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Road quality service levels and innovations to meet user expectations

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SUMMARY

1 – In the past 20 years, the Portuguese road network has been under considerable development, not only in terms of coverage of the country, improving accessibilities, but also in terms of infrastructure quality in an endeavour to meet road users expectations. These expectations include higher speed, comfort and safety on the road.

This development is presently based on the National Road Plan drawn up in 2000, which structured the national road network, to a total of about 11,500 km, and defining a B minimum level of service (as established in the Highway Capacity Manual) for main routes, involving about 3 000 km, and a C minimum level of service for the remaining extension of the network.

2 – In order to guarantee the desired levels of service and adequate road safety, projects must comply with the Portuguese Road Administration (IEP) standards, which cover the geometry of the layout, traffic signing and road safety, as well as the other components of the project.

A nationwide project has recently been launched (SEQUER – Road Safety, Quality and Efficiency – 2000 to 2006). It is managed by IEP and involves a number of initiatives, such as defining the criteria for assessing the performance of infrastructures, setting up a safety auditing system and conducting in-depth investigations of accidents in the road network and any corrective measures that need to be taken. More than 30 public and private bodies are involved in the project, all linked to the planning, construction or operation of the network. The estimated funding is about EUR 9 million.

3 – Road users give high priority to the quality of road pavements, which affects the riding quality. The performance indicators that are used to describe it are defined in the road administrations' standards (IEP or motorway concessionaires). They vary, depending on whether the pavements are newly built or already in use and, in the latter case, they are related to the maintenance management systems adopted for each type of network. The performance indicators usually considered are surface distress, longitudinal and transverse unevenness, adhesion indicators (friction and texture depth) and bearing capacity (deflection).

4 – Pavement maintenance in the national network not under concession is currently performed through maintenance contracts. In the network under concession, routine maintenance is performed directly by the concessionaires whereas periodic maintenance, and especially rehabilitation works, are carried out by contractors.

5 – The maintenance techniques currently used are described in the report. The increased use of *in situ* recycling using emulsion and/or cement and in plant recycling are also mentioned. The use of foam bitumen, asphalt rubber and high-modulus bituminous mixtures is also becoming more common. Porous asphalt is usually used for wearing courses in areas with higher rainfall, while ultra-thin friction asphalt concrete layers are used in other areas.

6 – Maintenance works usually lead to traffic constrains. Traffic is diverted onto part of the carriageway and, eventually, on the hard shoulder previously strengthened, or diverted onto temporary diversions built off the carriageway. On motorways, the traffic is transferred to the carriageway not undergoing maintenance, at least during the construction of the wearing course. In urban areas and heavily trafficked roads (typically carrying more than 30,000 vehicles a day), the work is done at night time (10 p.m. to 6 a.m.).

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1 – INTRODUCTION

In the past 20 years, the Portuguese national road network has been under considerable development, not only in terms of coverage of the country and cross-border connections, but also in terms of the quality of the infrastructure.

The preparation of laws and regulations governing this development has naturally been the responsibility of the central Administration operating in this area, though there has also been some participation from population through local authorities (municipalities) and associations representing certain interests, such as environment and road safety. In many cases, the local populations, both the people who will be served by the infrastructures and the actual road users, have made important contributions for improvement of the solutions adopted, through a number of mechanisms such as: surveys and public hearings used in the assessment of the environmental impact of new projects, contacts between local authorities and associations and the central Administration and investment promoters, and sometimes the presentation of complaints and some pressure through the media.

2 – THE ROAD NETWORK AND QUALITY OF THE LAYOUT

2.1 – THE NATIONAL NETWORK AND LEVELS OF SERVICE

This improvement of the country's road network was based on the National Road Plan drawn up in 1985 (PRN 85), which substantially remodelled the previous plan, which dated back to 1945. The experience gained during more than 10 years of implementation of the PRN 85, and the socio-economic developments in Portugal after joining the European Union dictated the need to new plan. This plan was published in 2000.

The National Road Plan – PRN 2000 is a legal document, defining the mainland road network of domestic and international relevance. Its main goals are the development of regional potential,the appropriate articulation and reduction of costs of the transport system, the improvement of road safety and the satisfaction of international traffic needs.

According to the plan, the country's road network consists of the "fundamental" network (main routes) and the "complementary" network. The PRN 2000 also established a regional category of public roads of supra-municipal interest – "regional roads".

