CHAPTER V

DEFINITION AND CALCULATION OF BENEFITS AND COSTS OF MAINTENANCE

V.1. INTRODUCTION

The main aim of benefit and cost calculations is to enable managers to identify the most advantageous rehabilitation and maintenance strategy, given the budget and other constraints. A corollary, subsequent aim is to enable design engineers, at the project level, to associate the most economical maintenance profile which minimises total discounted work expenditure and user costs over the life cycle of the facility subject to policies established at the network level.

Chapter I set the stage for a discussion of benefit-cost calculations. First, it showed this analysis to be useful both at the network and project levels (see Figure I.3: network, programme and project levels).

Second, Chapter I also laid down the five interacting sets of costs that comprise total transport costs: (1) 'development' (new construction), (2) 'rehabilitation and (periodic) maintenance', and (3) 'operation' (and routine maintenance) costs spent by the road agency, (4) road user costs (which are primarily vehicle operating costs but also include some accident costs and time delay costs), and (5) external costs to society (including environmental pollution, societal costs of accidents, and development and production benefits).

Thirdly, Chapter I illustrated the significance of user costs in Figure I.2. The "benefits" from roads and from their maintenance come in the form of reduced user costs.

This Chapter enumerates and explains the benefits and costs that must be accounted for over the life time of a facility in order to maintain it so as to minimise its costs to society.

In order to minimise the transport costs over the life of any facility, maintenance profiles -- a concept pictorially introduced in Figure V.1 -- must be established based on known performance of road pavements supported by condition monitoring. In most countries these profiles are based on the assumption that traffic will not experience any discernable loss of benefit up to the point where maintenance intervention takes place. This is indicated by the flatness of user costs in Figure V.1., excepting during times of maintenance or rehabilitation when users experience travel time delays. In the event of intervention as intended in the maintenance profile, the works will prevent benefits from being lost as a result of deterioration had the works not taken place. In the event of intervention later than intended -- after the road deteriorates beyond the point where traffic flow and vehicles are affected -- the purpose of the works, which themselves will now be more costly, is to restore the real benefits for road traffic to the desired level.

In order to reach good decisions, managers and design engineers must establish clearly the following criteria and information:

-- The current discount rate to be applied to all quantified costs and benefits for years beyond the base year for the calculation. The rate varies from country to country, although rates between 5 per cent and 8 per cent would be typical in a Western European country. The higher the rate, the lower will be the influence of future costs and benefits, that is, a high interest rate favours low cost solutions (see Box V.1).

-- Reliable and accurate values for the various quantifiable costs and benefits listed in Sections V.2-5. These values will need to reflect both national and local conditions including traffic composition, speed flow profiles and local community costs.

-- Accurate records of the various factors listed in Table V.1 which will be included in the cost assessment. It is probable that specific surveys will be required to provide the information needed or at least to supplement that already available.

Using the information listed above, other relevant information, and the general framework of Chapter IV, a rehabilitation and periodic maintenance strategy can be established. This strategy will result in decision rules or policies to be adopted by design engineers in a particular rehabilitation or maintenance situation. Such a rule or policy may be given in the form of a maintenance profile shown in Figure V.1. The rule in Figure V.1 will require intervention treatments to be applied when deterioration has reached a pre-determined level; when that stage has been reached, the design engineer will seek to control costs so that the works will result in net benefits at a level not less than that identified in determining the rule.

It is important to recognise that the profile in Figure V.1 refers to the **engineering-economy** approach to rehabilitate and maintain roads. The maintenance profile for crisis management (**zero-maintenance**) approach is quite different and is shown in Figure V.2. In that management approach rehabilitation and maintenance are delayed until the road is badly deteriorated, making **both** the user costs (benefit losses) and the agency costs much larger than under engineering-economic rehabilitation and maintenance policy.

Different rehabilitation and maintenance management strategies will have a direct effect on the experienced costs and benefits. Some of these costs and benefits will be of a quantifiable and others of a non-quantifiable nature. The following paragraphs will set out the various costs of maintenance and rehabilitation split between those that are "internal" to the administration and road users and those external; some will be quantifiable and others non-quantifiable[1].

Similarly, subsequent paragraphs will consider the internal and "external" benefits of maintenance and rehabilitation whether quantifiable or non-quantifiable.

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1 Orthodoxically, external costs accrue to non-users and internal costs to users. This division has become hazy. The pragmatic approach taken here is that distinction between external and internal costs is noted in the text, if possible, but in so far as the calculations are concerned all quantifiable costs, whether internal or external, are included. The non-quantifiable costs are elaborated and taken into account in decision-making on a case-by-case basis.

Box V.1. **Rate of Interest**

The rate of interest measures the cost of capital to an administration. Clearly, if interest rates are high, the administration, when borrowing, will pay a high price for the investment because of the requirement to repay capital and interest. Conversely, if interest rates are low, the cost to the administration will be reduced.

However, even if the administration does not to borrow in order to finance works, there will be a "social discount rate" incurred because those funds will not be available for other investment which will either not take place or do so as a result of borrowing.

There are variety of possible combinations of interest rates and possible road rehabilitation strategies. The following illustrates a possible situation: If interest rates are relatively low in the short and long term, the administration will be faced with two options; it can either build more roads of a lower quality with more frequent rehabilitation and maintenance in the future, or build fewer roads of a higher quality which will require lower and less frequent rehabilitation and maintenance in the future. The decision will be influenced, in part, by the present and forecast traffic demands on the network during the planned life of the roads.

In the context of high interest rates, the consumers seek to avoid risks, and the discounted cost of future maintenance works will be relatively low, because of the weak influence of future costs and benefits. This will favour an economic basis for rehabilitating or building roads inexpensively to last for a short life span. By doing so, and because the discounted maintenance costs will be less significant, the result is more frequent interventions on the network.

With low interest rates prevailing and solid consumer confidence, it would be expected that traffic growth would be robust, resulting in higher road user costs when maintenance works take place. For this reason the strategy of higher quality construction standards with reduced levels of maintenance would be likely to prove economically best.

When investing in long term projects such as highways, the administration will consider not only current interest rates, which will affect decisions on its capital or new works programme, but also longer term forecasts of interest rates and many other factors to determine its maintenance strategy. A comprehensive assessment is required in all cases to establish the best strategy.

V.2. QUANTIFIABLE COSTS OF MAINTENANCE

The principal costs of maintenance fall to the administration (agency) in the form of those associated with the works, including the costs of planning, design, execution and supervision. Normally, it is only possible to include quantifiable costs in a life cycle assessment, but non-quantifiable

