Development Of A Pavement Management System In The Province Of Milano: The Validation Of Pavement Performance Curves

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SYNOPSIS

The transfer of competence on many state roads from ANAS to provinces (ex D.Lgs. 112/98) represented a turning point for the concept of road maintenance management for the Province of Milano.
In this context, a more rational approach to road maintenance was chosen by adopting objective criteria of intervention planning, oriented towards a subsequent outsourcing of maintenance activities with "global service" contracts, with which the selected company will guarantee predefined performance standards for different road elements (particularly pavements).
The search of technically-economically optimal solutions related to the quality of services, traffic safety and the goals of the Administration, ended up with the development of a Pavement Management System (PMS), with the support of Politecnico of Milano and international experts.
By means of this instrument, integrated with a database containing all the data related to pavement condition, different scenarios can be investigated, showing the impact of variable budget levels on the expected condition of the network and in relation to minimum acceptable values for condition parameters. This allows determining realistic budget levels to be used within the call for bids for a Global Service characterised by well defined performance specifications for pavement condition during and at the end of the contract period.
The definition of pavement performance curves is one of the key issues in the development process of a specific pavement management system (PMS). A bibliographic survey provides a wide range of proposals; however, their immediate use in a given situation is prevented by different reasons such as: the need for a higher number of additional parameters which are generally not easily available, specific conditions of the network with respect to pavement structure, traffic loads, climatic conditions, etc. Under these circumstances the Road Administration has to define its own performance curves.
Very frequently and depending from available budget funds for condition surveys, Road Administrations start gradually with the collection of pavement condition data. The task of developing performance curves can thus be quite difficult during the first phase (frequently covering a couple of years) due to limited availability of condition data in terms of their distribution in space and time (age). In spite of this, Administrations should not be forced to delay the implementation and operational use of a PMS. Therefore, the Province of Milano has initiated data collection, development of performance curves and the validation of the first hypothesis related to the former ANAS network within the Province. In the mean time, the system has already provided valuable results for the definition of optimal maintenance budgets for the Province of Milano.
The description of this experience is particularly useful because it addresses a maintenance approach (choice of condition parameters, processing of the data, proposal and validation of performance curves and definition of performance standards compatible with available resources) currently followed with great interest but still not explored in detail within real applications.

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INTRODUCTION

Following the adoption of a new law in 2001, major portions of the interurban state road network have been transferred from ANAS, the national road agency, to the jurisdiction of the provinces that so far only were responsible for a road network of less strategic importance. This transferral of competences brought up a number of consequences in the field of maintenance and management and in particular the need for the Provinces to optimise budget funds dedicated to the new additions to their road network.
In the case of the Province of Milano 10 interurban roads with a total length of 120 km radially distributed in the metropolitan area of Milano (Figure 1), constitute the network. All these roads have a considerable importance for transportation in the whole Province and even beyond for the whole Region of Lombardy from an economic, social and territorial point of view. This can be demonstrated by analysing their geographic distribution and also by the high traffic volumes and truck traffic percentages on the network. A typical example is SS 35 Nord (Figure 2) linking Milano to the Brianza area (a highly industrialised area north of Milano) with an AADT of 100'000 vehicles and 6% truck traffic (2 carriageways - 2 lanes each one).
This situation has led the Province of Milano to the adoption of a new approach for the task of pavement maintenance aiming at a more rational solution based on objective criteria for intervention planning [VYCUDIL 2000]. The agency has been considering outsourcing stepwise maintenance activities by means of "global service" contracts, under which private companies will have to warrant predefined performance standards for different parts of the infrastructure and in particular for pavements [UNI 10685/98].
The development of the system is currently in a crucial phase where expected performances of the pavement have to be defined in accordance to available levels of expenditure. The Province of Milano has decided to use and to develop a Pavement Management System for the search of economically optimal solutions in accordance with the goals of the agency in terms of traffic safety and of level of service (defined by selected condition parameters and corresponding limit values). It has to be emphasised that a PMS is non compulsory in Italy as in other cases [IRRGANG 1993], but completely optional. This approach adopted by this province for the former ANAS network is therefore a completely experimental step in Italy.

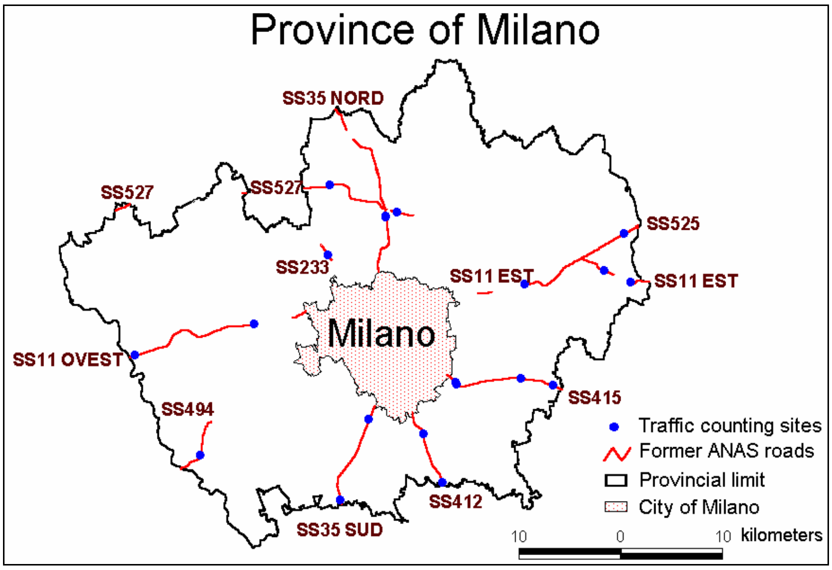


Figure 1: The former ANAS road network in the Province of Milano with traffic count sites

The former ANAS network is composed by 10 roads, covering a length of 119 km, the 20% of which (25 km) is of the dual 2 carriageway type (2 lanes each direction).
When the roads were transferred the Province received the following data from the preceding administration:

- general data: geographic data, staff, patrimonial data, maintenance of equipment and organisation of services;
- geometrical data: geometric dimensions of the right-of-way, intersections, ramps and structures;
- summary data: concessions, intersections and structures;
- statistical data and documentation: AADT, state of maintenance of the network.

The received data were far from being complete and up to date. Traffic data for instance, a key factor for evaluating the importance and the loading of the roads, were only available for 1990, which is definitely inadequate for characterising the situation when the transfer of competences actually happened.
All the data available at the moment of the transfer of competences show in any case that the general condition of the network is far from optimal, in particular in view of the most recent standards of safety and quality.
The transfer of competences has also highlighted a complete lack of data in the area of maintenance history and condition data, in particular in relation to pavements (existing distresses, roughness, skidding properties, pavement structure, etc.).

