Introduction
The evaluation of the effectiveness of a design for a road utility is a rather recent subject. Like any other Economic Science, this one stemmed out from the ever-growing gap between demand and scarce supply to fulfill this very demand due to progressive exploitation of resources. Therefore, reasoned choices must each time result from general and homogeneous criteria able to supply best results at lowest cost for the examined sector.

In the road sector, as for any other Public Work, these aspects are apparent at every stage of the asset-building procedure: planning, selection of the funding system, designing, construction phase and strategy of maintenance Planning for clear reasons of general choices and priorities. The selection of the funding system, either by an annual or multi-annual budgeting or with a deferred payment or franchising, for reasons of depreciation to be included in the cost-benefit balance account. Technical designing for the reasons and criteria to be detailed hereafter. Management strategy in order to determine the actual costs of future operations necessary to preserve road operational and geometrical characteristics.

There are no phases of greater or lesser importance that would require a greater or lesser commitment from the operator. Of course, upstream choices will carry out an effect downstream. Very often, unsatisfactorily results of subsequent sub-phases may involve, at the moment of general planning, a thorough re-evaluation of the previous procedures and choices. Additionally, the skipping or the breakdown of specific stages in the procedure may thwart initial forecasts and lead to objective fall off.

1 Pavement Design Performance
Technical and microeconomic but also macroeconomic criteria are being used in design evaluation. Therefore, such criteria require a cost-benefit analysis to be performed over a range of specification covering a much wider area than issues related to the road itself: social costs for investments and environmental fall out, political and economic benefits for the Society as a whole such as production growth, protection of social classes, income redistribution etc...

These are all very interesting and topical issues, based on the principle of optimisation of a community welfare and concerning mainly the stage when investments are to be planned. The analyses of criteria allowing to appreciate a design effectiveness for a road construction project, at a moment where "macro" aspects have already been set for and subsequent decisions for the technical and economic aspects have to be made yet leads prior to the examination of different hypotheses for action. This approach is used as well to evaluate the pavement only.

1.1 Design Criteria and Methods: Present Situation and Developments
At present, a useful reference for road design is "the Catalogue for Road Pavements", (Commissione "Strade" CNR, 1995). The type of pavement selected according to the type of road, of subgrade and of forecasted circulation during the road useful life; besides any possible combination of parameters as an input, a range of possible solutions to be considered as equivalent as for the resistance to fatigue are given as output. However, a limited amount of maintenance operations should always be budgeted to restore surface characteristics of pavement (Giannattasio, Domenichini, Marchionna et altri, 1993).

A correct design prevents therefore early pavement deterioration. This latter is divided into early deterioration and deterioration deferred in time. The former refers to mechanisms of subsidence when applying the first loads, the resistance threshold of material is overcome. This occurs to rigid pavements under the action of...
exceptional loads while for flexible and semi-rigid pavements, peculiar properties of deformability of asphalt mix avoid to overcome the cracking threshold. Deferred cracks occur when there is a repeated application of loads. Cracks are caused fatigue and/or deterioration after cumulating irreversible deformations. This latter is typical of flexible and semi-rigid pavements. Therefore, in order to design a pavement able to resist against these main causes of deterioration, it is necessary to know the values of the stresses and deformations provoked by vehicle circulation. This is made possible by rational calculation methods.

At present, there is a trend towards the use of these calculation models because of the awareness, among designers, of their actual advantages if compared to models based on charts and formulae resulting from test results. These advantages consist not only in the possibility to forecast cracking and wheel tracking, but also to design pavements able to respond new and different situations. However, this wider range of utilisation should not lead to consider old empirical models as totally overcome, especially the most recent ones that utilise theoretical considerations and development as the ASSHTO guide.

Design criteria adopted for pavement inserted in the Catalogue foresees a fatigue test to be made by the analysis of rational calculation methods and by the utilisation of the above-mentioned empirical-theoretical method. For rigid pavement, a previous test for immediate cracking is made with the passage of an exceptional load and/or a work vehicles used on work sites.

The following types of pavements are included in the Catalogue: flexible, semirigid, rigid in non reinforced concrete and continuously-reinforced concrete.

Design is also based on background conditions such as the type of road, circulation, bearing capacity of subgrade, weather conditions and construction materials.

In addition to the six urban and rural road types provided for by the Road Code two new categories have been added: touristic rural roads circulated mainly by private cars and bus lanes in urban areas.

When making road design, engineers take only freight transport vehicles in consideration (overall mass corresponding to a total weight on ground higher or equal to 3 t.). Cars and other kinds of light-weight vehicles were not considered; the presence of construction vehicles is considered also.