The “main routes“ are the roads of highest national importance. They support the whole national network and interconnect the main cities with supra-district influence. They also connect these cities with the main ports, airports and borders.

The complementary road network connects the main routes to major cities and consists of “national roads“ and “complementary routes“. These include the main roads surrounding and providing access to the metropolitan areas of the country’s largest cities, Lisbon and Oporto.

The extension of the national road network established by the PRN 2000 and the minimum level of service (according to the definition of the Highway Capacity Manual – Special Report 209 – TRB) are as follows:

- Main routes 2,600 km level of service B
- Complementary routes 3,550 km level of service C
- National roads 5,350 km level of service C

In addition to the levels of service, the PRN 2000 defines which stretches of the main and complementary routes should have motorway characteristics.

In order to speed up the completion of the motorways included in the PRN 2000 without the State’s direct investments reaching levels exceeding the European Union’s convergence criteria, the Government decided in 1997 to launch a call for tenders for 30-year concessions to plan, build, finance, operate and maintain the new stretches of motorway included in the PRN 2000, so increasing to 2 700 km the total length of motorways under concession.

For reasons of inter-regional subsidization, insufficient traffic flow, absence of toll-free alternatives, etc., a user toll-free system (or SCUT) was introduced for the first time in Portugal. Under this system, the State pays the concessionaire directly, on the basis of the traffic flow. This type of solution, which is in use on some motorway sections, is currently being reassessed with respect to the concessions with real tolls.

Until 1997, there was only one concessionaire in Portugal – BRISA – operating with real tolls, i.e. the concessionaire collects tolls directly from users. In 1997, the market was opened to competitors.

2.2 –LAYOUT DEFINITION

2.2.1 – Design phases

Road design are developed in several phases. The following are usually the most important:

a) Preliminary study, usually at a scale of 1/5000, in which a comparative analysis of several alternative layouts passing through compulsory locations and complying with the levels of service established for the road in question is performed.

   The comparative analysis considers the quality of the layout, in terms of horizontal alignment and longitudinal profile, constructibility, including geotechnical and drainage aspects, environmental impact and costs.

   One of the most important parts of this phase is the environmental impact study, which analyses compliance with applicable environmental standards and compares the impacts of, and the minimising measures required by the different solutions envisaged.

   The preliminary studies and their environmental impact studies are then submitted to a number of bodies and made available to the public for consultation and discussion in public hearings.

b) Preliminary design, generally at a scale of 1/2000 or 1/1000, which is the development of one or more of the solutions considered in the preliminary study, including any adjustments or alterations suggested during its analysis. This phase is not always performed and the process may proceed directly to the next phase.

c) Execution design, generally at a scale of 1/2000 or 1/1000 with a complete description of the works.

2.2.2 – Quality of Layouts and Traffic Safety

2.2.2.1 – Road designs must comply with the standards laid down by the Portuguese Road Administration (IEP) in terms of geometry of the layout, traffic signing and other components of the design.

The aim of these standards is to achieve convenient and safe layouts, providing the desired riding conditions (levels of service). Particular recommendations are made with regard to the coordination between the horizontal alignment and the longitudinal profile and the homogeneity of the layout.

The idea is to meet road users main needs, which are based mainly on speed, comfort and safety on the road.

2.2.2.2 – In spite of the care taken with road designs, the accident rate on the Portuguese roads is high, and many efforts have been made since many years ago to study their causes. This includes detecting and analysing accident black spots, studying guidelines for corrective measures and, more generally, examining the characteristics of the traffic (such as speeds) on the basis of the geometric characteristics of the roads.

2.2.2.3 – This concern for the quality and safety of road infrastructure was recently embodied in a nationwide project included in the Operational Accessibility and Transport Plan (POAT 2000-2006). This project, called *SEQUER – Segurança, Qualidade e Eficiência no Sector Rodoviário* (Road Safety, Quality and Efficiency) has an estimated funding of EUR 9 million and is being managed by IEP in articulation with the Portuguese Road Centre (CRP), a technical association of public and private bodies working in the field of road infrastructure. More than 30 other bodies from different sectors (administration, motorway concessionaires, universities, industry, professional associations, road users, etc.) are also participating in the project.

