants preferred the use of narrow lanes. These simulator trials therefore suggest that narrow lanes should be considered for use whenever they allow an extra lane to be kept open (either to retain two-way working on a single carriageway, or to avoid reducing the number of lanes available to one direction on a dual carriageway).
It should be noted that the simulator trials also indicated that the lanes should be clearly marked. This may require the removal of existing lane markings. This consideration may restrict the use of narrow lanes at short term works.

7.3.2 Signing

Generally the trials contained little variation in signing. The most significant difference was the use of larger signs and mobile trailers to create a “gateway” effect in half of the VTI layouts. This had no effect on speed or deceleration, but did affect lateral position. When larger signs were used drivers positioned themselves further to the left at entry (ie nearer the centre). Possible reasons for this include the actual physical restriction of road space caused by the larger signs, possibly associated with a fear of hitting them, and the effect of drivers being able to see the signs from a greater distance.

It must be acknowledged that the principle of gateways is well established in the more general context and it may be that further trials could establish suitable gateways for use at works

7.3.3 Lane Delineators and Markings

The VTI trial used four different approaches to separating the opposing traffic flows:

- No marking
- Vertical markers
- Orange lines
- Studs

For the different types of delineation used in the VTI trial, average and maximum speeds through the works were lowest when the vertical markers were used. At the point where a bus was met, speeds were (non-significantly) lower without markings than with vertical markers, but both were lower than with studs or orange lines. It is important to note that the low speed without markings at this point was associated with a much higher rate of deceleration which could indicate a potential safety issue. The drivers positioned themselves further to the left (nearer the centre) without lane markings, and further to the right with the vertical markers which therefore achieved the greatest separation of opposing flows.

It seems that vertical markers are most often associated with behaviour which may be interpreted as "safer" – lower speeds, lower variation in speed, greatest separation between opposing flows. However drivers felt more relaxed with orange lines or studs than vertical markers, and regarded them as safer options, possibly because of a fear of hitting the vertical delineators. Overall studs were the drivers' preferred option even though the results suggest that vertical markers may bring more safety benefits. It may be that smaller vertical delineators would achieve the same actual reduction in speed without causing the same concerns for drivers.

The three layouts in the TRL trial using two narrower lanes (Layouts 2, 3 and 4), all used lines to separate the lanes (with traffic travelling in the same direction in both lanes):

- White lines as normally used at narrow lane sites in the UK
- Shorter white lines – intended to give an impression of increased speed
- Yellow lines spaced as for the standard markings but with the original white lines left in place

There was little difference in speed through the works with the three lane markings, although there was a suggestion that speeds were lower when yellow lines were used (layout 4). In addition drivers approached layout 4 more slowly than layouts 2 or 3. Considering Lane 1 ("slow lane"), traffic tended to travel furthest to the right (ie nearer the other lane) for the layout with yellow lines, this could be associated with the influence of the original white lines which were retained in this case (see Figure A5). For lane 2 there was no difference between the layouts.

The use of yellow lines in this way is not standard practice in the UK (indeed it is not permitted). Despite this, a large proportion of participants thought that the yellow markings were helpful. However a significant minority thought that they were either confusing or were dangerous. In this case the use of yellow lines had been combined with leaving the original white lane markings in place, many participants found the non removal of the white lines confusing and about a quarter of participants found them dangerous.

Since both the option without any lane markings (VTI trial) and the non-removal of the original white lines (TRL trial) did poorly both objectively (eg high deceleration approaching the bus) and subjectively (according to opinions of drivers), it is recommended that clear and unambiguous lane markings are used at all times.

7.4 On-Site Data Collection

This section covers the analysis of data collected from on-road trials. This is covered in more detail in FORMAT Deliverable D13.

An important aspect of FORMAT has been to base the work on practical experience and this strand of the work concentrated on results from on-road trials carried out specifically for the FORMAT project. These have mainly consisted of 3 sets of trials;

- Work specifically for WP5
- Work primarily for WP3 (the Pilot Trials of Innovative Maintenance Techniques)
- Work primarily for WP4 (validation of the Cost Benefit Framework)

The most productive source was information collected and analysed by the WP5 team from major works on the E411 and E25 in Belgium (see Jacobs, 2004). These works are being undertaken over a three year period and involve long-term operations on significant sections of two key routes. The study covered the evolution of the plans for this work, the performance of the initial layout, the reasons for, and consequences of, modifications to this layout, and the relationship of the results obtained to previous experience and other work within WP5 (particularly the simulator trials).

Problems were encountered with the initial traffic management scheme employed illustrated in Figure 7.6.

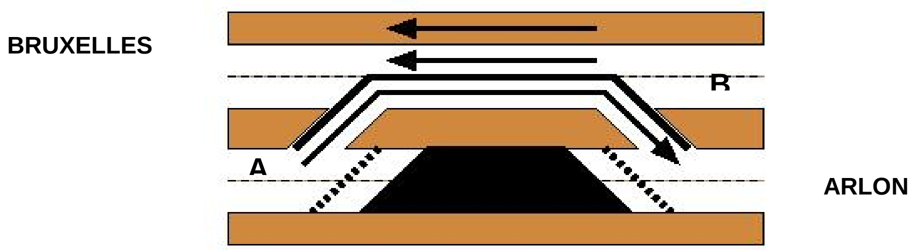


Figure 7.6: 2+1 type layout

There were two serious accidents on the opening day and 65 in the first two weeks (7 of these being injury accidents). Although these accidents do not represent a statistically robust sample, they were an understandable cause for concern. Attention was particularly focussed on the sections where a single lane was running on the hard shoulder. There was 3.35m available in this lane. However, the original white line delineating the hard shoulder had not been removed and this gave the impression that only 2.40m was available (see Figure 7.7)

Figure 7.7: Available lane apparently reduced by retained white line in the initial layout of phase 1 (E25) Photo MET D.132

In order to provide more generous lanes the site was re-configured to operate with one lane in each direction (see Figure 7.8). At the same time the pre-existing white lines were removed. This arrangement provided one very wide (5.05m) lane in each direction.

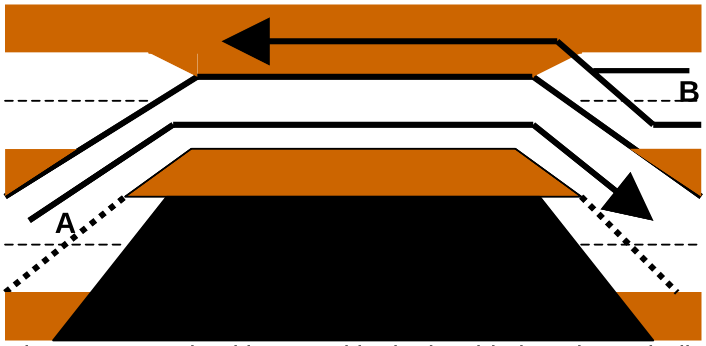


Figure 7.8: Revised layout with single wide lane in each direction

Following this change there was a marked improvement in the accident record (one injury accident in the following four months, less than the average number during normal, non-works, operation). Unfortunately, since the two changes were made simultaneously, it is not possible to separate the effects of removing the potential confusion caused by the redundant lane markings, from the change in lane width. In any case the length of time the two systems (especially the 2+1 operation) were in place is too short to derive robust results.

Overall the key results from the study in Belgium were:

- That it is essential that sufficient care is taken to ensure that lanes are clearly and unambiguously defined, particularly when using narrow lanes.
- That running with a single lane in each direction can be a good option from a safety perspective provided sufficient capacity is maintained using only one lane, and careful consideration is given to the potential for severe problems to develop when breakdowns and incidents occur in single lane working.
- That it is vital to monitor accidents at the commencement of the works, so that any problems could be identified and rectified quickly.
- That the use of very long stretches of works can exacerbate delay problems due to accidents and incidents; both in severity as emergency vehicles can be hampered by long queues

restricting access; and in frequency since longer works may cause increased likelihood of accidents due to tiredness and loss of concentration, and breakdowns due to extended start-stop operation. It may therefore be preferable to carry out the works as a series of shorter sections.

The aim of WP5 has been to assess the safety implications for road users and workers of different maintenance techniques. Particularly concentrating on the innovative treatments and procedures developed in WP3 'Technology'. Within this context it had been hoped that the Pilot Trials planned within WP3 could be used to test traffic management arrangements developed in association with the innovative maintenance techniques. In practice this has not been possible, mainly because of the lack of any scope for innovative traffic management arrangements and signing, and understandable concerns over liability issues on the part of road owners.

Other trials carried out by WP4 to validate the Cost Benefit Framework developed within FORMAT were also considered for use within WP5, but the nature of the data collected was not appropriate for such use.

7.5 Guidance on Traffic Management

FORMAT has sought to develop advice and guidance which will aid road owners and operators in all aspects of managing their maintenance activities. Particular points concerning the traffic management arrangements which may aid efficiency are discussed briefly here.

To seek to minimise any adverse effects of design detail, it is recommended that works are closely monitored during their first few days of operation. This should aid the identification of problem areas which can be addressed as a priority.

7.5.1 Delays

For road users, during maintenance activities, it is the traffic management arrangements which are the most visible part of the works, and the one which has most direct impact on their journey. The most noticeable impact is usually delays caused by reduced speeds, congestion and queues. This aspect is taken into account in the Cost Benefit Framework which has been developed in WP4. The key factors in estimating delay are the residual capacity during the works (which primarily depends on the number of lanes which remain open) and the traffic demand. Whenever possible the traffic management arrangements should seek to avoid excessive queuing, especially outside of peak periods.

A particular problem can occur when breakdowns, accidents, or other incidents occur within a section of single lane operation. In this case very significant queues can occur leading to severe levels of congestion and frustration (with associated implications for safety). This problem will be increased in severity and frequency in works with longer stretches of single lane operation.