Traffic levels used a background information to decide upon pavement design standards to be included in the catalogue, were selected so that - for a determined kind of road and a given bearing capacity of subgrade - when shifting form one level of traffic to the upper one, there are two possible pavement configurations which are different enough between each other as far as "structural resistance" - and costs - are concerned.

In order to set maximum circulation values, the capacity of the slowest riding lane was taken into account to carry off circulation composed by private cars and freight transport vehicles together with the percentage usually foreseen for these latter over the total of vehicles.

As for the minimum value, the number of freight transport vehicles was selected so that pavements would have layers thick enough to respond to high-load requirements. Six levels of circulation were considered and range from 400,000 to 45,000,000 of freight transport vehicles circulating on the road during useful life. But a given category of road is actually circulated only by a few levels of circulation (the most intense circulation is recorded on motorways of course).

The parameter used to qualify the bearing capacity of subgrade is the "resilient modulus" Mr: this parameter was chosen because it better takes into account the behaviour of the subgrade.

Three categories of subgrade soils having a good, average and poor bearing capacity were considered whose resilient modulus Mr is respectively equal to 150 N/mm², 90N/mm² and 30 N/mm².

Weather conditions have great influence on the duration of a pavement. In flexible and semirigid pavements, they carry out an influence on the values of the complex moduli of and Poisson coefficients. Therefore they condition the tensional and deformation forces generated on the pavement under the action circulation loads; additionally, they are responsible for irreversible viscous deformations. In rigid pavements, on the contrary, weather conditions provoke tensional states that are superimposed to those caused by vehicle circulation.

Pavement design on the catalogue were decided under different weather conditions in order to keep into consideration the varying sensitiveness to weather variations of the different pavements. In flexible and semi-rigid pavements, average weather conditions were referred to as those of Central Italy. However, it should always be considered that varying weather conditions do not actually involve sensible differences in the duration of the useful life thanks to the compensation between resistance to fatigue of bituminous materials and deformations caused by weight bearing. On the contrary, for rigid pavements, reference was made to more severe Northern Italy weather conditions because of the greater sensitiveness of this pavement to maximum values of stresses.

It is interesting to note how design methods can nowadays benefit from on-site non destructive tests. A survey (Marchionna, 1998) made on some semi-rigid motorway pavements built in different periods (the oldest ones were built in 1974) can support this evidence. On the background of deflection measurements by FWD collected in a five-year time span, it was possible to trace back evolution in time of structural characteristics of the cement-bound grade aggregate subgrade layer. The interpretation of deflection measures with a "back analysis" procedure has allowed to determine values of the elastic moduli of the cement-bound grade aggregate in the examined pavements. Such moduli were then related to the passage of freight transport vehicles circulated on pavements from the moment of construction to the moment of measurements. Results that were obtained were subsequently analysed in statistical terms and the result was that Weibull distribution curve is well adapted to the moduli obtained from
measurements made on road sections characterised by the same amount of traffic. According to such distributions, isoprobability curves were made (fig. 1). They represent the deterioration of the modulus while traffic increases. Isoprobability curves were drawn on the grounds of these distributions. They are shown at fig. 1: they represent the modulus deterioration as traffic increases.

![Figure 1](image)

These curves show out two different phases, in the behaviour of the cement-bound grade aggregate under the action of traffic, where moduli are totally different:

In the first phase, the modulus decreases although high initial values were high (between 5 and 6 times higher than final values); such initial values are widely scattered. In the second phase, the modulus does not evolve and it shows out less scattered and rather low values (in 85% of cases values are lower than 12.00 Mpa); these values represent a state of complete cracking of the material.

The rate of modulus deterioration under the action of circulation in the first phase depends from the initial value and is all the more important as the initial value is high. On the grounds of these observations, it becomes possible to get useful indications for the structural analysis of this type of pavement. The model of structural analysis to be adopted will depend upon the initial stiffness of the cement-bound grade aggregate and its resistance to fatigue: should the stiffness and resistance be low, the value of the modulus corresponding to complete cracking will be assumed in the structural analysis and the verification of fatigue can be limited to the layers bitumen-bound. If, on the contrary, the initial (mechanic) characteristics of cement-bound grave aggregate were good, therefore the structural analysis may be organised in two phases:

in the first one resistance to fatigue of cement bound aggregate will be considered, in the second, on the contrary, the layers bound with bitumen will absorb stresses caused by circulation load.

An “empirical-mechanistical” model allowing to evaluate the deterioration of evenness in time as a function of pavement structural characteristics (intended both as average values and as variability connected to average), of environmental conditions and initial irregularity has been recently developed (La Torre, 1998).