It is organised around five basic work package, including:

a) defining criteria for assessing the performance of road infrastructure, including the identification of performance indicators to be considered into operating concession contracts and in road maintenance and rehabilitation contracts;

b) creating a road-safety auditing system, including the preparation of “auditing manuals” and the training and accreditation of auditors;

c) studying accidents in the road network, including methods for accident diagnosis, criteria for studying accident black spots, monitoring the number of accidents and evaluating the efficiency of corrective measures at black spots, re-assessment and updating of the national accident database and issuing of recommended (preferably low-cost) measures to reduce accidents.

3 – PAVEMENT QUALITY

3.1 – QUALITY REQUIREMENTS FOR NEW ROADS

3.1.1 – General considerations

The quality requirements for new road pavements are laid down in IEP specifications as a national reference, and also in the specifications of the concessionaires which have to be approved by the IEP.

As usual, they cover the characteristics and application of the materials in the different layers and the foundation and also the surface characteristics of the pavement layers. IEP specifications consider the following parameters and values.

3.1.2 – Deviations from the Design

Deviations from the design in the longitudinal section and cross-section should be less than 1.5 cm at any point.

3.1.3 – Unevenness

Unevenness measured with a 3-metre fixed or mobile straightedge should not exceed the values shown below.

Unevenness	Wearing course	1st layer below	2nd and underlying layers
Longitudinal unevenness	0.3 cm	0.5 cm	0.8 cm
Cross-section unevenness	0.5 cm	0.8 cm	1.0 cm

Except for smaller or less important works, longitudinal unevenness is also measured using a laser or APL profilometer on the two wheel tracks of each lane, at sampling intervals of 0.25 m. The unevenness is expressed by the average IRI (m/km) of the two wheel tracks, calculated for 100 m long sections, and it should fall within the following values:

Layer	Percentage of extension of the work		
	50% (50%)	**80% (75%)**	**100% (90%)**
Wearing course	≤ 1.5 (≤ 2.0)	≤ 2.5 (≤ 2.5)	≤ 3.0 (≤ 3.0)
1st layer below	≤ 2.5	≤ 3.5	≤ 4.5
2nd and underlying layers	≤ 3.5	≤ 5.0	≤ 6.5

NB: The figures in brackets are for rigid pavements.

3.1.4 – Texture

The texture depth of the wearing courses, measured by the sand patch method, should fall within the following limits.

Type of layer	Texture depth (mm)
Asphalt concrete	≥ 0.6
Porous asphalt	≥ 1.2
Friction asphalt mixture layer	≥ 1.0

3.1.5 – Friction coefficient

The transverse friction coefficient continuously measured with the SCRIM equipment, should be no less than 0.4 when the measurements are made at 50 km/h.

3.2 – QUALITY REQUIREMENTS FOR EXISTING ROADS

The quality requirements for existing roads are generally related to the maintenance management systems adopted.

In Portugal pavement maintenance management systems (PMS) are being set up or are already in use for the motorways under concession. Several years ago, a pavement management system was studied for the main network not under concession, but it was not yet applied due to the reorganisation of the road administration. The process is now under way again.

3.2.1 – BRISA's Pavement Management System

BRISA has adopted the Spanish pavement management system GEFIREX, with adequate adjustments, in which the pavement condition indicators, under systematic monitoring, are surface distress (potholes, cracking), longitudinal unevenness, rut depth, deflections measured at 100 m intervals with a Falling Weight Deflectometer (FWD) and skid resistance expressed by the transverse friction coefficient measured with the SCRIM equipment.

Condition surveys are generally carried out every four years, though they may be conducted more often in case of unusual surface deterioration or unexpected traffic growth.

The thresholds for "recommended action" and for "compulsory action" are as follows.

Indicator	Action	
	Recommended	**Compulsory**
Potholes (% of area)	≥ 5	≥ 10
Cracks (% of the area)	≥ 10	≥ 15
IRI (m/km)	≥ 3	≥ 3.5
Rut depth (mm)	≥ 5	≥ 10
Deflections (μm; 78 kN load)	≥ 700	≥ 900
Skid resistance	≤ 0.5	≤ 0.4

The performance models for the different indicators adopted in this pavement management system are based on the HDM models developed by the World Bank. Selected test sections of the motorways are being periodically monitored in order to calibrate the default models.