Figure 2: Meda access to ex SS 35 Nord "dei Giovi"

STRATEGIC GOALS

The aims of the Provincial Administration are: safety, quality, reduction of responsibilities and minimum costs. The costs of the agency are a fundamental aspect in view of the level of service provided; in fact available resources are limited, and this forces an agency to search for optimal solutions, in particular in the case of networks of strategic importance.
Collecting information on the asset value through a number of objective data has been the first step towards the construction of a management model. To this purpose different data collection campaigns distributed over the years in a four year cycle have been carried out. This approach allows a collection and storage of historical data in a reasonable sequence without overstressing the budget of the agency.
It is quite obvious, that the problem of maintenance management is a very complex one, as it requires definition and understanding of the values of the influencing parameters as well as to carry out a large number of intensive computations in view of searching the optimal economic solution. The degree of complexity even tends to increase when the "global service" solution is being considered as a specific goal. The adoption of a highly rational approach, considering objective planning criteria and structured in the terms of an innovative solution such as a pavement management system is essential for success when facing the complexity of the system. In the present case the function of a pavement management system goes beyond optimised and planned maintenance and also includes the development of the following contract maintenance under "global service" conditions [Crispino 2004 a]. This kind of contract, according to the official definition of a Global Service, represents a "performance based maintenance contract, under which a contractor is fully responsible for the organisation of the maintenance and for the results…" [UNI 10685/98]. While this allows meeting as close as possible the management goals of the Administration, it also creates the problem of the planning of resources for contractual periods of uncommon duration at least 5 years).

DEVELOPMENT AND IMPLEMENTATION OF THE "PROVINCE OF MILANO PMS"

The pavement management system has been structured into three main phases or elements [dTims 2002]:

- Input (Setup of the system): the conceptual design and modelling of the system and the implementation into a software application. It includes setting up a database, defining the condition indices to be used and the definition of an appropriate catalogue of treatments.
- Analysis: calculations meant to generate a list of possible strategies and their optimal selection. This phase requires the selection of the determinant optimisation criterion, the definition of an analysis period, of economic parameters and of the way to actually conduct the optimisation.
- Output: this phase provides different ways to look at the results of the analysis, both from the engineers' point of view (project level) and from the manager's point of view (network level). Data table and graphs will highlight the choice of the proposed optimal solution with costs and benefits and show the impact of different budget options on the condition of the pavements, the selection of different strategies, etc.

Input Data

The input phase includes the conceptual design of the PMS based upon available data on the pavements and their necessary use in the analysis process. In the case of the former ANAS network, where data were initially far from being complete, additional efforts were needed in order to obtain sufficient data on pavement condition (roughness, adherence, bearing capacity and traffic).
The condition surveys provided network-wide data for March-April 2002 and September-October 2003 periods. The database of the network has been completed with the following data, necessary for the analysis process [Shahin 1994]:

- Geometric data of the pavements (length, width, structures),
- Current condition of the pavements (skid properties, roughness, distress, bearing capacity),
- Traffic and traffic growth rate,
- Performance models for pavement condition,
- Catalogue of treatments (costs, trigger limits, effects, etc.).

For the evaluation of a global condition index of the network the following parameters have been used: IRI (International Roughness Index), CAT (Italian Sideways Force Coefficient at 60 km/h) and the percentage of cracked surface (including all types of cracks) [Shahin 1994]. These parameters describe quite accurately the general situation of the pavement both by the point of view of its conservation and by the points of view of riding comfort and user safety. Results from bearing capacity measurements obtained by FWD testing have not been included in the calculation of the Global Index. This was mostly due to the fact that the available data did not cover the complete length of the network and an estimation of the structural condition by other means was not considered as a valid and accurate alternate solution. In particular some verification has shown that the presence of cracks does not correlate very clearly with bearing capacity, while the correlation with the results of roughness measurements is much more promising.
A first set of additional data regarding pavement distress has also already been collected but not yet used in the implementation of the PMS: percentage of ravelled area and number of potholes.
Traffic data, essential for pavement management, had also to be collected from scratch by the use of inductive loops at fixed locations. The numbers reported from these counts are AADT and the percentage of heavy commercial traffic, this last category includes all vehicles with a total length of 8 and more meters [CNR 93].
The functional quality of the pavements has been evaluated by means of the afore-mentioned pavement quality index IQS [Crispino 2004 b] which is a global quality index verified for this specific network using available parameters and corresponding field data. The index IQS depends thus on: pavement roughness (IRI), skidding properties (CAT) and percentage of cracked surface (%CRACKING). These parameters have been combined with equal weight into the global index IQS calculated on the basis of an equation derived from a theoretical study of Politecnico of Milano on the possible range of values of the different parameters. The equation is:

$$IQS = \min\left\{30\,;30{,}38\text{ - }\left[(IRI\cdot 2{,}5)+50*\left(\frac{6}{CAT}-\frac{6}{65}\right)+\left(\frac{\%CRACKING}{10}\right)\right]\right\}$$

where: IRI = IRI value (longitudinal roughness) [m/km], base length 320 m,
CAT = value of the side force coefficient (skid property),
%CRACKING = percentage of cracked area of the pavement [m^2/m^2].

The IQS value determined by the equation indicated above allows an evaluation of the general condition of the pavement on a scale ranging between 0 and 30 in which the following condition classes have been defined.

Table 1: Pavement condition classes

Range of IQS	Pavement condition
0 – 12	Poor
12 – 16	Critical
16 – 20	Sufficient
20 – 24	Fair
24 – 30	Excellent

The analysis of the IQS values for year 2002 has shown that the average value for all roads is 19.86, a value indicating a network which is sufficient in the average.

Performance Models

A performance model specific for the network has been determined for each one of the different condition parameters in order to calculate their evolution over time. A lack of knowledge on the age of the pavements or at least on the date of the last rehabilitation has prevented the use of various formulas found in different sources ([Camomilla 1992], [Marchionna 1994], [Crispino 1998], [HDM4 1995], [Cost324 1997] e [RIMES 1999]). It was thus necessary to define a set of new curves for the different parameters.

Analysis of the data from the first data collection campaign

In the first year of study ended in March 2003, having only the first survey data, the same approach was adopted for all parameters (IRI, CAT, percentage of cracked area). The following description takes the case of the curve for IRI as an example. A general and forced assumption, due to the presence of single year data, was that all pavements had been designed correctly for a design life of 20 years in the case of roughness. The frequency distribution of all data on the network (Figure 3) shows that the sample essentially includes pavements with a range of IRI values between 1 and 4 m/km.