Figure V.1. **Typical Deterioration and Maintenance Profiles**

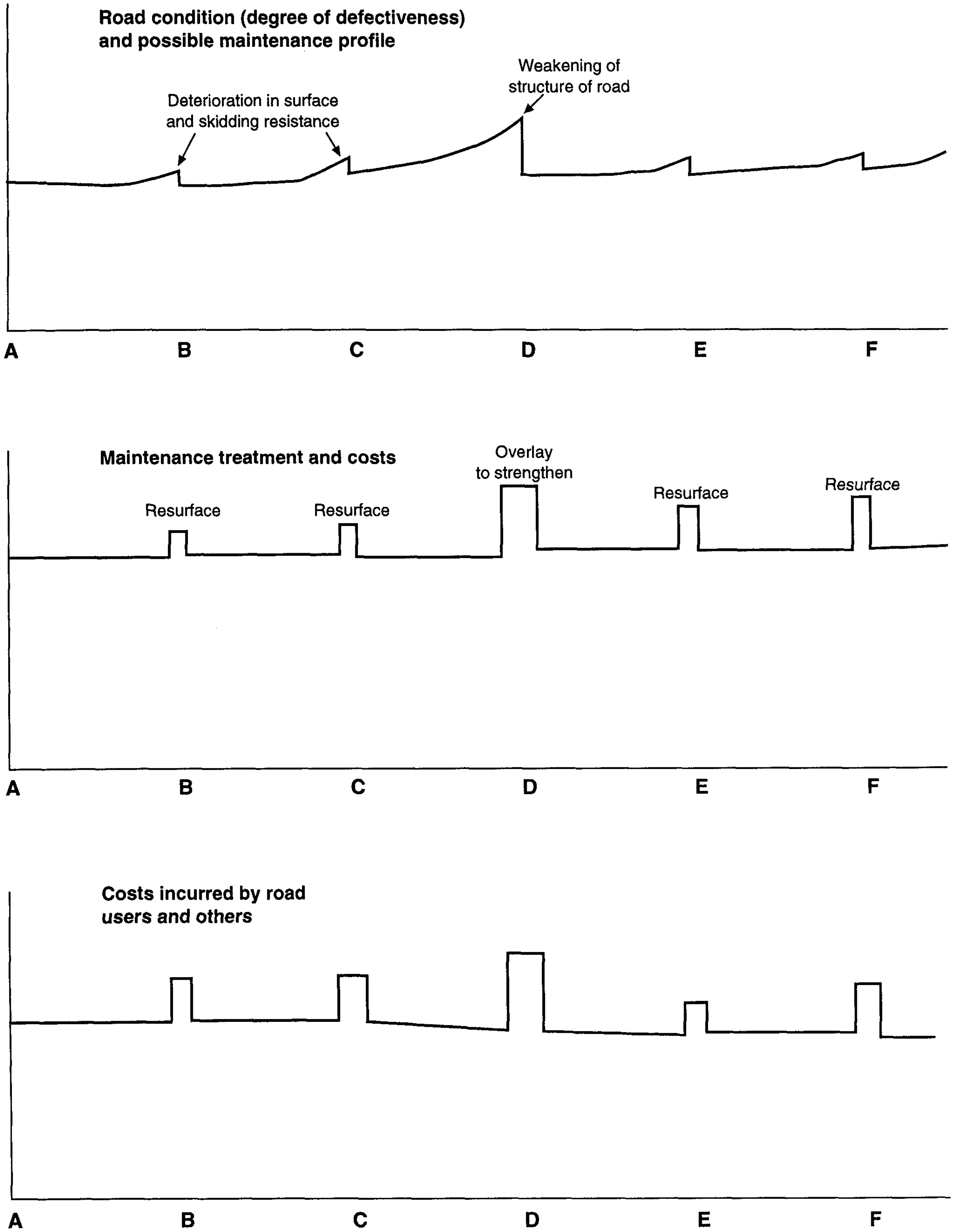


Figure V.2. **Maintenance profile based on a policy of reaction**

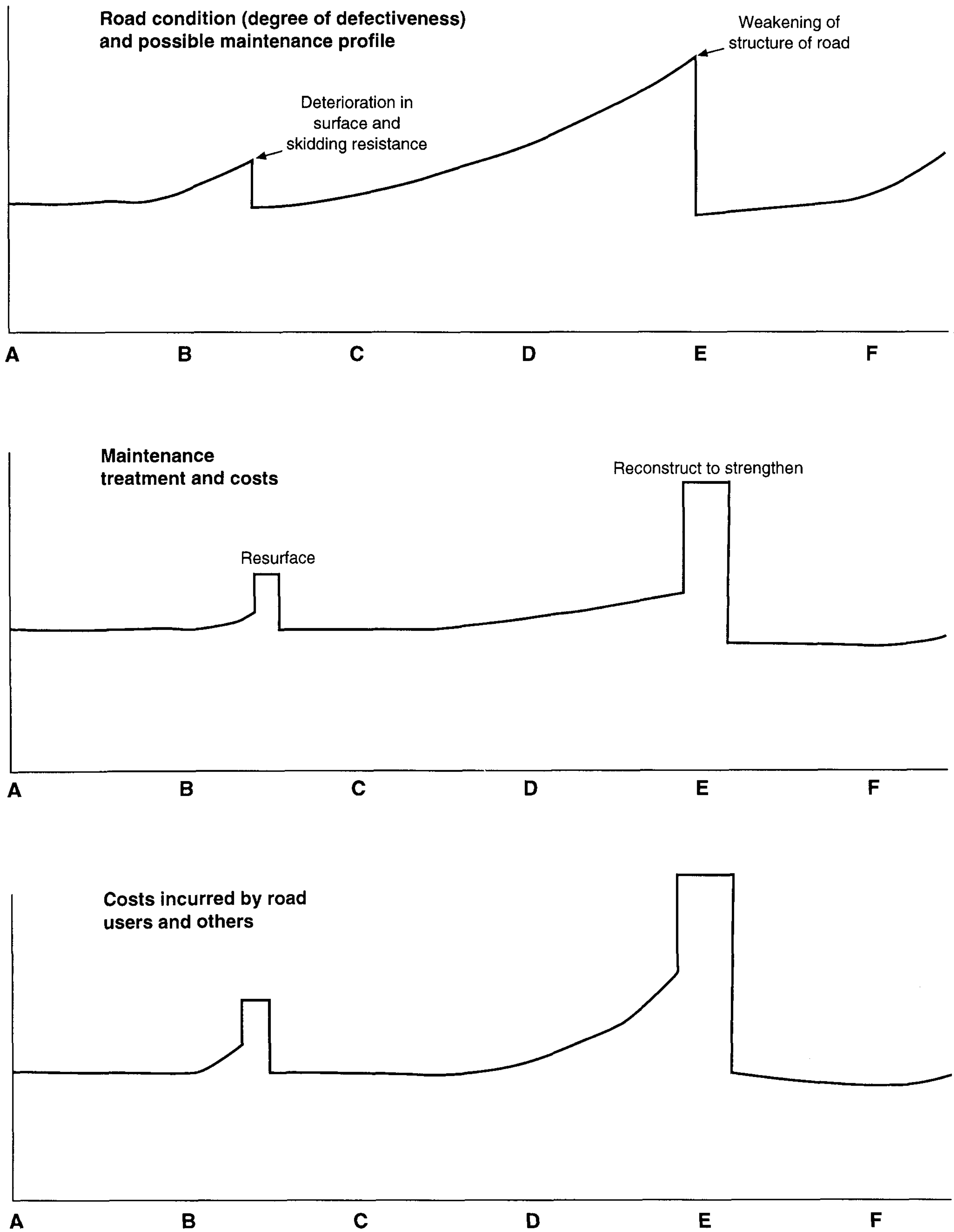


Table V.1. **Summary of quantifiable costs and benefits of maintenance**

	Chapter V References	Costs[1]	Benefits[1]
Administration			
Procedural requirements	V.2	✓	
Works	V.2	✓	
National objectives (economic prosperity)	V.4		✓
Road Users during works			
Private user	V.2	✓	
Public Transport	V.2	✓	
Road users after works			
Time	V.4		✓
Operation	V.4		✓
Maintenance	V.4		✓
Accidents	V.4		✓
Local residents			
Traffic delay	V.2	✓	
Accidents	V.2	✓	
Local Businesses			
Transport	V.2	✓	

1 In comparison to 'do nothing' alternative

costs can be considered separately where they are significant, for example, as constraints to allowable rehabilitation or maintenance strategies.

Two other sources of agency costs are worth pointing out, although they routinely are included in the direct costs of works. Both of these have a tendency to increase the road administration's costs and are done to internalise the otherwise external costs of rehabilitation and maintenance.

The first of these costs is incurred in order to avoid excessive user costs during the works. Road users will often be required to bear a cost during the maintenance works. This is normally in the form of increased cost of time, but operating costs will also increase particularly on congested roads where maintenance works will result in increased and possibly severe delay. Moreover, accident rates and their associated costs may increase when maintenance works are in place on the road. To mitigate these costs the administration needs to balance the total cost of works with those to the road user and plan the works and traffic control as a whole to ensure that combined costs are minimised.

The second source of costs is similar to the first, but is incurred because of the non-users. The presence of maintenance works on a section of road may have a variety of cost implications for those living or working in the vicinity, but not directly connected with the project. The impact will change, often significantly, depending on the nature and location of works, the local road network and the nature of the area and the community. As a result of these factors, quantifiable costs can be incurred by:

-- Local residents affected by traffic disruption in the vicinity of the works;

-- Local public transport operators affected by disruption due to the works;

-- Local businesses where delivery or collection of goods and materials can be affected by the works; and

-- The possibility of increased accidents, with their associated costs such as loss of employment, to both local residents as well as the road user.