This new model (called ROUGHTIME) was developed to be applied to the monitoring of existing pavements. Actually, this hypothesis was used as grounds: a pavement is theoretically and ideally constructed with a perfect homogeneity and with a total absence of unevenness. It will be uniformly deformed in times and will show out a progressive wheel-tracking although no longitudinal unevenness.

Actually, this hypothesis was used as grounds: a pavement is theoretically and ideally constructed with a perfect homogeneity and with a total absence of unevenness. It will be uniformly deformed in times and will show out a progressive wheel-tracking although no longitudinal unevenness is coupled to that. Unevenness is mainly caused and triggered out by the fact that a road section is never perfectly “even” and structural characteristics are never perfectly uniform.

If we consider the longitudinal axis passing through the wheel tracks, the fact that the section is never “even” involves an increase or a decrease of loads applied to pavement and, as a consequence, the actual load applied to each point of the axis varies continuously. The lack of unevenness involves the fact that in different points of the very axis the pavement response in terms of permanent cumulated deformation will be different although the applied load does not vary.

The consequence of these two effects combined together is different permanent deformations along the axis and a pavement longitudinal section strays more and more from the ideal.
plan of the project due to these differential deformations. Fig 2 shows how this model works.

Starting from the longitudinal section at times $t_0$ (starting point of the analysis) and from the mixture of circulation over the pavement to be studied, dynamic loads are calculated and associated to the single points of the pavement. Average seasonal temperatures and structural characteristics of the pavement expressed as an average, as standard deviation of thickness and as elastic parameters of the different layers allow to define the characteristics of the very structure in each point of the longitudinal axis.

According to the applied loads and local structural characteristics, permanent deformations associated to each single point are calculated. These ones lead to the definition of a new profile, to be calculated by subtracting to the given longitudinal section, the permanent deformation calculated at each point, and of a new pavement structure. These new data, together with data on traffic flow which are supposed as steady, are used to reiterate this procedure up to the end of the pavement design life.

As far as the evaluation of permanent deformation is concerned, a specific model has been developed which allows to evaluate the response of a flexible pavement submitted to any circulation flow range. [Ali, Tayabji, La Torre, 1998].

The general formulation of the calculation model for permanent deformations allows to calculate the total “wheel track” depth by the following mathematical expression:

$$\delta_p = \sum_{j=1}^{k} \left( \frac{1}{\sum_{i=1}^{b_j} \delta_{e(i,j)}} \right) b_j \cdot N_i$$

$\delta_p$ represents the overall total surface deformation (depth of the “wheel-track”);

$\delta_{e(i,j)}$ is elastic deformation of the $j$-th layer due to the $i$-th load;

$A_j, B_j$ are couples of coefficient (one couple for each layer) to be determined experimentally.

$A_j, B_j$ coefficient featuring the model were weighed on the grounds of data collected during the LTPP (Long Term Pavement Performance) program funded by the Federal Highway Administration.

1.2 Whole Life Performance Criteria

Operating conditions of pavement during useful life are influenced not only by traffic and environmental conditions but also by design choices made at the initial design phase; such choices will further involve a lesser of greater quantity maintenance and rehabilitation works so that pavement is able to keep pavement required performance during useful life. Different alternatives responding to all required performance levels (initial and minimum) are possible but they are different in terms of cost-efficiency (fig. 3).

Here, the best indicator for economic-effectiveness of choices is the present net value. The search for the alternative maximising cost-effectiveness means the one minimising costs is identified, since the benefit flow during the period of the analysis can be considered as indepent with a great deal of accuracy from the considered maintenance alternative.

Usually, when the balance sheet of a whole life of a pavement is to be drafted, three items should be considered: initial costs, differed costs and residual value. For whatever project concerning pavements, either these ones are new, or they have been totally rebuilt, or deeply or superficially rehabilitated, the period of the analysis, or whole life analysis, must be long enough so that all every difference between the different economic strategies can be highlighted on the long term. But, at the same time, time span must be short enough (30 years) so that analysis are not undermined by economic uncertainties like long term pattern of actual costs (due to exhaustion of raw material supply sources or to technological breakthrough) or technical problems (as the impossibility to predict required maintenance or reinforcement works ensuing changes in the composition of vehicle ownership and utilisation patterns of the road). Differed costs not only include time-discounted costs for maintenance and reinforcement operations but also costs to be backed by users because of works in progress. This expenditure item considers only the cost increase due to delays caused by operating work sites while operational costs for users due to pavement situation, can be considered as steady with a good deal of accuracy for the different alternatives. They can therefore be omitted.