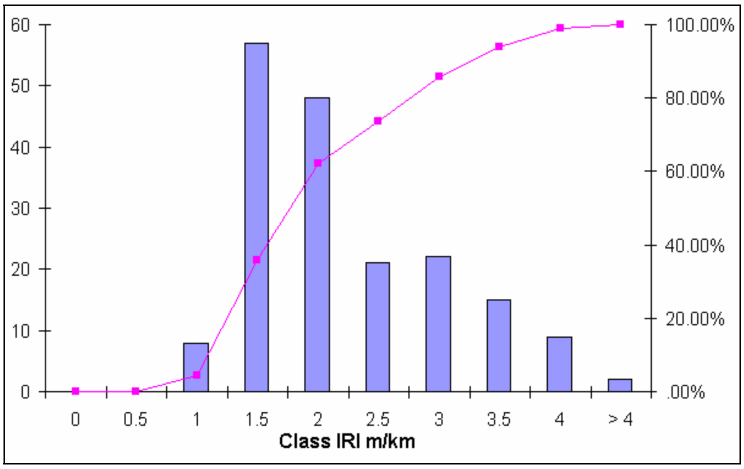


Figure 3: Histogram of IRI values for the whole network (144 km of total carriageway length)

The performance curve was determined in the following way: the IRI value of a pavement after 20 years of service life is considered to be equal to the 85-percentile of the cumulative distribution of the analysed sample, in this particular case 3 m/km. It is also additionally considered that the mean value of the sample is representative for pavements with 10 years of age, in this case 2 m/km. In consideration of a linear shape of the performance curve the IRI value for a new pavement is 1 m/km. The following Figure 4 shows the performance curve for IRI, developed from the data of the analysed sample network.

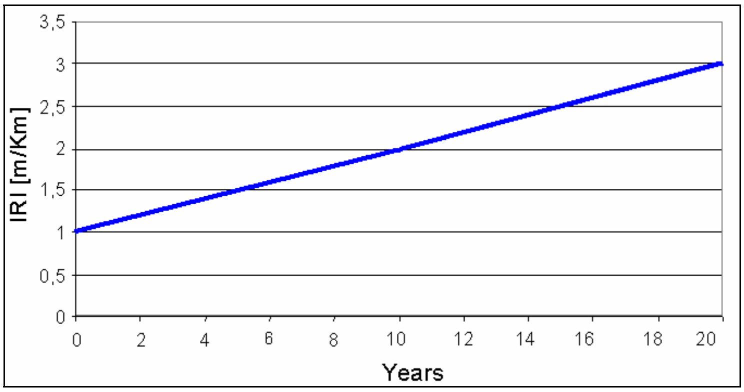


Figure 4: Performance curve for IRI

The performance curve for IRI can thus be represented by the following relation:

$$IRI_{year\,i} = \min[4;\; IRI_{year\,i-1} + 0{,}1]$$

It is worth noticing that the linear model which has been adopted in this particular case is quite close to the performance "curve" derived from HDM4 studies [HDM4 1995].
The same approach has been adopted in the case of the performance curves for skidding properties (CAT) and percentage of cracked area, shown in the following figures.

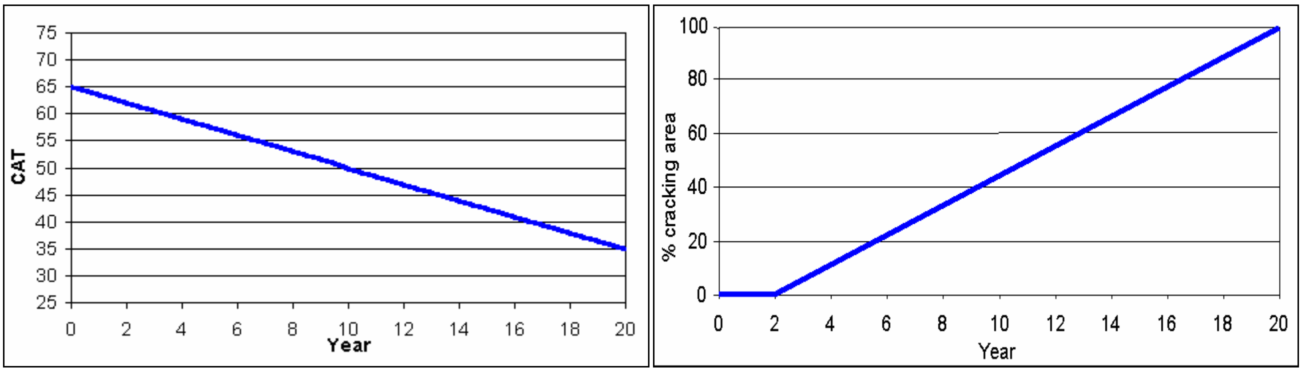


Figure 5 and 6: Performance curve for skidding properties (CAT) and % cracked area

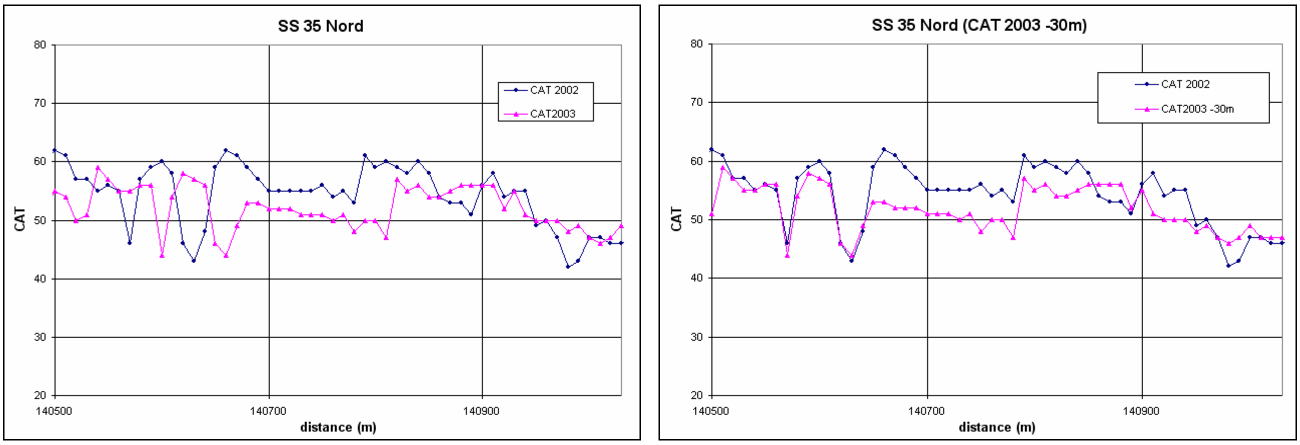
Analysis of the data from the first and second data collection campaign

The most important step in the second year of the study was the analysis and comparison of the data from the second data collection campaign with the objective of validating the performance curves developed with the data from the first survey (2002). This validation study of performance curves was limited to the parameters of roughness and skid properties. The time spacing of the two data collection campaigns is of 18 months and the survey seasons – March/April 2002 and September/October 2003 - are comparable [Canale 1996].
The validation was carried out on a sample of 16% of the total length of the network, using data from the road sections indicated in Table 2.