7.5.2 Accidents

The presence of works can have an impact on accident risk and much of the work of WP5 has concentrated on this vital aspect. Accidents can vary greatly in their severity from ones involving only damage to vehicles to those involving injuries and fatalities. Even damage only accidents can be traumatic experiences, have significant financial implications for those concerned, and have adverse effects on capacity and delay. However their overall impact is much smaller than accidents involving injuries. Injury accidents obviously include the dimension of human suffering, and in addition usually have a greater impact on capacity and generally take longer to remove thus extending their adverse effect on traffic flow.

The key results from WP5 have been incorporated in the Cost Benefit Framework developed within WP4. This forms one of the main ways of making the results from FORMAT accessible. An important contribution to this Framework from WP5 was the derivation of estimates of the effect on accident cost of the presence of works. Direct measurements of this changed cost, or even of the difference in accident risk with and without works, are not widely available. The computer tool allows the use of proxy values for situations where relevant, local, data have not been developed.
In addition, within FORMAT, some work was carried out to develop applicable results from more limited data.

It is recommended that all countries should implement regular monitoring of accidents at works. One aspect of this would be to ensure that regular data collection exercises are undertaken to establish the number of accidents occurring at works and compare this with the total number of accidents, this could be used to identify general trends in works safety.

In addition, more detailed studies should be undertaken to directly compare the numbers of accidents on specific stretches of road with and without works. These studies should enable direct calculation of the change in accident risk during the works. If sufficient detailed data can be collected these types of study can also indicate problems with particular types of layout, or the prevalence of certain types of accidents. It should be noted that the collection of sufficient data requires significant investment in resources, but that the results obtained can provide key information in seeking to reduce accident risk at works.

7.5.3 The Effect of Speed

Speed is clearly a vital issue in that reduced speed is the main adverse impact of works which is felt by road users, and the resulting increase in journey times is an important economic impact. There is thus an incentive, both in user perceptions and monetary terms, to maintain smooth flows at near normal speeds. However, the works situation is different to normal operation. Most importantly there is the presence of the workforce close to moving traffic, in addition there are the possible effects of temporary signing and marking, reduced sight lines, potential distractions from the works, and the possibility of queues of stationary or slow moving traffic. All of these may increase the accident risk and make a lower speed more appropriate.

Speed is seen to be an important factor in establishing safe operation and it is recommended that measures be put in place to maintain appropriate speeds. One method would be the use of speed cameras.

One particularly interesting result from the studies mentioned above, was the change in relative risk with and without works over time. For the UK, the results of successive trials had suggested that the reduction in accident risk at works had not been as great as the reduction in risk on the general motorway network. However, the most recent trial suggested that the risk of injury accidents at works is now comparable to the risk when no works are present. This initially surprising result may well be due to the significant efforts made to reduce speed through works, particularly by the use of speed cameras.

7.5.4 Narrow Lanes

Consideration of speeds and delays lead to the conclusion that there are obvious benefits in making as many lanes as possible available to traffic. One possible option is the use of narrow lanes. At high flows, the use of narrow lanes can remove the necessity to close a lane to traffic thus maintaining much higher throughput. In many situations this can prevent, or at least greatly reduce, the development of queues and so significantly reduce delays. However at lower flows, when traffic is moving freely, the more constricted feel brought about by the presence of narrower lanes can reduce speeds and so contribute to improved safety. The FORMAT simulator trials explored the use of narrow lanes and identified benefits associated with their use. They also showed that details of lane markings and delineations can have important effects, and this was underlined by the results from the study of the E411-E25 which highlighted the need to ensure that narrow lanes are of adequate width and clearly delineated.

7.6 References

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8. Summary of research conducted on ‘Cost Benefit Analysis’

8.1 Introduction

8.1.1 Objectives and programme of Work Package 4

The aim of WP4 ‘Cost Benefit Analysis’ (CBA) was to develop a method of comparing pavement maintenance techniques and strategies in terms of overall cost-effectiveness. The previous work done within the framework of the PAV-ECO project led to consider both the maintenance and the extra user costs associated with road works.

WP4 is split into three Tasks, as follows:

- Task 1: Costs of pavement deterioration,
- Task 2: Additional costs at road works,
- Task 3: Integration and validation.

The models have been developed and integrated into a prototype MS-Excel file, which calculates, for a given “project” (projection of what will occur on a given road section within a long time range, e.g. 30 years), pavement deterioration and additional costs at road works:

- Pavement preservation costs,
- User delays and extra fuel costs during maintenance works,
- Safety extra costs during maintenance works,
- Agency and environmental costs.

8.1.2 Financial and economic approaches

To make the best possible decision, an “economic agent” has to project in the future what will be the consequences of his choices, and try to find the solution that yields the best possible total. This consists in adding, for a given number of years, the differences between “benefits” and “costs”. Costs of items which have no market price (pollution, noise, travel time, human life…) may be based on documents issued by governments or international organisations (like OECD), or may be estimated by different methods. The discount rate expresses the “Social Time Preference”, which is not directly linked to interest nor inflation rates; in most cases its value is set by governments (in Europe, its range extends from 3.5 % in UK to 8 % in France) or funding agencies.

8.1.3 The Net Present Value (NPV) calculation

The result of CBA is the Net Present Value (NPV):

$$NPV = \sum_{i=1}^{i=n} \frac{A_i - B_i}{(1+a)^{i-1}}$$

where:
A_i is the total of benefits minus costs during year i for the studied alternative,
B_i is the total of benefits minus costs during year i for the base case,
n is the number of years for which the calculation is done,
a is the discount rate.

In the case of a maintenance policy, the base case can be either an "as usual" solution based on past habits, or a "minimum" solution. If $NPV < 0$, the studied alternative is not profitable compared to the base case.

8.2 The models

8.2.1 Pavement preservation

8.2.1.1 Pavement elements and performance indicators

Pavements are divided into structure elements, normally as four-layer constructions. Predictions of condition, effects of pavement maintenance and cost calculations are first done separately for the surface layer, the base layer (the main structural element) and the sub-base layer, which are then cumulated to a total value of pavement preservation. The sub-grade is not considered to be a part of the pavement construction and is hence not included in these calculations.

8.2.1.2 Technical condition of pavement elements

The condition of pavement elements are worsening in time, due to traffic loading and climatic effects, from an initial condition level ("like new") after maintenance or construction towards a condition threshold level, when some maintenance needs to be done on the road. Practically, every appropriate maintenance option that is applied on the road will restore the surface condition to its initial value (or at least very close to that), but not necessarily the condition of the base or sub-base layers. The actual difference in the efficiency and future performance of different maintenance options is depending on the condition of the road before treatment application and the selected treatment.

8.2.1.3 Residual value and pavement preservation

When alternative maintenance options are compared for their cost-effectiveness, the residual value of the pavement should also be considered. The residual life means the number of load applications or the time to reach some threshold level and the residual value is defined as the monetary equivalent of that residual life. The performance indicator, which indicates the lowest monetary value of the considered pavement element, is the one defining the residual value for that pavement element. The residual value of the pavement, at any specific time during its lifetime, is the sum of the monetary values of each pavement element. Pavement preservation cost is that of maintenance needed to restore the present pavement condition.

8.2.1.4 Monetary value of pavement elements

The actual difference of maintenance options on the monetary value of a pavement element is depending on the condition of the road before treatment application and the selected treatment. The new monetary value is a sum of the residual value of the layer and the cost of the new treatment. If an optimal maintenance option for the present condition is selected, then initial layer value and normal deterioration speeds are reached. This is illustrated by an example based on dummy values in Figure 8.1.

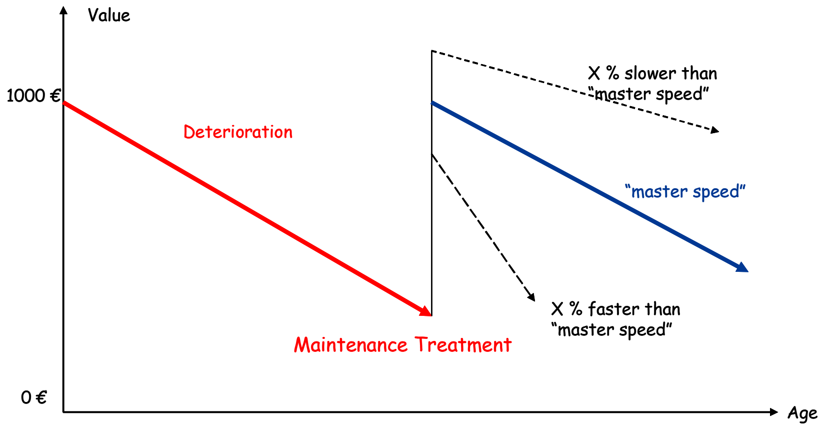

Figure 8.1. Maintenance effects on surface layer monetary value.

If e.g. for budgetary reasons a lighter and less expensive treatment (I) is selected, then it will not restore the value to the initial level and faster deterioration speeds are predicted for the future. Or, if for some reason a more expensive treatment (III) is selected, then the value will increase over the initial surface layer value and slower deterioration speeds might be predicted. The "master speed" curve, resulting from the optimal treatment (II) selection, is equal to the original deterioration speed of the pavement element.

8.2.1.5 Calculation of pavement preservation

Finally all values of separate elements in the pavement construction are cumulated to a pavement preservation value. This might also be calculated proportionally based on the construction costs of each element, which is illustrated in Figure 8.2.

Initial monetary value (% of construction costs)		Present monetary value (% of init. layer value)	Present monetary value (% of init. pavement value)
15	1. Surface layer	40	6
60	2. Base layer (main structural element)	70	42
25	3. Sub-base layer	80	20
Σ 100			Σ 68

Figure 8.2: Example of total cost of deterioration calculation.

In this example, the construction cost of the surface layer is 15 %, base layer cost is 60 % and the sub-base layer cost is 25 % of the total initial construction cost. At this present moment the residual value is respectively 40 %, 70 % and 80 % for the pavement elements. By adding these percentage shares of the initial values of the pavement elements a total residual value of 68 % is reached. In this case the pavement preservation value is equal to 32 % (100 – 68) of the initial construction costs.