These costs can be small or large but they are always difficult to estimate in advance. When a broad assessment indicates that they will be significant, the administration should include these costs when specifying the form of the works, planning restrictions and traffic control.

V.3. NON-QUANTIFIABLE COSTS OF MAINTENANCE

Local residents would be subject to intrusive effects of dust, noise and general disruption to movement near their homes, often despite any controls imposed within the works contract to mitigate these effects. In extreme cases clear restrictions may need to be placed on a contractor to minimise the effects particularly at critical times such as at night and weekends. Of necessity these decisions will often be made as a result of subjective assessments.

Maintenance works need to be supplied with a range of materials from quarries and batching plants, most of which will be located remote from the site requiring deliveries to be made by lorries, often using lower standard local roads. These movements are likely to result in accelerated wear and tear on these local roads and disturbance to residents and businesses along the routes. Again, planning controls may be necessary to minimise these effects.

It is possible that the adverse impact of works in the local area may act as a deterrent to the general public using road facilities while the works are in progress. This effect would be particularly difficult to assess since other influences also may contribute to such trends.

It is seen that non-quantifiable costs are most often related to the environment and their mitigation will be further considered in Chapter VII dealing with the environment and other externalities.

Table V.2. **Non quantifiable costs and benefits of maintenance**

	Chapter V References	Costs[1]	Benefits[1]
Administration			
Processing of taxes etc	V.3	✓	
Road users during works			
Environmental nuisance	V.3	✓	
Road users after works			
Reduction of post accident grief	V.5		✓
Local residents during works			
Environmental nuisance	V.3	✓	
Impact on local facilities	V.3	✓	
Employment	V.5		✓
Local residents after works			
Impact on facilities	V.5		✓
Wider Community			
Impact of deliveries to and from site	V.3	✓	
Post accident grief	V.3	✓	
Local Businesses			
Benefit of well maintained roads	V.5		✓

1 In comparison to 'do nothing' alternative.

V.4. QUANTIFIABLE BENEFITS OF MAINTENANCE

An essential objective of any national road network is to assist economic and social growth and prosperity by reducing transport costs. The benefits of providing and maintaining the road network to standards consistent with adopted policies can be assessed and quantified, although limitations in traffic modelling, valuation of time and external constraints will introduce a degree of imprecision into the assessments.

The principal benefits resulting from maintenance and rehabilitation works accrue to road users in form of reduced transport costs. A road surface, when new, will normally allow traffic to flow at a speed regulated only by traffic volume and speed limits. But when the road deteriorates to a significant extent, especially when rehabilitation will be required, the road users experience a degree of discomfort, speed reduction and other increased vehicle operating costs.

Maintenance of the road surface, as opposed to rehabilitation, normally has little effect on journey speeds, and the benefit of carrying out maintenance occurs, because deterioration has been checked and corrected so that traffic in future years will not incur costs which would have resulted from further deterioration, had the works not been carried out; the benefits identified from the original investment will be protected.

When roads deteriorate to the point where rehabilitation will be required, speeds will be progressively reduced in the interest of comfort and perceived safety. Through observation, this loss of speed, and the resulting increasing cost to the road user, can be calculated and so assist in the decision on optimum timing of the maintenance treatment. Investigations have further identified additional costs when road roughness reaches a significant level:

-- Vehicle maintenance costs increase especially due to additional wear and tear on suspension components;

-- Fuel consumption increases for vehicles travelling in a free flow situation; and

-- If road surfaces begin to lose chippings or other stone, there will be an increased incidence of vehicle damage, including to windscreens.

Additional benefits can accrue, or increased user costs can be reduced when carrying out maintenance or rehabilitation in a timely manner.

Maintenance and rehabilitation also improve the skid resistance of the road surface, other minor geometric improvements are also often done, and there will be benefits to the road user in the form of reduced accidents. Because the incidence of accidents is a rare event, these benefits can only be quantified and realised over a long time period.

Rehabilitation and maintenance works may also benefit others, besides road users, in a way which can be quantified. For example, the construction industry may increase its volume of activity, probably at higher profit levels in a growth situation and provide more employment.

V.5. NON-QUANTIFIABLE BENEFITS OF MAINTENANCE

Businesses depend on a good well-maintained road network. Not only will existing businesses benefit from good standards of road maintenance, but it is possible that other businesses may be influenced by the state of the local road network, when making a decision to expand or relocate its activities. These benefits would clearly be difficult to quantify, largely because they would be as a result of decisions, many of which would be made on the basis of commercial confidence and would not be available. However, general economic trends would be available from various sources and would give valuable information.

Maintenance works will create opportunities for employment not only locally from where the work force may be recruited, but also in the various supplies industries. These benefits are often difficult to assess because of other forces influencing the volume of work in the industry. Nonetheless, recently attempts have been made to quantify these benefits because of the local communities' interest in them. Similarly, well maintained roads bring with them other non-quantifiable social benefits, e.g. tourism.

Box V.2 develops a case study of quantifiable and non-quantifiable cost assessment and Box V.3 presents an example application of input/output analysis.

V.6. RELATION BETWEEN BENEFIT/COST AND MAINTENANCE LEVEL

Previous sections of this Chapter have described the various benefits and costs which contribute to the overall decision making process regarding when and how to maintain or rehabilitate a road. These were set out in the Table V.1.

As a concrete example how a preferred strategy -- derived through an engineering-economic management approach -- would look like, a case of periodic maintenance of a single road is shown in Figure V.1. The upper plot indicates surface condition and ride quality deteriorating slightly (to say point B), but not to the extent where it would noticeably increase road user costs. The centre plot shows a treatment (at point B, resurfacing) to restore the road condition to its original level. The centre plot also shows that, because the surface condition is prevented from deteriorating to a poor state, no significant expenditure on maintenance is incurred between the specified intervention points (B, C, D etc.). The lower plot indicates that because surface condition is always relatively good and only routine maintenance is carried out between planned interventions, the road user only incurs additional costs because of delays when the planned interventions (B, C, D, etc.) occur.

Road condition monitoring, an integral part of the Road and Bridge Management System, suggests the need for treatments at various stages. By carrying out the appropriate treatments at these stages the administration would ensure that the level of service envisaged at the time of construction would be achieved throughout the life of the road. By following this strategy a series of events would occur as shown in Figure V.1:

time	A	Road constructed;
times	B,C,E,F	Road resurfaced when minor deterioration and/or loss of skidding resistance occurs;
time	D	Road is overlaid when indicated by policy and condition data.

Box V.2. **Examples of quantifiable and non-quantifiable costs**

Examples of quantifiable and non-quantifiable costs taken into account in planning reconstruction of a section of a semi-urban motorway close to an urban conurbation:

QUANTIFIABLE

a. Administrative Requirements

Date of Scheme	....
Design Fees	\$260,000
Site Supervision	\$170,000

Design Fees are based on the Consultants Commission Fee Scale. In addition extra fees were paid for works considered to be beyond the norm eg publicity material etc. These amounted to \$8,500.

b. Works Cost

Tender Sum	\$11.30 M	Contract Final account \$13.30
Total Scheme Cost	\$14.70 M	Includes fees, supervision etc

c. National Objectives

The scheme was virtually 100 per cent reconstruction. The motorway had been built 20 years earlier. It had remained a local authority road with no significant maintenance until April 1989 when it became a national road.

d. Private Road User Costs

The daily road user cost for "High Growth" travel demand scenario was \$70,000. The Consultant had difficulty in modelling the urban links affected because of their complex nature and felt that this was an underestimate of the effect on the urban roads.

e. Public Transport Costs

Consideration was given to the provision of park and ride sites, but this was not pursued. The only cost to the administration was in providing signs on and off the motorway to an existing park and ride site at one of the main commuter railway stations on the outskirts of the City. The cost was a few hundred dollars.

Meetings were held with the Passenger Transport Executive to keep them informed of the works programme. Traffic congestion was less than predicted; thus disruption and inconvenience to public transport was less than predicted and definitely less than originally feared by the operators.

f. Road User Costs After the Works

No details of the do nothing road user costs. The predicted cost of immediate maintenance works, if the major scheme had not gone ahead, was $640,000, to maintain a safe and adequate road surface. This would have increased significantly annually.

g. Local Residents

A survey was taken to compare the journey times on the major commuter route affected by the works. The survey showed that journey times via the motorway were not affected by the works but, in the major alternative route, journey times increased by approximately 10 per cent during the works because of the transfer of traffic. This however represented only a 3 minute increase in journey time.