Table 2: Lanes with surveys in years 2002 and 2003

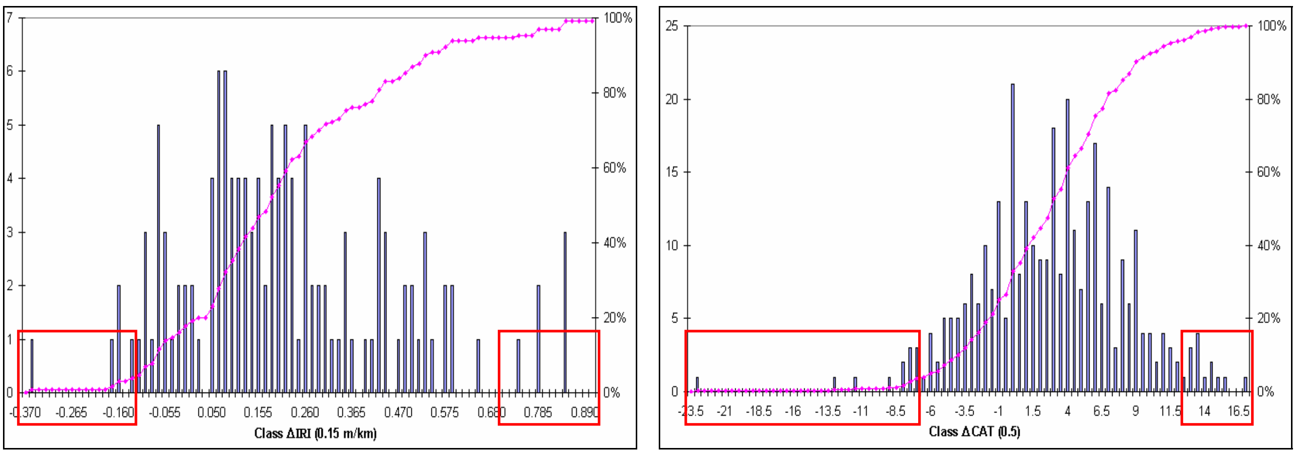
Former State Road	Lane length	Direction	Carriageways	AADT	% Truck
SP ex SS 35 NORD “dei Giovi”	16550 m	North – slow lane	2	24500	8.6 %
SP ex SS 412 “della Val Tidone”	2200 m	North – slow lane	2	11000	4.6 %
SP ex SS 527 “Bustese”	360 m	West	1	13000	5.3 %
LENGTH	**19110 m (16% network)**				

The first analysis of the data indicated the need of some corrections in the spatial position due to location errors of field data derived from differences in the initial point of a measurement and from the variable trace followed by moving vehicles in different years. The correction was done by aligning the maximum and minimum values of the data at the same location and using the spatial location reference of the first survey (2002).
Figures 7 a and b show the successful repositioning of the 2003 data in order to obtain the same pattern of the data as in the previous year.



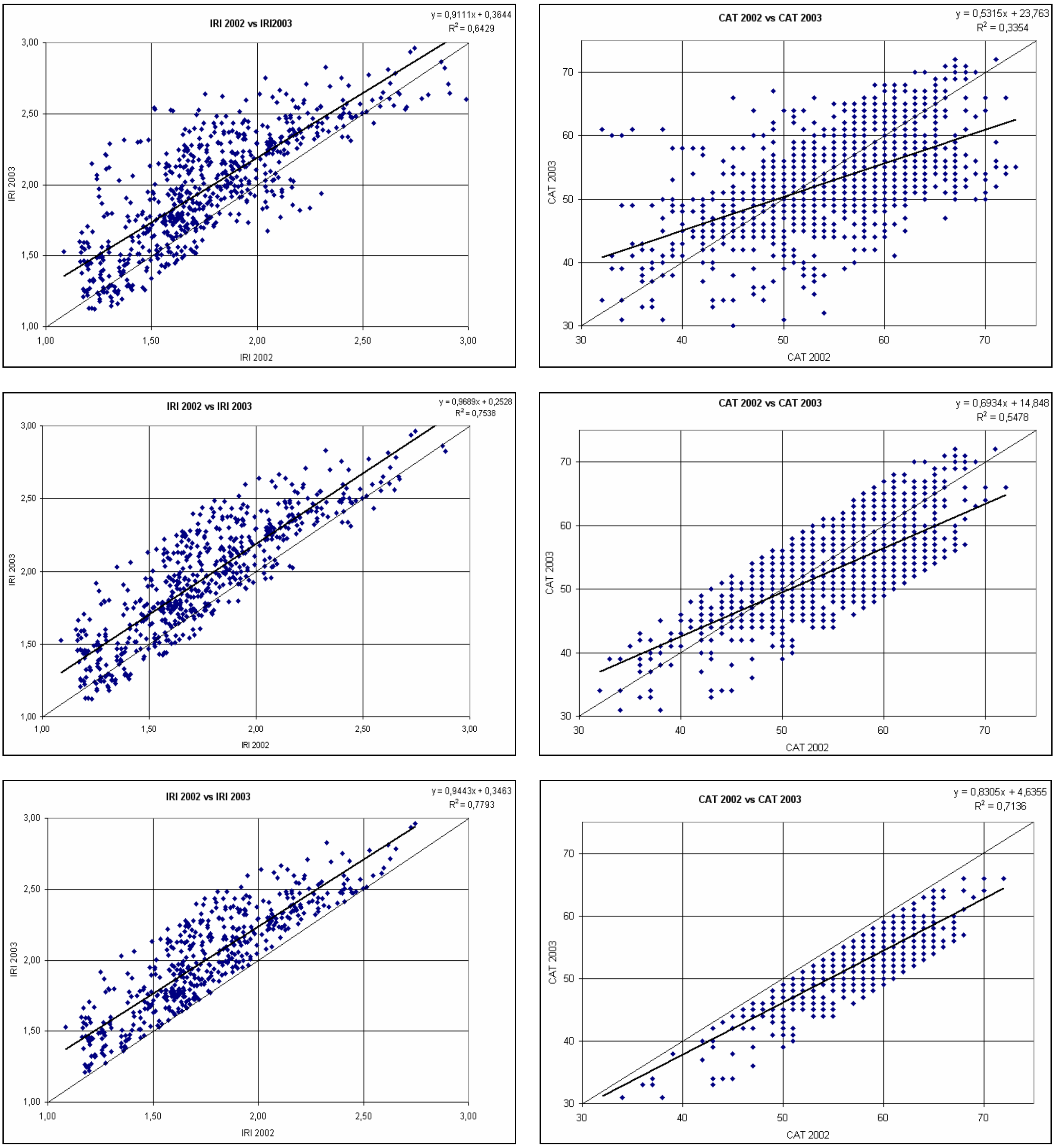
Figures 7 a, b: Comparison of CAT values for 2002 and 2003 before (a) and after (b) repositioning

Having obtained the data sample for the comparison of the 2002 and 2003 data, the next step was to eliminate all sections which had received maintenance actions between the two surveys. Additionally, IRI values originally reported in 20 m intervals have been recalculated for a reference length of 320 m [Sayers 1986]. This has caused a limited loss of data. The different steps indicated above have finally defined the data sample to be used in the statistical analysis for the determination of the current rate of deterioration of the network.
The analysis has been carried out in successive phases described in the following and illustrated by Figures 10 a, b, c by means of xy-diagrams of the 2002 and 2003 values for IRI and CAT.
Phase a): Figure 10a shows the scattering of the data of the original sample.
Phase b): in a following step the extreme values of the frequency distribution of the differences between the values obtained from the two surveys 2002 and 2003 have been eliminated, leading to the data distribution shown in Figure 10b. The elimination process affected all the data below the 5% value and above the 95% value of the cumulative distribution, considered to have a very low probability of occurrence. The data histograms of the differences ΔIRI and ΔCAT are shown in Figures 8 and 9, where the range of eliminated data has been highlighted.