As already said, while evaluating the different design alternatives, the analysis can be limited to a time span being wide on the one hand (useful life) but this time is also limited if the limited role to be played by the very pavement beyond this time threshold is nothless considered; if an appropriate residual value is assigned to the pavement, a finite time limit instead of an infinite one can be considered. Such residual value can be connected to the area shown at fig. 4. If a finite time is considered, it becomes possible to reduce the complexity of the problem for choosing between the different alternatives which can be tackled with mathematical optimisation models.

It is always useful to carry out a sensitivity analysis to assess the influence of the assumptions and of estimates as input of the problem, in particular, the different rates of actualisation must be considered and the different values allocated to time; if suitable simulation techniques are used it becomes
possible to get to an evaluation, with probability terms, of risk connected to each of the considered alternatives.

![Figure 4](image)

**1.3 Analysis of Initial and Delayed costs**

It is interesting to study the case situation were a new portion is added to the network or a general upgrade of the whole network is devised. In this situation a cost decrease for transport is provoked from "a" to "b" and consequently, it is considered how the balance point supply/demand shifts from "A" to "B", that is benefit for users increases due to users attracted "Vb-Va". This is an indicator to evaluate the quality of the works performed.

![Figure 5](image)

A hint should be made as for interest and discount rates to be applied to financial operations which report, necessarily, at the same moment costs and benefits recorded in different moments. This rates carries out a greater influence on circulating capital, that is on costs, and therefore if these latter decrease, the usefulness of the work increases. Therefore, a criterion may be to identify a minimum acceptable usefulness find the necessary interest rate to the operation and compare it to that imposed by the funding system of the work (insertion inside the annual or multi-annual balance sheet, funding through loans or bonds, concession with or without contribution on the account of capital or interests). Often financial operations are carried out with a "social discount rate", that is with a hidden price allocated to the capital cost with social purpose in order to foster public investments besides private investments. This criterion may be justified by the fact that marginal road utility at the end of service life (considered as grounds for the operation) does not go to private profit but to the future generations’ profit who would then be called to contribute to costs for the received capital. The discount rate must then be subtracted from the one determined by a market economy where the supply and demand law applies. It should be given a lesser value in order to foster project with a higher yield on the long term.

**2 Performance Indicators**

As far vehicle circulation is concerned, a pavement state carries out an influence on the facility costs, riding quality, safety, noise, vibration, rainwater projection by circulating vehicles and visibility conditions in night riding or rainy weather.

Hereafter, some aspects of circulation quality that a user would expect to be satisfied by a franchisor. These aspects are connected to specific pavement characteristics.

Exploitation costs vary upon variation of surface pavement conditions, and in particular evenness, deterioration, and distress.

Safety is connected to skid resistance and to any possible small and medium wavelength unevenness especially in bends, so as rut, and conditions of surface drainage; the amount of sprayed water is also connected to this latter.

Riding quality, so as noise emission and vibrations are connected to the texture and surface evenness, the presence of distress or patching up; noise propagation depends upon pavement sound-deadening qualities, while vibration propagation depends upon pavement structure.

Finally, pavement texture and colour, under specific circumstances, may contribute to improve visibility. Theoretically, the objective to be focused when designing and managing a pavement is to contribute to the greatest satisfaction of quality perceived by the user as far as possible.

But, actually, technical problems and limited resources allow to optimize, at the designing of a pavement or the definition of maintenance or upgrade operations, only few pavement characteristics.

**2.1 Quality Concepts**

One of the objectives of modern road engineering consists in associating each road stretch to a single figure parameter which would represent the quality of the road service offered. At the occasion of the concession renewal from the
Government to the motorroad managing bodies (1997), a first definition was given to the concept of a road overall quality, and toll increase was anchored to this very concept. In this case (Camomilla, 1997), a road overall quality $Q$ was related to 4 partial $J_i$ indicators through adequate weights $\pi_i$, the formula is the following:

Four indicators were used. Two of them concern surface pavement layer (grip and evenness). Two concern accident rates: a distinction was made between accident rate in the valley and on mountains. The formula of the overall quality index can be periodically reviewed.

In particular, indicator values connected to grip of tyres and evenness are respectively calculated starting from measurements of Side Force coefficient and IRI measurements. The values of each measurement range from 1 to 5 or 6 levels, after measurements were performed, the percentages of road to be inserted in each level are identified; the value of the indicator is obtained by an appropriate weighing (the higher weight will be associated to the better level) percentages of road sections falling in each level.

Accident rates (TAR) considered for the evaluation of indicators are related to the totality of the accident recorded on the different motor-way sections.

Tab. 1 reports rates ($n^2$ of accidents/vehicles.Km) associated to the different levels.