3.2.2 – The Pavement Management System in the Network not under Concession

3.2.2.1 – The performance indicators used in the pavement management system developed in 1995 for the network not under concession are surface distress, longitudinal unevenness, bearing capacity (deflection) and, in addition, skid resistance (transverse friction coefficient).

The pavement condition is classified with respect to each performance indicator, depending on the traffic category, defined as follows:

Type of Traffic	Annual Average Daily Traffic
1	< 3000
2	3000 – 8000
3	> 8000

The classes of deflection measured with a Lacroix deflectograph and expressed in hundredths of a millimetre are as follows.

Class of deflection	Type of traffic		
	1	2	3
1	< 100	< 70	< 40
2	100 - 150	70 –120	40 - 80
3	> 150	> 120	> 80

Pavement distress is expressed by its density (D_i) and severity (S_i), considering only cracking in its different stages of development. Four types of distress density are considered (D_0 to D_3), depending on the deteriorated area. Four types of severity of deterioration (S_0 to S_3) are used, depending on the area of most serious cracking (alligator cracking). The combination of D_i and S_i defines 10 classes of surface distress (D_0S_0 to D_3S_3).

Longitudinal unevenness is characterised by wave band marks (notation par bandes d'onde, NBO, in French), mainly in short-wave band, obtained using French APL equipment. The classes of unevenness considered are as follows.

Classes of longitudinal unevenness	Type of traffic		
	1	2	3
1	> 6	> 6	> 7
2	4 - 6	5 and 6	6 and 7
3	< 4	< 5	< 6

Unevenness can also be defined by IRI through the ratio between this indicator and wave band marks.

Taking into account the number of classes of deflection (3), of distress (10) and of longitudinal unevenness (3), it is possible to define 90 possible “states of pavement condition”, characterised by a number that acts as an overall indicator, while still showing the importance of each component defining the “state of the pavement condition”.

There are two alternative maintenance actions associated with these “states” and they may be of a functional or structural nature. Generally speaking, for each parameter, class 3 corresponds to the need for structural rehabilitation, while class 2 represents an alert, after which it is advisable to monitor the pavement condition more closely.

Skid resistance is assessed by the transverse friction coefficient and three classes are also defined.

Class	Transverse friction coefficient
1	> 0.65
2	0.35 – 0.65
3	< 0.35

This parameter is not directly considered in the pavement management system. Class 3 stretches are considered to need action to restore safety conditions.

3.2.2.2 – Although the system described above has not yet been put into practice, further research has been undergoing, in order to search for more adequate thresholds for the condition indicators namely longitudinal unevenness and surface distress since these are the ones that road users consider most important when characterising the quality of pavements.

A study on longitudinal unevenness conducted recently included: i) a profilometer evaluation of the unevenness of 50 road sections with IRI ranging between 0.5 and 10, ii) evaluation of the accelerations induced to an instrumented vehicle when riding on these sections and iii) evaluation of the quality of the pavement by a panel of road users (graded from 1 to 10).

The aim of the study was to develop a model relating the classification given by the panel to the indices defining unevenness, i.e. the IRI and the short, medium and long-wave marks.

The conclusions drawn from the study were:

a) the wave band marking, especially short wave, provides a better characterisation of riding quality, as assessed by the panel, than the IRI. However, the IRI-based models were still considered satisfactory;

b) the wave band marking has the advantage of being able to diagnose defects in the three bands and therefore provides better guidance to the selection of rehabilitation works needed to achieve a particular quality (for example, number of layers to be applied and type of levelling system to use in the paver).

New unevenness specifications were proposed for rehabilitation works on the basis of this study.

3.2.2.3 – In 1999 a programme for systematic visual assessment of the network pavements condition went into operation in order to reassess the condition indicators of the network and define the actions to be taken. The data obtained are being processed and collected in a database.

Pavement condition control are being made by district management bodies (Road Directorates) at two levels of intervention. One implies either surface rehabilitation or the adoption of simplified structural rehabilitation solutions, according to a ″Flexible Pavements Rehabilitation Manual″ which follows the orientation described in 3.2.2.1. The other, corresponding to more complex situations, implies the intervention of special units from the Road Directorates--Operational Centres.

3.2.3 – Pavement Management Systems in Municipal Road Networks

In recent years, pavement management systems have been developed for the road networks of two large cities, Coimbra and Lisbon.