Figures 8 and 9: Distribution of the differences of IRI and CAT values for the two condition surveys

Phase c): data considered to show an abnormal situation, such as the improvement of the index value even without maintenance treatments, were eliminated in the last step. The resulting data distribution is shown in Figure 10c.



Figures 10 (a, b, c): Scattering of the data samples for IRI and CAT. a) full sample, b) sample without extreme values, c) sample without extreme values and without abnormal data

The following Table 3 summarises the mean values, the differences of the mean values between the two surveys, the number of data points and the regression coefficient for the different phases described above.

Table 3: Mean values, number of data points and R^2 for IRI and CAT according to the different steps of the analysis

Mean IRI 2002	Mean IRI 2003	ΔIRI	Data points	R^2	Mean CAT 2002	Mean CAT 2003	ΔCAT	Data points	R^2
original sample					**original sample**				
1.77	1.98	0.21	664	0.643	56.32	53.70	2.62	1678	0.335
sample without extreme values					sample without extreme values				
1.76	1.95	0.19	594	0.754	56.46	53.99	2.47	1497	0.548
sample without extreme values and without abnormal data					sample without extreme values and without abnormal data				
1.76	2.01	0.25	500	0.779	58.29	53.04	5.25	967	0.714

For the use within a PMS all performance data should be related to the same standard reporting length, with extensions usually comprised between the following values:

- 100 m and 200 m for IRI (according to European practice);
- 50 m and 100 m for CAT (minimal value according to standard specification CNR 147/90).

Standard reporting intervals of 100m for IRI and of 50 m for CAT have been selected on the basis of the statistical analysis results reported in the following Table 4.

Table 4: Mean values and R^2 for IRI and CAT according to reporting interval length

Mean IRI 2002	Mean IRI 2003	ΔIRI	R^2	Mean CAT 2002	Mean CAT 2003	ΔCAT	R^2
sample without extreme values and without abnormal data				sample without extreme values and without abnormal data			
1.76	2.01	0.25	0.779	58.29	53.04	5.25	0.714

Mean IRI 2002	Mean IRI 2003	ΔIRI	R^2	Mean CAT 2002	Mean CAT 2003	ΔCAT	R^2
reporting interval of 100 m without extreme values and without abnormal data				reporting interval of 50 m without extreme values and without abnormal data			
1.77	2.01	0.24	0.783	57.99	53.15	4.84	0.689

Mean IRI 2002	Mean IRI 2003	ΔIRI	R^2	Mean CAT 2002	Mean CAT 2003	ΔCAT	R^2
reporting interval of 200 m without extreme values and without abnormal data				reporting interval of 100 m without extreme values and without abnormal data			
1.77	2.00	0.23	0.774	57.39	53.04	4.35	0.691

IRI values reported on 100 m intervals have the highest R^2 value. The shortest interval (50 m, minimal value according to Italian standard specification CNR 147/92) has been selected for the CAT value, as the two regression coefficients are practically identical.
The differences in the mean values for each indicator are due to the presence of a number of elements with a shorter length and irregular in the data set of the sample.
The regression lines of the distributions (Figures 10 a, b and c), shown by the bold black line, need some comments. The angular coefficient for IRI has a value of 0.94, which is quite close to but lower than 1. In this case it is admissible to adopt a constant value for the annual deterioration rate, independently from the previous value. Indeed, a value of 0.94 is an indicator of the IRI difference in relation to the value of the previous year.
The distribution of CAT values shows an angular coefficient of 0.83. With this larger difference from a value of 1 it is suggested to develop a performance curve depending on the value of the previous year (see the comments in the following).
It is finally worth noting, that the number of data points used has been indicated in Table 3 in order to evaluate the size of the data sample used.

This analysis work has allowed to correct the performance curved obtained after the 2002 set of survey data.
Considering the time interval of 18 months between the two condition surveys and with reference to the data of Table 4, the annual deterioration rate for IRI corresponds to 0.25/1.5 = 0.17 m/km per year.
The performance curve for IRI has therefore the following equation (see also Figure 11):

$$IRI_{year\,i} = \min\left[4;\ IRI_{year\,i-1} + 0{,}17\right]$$

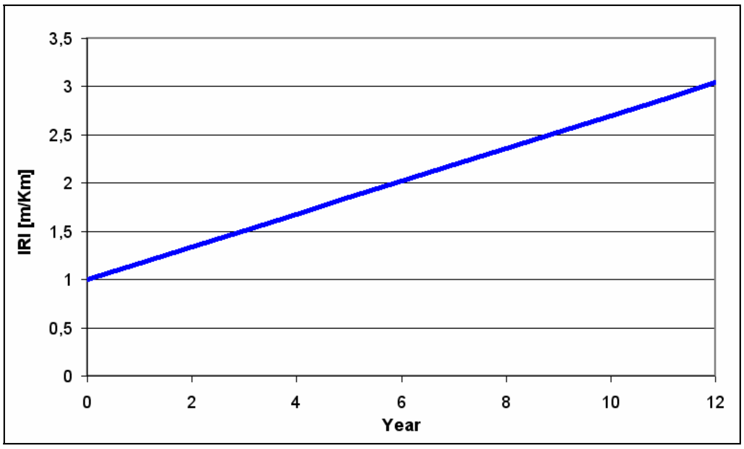


Figure 11: Performance curve for IRI after second year analysis (2004)

The resulting value for the mean annual deterioration of CAT over the network corresponds to 5.25/1.5 = 3.5 between 2002 and 2003 (see Table 4). Even if it would be preferable to maintain a dependency from the CAT value of the previous year as mentioned, a simplified approach with a yearly constant deterioration has been adopted. The equations for the simplified CAT performance curve (currently used in the PMS application) and for the performance curve depending from the previous value are indicated below.