<table>
<thead>
<tr>
<th>Level</th>
<th>Plain</th>
<th>Mountain</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>TAR ≤ 50</td>
<td>TAR ≤ 60</td>
</tr>
<tr>
<td>B</td>
<td>50 &lt; TAR ≤ 65</td>
<td>60 &lt; TAR ≤ 80</td>
</tr>
<tr>
<td>C</td>
<td>65 &lt; TAR ≤ 78</td>
<td>80 &lt; TAR ≤ 100</td>
</tr>
<tr>
<td>D</td>
<td>78 &lt; TAR ≤ 95</td>
<td>100 &lt; TAR ≤ 120</td>
</tr>
<tr>
<td>E</td>
<td>95 &lt; TAR ≤ 115</td>
<td>120 &lt; TAR ≤ 140</td>
</tr>
<tr>
<td>F</td>
<td>115 &lt; TAR</td>
<td>140 &lt; TAR</td>
</tr>
</tbody>
</table>

Table 1

The concept of overall quality can be formulated in several ways according to the field of application.

A recent survey (Colonna, 1998) has introduced the concept of "Enhanced service level". This one is no longer based on circulation density and therefore on journey timing, but on a series of other indicators which highlight the offered service in terms of safety, riding quality, ancillary services, and which keep in account consequences that road exploitation involves outside. A first group of these indicators is referred to the "safety" parameter and concerns geometrical characteristics of homogeneous stretches, structural and functional characteristics as well as external interferences. A second group concerns journey timing; different possible time losses are analysed, to get to an actual journey delay, to be compared to a same timing in condition of free circulation. Another group of indicators is related to ancillary services the road offers being directly perceived by the user. Another group is referred to environment: sound and air pollution are assessed together with visual impact of the road over the landscape. Other groups of indicators consider traffic and riding quality perceived by the user, the proprietor and outside environment; additionally, each indicator has its specific weight against the others. It becomes therefore possible to get to a weighed mean which defines "the enhanced service level" which gives the possibility to set the road inside one of the seven possible levels, which range from a maximum theoretical value (correspondent to the presence of all possible service levels with the best efficiency) to a minimum admissible value (which supplies at least basic function).

2.2 Influence of Indicators on Maintenance and Rehabilitation

The process leading to the formulation of maintenance programs can be summed up as follows:

1) Detection of pavement conditions
2) Identification of homogeneous stretches
3) Evaluation of pavement characteristic deterioration
4) Identification of best maintenance techniques
5) Definition of intervention programs

Detection of Pavement Conditions

Data collected supply the measures of main pavement characteristics: bearing capacity, grip of tyres, evenness. Such measurements allow to calculate indicators describing such pavement conditions.

In order to identify the pavement situation during useful life and define necessary maintenance operations, set for priorities, it becomes necessary to "monitor" the pavement by using non invasive tools, and to have available a constantly updated data base where information relating to network
composition, geometry of the different stretches and miscellaneous information such as on circulation, on accident rates, on historical series of measurements of characteristics of pavements, data on maintenance operations and related costs can be drawn. The cross cutting of all these information will permit to define a multi-annual maintenance program compliant to constraints.

Fig. 6 shows an information flow-chart.

**Classification of Homogeneous Sections**

According to punctual values, a series of homogeneous stretches are identified for each indicator. Each homogeneous stretch is characterised by an average value, being different from that of the next stretch (preceding or subsequent) in significant way, and identifies the area where, if necessary, it is possible to intervene in the same way with one single and plain technique.

**Pavement Characteristic Deterioration Evaluation**

Data from homogeneous sections are analysed with accurate deterioration models.

Deterioration curves are used to describe pavement behaviour during useful life. But it is necessary to identify an “indicator” representing the pavement “state” in order to describe evolution under time and traffic effects.

The indicator of the state can be linked to different pavement characteristics. These latter may concern only surface (distress, grip, evenness) or general structural conditions (layer thickness, mechanical property of pavement components, bearing capacity of subgrade).

Statistical calculations may supply rules on deterioration if a sufficient number of measurements are made at different moments on the same pavement or at the same moment on different pavements circulated by a different composition of traffic. If statistical information is not available, this may be replaced by theoretical calculations based on circulation, environmental and weather conditions, types of construction materials used, etc...

A “Synthetic Indicator” of a pavement bearing capacity has been introduced in order to optimise maintenance operations. It can be used to analyse a pavement behaviour during useful life. This indicator is the ratio between the initial and the actual rigidity of the pavement layers which is a function of layers’ thickness and of moduli. As for flexible pavements it becomes a ratio between moduli only.