8.2.2 User delays and extra fuel costs

8.2.2.1 Introduction

The proposed model calculates the extra travel time and fuel consumption undergone by road users getting through a maintenance work site; the model considers three cases:

1. The vehicles run freely but the speed limit is lower than normal,
2. The vehicles use a diversion.
3. The vehicles have to wait before entering the site because of congestion,

Case 3 occurs when the traffic flow exceeds the road residual capacity; the model then calculates the number of excess vehicles, and the time they need to enter the work site; the model then adds all time lost during a given day, and the extra fuel spent while idling.

8.2.2.2 The traffic prediction

Adopting a probabilistic approach to model building makes it possible to overcome the difficulties linked to traffic instability when traffic flow is close to the residual capacity. The proposed model uses a calculable continuous function based on a limited number of parameters. Observations of a number of traffic curves obtained on different sites have always shown two or three peaks, which individually resemble a “bell-shaped” function. It was therefore proposed to predict traffic flow as the sum of three such functions plus a constant:

$$T(t) = a_0 + \sum_{i=1}^{i=3} a_i \exp(-\lambda_i (t - m_i)^2)$$

where:

t is the time, expressed in decimal hours from zero for the considered day (for real counts, the midpoint period is to be considered);

T(t) is the predicted value of relative traffic (it is a dimensionless number equal to the ratio between traffic flow at time *t* and the annual average traffic flow);

a_0 is the relative traffic flow during off-peak periods;

a_i represents the maximum value of the peak;

m_i is the value of *t* that maximises the function;

λ_i represents the sharpness factor, which indicates to what extent the phenomenon spreads.

This reflects the model's so-called “deterministic component”. All ten parameters (three a_i, m_i and λ_i plus a_0) may be calculated from real data, by means of a procedure called non-linear regression. The traffic counts used for this step must be representative of both the site and the kind of day for which the predictions are intended.

Such an approach obviously cannot yield exact traffic flow values for a given time of a given day, but merely provides an evaluation, on top of which a probabilistic component may be added. For a given time t, a probability p that traffic flow is below $Q_p(t)$, according to a formula based on a normal (Gaussian) distribution, can be derived by using the deterministic component as the "average" value and the “standard error on predictions” (resulting from the non-linear regression step) as the standard deviation:

$$U_p(t) = max\ (0, T(t) + S\ N(p))$$

where:

T(t) is the estimated value of traffic at time *t* (the deterministic component according to the previous formula);

S is the mean standard error on the prediction;

N(p) is the cumulative probability function of the standardised normal distribution.

The following steps consist in converting the relative traffic $U_p(t)$ into the absolute equivalent traffic $Q_p(t)$ flow entering the work site:

- Calculation of absolute hourly traffic flow by multiplying by AADT (average annual daily traffic) and dividing by 24;
- Deduction of the diverted traffic flow (if any);
- Conversion of "all vehicle" traffic into "equivalent" traffic expressed in PCUs (passenger car units), according to the percentage of heavy vehicles.

Figure 8.3 shows a series of curves associated with various probability levels, e.g.: at 6 pm, the flow has a 90 % probability of being below 533 veh/hr, a 50 % probability of being below 400 veh/hr and a 10 % probability of being below 278 veh/hr.

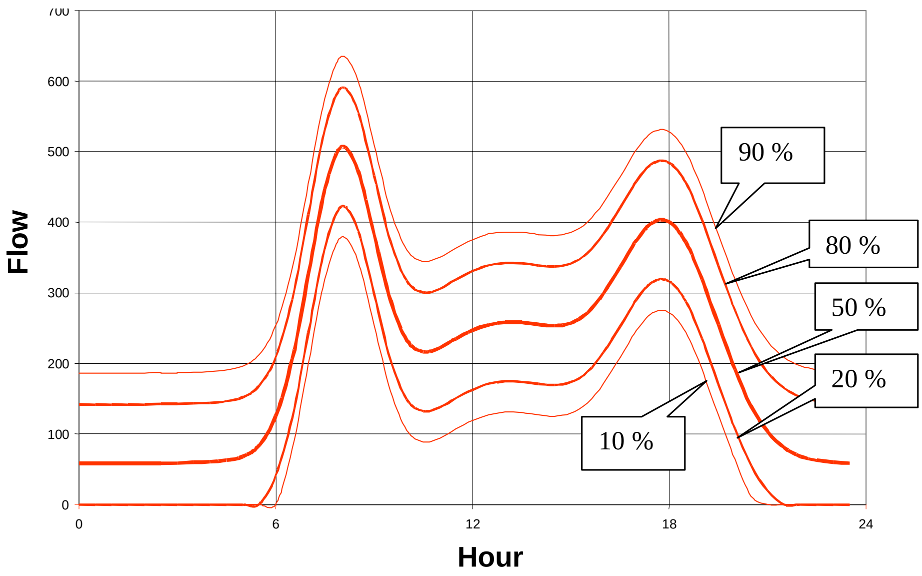

Figure 8.3: Example of probabilistic predictions

8.2.2.3 Evaluation of time lost in queues

By knowing traffic flow $Q_p(t)$ at time t with probability p, one can then deduce the number $L_p(t)$ of vehicles present in the queue formed when $Q_p(t)$ exceeds C (road capacity). A very simple model was used to perform this step; during a given period of time, the following was considered:

- If no queue had been present during the previous period and if capacity is not exceeded, then queue length remains zero;
- Otherwise, the difference between $Q_p(t)$ and C is algebraically added to the number of vehicles already present in the queue; if the result is negative, the queue disappears.

8.2.3 Safety

8.2.3.1 Background

One of the tasks of WP5 has been the collection of accident data in all Europe, both for road sections with and without work zones. This enabled in the model to calculate extra user safety costs depending on working zone closures. Subject to the available accident data, on the one hand very detailed data with influence of the existing cross section can be edited in the input sheet. On the other hand, with general accident costs and accident rates supplemented by an estimated factor describing the extra user risk in working zones, a rough calculation of the extra user safety costs can be carried out.

8.2.3.2 Purpose

The “safety” part of the integrated model can calculate the extra user safety costs for a specific situation of road or lane closure during one treatment. The bases of the calculation are accident statistics at roads with and without work zones as well as the vehicle kilometres on the closed road section and – if available – on a diversion.

8.2.3.3 Limitations

All conclusions of extra user costs are depending on statistical safety data of the regarded network or – if not available – on data from similar regions or countries. Because of that the quality of the results are depending on detailed information for specific influences of the closure. Tendencies of the safety influence of different types of closure are possible even with marginal data.

8.2.3.4 Data exchange with other models

The extra user safety cost model is part of the integrated model, allowing calculations of the costs of safety risks indicated by road or lane closures. The used road types for the regarded road and diversion, duration of closure, length of the closed section and diversion are the main inputs for the model. Calculated output from other models used in the safety model is the traffic amount at the closed road section and a diversion.

8.2.4 Agency and environmental costs

8.2.4.1 Introduction

The Agency costs are the direct costs incurred by the Agency responsible for undertaking the pavement maintenance and are dependent upon the type, extent and duration of treatments, the traffic management closure at the road works. The environmental costs are the indirect costs that are imposed on society due to the impacts of noise and fuel emissions as a result of performing the maintenance option.

8.2.4.2 Agency cost model

The Agency cost model within the cost-benefit spreadsheet is designed to evaluate, for each maintenance option:

- Costs and durations of carrying out the identified maintenance,
- Costs and durations of carrying out the future maintenance treatments,

- Residual value at the end of the scheme evaluation period.

The model requires the user to enter information before the analysis is undertaken. Once those details are entered, the user can also choose to include non-pavement works costs (e.g. drainage, safety fencing or lighting) carried out during the maintenance. Once the pavement works treatment is selected in accordance with the pavement preservation model, the user must then select an appropriate traffic management option for each year of treatment.

Some of the key features of the Agency model are:

- For any analysis, representative default values have been set as background data in the model. However, the model has the facility to allow the user to provide values of costs and output rates for the maintenance treatments that are specific to the scheme;
- The model allows treatment in any scheme to vary at any point both along and across the carriageway (e.g. by lanes); it is also possible to include lengths where no treatment is required in a particular intervention;
- The same default values are used to calculate costs in any year of the evaluation period; the future costs do not therefore include any element for inflation so as to ensure a common cost base for all future costs.

8.2.4.3 Environmental cost model

There is now a growing interest in extending the investment appraisal process to include key factors such as environment and sustainability in an effort to evaluate the true whole life costs of options (i.e. a move towards identifying the best value option in whole life terms).

The environmental cost model addresses those impacts that can be expressed in monetary terms:

- Fuel emissions as a function of:
    - Material lorry movements,
    - Speed during traffic management/diversion routes.
- Traffic noise.

The fuel emission cost in the model during maintenance considers:

- The differences in vehicle speed through the road works site with and without road works;
- The increase of distances by using diversion routes at the road works.
- The differences in transport movements related to the distance of materials source, the amount of (and hence the number of lorries used) of materials imported to the site and disposed to landfill sites.

Traffic noise generation is a complex process and is influenced by several factors including vehicle type, road characteristics, driving condition etc. The impact of the noise generated is subject to large uncertainties and the perception of noise depends on a number of issues such as the nature and duration of the noise, ambient noise conditions, source of the noise etc.

Noise is determined by the surface material type and the growth in traffic flow between maintenance options. A threshold value is used to determine the value over which noise becomes a nuisance and the cost impacts of this nuisance. Using a simplified noise-distance deterioration equation, the model calculates the distance from source to the point where the noise level drops below the threshold.

The cost of noise is considered as affecting the population per kilometre length of the carriageway on both sides of the road, assuming a flat landscape with no obstructions nor wind effects. It is calculated form the number of houses affected as a function of the population density and area affected.