These two systems have identical structures to those for the rural roads and, in both cases, the pavement condition is defined by the IRI_t (mm/km) in year t, the average rut depth R_t (mm), the area of cracking C_t ($m^2/100m^2$), the area of surface defects (potholes and ravelling) S_t ($m^2/100m^2$), and the repaired area P_t ($m^2/100m^2$), through the global PSI (Present Serviceability Index) defined by the equation

$$PSI_t = 5.e^{-\frac{0,0002598.IRI_t}{4}} - \frac{0,002139}{4}.R^2{}_t - 0,21(C_t + S_t + P_t)^{0,5}$$

This equation is an adaptation to urban conditions of that used by the Nevada DOT (USA).

The type of performance models used to describe the evolution of the pavement condition in the Coimbra PMS is probabilistic, whereas the model used for Lisbon are deterministic. Both systems include optimisation models that aim at minimising total costs (maintenance costs, road user costs and the residual value of the pavement).

4 – ORGANISATION OF ROAD MAINTENANCE ACTIVITIES

4.1 – NETWORK NOT UNDER CONCESSION

The work involved in maintenance activities on roads not under concession – periodical maintenance and routine maintenance – is under the responsibility of the Road Directorates. Today, the model for management of human resources and equipment involves external contracting for most of the work, while the Road Directorates merely play a supervisory role.

Periodical maintenance activities, which mainly includes functional rehabilitation of the pavements, have been done by private contractors for a long time now. This is due to the increase in the size of the network and to the technical innovations in terms of materials and technology, which requires large investments in equipment and human resources quite incompatible with the management models usually adopted by the central administration.

Routine maintenance, which includes activities more of an environmental and corrective nature, such as pothole filling, grass mowing, maintenance of shoulders and ditches, cleaning pipes and maintenance of traffic signs and guardrails, is also being gradually contracted out due to the shortage of human resources available in the Road Directorates.

The present general shortage of human resources led to the decision to hire private contractors for routine maintenance throughout the road network not under concession. The model adopted involves two contracts per district, making a countrywide total of 36 routine maintenance contracts. Some of the contracts are already ended, while others are subject to calls for tenders or their bids are currently being analysed.

Activities associated with the road environment will normally be carried out twice a year on main routes, complementary routes and roads with substantial amounts of traffic and once a year on other roads. These contracts are for price series for the quantities envisaged based on the characteristics of the road network and levels required. The contractor does the work in accordance with the quantities predicted in the plan.

Experience gathered with these contracts has been positive, especially with regard to programmable activities, where it is possible to achieve high outputs. Activities of a more corrective nature, such as pothole filling, have been less effective, as the appropriate human resources and equipment are not always available and it is therefore necessary to adapt the programme.

Structural rehabilitation works are usually planned by consultants and carried out by contractors.

4.2 – NETWORK UNDER CONCESSION

The concessionaires' regional bodies have the resources needed for routine maintenance, as failure to carry it out rapidly (pothole filling, patching, traffic sign and guardrails repairs, etc.) may affect safety, due to the high speeds practised on these roads.

Periodic maintenance works (improving the functional and structural quality of the pavements) are usually subject to detailed plans, divided into stretches of about 20 km between interchanges, and are carried out by contractors.

5 – MAINTENANCE TECHNIQUES

5.1 – TECHNIQUES USED

5.1.1 – The most appropriate technique for each case is selected after a diagnosis of the causes of the deterioration and, often, on the basis of the knowledge about the existing pavement structure and material characteristics, traffic flow, climatic conditions and other parameters, taking into account the different rehabilitation procedures available.

Maintenance techniques vary, depending on whether the objective of the work is surface rehabilitation, structural rehabilitation, or both.

5.1.2 – For surface rehabilitation the most common techniques used are:

a) surface sealing in order to seal small cracks that not yet require structural rehabilitation, preventing penetration of water and other materials, also contributing, to some extent, to structural maintenance, by preventing or delaying the progress of deterioration;

b) pothole filling using cold bituminous mixtures with grading between 0/25 and 0/12.5, depending of the thickness of the treatment;

c) application of ultra-thin layers (cold bituminous mixtures, slurry seals, surface dressings, etc.), which do not make any significant improvement on the structural capacity, but renew the pavement and correct surface defects.

