Including Bearing Capacity into a Pavement Management System

M. Crispino
Road Section - Hydraulic, Environmental and Surveying Engineering Department (DIIAR), Politecnico of Milano, Italy

G. Olivari & M. Poggioli
Maintenance Section, Roads Department, Province of Milano, Italy

I. Scazziga
Viagroup SA, Winterthur, Switzerland

ABSTRACT: Since three years the Province of Milano is conducting performance surveys of the road network. The survey includes roughness (IRI by ARAN), distress (percentages of cracked and ravelled area, potholes), friction (SFC at 60 km/h by SCRIM) and bearing capacity (deflection by FWD). The purpose of the work is to set up, with the support of the Technical University (Politecnico) of Milano, a specific Pavement Management System (PMS) for the main road network of Province of Milano (covering a total length of 120 km with high AADT values and heavy traffic percentages). The PMS developed two years ago is already used to support technical decisions concerning planning of maintenance works, the evaluation of budgets according to expected performance levels etc. The first implementation included only three of the indexes surveyed: $SFC_{60\ km/h}$, IRI and percentage of cracked area. After completion of the survey concerning bearing capacity of the pavement over a wide part of the network also this parameter is being included into the PMS. Currently, bearing capacity data are available almost network-wide and the criteria used in the implementation of the bearing capacity in the PMS have been defined. The paper presents the data on the distribution of bearing capacity conditions over the surveyed network and shows how the influence of bearing capacity has been taken into account in the latest modification of the PMS developed for the main network of Province of Milano. The experience may be of particular interest for other Administrations facing the development of a PMS.

KEY WORDS: Performance curves, Pavement Management System, road survey, pavement residual life.

1 INTRODUCTION

In 2001 major portions of the Italian interurban state roads have been transferred from ANAS, the national road agency, to the jurisdiction of the provinces that so far were only responsible for networks 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 (main or secondary roads with high traffic volumes and percentages of trucks), radially distributed in the metropolitan area of Milano, constitute the network transferred (Figure 1). All these roads have a considerable importance from an economic, social and territorial point of view for transportation in the whole Province and even beyond for the whole Region of Lombardy.

This situation has led the Province of Milano to the adoption of a new approach for the traditional task of pavement maintenance, aiming at a more rational solution based on the adoption of objective criteria for intervention planning (Crispino et al. 2004 b). The agency has been considering the option of outsourcing step by step maintenance activities by means of "global service" contracts, under which private companies will have to warrant meeting predefined performance standards for different parts of the infrastructure and in particular for pavements (UNI 10685/88).

The province of Milano has decided to use and to develop a Pavement Management System (Crispino et al. 2004 a) 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). The approach adopted by the Province of Milano for the former ANAS network is therefore a completely experimental step in Italy.

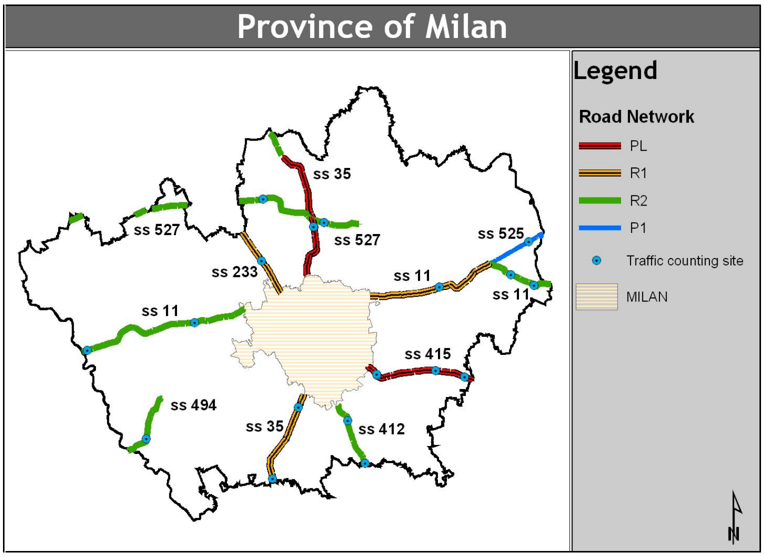

Figure 1: The former ANAS road network and traffic counting sites in the Province of Milano

2 PMS IMPLEMENTATION

A pavement management system is structured into three main phases:

- Input (Setup of the system): this is the conceptual design and modelling of the system and of the implementation of the concept into a software application. It includes setting up a database, defining the condition indexes 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: The output 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 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.

The following subchapters illustrate the PMS before the introduction of bearing capacity in the modelling of the decision process.

2.1 Input

Condition surveys (IRI, $SFC_{60km/h}$, bearing capacity, percentage of cracked surface, ravelled area and potholes) have provided network-wide data for the period March-April 2002, September/October 2003 and September/October 2004. The database of the network has been completed with other data, necessary for the analysis process (Shahin 1994) such as: geometric data, traffic and traffic growth rate, performance models for pavement condition and catalogue of treatments (costs, trigger limits, effects, etc.).

Traffic data, essential for pavement management, have been collected from scratch by the use on 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 1993).

For the determination of a global condition index for the network the following parameters have been used: IRI, $SFC_{60km/h}$ and percentage of cracked surface (including all types of cracks). These parameters describe quite accurately the general situation of the pavement both from the point of view of its conservation and from the point of view of riding comfort and user safety.

Results from FWD measurements have not been included in the first calculation of the Global Index (2003) because the available data did not cover the whole length of the network and an estimation of the structural condition by other means was not considered as an accurate alternate solution. A first set of additional data regarding pavement distress has also already been collected but not yet used: percentage of ravelled area and number of potholes.