8.2.5 Integrated spreadsheet

The Cost Benefit Analysis (CBA) model, also called "integrated spreadsheet", gathers all specific models that allow calculating the global cost due to maintenance roadwork. Each model is specific to one type of cost that has a direct or non-direct link to roadwork. This integrated spreadsheet answers to road managers new need which is the estimation of the real total cost due to a maintenance work. The CBA model is composed of six different types of cost: pavement deterioration cost, pavement preservation cost, agency cost, environmental cost (fuel consumption, emission of CO_2, noise), users extra cost (extra time, extra fuel), safety cost.

8.3 Validation of delays model

8.3.1 General

This task aimed at validating the conclusions of previous works done in the framework of WP4, by studying several real work sites, where a full set of data were collected: detailed traffic data with and without works, speed and travel time measurements, visual observation of queues, etc. The observed data were then compared with the conclusions from models, in order to validate them.

The Table 8.1 displays a global description of the studied experimental sites.

Table 8.1 - Main characteristics of studied work sites

Case	Cross profile	AADT	% HV	Open lanes		Contra-flow	Schedule	Diversion
				Direct. 1	Direct. 2			
Toulouse (France)	2x3	100 000	5	None	All	No	Night	Local + Long dist
A7 (Spain)	2x2	20 000	30	1	All	No	Daytime	None
				1	1	Yes	Daytime	None
A72 (France)	2x2	15 000	12	1	1	Yes	24 hour	None
N157 (France)	2x2	28 000	10	1	1	Yes	24 hour	None
N137 (France)	2x2	32 000	15	1	1	Yes	24 hour	None
A9 (Switzerland)	2x2	43 000	7	1	1	Yes	24 hour	None
A1 (Slovenia)	2x2	40 000	15	1	2	Yes	24 hour	None

Some extra data (about pavement structures, maintenance techniques and costs, but neither safety nor environmental data) were also collected for use in the other models.

The economic evaluation, based either on observed data (queue length, travel time, speeds) or on the model results, takes into account:

- The time spent by light and heavy vehicles, multiplied by a unit cost representing the "value of time" based on economic and social considerations;

- The light and heavy vehicle fuel consumption, based on provisional relationships between speed (including idling) and the economic (before tax) unit cost of fuel.

It is worth noting that some other aspects are not taken into account in this evaluation: vehicle operating costs (other than time and fuel, e.g. tyres, lubricant, parts wear, etc.), increase of accident risks (due to the very works or to the characteristics or length of diversions), passenger discomfort, noise, polluting emissions, etc.

A particularly important parameter used in the model and that determines the presence and importance of queues is the residual capacity of the road under works; in the cases where queues were reported, the observed data were used to calibrate the value of that parameter; but in the general case the real value is not known before works start, and one has to trust in values derived from similar cases, or found in the official literature.

The other cause for uncertainty is the user behaviour when confronted with road works: it is difficult to know by advance if they will try to cancel their trip, change their timing, use diversions or simply accept the loss of time.

8.3.2 Spain

The pilot sections are located on the A7 motorway, part of the E15 route, running along the Mediterranean coastline; it is a toll motorway, operated by AUMAR Company. The cross-profile is a dual two-lane type.

The studied works included two phases (see Figure 8.4), with different layouts, one (grouting works) with the closing of one lane, and the other one (whole surface renewal) with closing of one carriageway, the other being operated as a bi-directional road with contraflow. In neither case, queues were observed, nor predicted by the model. So, the only significant extra costs for users resulted from the speed reductions. Observed speeds led to an economic evaluation, with a total result that is small (600 /day for phase “a” and 3600 /day for phase “b”) compared to the work total costs.

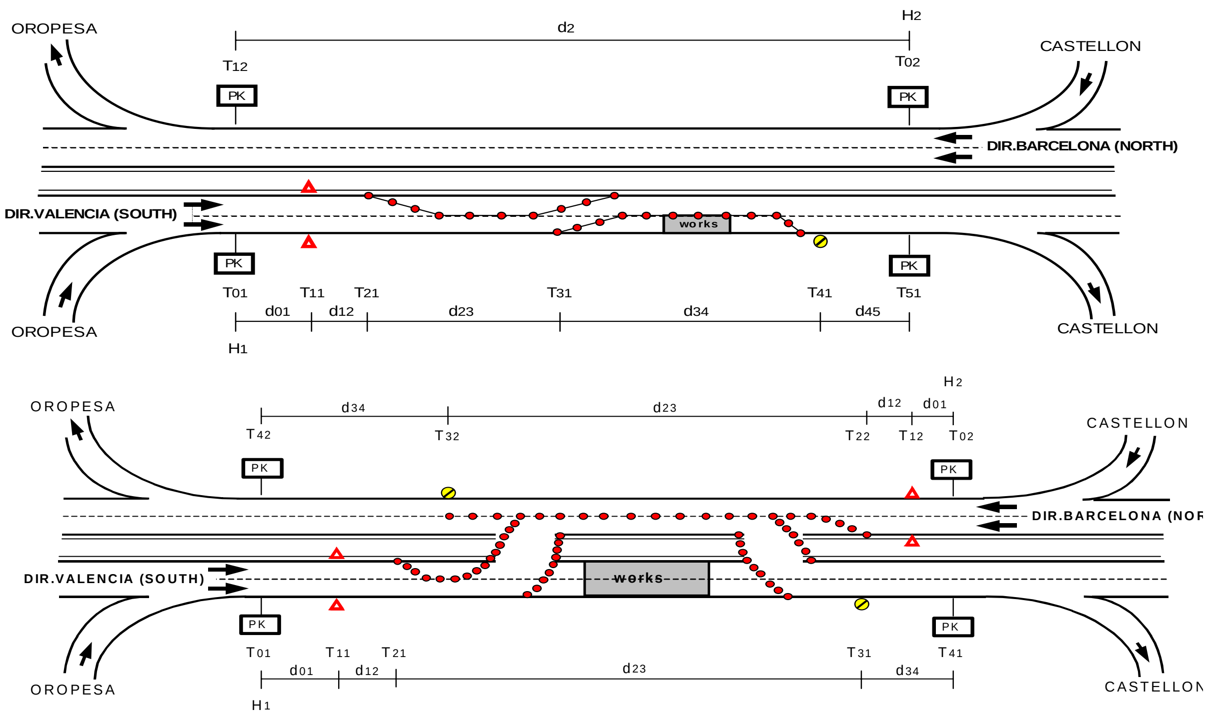

Figure 8.4: Work layout and time measurement points for the phases "a" and "b"of Spanish test

The traffic predictions based on the probabilistic model are in agreement with real counts, and the probability for the traffic flow to reach congestion levels remains very low, so the impact of probable queues in the simulation remains negligible.

8.3.3 France

8.3.3.1 Toulouse eastern bypass

Toulouse city (population about 400 000) is surrounded by a bypass system allowing traffic distribution on its outskirts, and which bears the transit traffic. This system includes two motorways, which are:

- The "Eastern bypass" (13.9 km, 8 junctions);
- The "Western bypass" (18.3 km, 15 junctions).

The concerned road works consisted in a pavement surface renewal on the entire length of the Eastern bypass. During works, which were carried out at night during the week, one carriageway was totally closed, while the other one remained fully open. The works occupied two inter-junctions, and each new phase involved an onward shift by one inter-junction distance.

Two types of diversions were set during works (for only one direction at a time):

- Dedicated signs informed users approaching Toulouse by radial motorways about the works, and advised them to use the Western bypass as "long distance diversion",
- Traffic arriving at the junction where the works started was forced out of the motorway, a "short distance diversion" being proposed, using local roads and streets (with an increased distance of several km in most cases).

It must be noted that the total distance for the complete trip is not always longer on the “long distance diversion” than on the “short distance diversion”.

Permanent hourly traffic counts were done on different points of the western and eastern bypasses, in order to know the change of traffic distribution during works; their exploitation showed that 20 % of traffic used the “long distance diversion” and 80 % the “short distance diversion”, with no significant change in the total of both routes.

Travel time measurements were also made by means of a “floating vehicle” on the different routes: western bypass, eastern bypass without works, and short distance diversions.
Table 8.2 shows the economic evaluation of consequences for users, in terms of lost time and extra fuel consumption; it shows that the total amount is relatively low compared to the direct costs of works.

Table 8.2 – Economic evaluation of user extra costs for two phases of the Toulouse test

Junction	Roseraie (junction 15)			Soupetard (junction 16)		
Direction	South			South		
Date	April 22-23			April 23-24		
Vehicle	LV	HV	Total	LV	HV	Total
Short diversion traffic count	2 536	267	2 803	3 515	292	3 807
Short diversion extra km	1.8	1.8	1.8	3.2	3.2	3.2
Short diversion extra time (min)	6.0	7.0		7.5	10.5	
Short diversion extra time (veh_hr)	254	31	285	439	51	490
Time unit cost (/hr)	13.7	40		13.7	40	
Short diversion time cost ( )	3 474	1 246	4 720	6 019	2 044	8 063
Long diversion traffic count	591	62	653	881	73	954
Long diversion extra km	4.8	4.8	4.8	4.8	4.8	4.8
Long diversion extra time (min)	3.5	3.5		3.5	3.5	
Long diversion extra time (veh_hr)	34	4	38	51	4	56
Long diversion time cost ( )	472	145	617	704	171	875
Total time cost ( )	3 946	1 391	5 338	6 723	2 215	8 938
Fuel consumption (litres/km)	0.133	0.5		0.133	0.5	
Extra fuel (litres) on short diversion	607	240	847	1 496	467	1 963
Extra fuel (litres) on long diversion	377	149	526	562	176	738
Fuel unit cost (/litre)	0.4	0.3		0.4	0.3	
Extra fuel cost ( ) on short diversion	243	72	315	598	140	739
Extra fuel cost ( ) on long diversion	151	45	196	225	53	278
Total fuel cost ( )	394	117	511	823	193	1 016
Total cost ( )	4 340	1 508	5 848	7 547	2 408	9 954

The simulation program could be used to confirm these results. Simulation based on alternative configurations for the same site showed that the economic user cost (primarily based on travel time, and waiting time if any) remains low as long as the capacity exceeding remains unlikely; it is not any more the case, however, as soon as one moves away from the work schedules applied here (10 PM to 6 AM); in such a case the economic cost may increases sharply and reach unacceptable levels very quickly.