In a recent survey (Marchionna, 1998) on flexible airfield pavements, this parameter has been used to represent pavement behaviour. A deterioration curve was obtained (fig. 7) from the cross cutting of two different ratios. On the y-axis, the ratio between the modulus E of bituminous dressing evaluated in real on-site conditions by deflection measurements and the modulus E0 at start-up non-degraded conditions. On the x-axis, the ratio between the circulation Nr the pavement can still bear when the dressing modulus is equal to E, and circulation NO that the pavement has been able to bear since the construction.

**Identification of Best Maintenance Techniques**

An appropriate decision-making algorithm based on the knowledge of the present state of the pavement (homogeneous sections) and on the evaluation of possible future deterioration (residual life) allows to decide upon and schedule the most efficient maintenance program (in the time span of residual pavement life).

Maintenance operations are selected according to optimisation techniques which consider several alternative solutions.

**Optimisation of Maintenance Planning**

As far as the road sector is concerned, the search for the best maintenance strategy can be divided into two different management levels: Network level and Design Level.

As for the Network level, the management body defines priorities, funding and the functional level of all the pavements as; this strategy is based on a general overview of pavements. As for the design level, maintenance and rehabilitation or upgrade programs are defined for each single pavement section. Designers would not only consider constraints at network level, but also any other limit caused by factors which were not considered previously.

Maintenance operations can be optimised on the base of the following data:

- guidelines for selecting best maintenance operations according to residual life, bearing capacity and regularity;
- alternative methods and material to be used for maintenance operation according to detected defects (bearing capacity, grip of tyres, regularity) compatible with the type of road;
- operation timing according to the work site productivity;
- logistic constraints linked to time-schedule of work sites being contemporary in progress; this program will accurately consider circulation requirements and location of works signalled by the road Administration Bodies;

The program may follow this pathway:

a) Identification of any possible sequence of maintenance works to be carried out in the period of the planning will excluding technical combinations incompatible between them.

b) Identification, for each section, of homogeneous stretches where the values of the indicators are steady, through
cross-cutting of "stretches with similar conditions".

c) identification for each "homogeneous area", of the best moment for carrying out works hypothesised in each sequence. This operation will be carried out by searching an optimisation algorithm, timing for each sequence of maintenance operations able to maximise the area under the bearing capacity deterioration curve, in compliance to constraints represented by regularity and grip deterioration curves whose values must be lower than already-set thresholds.

d) selection, for each "homogeneous area", of the best sequence of maintenance operations, that is the sequence supplying the largest area under the deterioration of the bearing capacity; this is the sequence with the best technical characteristics.

e) harmonisation of maintenance operation for each measurement process in order to narrow the field of interventions.

2.3 Innovation as Regards Indicators Used in Pavement Management

Recently, a new procedure (Marchionna e Paoloni, 1998) for the selection of maintenance operations expressly targeted to motor-way pavements was introduced. This one takes into simultaneous consideration several indicators and is based on an Markov-type optimisation aggregate model. The pavements of a given network are divided into families and the resolution of the problem of optimisation is solved by defining maintenance strategies for each family of pavements.

On the grounds of data from environmental conditions, circulation, structures and the history of the each pavement, it is possible to break down the different sections of the network into homogeneous classes defined as pavement families. Inside each family, the pavement behaviour is supposed to be homogeneous and this only depends from the general conditions and maintenance works to be started. Table 2 reports parameters and classes used to group the pavement of a network. The combination of these classes give out all the possible families of a network.

Additionally, an aggregate model allows to describe the pavement behaviour of the road network through percentages over the overall mileage of the family or of the sections featured by a determined conditions or performance. Maintenance strategies are therefore identified when they define for each year of the program, the network portion to be maintained. This portion is composed by the sections showing the same conditions of deterioration. It is the starting hypothesis of the problem, whose resolution is possible only if "transition probabilities" are identified. This is the probability that a given pavement, or a group of pavements, shifts from state i to state j in one year after the maintenance operation ak is carried out. In order to assess these probabilities - called TPM in matrix form- it is necessary to analyse the evolution in the network conditions. But pavement conditions must be monitored and maintenance operations must be decided upon before this analysis is carried out.

Only pavement characteristic features from continuous measurements were considered to define indicators. At first, only SFC and IRI were used as indicators because they were considered reliable enough to supply a synthetic description of the different parameters featuring road pavements (safety, riding quality, structural capacity). Then, for each one of them was broken down into classes with a pre-established spread of values. An evaluation of the pavement conditions is associated to each class. Each class is coupled to an appreciation of the pavement conditions. The total number of a pavement conditions can be drawn from all the possible combinations of classes with the different indicators. Subsequently, a weak connection was noted between these conditions and the actual structural capacity of the pavement. Therefore, the need to introduce a sensible parameter was felt. Tests were carried out to collect data on surface deterioration (cracks) through the analysis of videos filmed from an adequately-equipped vehicle. In the years to come, when enough data are available, the possibility will be envisaged to adopt a further parameter linked to surface deterioration. For the time being, a further indirect parameter connected to structural conditions, that is the age of the pavement, is being used. This is intended as the number of years passed since the opening to circulation after the road construction or after a rehabilitation process. Three classes were envisaged for grip and evenness. Two classes were envisaged for age. Edge