There are no accident figures in relation to accidents away from the motorway.

The administration paid for minor works on the main alternative commuter routes to improve traffic flow during the works eg temporary traffic restrictions and minor radii improvements. The cost was $115,000.

h. Local Businesses

No estimate of financial impact. A pre works meeting was held with the Chamber of Trade to explain how the administration was planning to minimise delay and disruption. The Chamber expressed their concerns. However after the works letters of praise were received from the Chamber and individual shops. Therefore the impact of the roadworks was minimised.

NON-QUANTIFIABLE

a. Administration

There were no problems but the preparation work was greater, both for the agent administration, than for a typical maintenance scheme. The publicity campaign was the most significant aspect. This included:

- i. TV, Radio and Press Conferences,
- ii. Publicity leaflet distributed to commuter car parks in the City,
- iii. Mail shot to all businesses in the area,
- iv. Press advertisements,
- v. Provision of a telephone hotline -- this was updated daily when necessary. The message gave details of slip road closures etc.

The design of the traffic management proposals was more extensive than a typical scheme.

b. Road Users during the Works

Publicity campaign was aimed at persuading people to use alternative modes of transport, car share and avoid the motorway at peak hours. The scheme was programmed to take full use of the school summer holidays, when flows into the city are lighter and to be completed before the Christmas shopping season.

c. Road Users after the Works

The scheme provides a 20 year design life for road users with programmed resurface works in 10 years. The overall aspect of the motorway was improved eg new signs, white lines, safety fence etc.

An improvement to a junction layout (signing and white lines) reduced queues at peak times.

d. Local Residents during the Works

Local residents were affected by noise and dirt. The contractor also had claims for vibration damage from some residents immediately adjacent to the motorway. The main contractor was from the region, as were most of the sub-contractors, but this would not benefit the local residents.

e. Local Residents after the works

The purpose of the works was to provide a reconstructed carriageway and upgrade the motorway furniture. The administration did not take the opportunity to provide noise barriers etc. as this was not considered appropriate. This section of motorway passes through the Development Corporation area. As a separate exercise the landscape planting was enhanced on the motorway "Gateway" corridor. This will have had some incidental benefit to adjacent residents.

f. Wider Community

No planning controls were enforced with special reference to the scheme. One sub-contractor was prosecuted by the local authority for depositing waste material from the site on an illegal site (ie without planning consent).

g. Local Businesses

No significant difference to businesses between the pre and post works scenario, apart from an improvement in traffic flow into the city at peak times.

Box V.3. **Analysis of indirect impacts of road investments using input/output analysis**

APPROACH

Regional economic development can be defined as an increase in the welfare and revenues of citizens and enterprises in that region. A road investment in a certain area can lead to economic development, i.e. growth of production and revenues, if:

-- new production capacity is enhanced due to the new road,

-- decreases in transport costs improve the productivity of the companies and, in consequence, the welfare and revenues of people in the area.

These regional impacts can be analysed with the help of input/output models developed by W. Leontief. Input/output tables are based on the theory of general equilibrium which summarises and explains the dependencies and interactions between different sectors of the economy.

In addition to the direct impacts of a road investment, input/output tables make it possible to analyze the indirect effects. These indirect or multiplier effects depend on the structure of the economy and the productive sectors. Of course, the multiplier effects are rude estimates as the production structures change constantly and rapidly.

The input/output tables are based on the fact that every productive sector needs goods and services of other sectors in its production process. When its production increases, its demand for raw materials, services, machines and equipment produced by other sectors increases. This in turn increases their demand for goods and services produced by third sectors etc.

The input/output model allocates the impacts of a road investment to the different groups of the economy as follows:

-- enterprises by sector (savings in transport costs/improvement of productivity, increase in demand/sales),

-- households (employment/salaries),

-- public sector (tax revenues).

A highway investment is divided in two phases in the analysis: the investment or construction phase and production phase when the road is opened to traffic. The first lasts usually 2-4 years after which the multiplier effects fade away, unless the road investment and rehabilitation activities continue at the same level in the region. On the other hand, the effects of the latter, generated by the transport cost savings, are more or less permanent.

One of the major problems of input/output analysis is due to the fact that regional input/output tables usually do not exist, but the analyst has to be content with national figures. Regions with a production structure that differs considerably from the national average cannot be taken properly into account. As a consequence, the accuracy of the input/output to estimate regional effects is somewhat questionable.

EXAMPLE

Investment phase

The improvement of Lansivayla, a major motorway leading form the central business district of Helsinki to the west, costs approximately 250 million marks and will take 4 years. The indirect effects of the investment amount to 635 million marks and are about 2.5 times the original investment. The productive sectors will benefit of 40 per cent of the total or almost 300 million marks as increased sales. The households salary revenues increase 100 million as well as the revenues and profits of entrepreneurs. The public sector's tax revenues increase by 70 million marks. 8 per cent or 50 million marks of the indirect effects will benefit foreign companies as imports increase.

The sales of services increase 170 million marks. The most benefitting sectors are: transports and wholesale and retail trade. Among the industrial sectors, which gains 100 million marks as increased sales, the most benefitting sectors are metals, chemicals, oil products and food industry.

Due to the increased sales, companies are able to hire almost 3000 additional workers. These new employment opportunities will, however, last only as long as the construction activities take place or 4 years.

Production phase

When the Lansivayla improvement work is achieved, monetary transport costs (excluding time savings) will decrease by almost 17 million marks per year. These savings will stimulate the economy with more than 40 million marks every year. From this, companies benefit 20 million as increased sales, households 7 through higher salaries and entrepreneurs 9 million marks due to increased profits. Tax revenues increase by almost 4 million.

The increased demand and salaries, generated by the transport cost savings, makes possible the creation of 80 permanent employees. Most of them will be in the service sector (43) and among the industrial sectors in the food producing sector.

The resurfacing treatments specified above would cost in real terms similar amounts at stages B, C, E and F, productivity gains offsetting the eventual price increases. The increases would reflect both the need for new and better materials as well as the increased costs of working on very congested roads.

Figure V.2 shows a maintenance profile based on the "crisis management" approach. An intervention is carried out when the deterioration approaches a certain level which is considered unacceptable, because for instance, the public and/or politicians complain about too extensive development of ruts and pot-holes. The upper plot indicates that surface deterioration has reached a substantial level before intervention is effectively forced on the administration. The centre plot indicates that after point B, deterioration accelerates and increasingly costly and frequent repairs are required to keep the road serviceable until the major intervention becomes essential. The lower plot demonstrates that the deteriorating condition and routine maintenance works required impose on road users high costs, because of increased journey times, vehicle operating costs, and delays as minor and major works are carried out.

In adhering to the "crisis management" policy indicated in Figure V.2, the following events would occur:

A Road constructed;
B-C Road resurfaced as a result of substantial deterioration of surface; and
D-E Road reconstructed as a result of major structural deterioration.

The maintenance works indicated in Figure V.2 will be significantly different from those indicated in Figure V.1. At a time between B-C the cost of patching will be great and limited repairs could not ensure the integrity of the road, hence necessitating major resurfacing works. Depending on the degree of deterioration it may be necessary to carry out more extensive works than simple resurfacing, such as partial reconstruction. User costs incurred as a result of reducing speed over the deteriorating surface will increase over time.

At times between D and E, the road will be at or near the failure condition, user costs will increase exponentially and probably be at an unacceptably high level by the time the reconstruction works are carried out.

The strategy in Figure V.1 shows clearly that the effect of planned and timely preventive maintenance based on accurate condition data will ensure that the benefits expected from the investment in the new road at the time of construction will be achieved throughout the time. The strategy in Figure V.2 illustrates that as condition deteriorates, many of the benefits expected of the investment in the road will be reduced and as deterioration increases further, the loss of benefits can be very substantial especially on a major busy highway where free flow speeds would otherwise be possible.

Figures V.1 and V.2 are diagrammatic schemes seeking to illustrate the general effects of different strategies. It should be noted that the scales indicating works and user costs have not been quantified and could be widely different. On roads carrying very low levels of traffic flow, the works costs could be higher than the user costs, but on very busy roads, the user costs could be very much greater than the works costs.