8.3.3.2 A72 Clermont Ferrand-St Étienne

The works consisted in a surface course renewal, with the same layout in phase “b” of Spanish test. According to works progression, the concerned zone was moved so that it occupied an interdistance between two interruptions of the central reservation (normally 5 km). The speed limit was 90 km/h, instead of 130 for light vehicles and 100 for heavy vehicles in absence of works. Although the works were carried out only during daytime, the closing was permanent. The conclusions are the same as in the Spanish case:

- As long as the probability of queues is low, the cost of delays is based only on speed reductions, and remains at an acceptable level;
- In these conditions, the total extra costs for users stay far below that of works;
- The model prediction of traffic flows is well in agreement with observed traffic counts.

8.3.3.3 N157 Le Mans-Rennes

The cross-profile is also a dual two-lane type; works are also a surface renewal involving a carriageway closing, the open carriageway being used as a bi-directional road with contraflow. Unlike the previously described experiments, this one involves the formation of queues. If everything had occurred as planned, it would not have been so, but on one Friday afternoon, the reopening of the road was postponed, and this led to the formation of a queue.

During that episode, traffic speeds and flows were recorded, and this allowed the experimental calculation of residual capacity: 1 357 PCU/hour/lane in the direction of closure and 1 461 in the opposite direction.

The application of PAV-ECO and FORMAT models, based on experimental values of residual capacity, lead to the same conclusion as observed reality for the prediction of queue initiation; the results differed, however, on the importance of queues: the comparison between observed values, PAV-ECO and FORMAT shows differences (respectively about 1 500, 303 and 2 012 hours lost).

8.3.3.4 N137 Nantes-Rennes

The case is similar to the previous one, and the same kinds of data were recorded; however, the recorded queues were far more important: once or twice in a day, in each direction. The experimental calibration of residual capacity led to smaller values (1 080 and 1 350 PCU/hour/lane).

The difference may be explained by a slightly higher traffic (the difference amounts to about 10 %) and a higher heavy vehicle percentage (15 vs 10 %), but it seems that the most important factor is a lower residual capacity (based on observed speed flow relationship), which is probably a consequence of more severe geometric conditions (the present site includes a 4 % slope on 2 km).

Both models (PAV-ECO and FORMAT) make accurate predictions about the queue initiation, but as a whole they tend to overestimate their consequences expressed in lost time. The prediction of traffic demand in the FORMAT model seems to be accurate (see figure 8.5), but obviously it cannot take into account the user reactions (users change their trip timings backwards or forward in order to avoid queues) or unpredictable events (accidents or unexpected road closures).

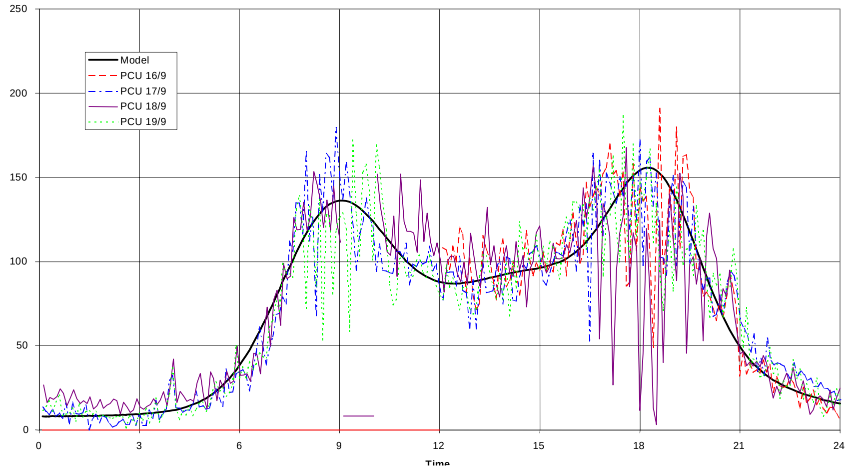

Figure 8.5 – Traffic simulation (Southwards, Monday to Thursday, non-summer season, probability 50 %) and real counts (Monday 16 to Thursday 19 September 2003); low values observed on Wednesday 18 around 18:00 are due to an accident

Table 8.3 recapitulates the different results, from observations and from the different models.

Table 8.3: Comparison of experimental and model results (Thursday 19)

Lost time	Direction	South				North			
Observed	Period	LV	HV	PCU	All	LV	HV	PCU	All
	Fluid (h)	211	67	318	278	115	44	186	159
	Congest. (h)	618	124	816	742	286	37	345	323
	Total	829	191	1 134	1 019	402	81	531	483
Probabilistic	Fluid	347	51	429	398	344	51	426	395
FORMAT model	Congested	7 911	1 916	10 977	9 827	927	225	1 287	1 152
(hours)	Total	8 258	1 967	11 405	10 225	1 271	276	1 713	1 547
Deterministic	Fluid	347	51	429	398	344	51	426	395
FORMAT model	Congested	3 129	887	4 548	4 016	927	95	489	432
(hours)	Total	3 476	938	4 977	4 414	680	146	915	827
PAV-ECO model	Fluid				550				605
(hours)	Congested				1 803				1 422
	Total				2 353				2 027
Time in queue (m:s)									
Observed	Maxi				8:30				1:10
Prob FORMAT model	Reference				38:00				6:51
Det FORMAT model	Reference				21:53				4:36
PAV-ECO model	Maxi				28:03				29:03
Queue duration (h:m)									
Observed					5:30				2:06
Prob FORMAT model					11:30				4:42
PAV-ECO model					11:07				7:24

According to observed figures, the total disturbance caused by pavement work only can be evaluated to:

42 063 x 18 days = 757 000 .

This figure is to be compared to the total expenditure devoted to the pavement work itself (including directly associated work like shoulder and barriers levelling, etc.), namely 938 000 . Thus, on this work zone, the disturbance caused to the users by the traffic restrictions represents for the community a cost whose amount is about 80 % of the direct expenditure devoted to works.

8.3.4 Switzerland

8.3.4.1 Purpose

Two main objectives have been assigned to the experiment: determination of the traffic parameters and validation of the users delay model. All model coefficients were calculated from the traffic observed at the worksite without roadwork. After obtaining these coefficients and other standard inputs, the next stage is the calculation of the users total extra cost.

8.3.4.2 Presentation of the experimental site

The Glion tunnels are located on the 2x2 lanes national highway A9 between Lausanne and Sion. The maintenance costs are estimated around 70 M and the work duration is split in two phases: phase 1 (maintenance of the southern tunnel from mid-April 2004 to the end of November 2004) and phase 2 (maintenance of the northern tunnel from mid-April 2005 to the end of November 2005). The annual average daily traffic (AADT) is 43 090 vehicles (year 2003). During these works all the traffic use separate lanes with contraflow (1 open lane per direction). Although the length of the tunnels is only 1 350 m, the work zone (with closures) totalizes a length of 10 400 m.

8.3.4.3 Traffic model calibration

The calibration (Figure 8.6) was based on a six-minute count for all representative days (Monday-Thursday, Friday, Saturday, Sunday). The quality of the results are very satisfactory (average R^2 = 0.959).

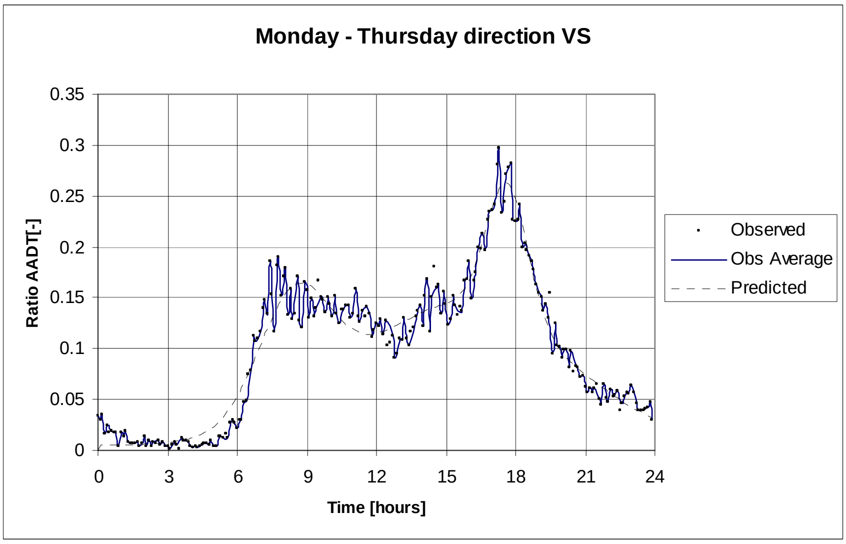

Figure 8.6: Observed and predicted traffic flows

8.3.4.4 Validation of the users delay model

In situ observations were carried out in order to validate (assess) the model. The delay was measured every 15 minutes from 00:00 to 24:00 for each scheduled day. All scheduled days (106) are considered representative for the study of the delays because they do no interfere with any day off. The calibration spreadsheet allowed calculating the users delay at every time in a day. Figure 8.7 illustrates the observed and calculated delays for one representative day.