<table>
<thead>
<tr>
<th>Description parameters</th>
<th>CLASSES</th>
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<tbody>
<tr>
<td>Description</td>
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<tr>
<td></td>
<td>description</td>
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<tr>
<td>Pavement type</td>
<td>TP</td>
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<td>Climatic region</td>
<td>RC</td>
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<tr>
<td>Section type</td>
<td>TS</td>
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<td>Average daily circulation</td>
<td>TGM</td>
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</tbody>
</table>

Tab. 2
values are reported in Table 3. All possible combinations between classes supply every possible state of motorway pavement (18 in this case).

<table>
<thead>
<tr>
<th>INDICATORS</th>
<th>grip</th>
<th>evenness</th>
<th>age</th>
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<tbody>
<tr>
<td>CLASSES</td>
<td>SFC</td>
<td>IRI (mm/m)</td>
<td>years</td>
</tr>
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<td>T&lt;=3</td>
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<tr>
<td>B</td>
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<td>2&lt;IRI&lt;3</td>
<td>T&gt;3</td>
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<tr>
<td>C</td>
<td>SFC&lt;=35</td>
<td>IRI&gt;=3</td>
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Tab. 3

2.4 Relation between Performance Indicators and Service Levels to Users
The definition of quality parameters between pavement condition indicators and parameters concerning the service level supplied (safety and riding quality) is the topic of studies aimed at identifying pavement types able to supply an ever greater effective response to the different requirements. On the other hand, the need for an overall quality indicator defining circulation quality and maintenance requirements is not felt as a priority. Nonetheless, different indicators are used straight, (voir 2.3) that is without being weighed, to define pavement conditions or to identify maintenance needs.

3 Technical Innovations with High Economic Performance
Different technical innovations were introduced in the last four years in earthworks of bridge and tunnel pavement. Hereafter a short description.

3.1 Earthworks
The scarcity of valuable soil, that is granular non plastic and low-content of fine part soils, has forced most of road building companies to seek for alternative solutions. The use of poor oils turns out to be as imperative in some cases.

From a research viewpoint, this is not new. Alternative material have been studied for years: soils stabilised with hydraulic binders, blast furnace slag, fly ash, refuse from the building and construction sector etc., but their used has never been codified. Beyond whatever testing, it is indispensable to supply a contract tool for a controlled execution of their works.

Any road construction companies gives the task to the Work Director for this crucial choice. Nonetheless, no characteristic or performance of any material or work phase is supplied. As reported by a sectorial survey on High Speed (Cicini, 1998), the Italian National Railways Company are reconsidering contract specifications in order to include additional materials for the construction of the 200 km Milano-Bologna High Speed railways line because of most of embankments are to be built in an area with scarce valuable construction material.

At present embankments are built with soils classified as A1, A 2-4, A2-5, A3 and A4 with reference to CNR UNI 10006: these are non cohesive, non plastic soils with mixed sieving. A2-6 and A2-7 soils can be used only under certain conditions. Any other material as soils stabilised with hydraulic binders, flu ash, blast furnace slag and wastes from the building sector can’t be considered although they have been widely and successfully used abroad.

Some embankments were built as trials to this purpose with alternative materials (lime stabilised soils, concrete stabilised soils, untreated uncohesive soils, wastes from the building sector) in order to define technical specifications for the road building sector.

Some of these were ended up and, according to the different results, technical specifications of the lime stabilisation of clayey and clayey-silt soils. Other surveys are being carried out at present.

In order to introduce new materials in earthworks, two fundamental aspects of contract specifications must be reconsidered: a different soil classification and specifications related to material compaction.

3.2 Pavements
In order to increase effectiveness and curb costs for the functional rehabilitation of pavements, a new technique was recently introduced in Italy: synthetic macro-reinforcement were introduced in bituminous dressings. This technique was already known but it was not employed due to the high temperatures it required for spreading due to the polymer melt temperature and to problems raised during works execution.