V.7. APPLICATION OF COST AND BENEFIT CONCEPTS TO THE RESOURCE ALLOCATION PROCESS

In the first three chapters resource allocation and distribution was discussed from the point of view of a government or the Central Administration which both collects taxes and allocates funds to the transport sector. This Chapter has focused on the "grass roots" level where the costs are incurred and where the allocated funds are spent. The network level distribution of monies meets the project level spending of these monies at this juncture.

The operating units of the administration, which in many countries are called the Regional Organisations as opposed to the Central Administration, will be required to take account of all the quantifiable and non-quantifiable factors listed in this Chapter and summarised in Tables V.1 and V.2 when distributing money from its funds to individual projects. Each operating unit will need rules and analytical procedures, to assist in this process so as to ensure even treatment throughout the administration. (Box V.2 presents an example enumeration of quantifiable and non-quantifiable costs considered in the reconstruction of a semi-urban motorway).

For these reasons, and for the reasons below, discussions about resource allocation and distribution take place at various levels depending on the structure and requirements of the Ministry of Transport and the Central Administration. Annual allocation based purely on the then known condition of the network in each year would result in an erratic variation of funding and works on the network. Such annual variation would not be helpful to the Ministry, which will need to constantly re-adjust its income targets. Nor would it be helpful to the construction industry, which will face high risks in investment in an uncertain future and the road user, which will face varying levels of works from year to year. The Road Administration (or the Ministry of Transport as the case may be) must, therefore, develop a long term plan to assess the net benefits of its road programme over a period of several years to provide stability in funding.

Formulating such a road rehabilitation and maintenance programme requires the quantification of net benefits, with a reasoned assessment of the non-quantifiable benefits, of road rehabilitation and maintenance at the network level rather than by individual projects. This approach is necessary not only to demonstrate the value for money of the plan, but also to offer a comparison of the social and environmental benefits which comprise other forms of national expenditure such as health, law and order, defence and social security.

The rehabilitation and maintenance programme must, therefore, be competitive even though there are difficulties in making true value-for-money comparisons. An example of this difficulty is that maintenance is usually carried out as a preventive treatment before serious deterioration occurs and little information is available on the true economic cost to the road user of delaying maintenance until deterioration reaches an advanced state.

Before concluding this Chapter, it is important to point out one more cloudy aspect of resource distribution to operating units and projects. If one operating unit, because of the nature of its maintenance projects, directed a higher proportion of funds to non-quantifiable factors in a particular year, it will result in fewer funds being available for maintenance and rehabilitation treatments. This shortfall will be simply detected by future condition surveys which would indicate the need for a higher proportion of funds, as a result of assessment of quantifiable benefits, for such an operating unit in future years. In this way this particular operating unit has ensured itself a high funding level over the years, first on the basis of non-quantifiable benefits, and then on the basis of quantifiable benefits. A consistent and comprehensive procedure is therefore required to ensure (regional) equity.

It warrants restatement that the proposed three-tier hierarchy[1], network-programme-project, is a necessary feature of resource allocation and distribution. The hierarchy helps ensure fairness, to avoid mis-allocation or mis-distribution of monies, and, over time, to ensure a consistent and well-justified level of funding for maintenance and rehabilitation.

[1] In Chapter I the relationships between three hierarchical levels were explained. As noted then, the program level is an intermediate activity which ties together the network level resource allocation/distribution with the project level expenses.

CHAPTER VI

CHARACTERISATION AND MEASUREMENT OF HIGHWAY CONDITION

VI.1. ROAD AND TRAFFIC INFORMATION SYSTEM

A road administration necessarily collects huge amounts of data. The mission of the data collection personnel in a Road Administration is *to enable management to strengthen the decision-making process and increase productivity.* Figure VI.1 shows how this mission relates to the management system, such as that articulated in this report.

As road systems have become more complex, so have the aims and methods of data collection. Historically, traffic counting systems were the first to be developed in a systematic manner; they were later extended by speed and accident studies. Soon the development of "road data banks" followed containing information on the road network and the physical characteristics of its links. With time, it became apparent that an integrated traffic monitoring system was required. Road condition, traffic management, weather, and, last but not least, weigh in motion data were included in the Road Administration's information system. Today, the road and traffic monitoring system is an important module in the road administration's information system, as is shown in Figure VI.2 (that it is regarded as only a module is because the full information system contains also socioeconomic, cost, and other relevant information).

The key to the effectiveness of a Road Agency's information system is a location reference structure which enables the user know the time and place of each data item. For example, the road information system contains data on the network configuration (administrative and functional classification), surrounding environment, physical characteristics of the road links, road surface, pavement, structures, traffic, accidents, actions taken, and other elements considered necessary in road agency management, including updates and changes. This information is not optimally useful unless it can be located precisely in time and space.

The information system normally serves multipurpose objectives of the Road Agency, such as Central Administration's needs regarding planning and investment as well as rehabilitation strategies, or the Regional Administration's needs for organising routine maintenance activities. The greater the complexity of the multipurpose objectives, the more elaborate are the requirements on the system's information management capabilities. A wide variety of systems, including hardware and software, is available to meet specific needs. The good ones enable user-friendly input and output as well as classification and organising of information of any type that has been inventoried or monitored.