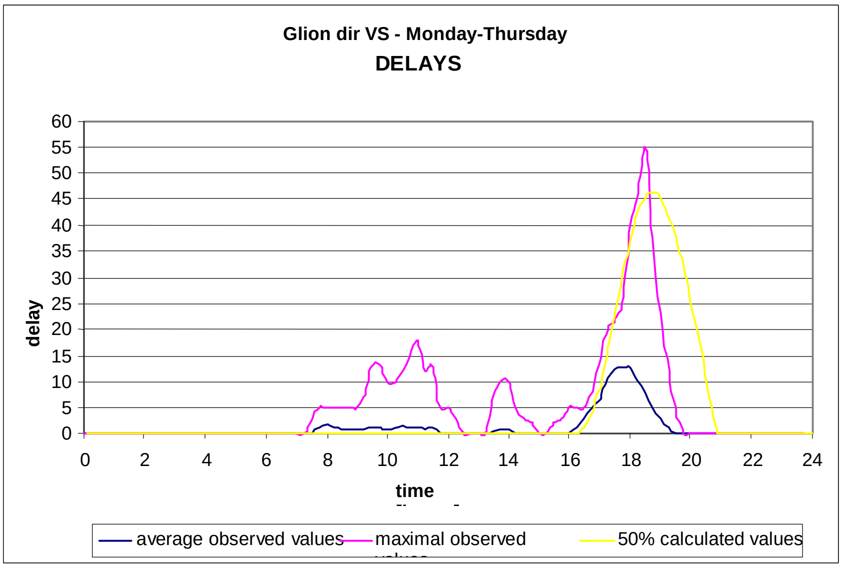

Figure 8.7: Observed and calculated delays

As a whole the calculated delays are higher than the observed ones. Indeed, the calculated peaks are close to the maximal observed delays (Glion dir VS, Monday-Thursday and Friday) and a time-shift exists between the two peaks (calculated peaks occur later).

8.3.4.5 Conclusion

This experiment allowed to create a complete data base by collecting the observed delay data, and to calculate the model coefficients for the different day types. Because of the change of the users habits (time for departure) it was sometimes difficult to obtain a good agreement between observed and calculated delays, particularly on Saturdays. Nevertheless it was possible to make predictions close to real delays (especially on Sunday in the two directions and on Monday to Friday direction VS), and hence of the economic consequences of works for users. However, the result is often closer to the observed maximum than to an observed average. At any rate, the total economic estimation of user delays cost is important, in the range of 50-65 M .

8.3.5 Slovenia

8.3.5.1 Sites

In Slovenia the experimental site was located on the A1 motorway linking Ljubljana to the seaside; this motorway carries an average total traffic of approximately 40 000 vehicles per day (vpd). The works consist in a bridge reconstruction, which involves a carriageway closure on about 450 m, the other carriageway being used as a three-lane bi-directional road with contraflow, the hard shoulder being used as a traffic lane. Important queues have been recorded, mainly on Friday and Sunday evenings, respectively toward the seaside and Ljubljana.

8.3.5.2 Procedure

The following data were recorded on the site:

- Speed in the work zone,
- Travel time through the work zone,
- Queue length,
- Hourly automatic traffic counts during the experimental procedure.
- Then the simulation and economic evaluation were performed:
- Calculation of coefficients for each representative day;
- Calculation of delays and queue lengths for each type representative day by the model;
- Comparison of observed and calculated time lost;
- Comparison of observed and calculated queue lengths;
- Calculation of user total extra costs.

8.3.5.3 Simulation

The model coefficients were estimated from the hourly counts, for the four classes of “non summer” days; a first run based on the standard value of residual capacity concluded to very important queues, incompatible with observations; therefore, this led to an important increase of the residual capacity when there is one lane left open in the considered direction: the value was raised to 1700 PCU per hour instead of 1350, which is the most commonly used.

In these conditions, the total cost of the works for users amount to about 3 million Euros.

8.3.5.4 Main conclusions

The main conclusion is that, if the standard values for the residual capacities were used, the predicted queues would be far more important than the observed ones; this led to an adaptation of the residual capacity from 1350 to 1700 PCU per hour for a one-lane flow with contraflow.

It remains to be seen if that value is representative of the real case, or if the traffic flows predicted by the model are overestimated, because the days used for calibration would not be really representative.

8.4 Agency and environmental cost assessment

8.4.1 Introduction

Assigning monetary values to environmental impacts comes up against many difficulties in both obtaining the values and using them in an accepted methodology. Three areas where Agency and environmental effects impact on maintenance are included in the FORMAT cost benefit analysis model:

- Use of recycled and secondary aggregates in pavement construction,
- Pollutant impacts from changes in fuel consumption and emissions,

- Noise impacts related to pavement maintenance.

8.4.2 Use of recycled and secondary aggregates in pavement construction

The cost implications of materials (primary, recycled or secondary) for use during maintenance options are issues that need addressing at the design stage. Data were collected to verify the components included in the model to enable comparative evaluation of the use of primary and recycled materials in maintenance. The case studies examined included data on the use of recycled and secondary aggregates in a range of construction projects, including infrastructure projects, housing development and commercial buildings. From interrogation of these case studies it was possible to gather data from 52 case studies. Data from the case studies and follow up interviews was used to confirm the fields for use in the model, and included:

- Costs of primary material and comparable recycled/secondary material,
- Volume,
- Tax/levy,
- Distances to material source,
- Lorry journeys,
- Durations of treatments.

Some data is not expressed as a monetary value but it is possible to translate them into an environmental cost saving, one example being lorry movements and the costs associated with the difference in fuel emissions.

The schemes reported on varied in size, with the secondary or recycled material cost savings ranging from cost neutral to saving £16.5M. Table 8.4 demonstrates the ranges of values that the case studies provided.

Table 8.4: Summary of range of data provided from case studies

Reported field	Unit	Range
Aggregate quantity	Tonnes	4 – 900 000
Aggregate cost saving	£/Tonne	Cost neutral – 17.31
Aggregate levy	£/Tonne	1.60
Landfill tax	£/Tonne	2 – 14
Distance to supplier	£/Tonne	5 - 15
Lorry capacity	Tonnes	20
Journeys saved	-	100 – 42 000

8.4.3 Pollution impacts from fuel consumption and emission

Fuel consumption and emissions can be used to assess the change in cost associated with using different materials, where the materials in question have different transportation distances. This requires monetary values for the social cost of CO_2 emission to assess the impact on the environment. A joint Defra-Treasury publication suggests that in 2004 a value of 72 £ per ton of carbon is suitable, equating to just over 100 . One source of data from Finland stated unit emissions of freight vehicles for an earthmoving lorry, with a gross vehicle mass of 32 t, and a pay load capacity of 19 t (Table 8.5).

Table 8.5: Freight vehicle fuel consumption and emission values.

	Highway	Urban
Fuel Consumption (*l*/100km)		
Full loaded (19t)	35.1	56.0
CO2 (g/km)		
Full loaded (19t)	934	1491

Converting the above figures into the units required for the CBA model allowed for both fuel consumption and emission values for the different road conditions to be obtained. The calculations produced values for fuel consumption of 285 and 180 km/100 litres for highway and urban roads respectively, along with fuel emission values of 2.66 and 2.71 kg/litre for highway and urban roads respectively.

The above calculations were in agreement with values used in a report by a leading UK supermarket chain and information supplied from a quarrying company. They used CO_2 emission factors ranging from 2.57 kg/litre to 2.82 kg/litre and a fuel consumption value equating to 247.8 km/100 litres.

For light vehicles, data for some common models with emission figures are shown in Table 8.6.

Table 8.6: Light vehicle example emission calculations.

Model	Fuel type	Year	CO2 emissions (g/km)	Equivalent CO2 emissions (kg/litre)
Ford Mondeo	Diesel	1996	183	2.98
Ford Mondeo	Petrol	1996	187	2.38
Citroen C5	Diesel	2001-05	170	2.65
Citroen C5	Petrol	2201-05	185	2.36

Average fuel consumption figures were obtained form the Department for Transport (UK), with the average fuel consumption for all vehicles given as 8.9 litres/100km, which equates to 1 123 km/100 litres.

For both freight and light vehicles a figure of 2.7 kg/litre is appropriate to use for the CO_2 emissions. For fuel consumption of heavy vehicles a maximum value of 200 km/100 litres for an urban environment, and 300 km /100 litres for the rural calculations was used. For the fuel consumption of light vehicles a maximum value of 1100 km/100 litres was used for the fuel consumption.

8.4.4 Noise impacts related to pavement maintenance

The study of traffic noise generation and the deterioration of road surface noise over time is a complex process. One aspect is the level at which noise becomes an annoyance factor and data for the UK currently states a threshold value of 55 dB(A), above which noise is regarded as being a discomfort. To assess the impact of noise, the model required noise deterioration rates for different surfaces to calculate the cost of the noise on the surrounding population. However, there is currently very limited data on surface noise deterioration. Surface texture is important in terms of noise generation, and limited studies have used surface texture measurements to predict surface type and noise characteristics. It is anticipated that in the future, there will be a wider base from which to obtain data.

Manipulating the data allowed graphs of noise level (in dB(A)) against surface age (in years) to be plotted for the different surfaces: exposed aggregate concrete (EAC), hot rolled asphalt (HRA), thin surfacings (TS). The equations from the lines of best fit for each graph allow for the calculation of the deterioration rates.

8.5 Extension to network level

8.5.1 Limitations of the "project level" model

The FORMAT model considers the "project" level; it is intended at calculating different costs associated to road maintenance for a given "project", which considers only one section at a time for a given time span (during which several maintenance operations may occur). Its main limitations may be summed as follows:

- The model considers only one section (although it can consider diversions during maintenance works);
- The model supposes that the traffic demand is already known, and that it does not depend on the traffic flow condition;
- The model supposes that, during works, the distribution of traffic between main road and diversions is already known, and remains the same at any time and for all traffic flow conditions;
- The model ignores congestion effects on diversions.

To be extended to the "network level", such a model would have to deal with many sections, but considering the "project level model" as the addition of as many "project level models" is not realistic: first this would suppose the ability to calculate the consequences of maintenance works on the traffic distribution on the considered "network".
Nevertheless, some ideas developed in the project level model may be useful in a computer system managing a whole network.

8.5.2 Useful functions at "network level"

A given work project has many effects on traffic distribution, particularly on adjacent sections of the same road, but also on alternative routes that may be used as diversions, even if no temporary road sign give such indication. In fact, the implications of road works at the network level concern different fields (traffic management, pavement management, etc.) for which the implications are different.