These techniques are used to improve the pavements skid resistance, when problems like bleeding or aggregate polishing occur at the surface, especially in specific locations like bends, high gradient sections, fast stretches, etc., and other critical areas with poor visibility caused by splash and spray or light reflection;

d) grooving of the pavement, application of pre-coated chippings, surface dressings, porous asphalt and thin or ultra-thin friction asphalt concrete layers to improve macro-texture or adhesion between tyre and pavement, especially in rainy weather;

e) in the case of rigid pavements, which are not commonly used in Portugal, the joints are periodically repaired, with replacement of joint sealants, edges repairs and cracks sealing.

5.1.3 – Structural rehabilitation techniques almost always include pavement strengthening by applying bituminous overlays. Given the increase in traffic flow observed in recent years in Portugal, this is often applied in thick layers (until 15 cm or even more).

Preparatory works are usually carried out before strengthening, depending on the types of distresses identified during visual inspections of the pavement's surface. Those most frequently used are:

a) localised reconstruction in any areas where the pavement has significant settlements. This phenomenon is generally caused by deterioration in the underlying granular layers at sensitive points, due to construction deficiencies, inadequate bearing capacity of the subgrade or even insufficient drainage.

This reconstruction may also be carried out in areas where there has been localised heave of the pavement caused by the roots of trees growing alongside the roads.

In some places with substantial deterioration, the reconstruction includes removing all the layers of pavement and about 20 to 30 cm of the subgrade soil and replacing with new materials.

b) milling of bituminous layers that are seriously cracked or that are found to be separated from the underlying layers.

The bituminous layers removed by milling are replaced with the same thickness of new bituminous materials usually a dense mixture with a grading adjusted to the thickness to be applied.

The milled material used to be thrown away, but today's projects usually foresee the reuse of these materials in embankments of bypasses or even recycling them for use in overlays.

c) filling depressions, especialy rut filling, using bituminous concrete in order to re-profile or plane the pavement's surface before strengthening. Bituminous mixtures are often hot mixed, with a range of gradings, depending on the depth of the depression to be filled.

d) crack sealing using the same materials as in surface rehabilitation works as well as cold asphalt mixtures (asphalt mortars and slurries), and hot bituminous mortar (SAMI), mainly applying those containing bitumen modified with elastomers in order to minimise the reflective cracking.

In some situations, geogrids and bitumen impregnated geotextiles are used. They are attached to the pavement and covered with slurry-seal or similar materials.

Sometimes the combination of two types of treatment may be advisable, such as the application of a bitumen mortar with modified bitumen to seal cracks and dense bituminous mixtures for re--profiling.

5.1.4 – The application of a tack coat to ensure that the layers work together in the whole structure of the pavement is always mandatory. Modified bitumen emulsion is usually used as it allows application rates of 0.4 to 0.8 kg/m^2. Higher values are applied in cases where the layer is badly cracked or aged.

5.1.5 – To reduce the risk of accidents, wearing courses with better adhesion have been used on main routes and many other roads. Porous asphalt is used in the rainier areas of the country, such as the northern region, while in the rest of the country ultra-thin friction asphalt concrete layers are normally used. Modified bitumen with the appropriate polymers is used in these bituminous mixtures.

Porous concrete is an open-graded mixture 0/19 type applied in thickness between 4 and 5 cm (thin layers), which ensure drainage of surface water to the shoulders, excellent visual comfort (no splash and spray) and acoustic comfort (inside and outside the vehicle) on the road. The reduction in the noise produced has led to its adoption on urban roads, even in drier areas.

Ultra-thin and thin friction asphalt concrete are bituminous mixtures with gap grading, rich in bituminous binder. The thin layers have 0/19 type and are applied in a thickness of about 4 to 5 cm. The ultra-thin layers have 0/12.5 grading and they are applied in thicknesses of 2 to 3 cm.

5.2 –RECENT DEVELOPMENTS

Recently, high-modulus bituminous mixtures have been used in maintenance works, in order to reduce the required overlay thickness, either for environmental reasons or to keep the surface levels of the pavements, especially in the case of cross-town links.

In the past few years, deteriorated bituminous mixtures have been recycled either *in situ* or at plants. Cold *in situ* recycling most common uses bituminous emulsions. Plant recycling is also used, mainly when there are significant quantities of milled materials involved.