Figure VI.1. **The mission of data collection in a road administration**

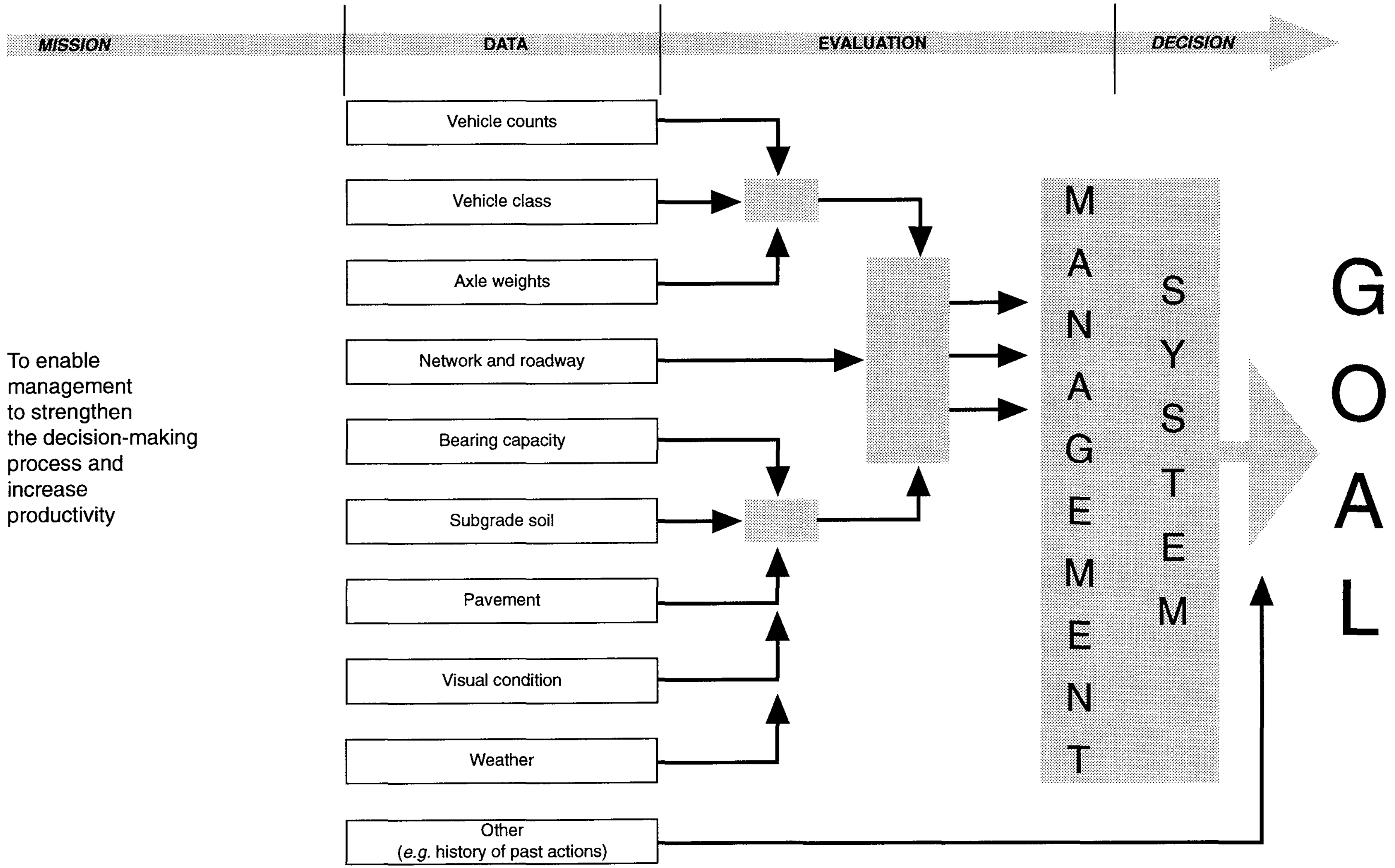
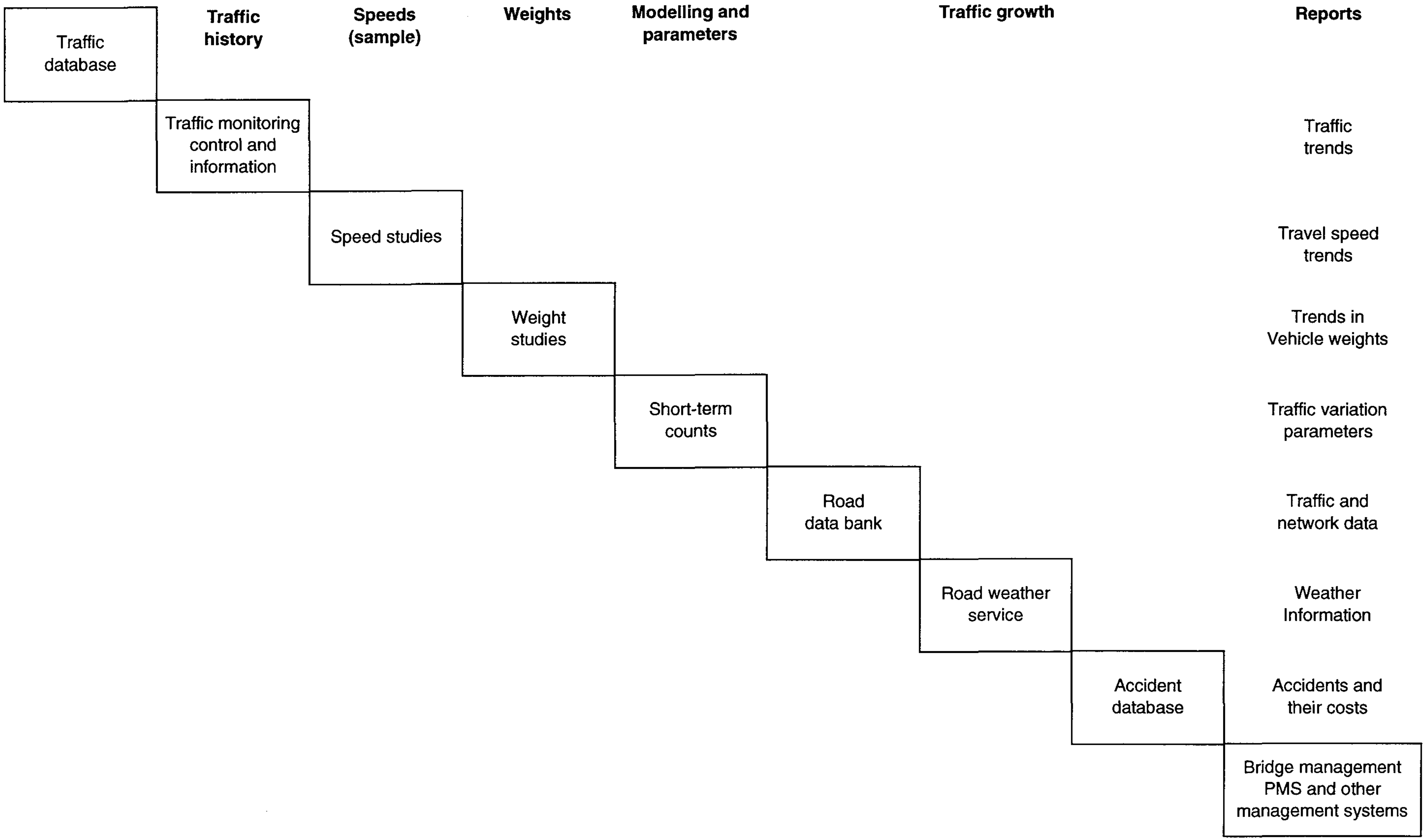


Figure VI.2. **Road and traffic monitoring system**
(a part of integrated information system)



The usefulness of any information system[1,2] depends to a large extent on the quality of the data it contains. This rests not only on the appropriateness of the monitoring procedures but also on the error-free characteristics of the data compiled; any input of information into the data base must be controlled and validated. The validation should be performed right after the monitored data has been controlled for coherence and, the second time, at the stage of physical loading of the data in the data base, especially if data input is done manually.

The information system is merely an information organiser, but a necessary one. An important function of the system is its usage together with analytical procedures and management systems, such as described in this Report so as to optimise resource allocation and distribution for road rehabilitation and maintenance.

VI.2. ROAD CONDITION MONITORING

Road condition monitoring[3] is a process of tracking time-dependent changes in the observed condition of a road and its environment (for example, progression in surface deterioration, climatic conditions, traffic patterns, maintenance activities).

Compared to, for example, traffic counting, road condition monitoring has not reached the same degree of uniformity as regards definition of variables, sophistication in statistical procedures to minimise data collection, and even acceptance as a legitimate periodic road agency activity. Therefore, there exists a degree of variance -- a searching for cost-effective "best practice" -- in current road monitoring procedures. What is described in this Chapter is merely a good prototype, not necessarily a recommendation. Moreover, road condition measurement conventions and variables which are measured depend on management practices, available measurement and information technology, and expertise of the road administration personnel. Suffices it to state that in a modern road administration, road condition measurements are made with fast, automatic multi-parameter devices, which utilise Global Positioning System (GPS) for the location of measurements.

VI.3. LEVELS OF ROAD CONDITION MONITORING

Monitoring can be classified and is often organised according to levels of accuracy and frequency, as is customary also in traffic counting. Another purpose of a monitoring structure by levels is to allow

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1 PATERSON, WILLIAM D.O. and THOMAS SCULLION (1990). *Information Systems for Road Management: Draft Guidelines on System Design and Data Issues*. World Bank Technical Paper, Report INU 77. World Bank. Washington, D.C.

2 The 1992 OECD report on *Bridge Management* proposes a similar approach to bridge data collection and management and presents a detailed review of developments so far, issues and future perspectives.

3 The reader is also referred to the OECD/World Bank report on DC1 *Road Monitoring for Maintenance Management* (Volume 1) published in 1990 which -- albeit centred on developing country issues and visual inspection -- develops a systematic framework for road damage recording.

for the assessment of road conditions in a wide variety of circumstances and to serve many different needs of the administration.

Figure VI.3 presents a diagram describing five levels of monitoring structured according to frequency, amount of data collected, network size, use, degree of automation, data base support, and capability of providing input for policy and planning decisions. Although five levels have been defined, they can be separated into three groups: the first is level I, the second group comprises levels II and III, and the third is made up of levels IV and V.

The first group of road condition monitoring is designed for a preliminary study aimed at scoping the requirements for the planning of network (or region) wide maintenance works and/or for establishing statistical criteria, the location of permanent monitoring stations, and the equipment needs for continuous monitoring schemes. The infrequent, often 'one time only' survey may be followed by similar sample surveys to add new variables to be monitored or check the effectiveness of new maintenance initiatives, or inspect the quality of road maintenance at (regional) network level.