8.5.2.1 Traffic management

Many events like road works, but also accidents, demonstrations, sporting events, etc. may trigger road closures or traffic limitations, whose consequences on traffic distribution may extend to distant zones on the considered network. Dedicated software are able to predict such changes, either in real time to allow authorities to react and inform users about unexpected disturbances, or to make predictions in order to minimise the consequences of such events in the future. Such "traffic management systems", which need huge computing capacities, exist in most big cities, or at the national level, but this field is clearly outside of our scope.

8.5.2.2 Pavement management

Many pavement management systems (PMS) used at the network level include a function which allows the optimisation of the road maintenance policy, based on a cost benefit analysis. Of course, it is difficult to imagine the direct inclusion of the "project level" model as it is into such a PMS, because it would suppose that some detailed data about works are known for each section of the network, and this is unrealistic. However, thanks to a simplified model, the PMS would allow the calculation of a yearly optimal work program based on technical considerations and budget constraints, but also on the consequences for users.

8.5.2.3 Optimisation of strategic choices

Even if the "project level model" is not directly included into a general PMS, its use may prove useful in some types of decision making, for example to define decision criteria based on rational choices about maintenance work layouts.

In this way, the project level model may be used on a given number of typical cases existing on the considered network, in order to assess the impact of works on users. This may lead to an adjustment of the total economic cost of works, by including the extra costs for users, but also for the road agency (temporary traffic signs, police intervention, user information…) and consequences on work direct costs (night working is more expensive than day working).

9. List of Deliverables

Deliverables were defined for each work package to enable progress to be assessed by the European Commission and the Partners throughout the duration of the project and to contribute to the implementation of results for dissemination in WP7 'Exploitation'.

Table 9.1 lists the 18 Deliverables named in the contractural documents and gives the dates of delivery to the European Commission. It can be seen that all the Deliverables were submitted according to the agreed schedule.

Table 9.1: Overview of deliverables

Deliverable No.	Title of Deliverable	Scheduled delivery date	Actual delivery date
D1	Inception Report	July 2002	July 2002
D2	Report 'Selection of maintenance techniques and procedures for implementation'	January 2003	January 2003
D3	Report 'Basic model for financial evaluation of pavement deterioration'	January 2003	January 2003 See Note 1 below
D4	Report 'Basic model for financial evaluation of additional costs at road works'	January 2003	January 2003 See Note 1 below
D5	Report 'Collection of general accident data from across Europe'	January 2003	January 2003
D6	Report 'Optimised pavement condition data collection procedures'	January 2003	January 2003
D7	Report 'Technology Implementation Plan'	July 2003	July 2003
D8	Mid-Term Assessment report	July 2003	July 2003
D9	Report 'Performance of innovative maintenance techniques and strategies'	January 2004	January 2004
D10	Integrated prototype spreadsheet	January 2004	January 2004
D11	Report 'Analysis of general and specific accident data'	January 2004	January 2004
D12	Report 'Assessment of high speed monitoring equipment'	January 2004	January 2004
D13	Report 'Computer simulation of traffic management arrangements'	September 2004	January 2005 See Note 2 below
D14	Report 'Practical implementation of procedures for road maintenance works'	January 2005	January 2005
D15	Report 'Calibration and validation of the integrated CBA model'	January 2005	January 2005
D16	Report 'Assessment of innovative traffic management in driving simulator'	January 2005	September 2004 See Note 2 below
D17	Report 'Application of high speed equipment in pavement maintenance planning'	January 2005	January 2005
D18	Integrated Guide 'Fully Optimised Road Maintenance'	January 2005	January 2005 See Note 3 below

Note 1: With the agreement of the EC, Deliverables D3 and D4 were combined into one document Title: 'Basic model for financial evaluation of pavement deterioration and additional costs at road works'

Note 2: The timing of Deliverables D13 and D16 were interchanged with the agreement of the EC and in addition the title of D13 was changed to reflect a change in emphasis of the work to: 'On road trials of traffic management arrangements'

Note 3: An edited version of Deliverable D18 will be published by the consortium in 2005 and will contain a CD of all the Technical Deliverables and the published articles and conference papers from the FORMAT project

All Deliverables went through the FORMAT standardised approval procedure, which involves assessment of a first draft by the two Scientific Auditors of the project, followed by assessment and subsequent approval of the final draft by the Scientific Auditors and by the Project Steering Committee. The details of this process were documented for each Deliverable in a Deliverable Follow-up Sheet (see Appendix 1 for a blank copy of the sheet).

The Deliverables can be obtained from the FORMAT Project Secretariat: M.F. Sitanala, Rijkswatertstaat Dienst Weg- en Waterbouwkunde, P.O. Box 5044, 2600 GA Delft, the Netherlands, phone ++ 31-15-2518374, e-mail R.SITANALA@DWW.RWS.MINVENW.NL.

During the project, the following additional papers were produced and conference presentations were made:

- Hildebrand, G. and C.L. Hansen. *Vedligeholdse af veje med Faerre Vejardejder.* Viden om Drift af Veje (Knowledge about Operation of Roads), DRI Report 128, Danish Road Institute, September 2003.
- Lepert, P.and F. Brillet. *A model to estimate the time lost by users on maintenance sites*. 22nd PIARC World Road Congress, Durban, 19-25 October 2003.
- Turtschy, J-C. *Filling gaps in high-speed pavement monitoring.* 83rd Annual Meeting, Transportation Research Board, Washington D.C., January 11-15, 2004.
- Burrow, I. *Effect of different traffic management techniques on work-zone accidents.* 83rd Annual Meeting, Transportation Research Board, Washington D.C., January 11-15, 2004.
- Antunes, M.L. *Innovative maintenance treatments.* 83rd Annual Meeting, Transportation Research Board, Washington D.C., January 11-15, 2004.
- Michaut, J-P, and P. Lepert. *Implementation of porous asphalt wearing course on a highly trafficked ring: technological and economic considerations.* 83rd Annual Meeting, Transportation Research Board, Washington D.C., January 11-15, 2004.
- Sinis, F. *El Proyecto FORMAT de Conservación Totalmente Optimizada de Carreteras.* Ingeniería Civil, Num. 133 –ENE.FEB.MAR. – 2004. Ministerio de Fomento, Espana.
- Lepert, P, M.L. Antunes, I. Burrow and J-C Turtschy. *A European project to fully optimise road maintenance.* 2nd European Pavement and Asset Management Conference, Berlin, 21-23 March 2004.
- Antunes, M.L., A. van Dommelen, P. Sanders, J.M. Balay and E.L. Gamiz. *Maintenance of cracked pavements within the FORMAT project.* International RILEM Conference Cracking in Pavements, Limoges, France, 5-8 May 2004.
- Antunes, M.L., A. van Dommelen and M. Wistuba. *Performance evaluation of innovative maintenance techniques*. 3rd Euraphalt & Eurobitume Congress, Vienna, 12-14 May 2004.
- 7th Slovenian Congres for Roads and Traffic – 'Fully Optimised Road Maintenance' by Ph. Lepert, M. de Lurdes Antunes, I. Burrow, J.-C Turtschy and B. Leben

The following publications were made for national magazines:

- TRL News, December 2002 – Measuring road strength without disrupting traffic
- DRI report 128, September 2003 - "Vedligeholdelse af veje med færre vejarbejder" (Knowledge about operation of roads), by Gregers Hildebrand and Charles Lykke Hansen
- M de Lurdes Antunes (2003) Accelerated loading testing in the FORMAT project, ALT News, DRI
- Nieuwsbrief TU-Delft – LINTRACT in beweging "Europese project FORMAT, April 2004
- TRL News, FORMAT, January 2005
- RGRA No 827, Project Européen FORMAT, comparaison de techniques d'entretien (part 1), Michaut JP, Balay JM, Kerzreho JP, april 2004

- RGRA No 830, Project Européen FORMAT, comparaison de techniques d'entretien (part 2), Michaut JP, Balay JM, Kerzreho JP.
- RGRA No 831, Application FORMAT, Chantier du périphérique est de Toulouse en enrobe drainants, Michaut JP, Brillet F, September 2004.

A Workshop on FORMAT was held during the FEHRL Road Research Meeting of 14-17 June 2004 to which members of the FORMAT Reference Group were invited in order to seek their views on how the Integrated Guide (Deliverable D18) should be presented.

10. Comparison of initially planned activities and work actually accomplished

During the course of the project a few deviations from the work content of the Description of Work were made in order to ensure that the project was completed on time and that all the initially planned work was carried out. Also, in order to enhance the project some additional research was conducted that was not included in the Description of Work and therefore has not been charged to the Commission.

All the adjustments made to the initial planning during the project made no difference to the overall quality and quantity of the work or to the overall spend.

10.1 Work Package 1 'Management'

In this Work Package the actual management of the project, was conducted as originally planned. However, as described in section 11.5, more management responsibility and hence more management duties were carried out by TRL.

10.2 Work Package 2 'Elaboration'

In this Work Package the work was conducted as originally planned and the one output, the Inception Report, served as a blueprint to guide the project.

10.3 Work Package 3 'Technology'

Two deviations occurred in Work Package 3 in respect of the original planning. The most important and significant was that it was decided to bring forward the construction of the pilot trials on real road sites from year 3 of the project to year 2. The reason for this was the complexity of the pilot studies in terms of their planning because they involved work on in-service roads. Applications of innovative maintenance treatments need the early involvement of the owner of the road, and of the contractor hired to perform the works. The consequence of possible delays to the pilot trials was considered by the FORMAT team to be too risky to carry out this work in the final year of the project because if any problems had arisen then it might not have been possible to complete the work before the end of the project and the project would over run. Hence, the pilot trials were brought forward to the second year.

One important advantage of bringing the two planned pilot trials forward was that it provided an opportunity to conduct a second round of pavement condition monitoring at these sites which was performed one year after the trials were constructed. Furthermore, in year 3, an additional site was identified in Texas in the USA and this third pilot trial was performed at no additional cost to the Commission.