A recent survey (Dondi, 1998) highlights that recently, thanks to the development of materials having a high melt temperature and to refining of design techniques, there are greater possibilities to exploit this technology. The addition of intermediate layers, especially if the road is submitted to high traffic flow and heavy loads or in ordinary maintenance of heavily-cracked pavements is a solution that would contain the thickness of pavement and would simultaneously supply high service levels. In order to investigate on the actual effectiveness of the different types of strengthening, research programs are being carried out. At present laboratory tests are an over, and trials are being carried on the ground. In Italy, on A21 Motorway in particular, a testing field has been made. This is equipped with an electronic system which counts an weighs axles, and which include areas with synthetic intermediate layers having different physical and mechanical characteristics. The monitoring program also has a periodical verification of layer resilient moduli and evenness through F.W. and ARAN respectively. Results, interpreted according to different parameters, including the bearing capacity and IR will allow to make a comparative evaluation of effectiveness of the different types of intermediate layers.

A survey on recycling (Arena, 1998) of pavement materi has pointed out that these kind of procedures were being used also for cement concrete not only abroad but also in Italy lately. There are two different types of recycling techniques...
according to the origin of material to be recycled: cement concrete buildings, industrial wastes, old road pavements recycled on site or on factory. Whatever the origin, not only the use of recycling involves relevant economic savings but it also supplies environmental benefits due to a lesser mining of inert material and to reduction of run to spoil.

### 3.3 Bridges

Since the Fifties, large viaducts have been built with laid prestressed and prefabricated beams. The poor reliability of this approach has led road designers to reconsider the engineering of such viaducts. Continuous beams were then employed with a subsequent increase in structural reliability and riding quality.

An analysis of the present trends (Martinez y Cabrera, 1998) in the field of bridges observes that, whatever the situation, the cost-effectiveness of a bridge is influenced by the building technique. A bridge is a large structure and it is not the result of one single phase but of several subsequent ones. Also a bridge weighs much more any other pavement. Therefore, only an industrial-like building practice can supply good results. In particular, in viaducts whose span ranges from 30 to 100 m, with box girder and continuous beams, thrust launching is economically viable because this allows to compact the materials on one abutment. Even if momentary transition piers are used for bridges with more than 100 m. span, the thrust technique is always cost-effective. Additionally, at present arched bridges are being reconsidered, but prefabricated assembled materials are being used. Special bridges are being used in particular situations.

As far as costs are concerned, slab and beam bridges are highly cost-effective for spans up to 30 m, but if wider spans box girder are more viable. Engineering structures with very wide spans and suspension or cable-stayed bridges require investments difficult to be standardised.

### 3.4 Tunnels

The design of underground structures (road and railways tunnels, water piping, subway lines and stations and large underground parking) depends at present almost exclusively from shapes and sizes of perforation machines. Tunnelling machines can operate with a wide range of natural materials including compact rocks (traditionally excavated with explosive materials), soft cracked rocks, more or less cohesive soils and clays.

Traditionally, design for underground works was considered as superfluous because it was replaced by actual works. Against this, a recent analysis (Ranzo, 1998) has highlighted that it is necessary to start from accurate surveys (exploration tunnels) which utilises horizontal perforation machines, that is small-diameter millers. In particular, especially in Italy, with the re-evaluation of the design which must be able to manage ready-to-operate construction works, for underground works also, without resorting to "unexpected geological events", surveys are carried out very carefully. These are essential to organise a subsequent mechanised excavation and lining.

Many important works have been done in the last few years which have shown the usefulness of innovative technologies: Eurotunnel (France-England), the Great Belt railways-and-road bridge (Denmark), the tunnel under the river-bed of the Trans Tokyo Bay Highway and other engineering structures were excavation proved all their efficiency. The utilisation of these machines must become one of the engineering tools to be included in the work designing; the designer defines therefore the type of the machine and its performance characteristics since this one has to give an accurate forecast of costs and construction timing, as provided for by enforced norms and regulations.

Additionally, calculation models for soil structural behaviour both during excavations and exploitation, are by now available also with three-dimensional systems in non-linear fields. They allow to foresee forces and deformation with a great deal of accuracy. This is possible thanks to the data collected during surveys, especially if exploratory headings were made. These latter allows to try a "hybrid" simulation of the actual behaviour of soil layers, because parameters involved (soil or rock resistance and deformation) are actual values.

Additionally, mechanisation is presently applied to a new filed: upgrade of the existing tunnels with the broadening of the cross-section. Works are made without need to block circulation flow. Such important works still have to be ended up, but one is being started up in Italy on the A1 motorway, on the Rome-Orte stretch, to upgrade to three lanes per carriage-way. An automotive protection shield of traffic has been installed. Over it, a coaxial machine operates for mechanic pre-cut and for prefabricated lining. This same equipment dismantles the present lining and soil crown over the present soffit.

Finally, maintenance operations benefit from the adoption of mechanised procedures because construction inaccuracies (typical of the traditional method) can be avoided. These latter always involve a deal of risk especially for water drainage, landslides etc...

### REFERENCES