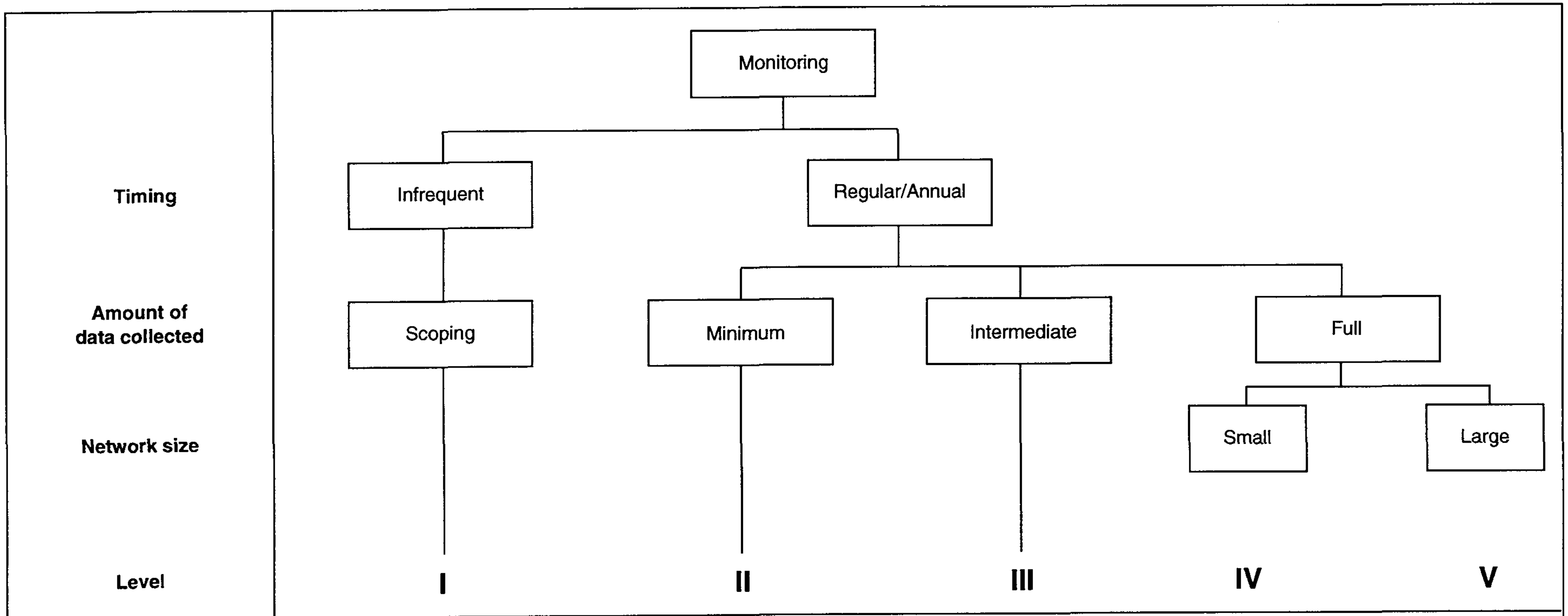
The second group, levels II and III, is the main data collection activity for road conditions. It is used when maintenance/rehabilitation policies are determined using an optimisation model and when the policies based on road surface condition are applied, requiring a certain amount of data to be collected. Detailed data are gathered normally on a sample of road links or groups of links, while the condition of others is forecast using deterioration models. Often only roughness and rutting are measured (because high efficiency, high speed equipment can be used). Measured distress condition and bearing capacity (deflection) data are averaged, typically in 100 m to 5000 m block lengths. These same data are used for auditing network condition, monitoring adherence to maintenance quality standards, for project implementation studies (in which case more detailed data may be collected or supplemented from other sources), and for estimating the deterioration and optimisation models and validating them. On average, this type of data gathering is done in two or three year intervals rotating the links or groups of links being sampled.

The third group of monitoring serves data collection for the design and implementation techniques of maintenance/rehabilitation works. For maximum coverage, continuous measurements (or nearly so) are used. These are required for precise identification of defective zones and their location to design and to apportion work zones accurately. It calls for high level automation of monitoring equipment to accommodate the relatively large amount of data collected on a relatively short period (one year) regular repetitive basis.

There can be a sixth level, or a fourth group, of road condition monitoring which is done at permanent locations (often coinciding with the permanent traffic counting stations) and which serves research and development studies. At these locations detailed data are recorded on a great variety of variables, including not only road conditions but also weather, axle loads, maintenance/rehabilitation activities, costs, etc.

There is an underlying ranking in monitoring levels allowing for 'downward compatibility'. The different levels are arranged to permit their staged and gradual implementation as to the number of items investigated, depending on network size, data collection technology, and institutional capacity. The 'downward compatibility' of monitoring levels will ensure that the different decision-making levels utilise the same data. As will be articulated in Chapter VIII, this is an important attribute of the road information system.

Figure VI.3. **Levels of monitoring road condition**



	I	II	III	IV	V
Use	"Scoping", establishing data collection and equipment needs, etc.	Maintenance programming for fixed policy and standards auditing; implementation studies; modeling.		Centralized administration implementation	Decentralized administration
Automation		Low	Intermediate	← High →	
Data base/ Environment	None	Simple road data bank, microcomputer	Road data bank, computer network	Road data bank, microcomputer	Road data bank, computer network
Level of accuracy	Sufficient	Intermediate	High	Intermediate	High

The levels of monitoring outlined above presume that a comprehensive inventory of the road system and traffic was undertaken when the information system was set up. For the purposes of rehabilitation and maintenance such inventory consists of data assembling prior to maintenance management (i.e. concerning past history), data that can be considered "permanent", such as:

-- past cumulative traffic data,
-- initial facility geometry,
-- initial structure and characteristics of subgrade soils,
-- past maintenance actions.

In summary, road condition monitoring is based on two approaches: statistical sampling on test sections belonging to road links or groups of links, and full length (continuous) measurements. Both slow, labour-intensive methods with manual data handling and semi- or fully automated measuring equipment with enhanced electronic data processing are used, depending on the circumstances and sophistication of the agency.

VI.4. CHARACTERISATION OF ROAD CONDITION

The information obtained from road condition surveys serves multiple objectives. The most important questions needing answers are:

-- What are the conditions or trends at a particular location of a network, or where are the locations with a certain condition?

-- On an aggregate basis and on average, what is the road condition as it appears to users?

To answer these questions two major types of data need to be collected: data on traffic conditions and data on pavement conditions.

Data related to traffic and climate exogenous to surface and road structure are dealt with here very briefly. The most important factors are (see also Figure VI.1):

traffic: gross load
axle and wheel configuration
frequency of load applications
speed

climate: rainfall
daily variation of temperature
frost heave
freeze-thaw and wet-dry cycles

In collecting traffic data, relationships between average daily volumes (considering vehicle type classification) and associated axle load distributions should be well established. This is essential for predicting future cumulative loads on road sections and assessing their residual lives in combination with pavement strength evaluation. These data, together with an evaluation of overloading risks and climatic conditions, are required to properly design rehabilitation or periodic maintenance measures for the purpose of extending service lives of pavements.

For road condition and for road management systems the level and amount of data required will have to be cut down for practical reasons to a necessary, but sufficient amount in order to make the network and project maintenance management operational. This depends on the methodology adopted. The methodology can assume that the concern of rehabilitation/maintenance is either on the functional condition of pavements (stressing surface characteristics conditions) or on the structural conditions of pavements (strength, bearing capacity and residual life oriented), or both. Because this report is concerned with both rehabilitation and periodic maintenance the interest is on both surface characteristics and the structure.

Research conducted for determining the important factors to characterise pavement condition suggests that they can be classified into three groups: surface, pavement and structure. Roughness (unevenness), rutting, and distress[1] appear to be the most important surface and pavement characteristics. Roughness has been shown to have a strong relation to car and truck operating costs and also encompasses many of the road condition attributes captured by rutting and distress. However, distress and rutting have their own causal factors and, often require different engineering interventions, so that they should be kept separate from roughness. As for pavement strength, structural number or residual life (bearing capacity) can be derived from test results.

A further consideration in quantifying surface, pavement and structural conditions is that the dimensions adopted should relate on the one hand to causal factors and, on the other, to engineering decisions to intervene with maintenance works. The features and dimensions used to quantify surface distress conditions and pavement structural conditions should help determine when the pavement has reached a condition which requires periodic maintenance or rehabilitation and what action should be taken.