$$CAT_{year\,i} = \max\left[25;\ CAT_{year\,i-1} - 3.5\right]$$

$$CAT_{year\,i} = \max\left[25;\ 0.83 \cdot CAT_{year\,i-1} + 4.6\right]$$

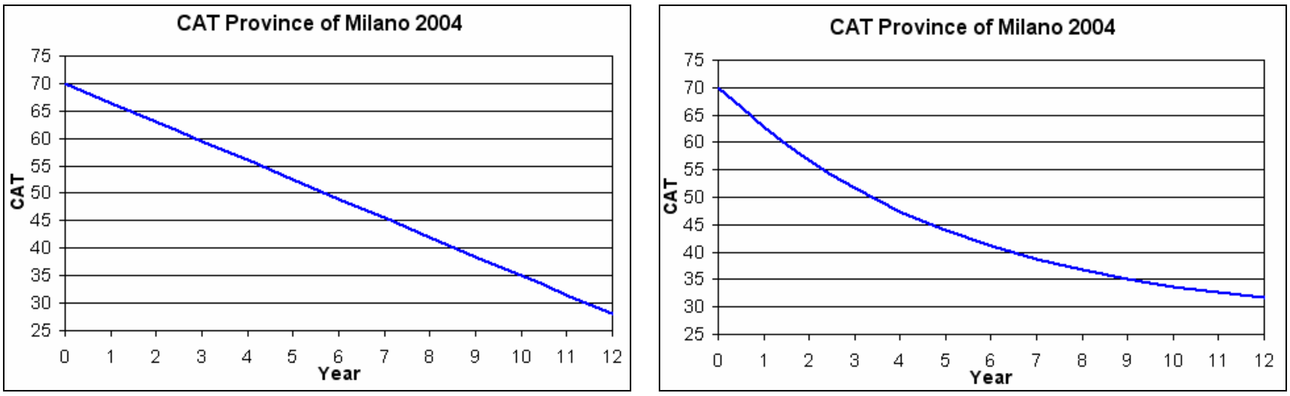


Figure 12: CAT performance curves: simplified (a) and depending from the previous value (b)

Treatments

After the determination of the set of condition parameters needed for the PMS concept and their variation over time by means of performance models, the possible treatments applicable in order to improve the functional and structural condition of the pavement were selected [Shahin 1994, NCHRP 1996, NCHRP 2002, FHWA 2002]. The treatments have been divided into 2 different main categories: maintenance and rehabilitation [TAC 1997, Haas 1994].

Maintenance type treatments will improve safety and user comfort conditions when only negligible or very limited structural damage (of the pavement or subgrade) has been observed. Rehabilitation type treatments will affect a major depth of the pavement and will be applied in the case of advanced structural damage.

Then trigger values for the application of treatments (Table 5) have been selected on the basis of literature surveys (in relation to safety, riding comfort, transport cost), construction practice and the data of the network [Hicks 1999].

Table 5: Treatment types, budget categories and triggers

Treatment type	Budget category	CAT		IRI		%Cracking
		Condition parameter				
Crack sealing	Maintenance	-	-	< 1,5	and	10 < < 20
Surface dressing	Maintenance	< 40	and	< 1,8	and	20 < < 50
or		-	-	< 1,5	and	20 < < 80
Very thin layer	Maintenance	< 40	and	< 1,9	and	20 < < 50
or		-	-	< 1,6	and	20 < < 80
Mill and replace surface layer, AC ≈ 4-5 cm	Rehabilitation	< 40	and	1,5 < < 2,5	and	< 60
or		-	-	1,5 < < 2,5	and	> 50
Resurfacing (overlay, thickness ≈ 5 cm)	Rehabilitation	-	-	2 < < 3,0	and	> 50
Partial reconstruction (mill and replace all AC layers) (≈ 24 cm)	Rehabilitation	-	-	> 2,8	and	50 < < 85
Total reconstruction (surface, base and sub-base, subgrade treatment) (≈ 51 cm)	Rehabilitation	-	-	> 3,3	and	> 80

Analysis Phase

Optimal strategies for the sections are determined through economic analysis on the basis of the Incremental Benefit Cost Ratio [dTims 2002]. This is the ratio between the increase of benefits and the increase in costs between two or more following strategies. In Figure 13 some representative points of the costs and benefits of different, technically possible strategies are indicated for a specific section of the network. The best strategy is the one that allows maximising the benefit within the limits of the available budget.

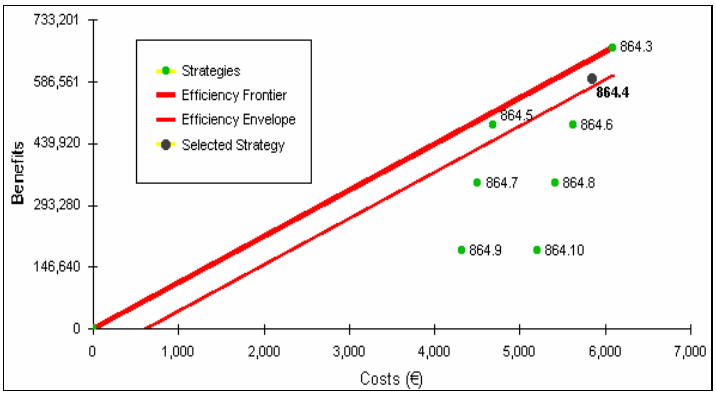


Figure 13: Efficiency frontier for incremental benefit cost

For the selection of the optimal strategy it was necessary, in a first step, to evaluate costs and benefits of each one of the possible treatment options. On the cost side only the direct costs of the Agency (present value of all treatment costs) have been considered as no data were available in relation to accident and user costs (tyre and fuel consumption, etc.). Benefits were evaluated though the improvement in pavement condition defined by the method of the area under the curve for the global index IQS [dTims 2002]. The line connecting the points with the highest benefit (at equal costs) is the "efficiency frontier" and the slope of the connecting line between two subsequent points is the "incremental benefit cost ratio". The software solution adopted (dTims CT) allowed to define a range in % which deletes from further analysis treatment options too far from the efficiency frontier. In this particular case the range has been set at 10% (efficiency envelop) [dTims 2002]. When the efficiency frontier has been defined for each section of the network the optimal strategy can be selected for all sections within the available budget.
The definition of the available budget is also one of the crucial points in the analysis process. Two different types of budget scenarios were used in the present case: three "Hypothetical" for different levels of expenditure (“Low”, “Medium 1” and “High”) and three ("Medium 2", "Medium 2-A", "Medium 2-B") based on the currently available resources and with different distributions between maintenance and rehabilitation options (Table 6).
A period of 5 years has been chosen as the duration of the analysis period [AASHTO 1993]. This limitation was adopted in order to avoid the possible errors deriving from the performance models used and other assumptions made in data treatment process.

Table 6: Budgets levels used for analysis

Budget type	Name of budget	Available Budget (€)	Budget Category	% distribution	Budget allocation (€)
Hypothetical	Low	600'000 €	Maintenance	05%	30'000 €
			Rehabilitation	95%	570'000 €
Hypothetical	Medium 1	1'200'000 €	Maintenance	05%	60'000 €
			Rehabilitation	95%	1'140'000 €
Real	Medium 2 (Actual)	1'500'000 €	Maintenance	53%	800'000 €
			Rehabilitation	47%	700'000 €
Real	Medium 2-A (Redistribution A)	1'500'000 €	Maintenance	05%	75'000 €
			Rehabilitation	95%	1'425'000 €
Real	Medium 2-B (Redistribution B)	1'500'000 €	Maintenance	13%	200'000 €
			Rehabilitation	87%	1'300'000 €
Hypothetical	High	6'000'000 €	Maintenance	05%	300'000 €
			Rehabilitation	95%	5'700'000 €

PMS Results

The software has selected an optimal solution for each individual section of the network within the analysis period. The comparison of the output of different budget scenarios is one of the most interesting parts in the evaluation of the results, as it will allow defining the necessary budget levels for the best management of the pavement asset.
Figure 14 shows the average network condition of IQS for different budget scenarios. It shows the dependency of the global index IQS from the available budget and from different budget allocation to maintenance or rehabilitation options. It also allows a global view of the condition of the network over the total analysis period. Looking first at the three scenarios "Low", "Medium 1" and "High", the improvement of the average pavement condition with the increase of the budget is very clear. The graph also shows that the "Low" budget level is hardly sufficient to maintain the initial condition.