By bringing the execution of the pilot trials forward, some adjustments had to be made on the work of WP4 ‘Cost Benefit Analysis’ and WP5 ‘Safety’. These were addressed at a specially convened meeting on the pilot trials and the research plan in these two Work Packages was adjusted accordingly.

There was a slight delay in completing two of the four planned Accelerated Loading tests. This was due to issues related with the availability of the special facilities at two of the organisations participating. However, this delay did not affect the planning for the final project Deliverables. It was also possible to conduct an extra test at one facility because the original programme of loading was completed in advance of expectation.

10.4 Work Package 4 ‘Cost Benefit Analysis’

As a result of brining forward the construction of the pilot trials, it was necessary to bring forward the collection of data from these sites for the verification of the traffic delay spreadsheet model.

In the first year of the project it was considered to be more efficient if the ‘safety’ module of the cost benefit model was developed in Work Package 4 with data input from Work Package 5 ‘Safety’. This transfer was approved by the Project Steering Committee.

The only other change to the original plans was that midway through the project the Steering Committee recommended that information on environmental issues should be collected to provide actual data for the environmental model instead of concentrating mainly on collecting data to check the traffic delay model. As a result data from 50 case studies in the UK were collected on the benefits of recycling and also data were collated on noise.

10.5 Work Package 5 ‘Safety’

The collection of general and specific data from across Europe and the USA was completed on time. However, as there was a lack of information, it was agreed that should further data become available, they can be taken into account in the final analysis. In the event only little further data was forthcoming and therefore less analysis could be conducted than originally planned. Consequently, with the approval of the Commission the driving simulator trial at TRL in the UK was enhanced with an additional driving simulator trial at VTI in Sweden.

With the agreement of the Project Steering Committee and the Commission, the timing of Deliverables D13 (‘On-road trials of traffic management arrangements) and D16 (‘Assessment of innovative traffic management in driving simulator’) was reordered. This reflected bringing forward the simulator work and taking advantage of the later opportunity to obtain safety information from an important road project in Belgium.

10.6 Work Package 6 ‘Monitoring’

In this Work Package the work was conducted as originally planned.

10.7 Work Package 7 'Exploitation'

In this Work Package, more work was conducted than originally planned. Although the plans included the production of technical papers in addition to the formal deliverables, more than double the number of papers was actually produced. Furthermore, a meeting was held with the Reference Group in order to present plans for the style and content of the final deliverable, the Integrated Guide and to seek their comments on these plans.

Management and co-ordination aspects

10.8 Project co-ordination aspects

The system for communication between partners was put in place at the start of the project, in conformity with the QA Plan. E-mail was the main mode of communication although contractual documents were exchanged by mail or courier services. All relevant documents are stored in the central project file at Rijkswaterstaat DWW, using the document identification system documented in the QA Plan.

The public project website (www.minvenw.nl/rws/dww/home/format/) was maintained throughout the project and will continue to be maintained for two years from 31 January 2005.

10.9 Meetings

Meetings were held of the Project Steering Committee at six monthly intervals, the Principal Contractors Committee at three monthly intervals and Work Package Teams as required. For the first two committees, a meeting schedule covering the entire duration of the project was set up at the start of the project. Although the meetings of the Work Package Teams took place as and when required, they followed an outlined plan. Additionally, dedicated Project Management team meetings were held.

By arranging the meeting dates at the beginning of the project, all meetings enjoyed on average more than 90% participation throughout the project.

A dedicated FORMAT workshop was held at the FEHRL Road Research Meeting of 14-17 June 2004, in Brussels. The Workshop focused on defining the content and structure of Deliverable 18, the Integrated Guide 'Fully Optimised Road Maintenance'.

10.10 Conference attendance

During the project eight papers dedicated to FORMAT were presented at international conferences and a number of papers were presented at national conferences.

10.11 Co-operation with other projects

At the start of the project two COST Actions and five RTD projects from the Growth Programme were identified as the prime targets for co-operation, as follows:

- COST Actions 343 ‘Reduction in Road Closures by Improved Pavement Maintenance Procedures’
- COST 347 ‘Improvements in Pavement Research with Accelerated Load Testing’
- SAMARIS ‘Sustainable and Advanced Materials for Road Infrastructure’
- ROSEBUD ‘Road Safety and Environmental Benefit-Cost and Cost-Effectiveness Analysis for Use in Decision making’
- TRAINER ‘System for Driver Trainer and Assessment using Interactive Evaluation Tools and Reliable Methodologies’
- RISER ‘Roadside Infrastructure for Safer European Roads’
- PENDANT ‘Pan-European Coordinated Accident and Injury Databases’

The co-operation with these projects was carried out in accordance with the planning. Deliverable Reports were received and relevant data and results were taken into account and used in the FORMAT project. For example, from TRAINER, results fed into Work Package 5 ‘Safety’; from ROSEBUD, one Deliverable served as input to Work Package 4 ‘Cost benefit analysis’. Results from COST Action 343 ‘Reduction in Road Closures by Improved Pavement Maintenance Procedures’ and COST Action 347 ‘Improvements in Pavement Research with Accelerated Load Testing’ provided information that was used in Work Package 3 ‘Technology’.

The technical Deliverables from FORMAT were sent to the leaders of these cluster projects as soon as the Commission approved them.

In addition, members of the FORMAT team participated in workshops run by the cluster projects.

10.12 Project scheduling and budget control

Throughout the project a close watch was kept on the financial spend and manpower effort of the participating organisations by reviewing the current situation at 3 monthly intervals. If planned activities were starting to go off course, actions were put in place to correct the situation. By this means the project was kept to plan for the duration of the project.

Some transfers of budgets were made, with the agreement of the Commission, during the project. A transfer was made from Rijkswaterstaat DWW to TRL for TRL to play a more important role in the management of the project. Also because the Dutch Road Administration could not participate in the project after it had started, the UK Highways Agency took on the work for the Western Europe road owner. Budget was therefore transferred from Rijkswaterstaat DWW to TRL in order for that work to be sub-contracted to the Highways Agency.

The minor adjustments to the original planned project schedule were reported to the Commission in the three Progress Reports and the two Management Reports. Details of the rescheduling of the technical work are given in the previous section.

10.13 Performance of the consortium and individual partners

The Management Team of FORMAT would like to congratulate the members of the consortium on their excellent performance throughout the project. The technical work was completed to an agreed schedule and all the 18 Deliverables were produced on time and to a high standard. The individual participating organisations provided high quality and dedicated staff to work on this project.

Over the course of three years it is inevitable that some individuals will change their employment and within the project one member of Work Package 3 team was changed and one member of Work Package 5 team was changed, each by another member of staff in the participating organisation. More importantly however, near the end of the project two Work Package leaders changed their employment. Jean-Claude Turtschy of LAVOC and leader of Work Package 6, changed his employment three months before the end of the project. Another LAVOC employee who was already participating in Work Package 4 replaced him. Similarly, Philippe Lepert from LCPC and leader of Work Package 4 was promoted within LCPC one year before the end of the project and although he intended to continue as Work Package leader he was unable to attend any FORMAT meetings from that time. However, his colleague Francois Brillet represented him from LCPC who acted as Work Package leader in M. Lepert's absence. In practice because of the strong support from the Work Package teams, these personnel changes did not detrimentally affect the outcome of the project.

The consortium would like to thank the project officers from the Commission, Mr Frank Jost, and dr. Bernd Thamm for their encouragement and strong support throughout the project. However, the consortium was very disappointed by the failure of the Commission to pay the invoiced COST Statements numbers 1 and 2 before the end of the project. This caused financial difficulties to several participating organisations.

10.14 Contact details of the FORMAT team

Further information about the project and the FORMAT Deliverables can be obtained from the FORMAT Project Secretariat: M.F. Sitanala, Rijkswatertstaat Dienst Weg- en Waterbouwkunde, P.O. Box 5044, 2600 GA Delft, the Netherlands, e-mail R.SITANALA@DWW.RWS.MINVENW.NL, phone ++ 31-15-2518374.

The contact details of the project co-ordinator and the Work Package leaders can be found on the project website (**www.minvenw.nl/rws/dww/home/format/**) for two years after the project was finished from 31 January 2005.

In addition, a list and contact details of the individual members of the FORMAT Project Steering Committee are given in Appendix 2.

11. References

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- 7th Slovenian Congres for Roads and Traffic – 'Fully Optimised Road Maintenance' by Ph. Lepert, M. de Lurdes Antunes, I. Burrow, J.-C Turtschy and B. Leben
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- TRL News, FORMAT, January 2005
- RGRA No 827, Project Européen FORMAT, comparaison de techniques d'entretien (part 1), Michaut JP, Balay JM, Kerzreho JP, April 2004
- RGRA No 830, Project Européen FORMAT, comparaison de techniques d'entretien (part 2), Michaut JP, Balay JM, Kerzreho JP.
- RGRA No 831, Application FORMAT, Chantier du périphérique est de Toulouse en enrobe drainants, Michaut JP, Brillet F, September 2004.

Appendix 1: Deliverable Follow-up Sheet for Scientific Auditors

DELIVERABLE FOLLOW-UP SHEET

FORMAT project		
EC Contract no. :	GRD1-2000-25255 S12.319665 FORMAT	
DELIVERABLE FOLLOW-UP SHEET		
Deliverable no.:		
Deliverable title		
Date due:		
DRAFT VERSION		
Date received:		
Comments delivered to:		
Date comments delivered:		
Overall assessments:		
Changes required		
FINAL VERSION		
Date received:		
Follow-up on previous comments:		
Date approved:		
Approved by:		
FINAL COMMENTS:		
SIGNED	**signature**	**date**
Project Co-ordinator		
WP Leader		
Scientific Auditor M. Gorski		
Scientific Auditor H. Litzka		

Appendix 2: FORMAT Project Steering Committee

FORMAT Project Steering Committee

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