In sum, then, besides geometry characteristics, the road endogenous factors are related to surface, pavement and structure, for example:

surface	roughness
and	rutting (including material loss due to studded tyres in some countries)
pavement	distress
structure	strength
	rutting (deformation)
	depth to water table

Finally, it is noted that rideability assessment can also be obtained from pavement condition monitoring by measuring road roughness. Roughness can also be related to traffic level-of-service (speed) and vehicle operating costs.

1 A study by Hajek and Haas -- HAJEK J.J. and RALPH HAAS (1987). *Factor Analysis of Pavement Distress for Surface Condition Predictions.* A Paper presented at the Annual Meeting of the Transportation Research Board. Washington, D.C.-- identified five factors of pavement distress, four of these described different kinds of cracking.

VI.5. MEASUREMENT OF ROAD CONDITION

There are combinations of procedures and measuring equipment that can be used to collect data on road and traffic conditions. It is not the scope of this report to make an exhaustive and detailed analysis of this topic, instead, only the principal features of the procedures and equipment are indicated.

Monitoring of a network will generally be performed in a staged manner. The hierarchy chosen is that discussed in Section VI.3 "Levels of Monitoring". Scoping, at Level I, is preferably done using fast monitoring methods, although that depends on the accuracy imposed. Monitoring at levels II to V will focus in detail on functional and structural road conditions.

However, the hierarchy of the levels is by no means orthodox. While those set out above are in agreement with the analytical procedures encouraged in this report, the primacy of one level over the other is a matter of debate and will depend on whether the issues at stake are on maintaining surface characteristics to a standard, which respond to performance (economic) criteria, or whether the aim is at preserving structural integrity (which extend the residual life of the road). Although these issues are coupled, the priorities will be dictated by whatever methodology is adopted.

Monitoring is often performed in an order which successively scans the characteristics related to:

-- the surface,
-- the pavement (layers), and
-- the structure (down to the soil).

Surface monitoring concerns the impacts of vehicle interaction. Pavement monitoring is concerned with mechanical fatigue and environmental distress of layers. Structural controls are linked to bearing capacity and, therefore, to service life.

VI.5.1. Surface conditions

When beginning to establish systematic road condition monitoring, there is general consensus that the first priority is to obtain rapidly a complete assessment of the road network surface condition. How this is done depends on the sophistication of the Road Administration.

The first time monitoring is undertaken, it is commonly done by a visual inspection survey combined with an evaluation of riding comfort. This effort usually is the reconnaissance aimed at estimating the overall relative distribution of network condition states and serves as a precursor for more advanced assessment. The drawback of this is its subjective character; the visual evaluation and rating will rest entirely on the expertise and judgment of highway engineers.

In subjective rating the following categories are normally used:

Good: Substantially free of defects and requiring only routine maintenance,
Fair: Significant defects; requiring periodic maintenance,
Poor: Extensive defects; requiring reconstruction or strengthening.

Complete coverage of the network can also be made through an automatic continuous measurement of pavement roughness (unevenness). Roughness is the most appropriate and sensitive parameter to be measured, particularly in view of condition trends. Although a high level of accuracy, in contrast with other highway characteristics, is required to measure roughness, technology has developed a range of reliable high speed equipment. Roughness (caused by longitudinal deformation of road profiles) is a product of both construction quality and a combination of distresses, it can be considered as the final signature of distress. It is also the aspect of road surface condition that mostly influences vehicle operating costs.

Another surface characteristic parameter that can be continuously monitored is skid resistance. Its measurement is based on a road friction test (for which a standard exists) which can produce either a transverse friction coefficient or a longitudinal one. Both are useful indicators for locating zones which are an accident hazard due to skidding. A new generation of monitoring equipment currently under development evaluates the surface textures from which skid resistance is inferred. Surface texture also has the potential for measuring surface drainage conditions and for being associated with some components of vehicle operating costs (tyre wear and fuel consumption).

When objective measurements are used, surfaces are no longer subjectively classified as 'good', 'fair', and 'poor', instead ranges of roughness (and skid resistance) values are used to classify the surface condition.

VI.5.2. Pavement distress

The distress patterns of pavements generally involve cracking (narrow and wide), materials losses (ravelling, disintegration, potholing) and deformation (rutting, plastic deformation in flexible pavements; settling, depressions and slab stepping and pumping in rigid pavements). Monitoring these features requires the ability to recognise the types and patterns of defects and quantify their severity and extent. Excepting the well configured case of rutting, for which automatic methods of measurement have been developed, all other distress conditions still rely on labour intensive visual inspection.

In visual inspection, catalogues are used to recognise the types of distress. They are quantified by averaging the extent of the area occupied by the distress over an arbitrary section of the road surface. A classification into three to four groups is normally used to quantify distress. In visual condition assessment, tentative explanation is provided for the probable cause of deterioration.

Research and development are under way to improve distress measurement by means of pattern recognition through electronic imaging of surface distress.

VI.5.3. Structural capacity

The objective of monitoring the structure is to provide information for strengthening pavements through overlaying or other rehabilitation measures[1]. Data are collected on either strength or bearing capacity of the road structure, or both.

For strength, a semi-destructive static fixed point test is available using the dynamic cone penetrometer. The data collected will contribute to evaluating the structural number of the layers and subgrade. The structural number is often calculated from the design data and adjusted for traffic and environment.

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1 OECD, Road Transport Research (1993). *Road Strengthening in Central and Eastern European Countries.* OECD, Paris.

Non-destructive methods have been developed to derive bearing capacity (remaining life) or structural number from deflection data. Four general classes of equipment are routinely used to collect deflection data:

-- Static Beam Deflection Equipment (Benkelman beam),
-- Automated Deflection Equipment (Deflectograph, Curviameter),
-- Steady State Dynamic Deflection Equipment (Harmonic Induce Load),
-- Impulse Deflection Equipment (Falling Weight Deflectometer).

Adopted rehabilitation designs must be field calibrated for local conditions and materials by the help of one of these methods.

Due to the low yield rate of measurement provided by these types of equipment there is a tendency to confine this mode of evaluation to the poorest condition class of roads for which annual or semi-annual roughness and distress condition data exist. Given that bearing capacity wears away slowly, its measurement fits perfectly to a rotating programme for road links and data are collected every four to five years, the intermediate years being estimated through a model. Structure evaluation is always done when designing road strengthening, in which context some additional local information is collected, such as:

-- drainage conditions (water table level and moisture content),
-- material properties (laboratory analysis of samples).

VI.5.4. State of engineering structures

The condition of engineering structures, bridges, tunnels and viaducts is evaluated on the basis of regular and thorough visual inspections. Periodically and when necessary special instruments are used to evaluate particular components of complex structures such as a piled foundations of bridges. This evaluation allows the structural condition of the engineering structure to be ascertained, superficial decay to be detected, deterioration to safety components (bridge parapet, guard rails, etc.) to be identified and protective coatings on metal surfaces to be assessed.

Some countries have at their disposal an operational system (for instance SCORPION) using gamma and X-rays, thermal mapping, georadar and other technologies enabling a thorough but non-destructive inspection of engineering structures. Important engineering structures, such as bridges, have their own special purpose management systems. Increasingly these systems have become a part of the same system used for roads. To be sure, the principles put forward in this report for resource allocation and distribution on roads can, and should, be also used for bridges[1].

VI.6. ROAD CONDITION MEASURING DEVICES

The quality and condition of the pavement are considered by the road user and road manager to be the most important parameter to assess the quality of the road changes with time and traffic, it is desirable to have quick, reliable and automatic systems of collecting and storing data. In the past few

1 See the aforementioned OECD Bridge Management report.

years, measuring devices have become automatised, the validation and some analyses of data are carried out by computers onboard the vehicle. Even relatively old measuring equipment are now modernised and computerised. This virtually eliminates data reduction and transcription errors and allows data collection on a large scale, at network level. Several multi-parameter devices are available on the market, such as the Canadian ARAN (Automatic Road Analyzer), the Swedish RST (Road Surface Tester), or the French SIRANO (Système d'Inspection des Routes et Autoroutes par Analyses Numériques et Optiques).