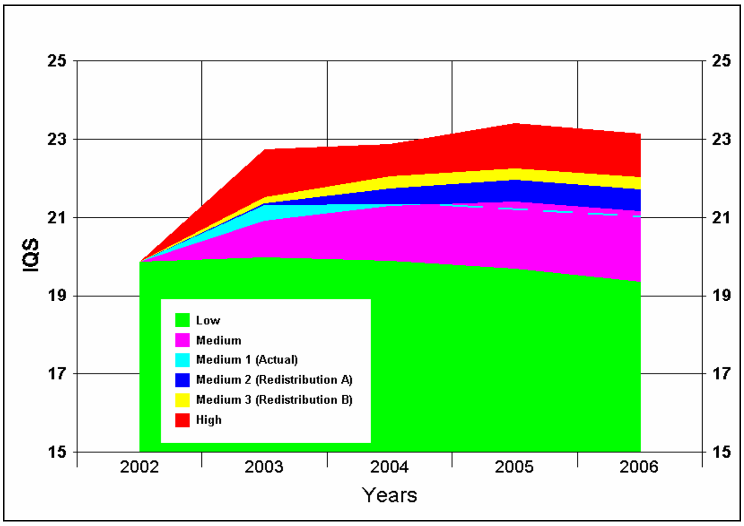


Figure 14: Average network condition (IQS) for different budget scenarios

The scenarios associated to the current level of expenditure ("Medium 2, "Medium 2-A", "Medium 2-B") lead to a similar result as the "Medium 1" budget scenario. However, the last one makes apparently a better use of the resources, which are actually 20% lower than in the case of the "Real" budget scenarios. Among these ones it is "Medium 2-B" which provides the highest increase in the average IQS. The "Medium 2" budget with an allocation of 53/47% between maintenance and rehabilitation is less effective than the two others (“Medium 2-A” and “Medium 2-B”) with different allocation percentages (Table 6).
In order to support the conclusions that can be drawn from analysing average condition it is also possible to evaluate the condition distribution on the network (Figure 15).

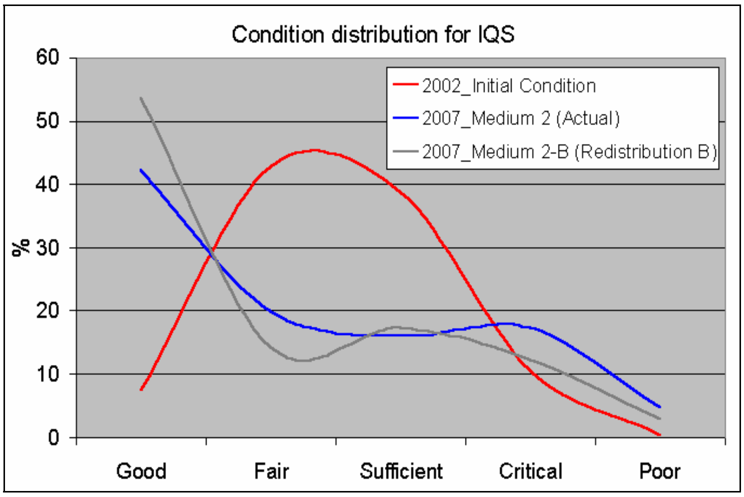


Figure 15: Condition distribution (IQS) of the network

This graph confirms the results already seen from analysing the average condition, as budget "Medium 2-B" leads to a significant improvement with a higher percentage of the network in excellent condition and a lower percentage in unacceptable condition. Both scenarios lead to an important increase of the percentage of roads in good condition. The light increase of the percentage of roads in poor condition is not regarded as a real problem as it is seen as the consequence of the relatively short analysis period selected in this particular case.
The direct link between the resources needed to maintain a desired level of the average condition of the network can also be shown in the graph of return on investment. This type of analysis is useful for the connection between expenditure and network performance and for the planning of the appropriate budget levels for an optimal management of the pavements. Increased investments always lead to a better average condition of the pavements and the graph also shows clearly that in the case of a "Low" budget the initial condition can not be maintained (see the red line "after 1 year" in Figure 16).

Table 7: Analysis on return on investment

Budget Scenario	$(A - I^{(*)})x10 / C$	C = Cumulative Investment [10^6 €]	A = Average Network IQS fifth year
Low	-1.78	2.93	19.34
Medium 1	2.32	5.52	21.14
Medium 2 (Actual)	2.69	4.27	21.01
Medium 2-A (Redistribution A)	3.03	6.10	21.71
Medium 2-B (Redistribution B)	3.53	6.11	22.02
High	3.65	8.95	23.13

(*) I = Initial IQS (2002) = 19.86

Figure 16 also shows that the line linking the three “Hypothetical” budgets ("Low", "Medium 1", "High") is always below the points obtained by the "Real" scenarios ("Medium 2", "Medium 2-A", "Medium 2-B"). This result depends from the definition of the chosen global index IQS, which is strongly influenced by surface characteristics and therefore more sensitive to scenarios with a higher portion of maintenance treatments. However, this result needs further clarification. A careful analysis of the preceding graph also shows that the available budget is not always fully used. In the case of the "Medium 2" scenario the cumulative investment is lower than for the two other budget scenarios with the same amount of funds. The effective program costs for the different options (Figure 17) help to clarify this phenomenon.
As it has been anticipated the available budget for scenario "Medium 2" is only fully used in the first year while during the following years important portions of the available resources for maintenance treatments are not used. After a first series of maintenance treatments (in year one) the resulting improvements of surface quality indicators will prevent from triggering again maintenance options (crack sealing, surface dressings and very thin layers) in the following years.