In *in situ* recycling, the deteriorated material from the initial construction is recycled to form a new layer of pavement with improved mechanical resistance. The processing involves adding the following materials, either separately or combined: water, to help compaction, cement, lime or other chemical stabilising agents, a bituminous stabilising agent (emulsion) and, sometimes, new aggregates to improve the grading or mechanically modify the recycled material. The bituminous binder is therefore a generally slow-breaking cationic bituminous emulsion of bitumen with penetration ranging from 50 to 180, with or without the addition of rejuvenators to rehabilitate the aged bitumen. The addition of 1% to 2% lime or cement facilitates or accelerates the breaking of the emulsion, reducing water susceptibility, especially in clayey or contaminated materials and increasing the cohesion of the resulting material. Sometimes, in-situ recycling is done using two types of binder (bituminous and hydraulic); this is often called mixed cold recycling. The thickness of the recycled layers is generally 12 to 15 cm, with a maximum of 20 cm. Thicknesses less than 5 to 6 cm has not been used. From the experience gather so far, we can conclude that it is not possible to achieve an efficient cure and good compaction in the lower part of the layers, if thicknesses over 15 cm are used.

One of the difficulties involved in using this technique is the sensitivity of the process to factors such as water content and the grading of the aggregates, weather conditions, and the absence of regulatory documents.

The recycled material has the characteristics of base course material and is therefore not used as wearing course. Even though cold *in situ* recycling is almost always completed with the addition of a wearing course, normally with a minimum thickness of 5 to 6 cm, this technique always results in an economy of materials in comparison to the conventional solutions described above.

The present state of recycled pavements after about 10 years of using the technique, and subject to substantial heavy traffic, is mostly good.

Studies and experiments are currently under way using foam bitumen or bitumen expanded by injecting a small quantity of cold water into hot bitumen during *in situ* recycling. The physical properties of the bitumen change temporarily, and its volume increases substantially (10 to 20 times) for a short time. This process considerably reduces the viscosity of the bitumen, which makes it possible to add cold and even wet aggregates, natural aggregates or sand and even low-plasticity clay.

Plant recycling by conventional methods involves milling techniques and production of hot bituminous mixtures. This type of recycling is sometimes used to take advantage of milled materials from other stretches of road. In these cases, the percentage of recycled material in the composition of the bituminous mixture is no more than 40% to 50% and the bitumen used is generally softer.

Another recent technique used in Portugal is *in situ* recycling with cement, mixing an hydraulic binder, water to hydrate the binder and possibly aggregates to correct the grading and additives. The amounts of cement used are no more than 5%. Due to the thermal shrinkage of these materials, it is normal to use transverse pre-cracking. A layer of bituminous mixture using bitumen modified with elastomer or rubber is usually applied on top of the new layer as an alternative to pre-cracking.

The use of asphalt rubber is a recent technique in Portugal. It first appeared as a way of protecting the environment. The powdered rubber is obtained cryogenically from recycled tyres.

The process consists of cutting up the tyres and then freezing the pieces with liquid nitrogen to a temperature of -180ºC for about five minutes. The frozen product then goes into a hammer mill and, when it breaks up, the three components of the tyres, rubber, fabric and steel, are separated. The steel is removed magnetically and the fabric by suction. The resulting rubber powder then passes through a dryer drum to remove moisture and through sieves into a silo, according to its grading. After being milled to round off the particles, the powder is put in sacks.

6 – MINIMISING INCONVENIENCE TO ROAD USERS

The network of roads not under concession has no formal internal procedures for minimising inconvenience to road users. During the planning stage, an analysis is made of the need for a specific operating file, covering these aspects, which will be included in the file of the call for tenders.

In general, it is the contractor's responsibility to establish procedures for minimising inconvenience to road users and they are included in the work plan submitted to the client for approval.

The aspects generally considered are traffic diversions, in coordination with the different phases of the work, and signing of the site.

These diversions may mean that work is done on only part of the roadway while the traffic is diverted to the other part and to the shoulder especialy strengthened, or sometimes to provisional diversions built off the roadway.

It is also important to install safety devices and appropriate signing.

Where signing is concerned, the procedures used are those laid down in the Temporary Signing Manual (JAE-1997), which abides by Portuguese legislation on the subject. It is applicable to both single and dual carriageways.

On motorways, maintenance work often involves constricting traffic. Traffic is diverted to the carriageway not under repair at least when the new wearing course is being applied.

In built-up areas or areas with more than 30,000 vehicles a day, the work must be carried out at night (10 p.m. to 6 a.m.).