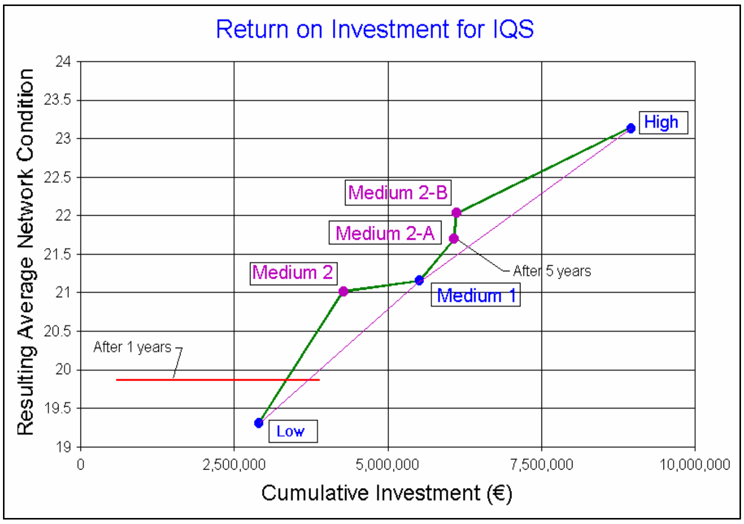


Figure 16: Analysis on return on investment

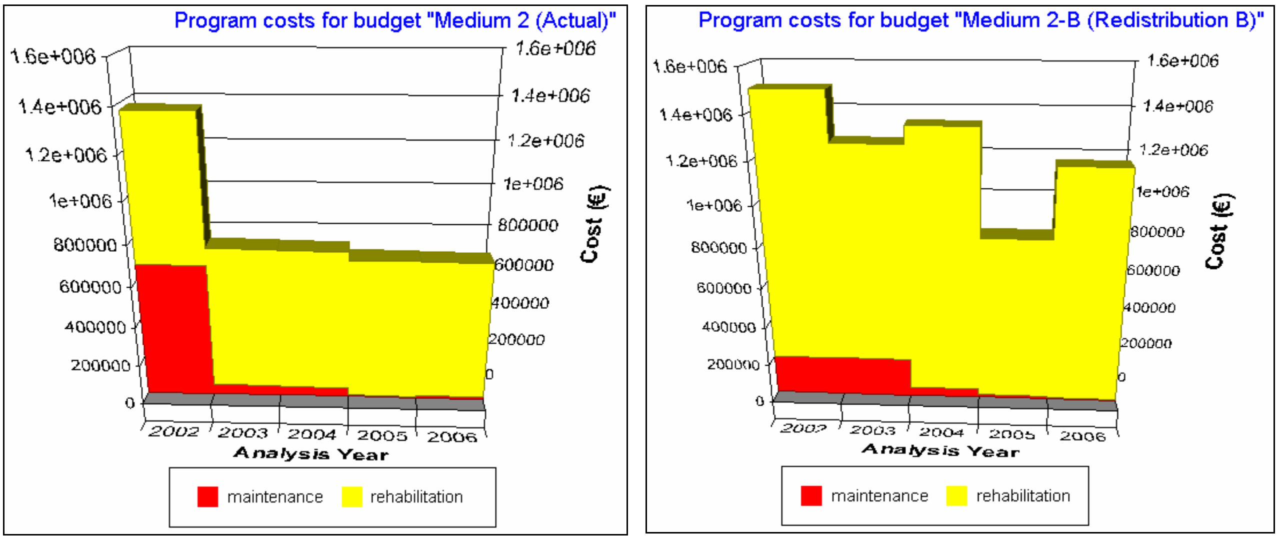


Figure 17: Program costs for treatments according to "Medium 2" and “Medium 2-B" scenarios

The analysis conducted so far on the basis of the global index IQS shows that this index represents essentially the surface condition of the pavement. While the study can be considered as a valid step for a first estimation of the budget levels needed for the maintenance of the network, future work will have to focus on modifying this global index into a more representative and consistent indicator. To this purpose the bearing capacity of the pavements will have to be an influencing factor for the determination of a global index.

A further improvement of the index can be obtained by modification of the calculation equation. So far, the three available parameters have been used with the same weight in the formula for the global index. This is not yet an optimal situation and it does not take into account the effects of large variations of the individual parameters.

CONCLUSIONS

The Pavement Management System developed for the Province of Milano has provided useful results for maintenance planning from the very beginning of its application. The evaluation of the minimal budget needed to maintain the network at a given service level is from an economic point of view one of the most interesting results coming from the PMS. The case study shows that a "Low" budget will not even allow to maintain the initial condition and that the minimal budget to achieve this target would be of about 4'000'000 € over a period of 5 years. A "Medium" budget will already lead to an improvement of the average global index value of 1.5 points.

The study has also shown that the relationship between the chosen global indicator and the budget allocation to different treatment types (maintenance or rehabilitation) is very important. The "actual" budget with the current allocation to different treatment types adopted by the province of Milano does yet not allow an optimal relation between expenditure and resulting quality; first of all because the available budget would only be fully used during the first year. This can bring important improvements after the first year but will finally lead to a decrease in overall quality in the medium term as such a system prevents to activate rehabilitation treatments needed to improve the structural condition. The budget part allocated to rehabilitation is hardly used and the overall quality of the network will suffer. These considerations are supported by the results obtained in the comparison of the "Real" budget scenarios, including different options ("Medium 2-A" and "Medium 2-B") for budget allocation.
Such results from the economic analysis lead to the conclusion that the Province of Milano needs to define a new maintenance policy in which the management of the pavement asset should give larger importance to rehabilitation options while reducing at the same time the expenses for routine maintenance.
The deterioration rate of the pavements has been determined by the comparison of the data from two successive condition data surveys and their statistical analysis which also allowed improving the performance curves used in the first phase of the study. Further improvements are expected after the next condition survey and data analysis. The approach adopted here with data samples and successive surveys is recommended for every Administration facing similar difficulties in adopting performance curves from literature surveys.
The adoption and definition of a Global Index, depending from the different condition indicators monitored on the network, is an essential step for a good PMS. The analysis conducted so far on the basis of the global index IQS shows that this index represents essentially the surface condition of the pavement. While the study can be considered as a valid step for the estimation of the budget levels needed for the maintenance of the network, future work will have to focus on modifying this global index into a more representative and consistent indicator. To this purpose the bearing capacity of the pavements will have to be an influencing factor for the determination of a global index. A further improvement of the index can also be obtained by modification of the calculation equation. In the present study the three available parameters had been used with the same weight in the formula for the global index. This is not yet an optimal situation and it does not take into account the effects of large variations of the individual parameters. An approach using a weighted average of the individual parameters corrected by their variability (standard deviation) as proposed in a study conducted in the US [Jackson 96] is being evaluated. Such a procedure will give a stronger weight to the worst individual parameter in the determination of the global index and provide a more realistic overall picture of the condition of the network.
It is interesting to note that the PMS developed in this study will also be used as support for Global Service contracts; so it will not only constitute the first step towards programmed maintenance, but also provide a solid support in the general and contractual planning phase as it will allow identifying: technical and economic criteria for the preliminary choices made at the planning stage, yearly maintenance programmes derived from multi-year analysis, and expected performances of the pavement as a function of the available budget in order to specify performance requirements.
Other advantages can be obtained during the contract period. The use of performance based Global Service contracts allows determining the costs of maintenance and the level of service to be expected at the end of the contract period. The conditions will be clear for both the administration and the contractor and a control system can be easily defined.

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