The global condition index IQS (road quality index) (Jackson 1996), specifically conceived within a research work conducted at Politecnico of Milano, has been developed using three parameters transformed to standard index values (x_{std}) on a scale from 0 to 10 and combined through the following equation:

$$IQS_{\text{mod}} = \frac{\sum \mathrm{x_i}}{n} - 0{,}625\sqrt{\frac{n\sum x_i^{\,2} - \left(\sum x_i\right)^2}{n^2}}$$

Where: $x_i = SFC_{60km/h\,std}$, IRI_{std}, $CRACKING_{std}$ and n = number of parameters.

Performance models have been determined for each different condition parameter in order to calculate the evolution over time. A lack of knowledge on the age of the pavements or at least on the date of the last rehabilitation prevented the use of different formulas found in literature sources (Crispino 1998, HDM4 1995 and Cost 324 1997). In the first year of study (2003), on the basis of the first set of survey data, a linear curve has been adopted. In the second year the performance curves have been validated by comparison with the data obtained in the second survey campaign (Crispino et al. 2004 c). The following figures show the validated performance curves.

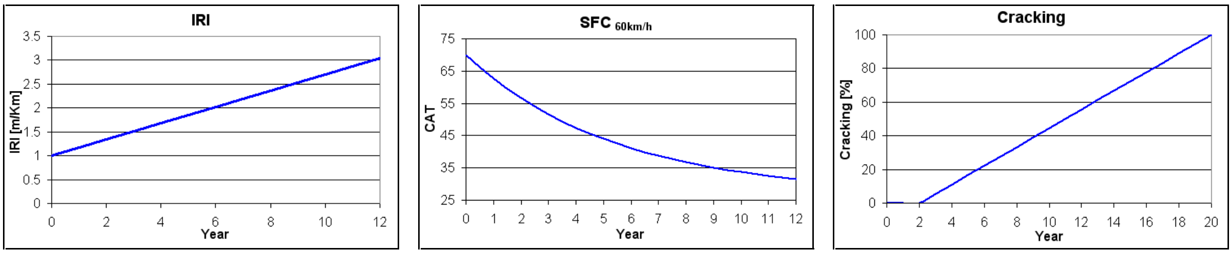

Figure 2: Performance curves for indexes implemented in the PMS.

Possible treatments applicable for improving the functional and structural condition of the pavement (Shahin 1994, NCHRP 2002, FHWA 2002) have been divided into two different main categories: maintenance and rehabilitation (Haas 1994). Then trigger values, expressed as a set of conditions, for the application of treatments (examples Table 1) 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.

Table 1: Examples of treatment types and triggers implemented into the PMS

	Condition parameter				
Treatment type	$SFC_{60km/h}$		IRI		%Cracking
Surface dressing	< 40	and	< 1,8	and	20 < < 50
or	-	-	< 1,5	and	20 < < 80
Mill and replace surface layer, AC 5cm	< 40	and	1,5 < < 2,5	and	< 60
or	-	-	1,5 < < 2,5	and	> 50

2.2 Analysis parameters

The optimal strategy for each section on the network is determined through economic analysis on the basis of the Incremental Benefit Cost Ratio (Deighton 2002), the ratio between the increase of possible benefits and the increase in costs between two or more following strategies. The best strategy is the one that allows maximising the benefit within the limits of the available budget.

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 user costs (tyre and fuel consumption, etc.). Benefits were evaluated through the improvement in pavement condition defined by the method of the area under the curve of the global index IQS.

2.3 Output

The software selected an optimal solution for each individual section of the network within the analysis period. The comparison of the output for different budget scenarios is the most interesting part in the evaluation of the results of the analysis, as it will allow defining the necessary budget levels for the best management of the pavement asset. The output example in Figure 3 shows the average network condition of IQS for different budget scenarios. This result is quite significant as it shows the dependency of the global index from the available budget and from different budget allocations to maintenance or rehabilitation options. It also allows a global view of the condition of the network over the analysis period.

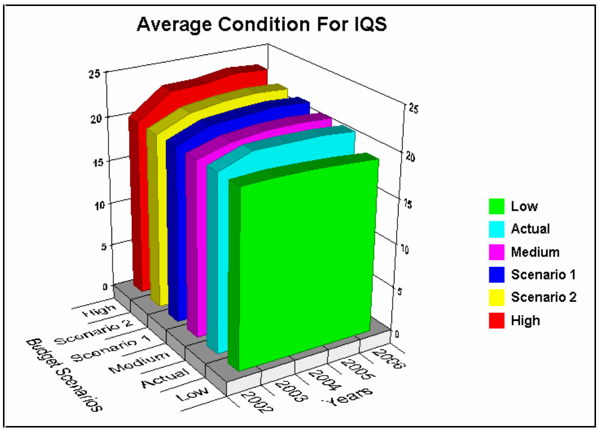

Figure 3: Average network condition (IQS) resulting from PMS analysis

3 IMPLEMENTING THE BEARING CAPACITY INTO THE PMS

3.1 The process

The implementation of bearing capacity into an existing PMS application is a process composed of different steps. In the case described in the paper this process has been subdivided into the following individual steps:

- Choice of a measurement method
- Define the evaluation method of the results, in the present case both deflection values and residual pavement life
- Determine the overall condition of the network in terms of bearing capacity
- Define the use of residual pavement life in the trigger conditions for the selection of specific treatments
- Evaluate the influence of changes in bearing capacity on other parameters (roughness: IRI-values).

3.2 Survey of bearing capacity

For the survey of bearing capacity the choice has been made to use FWD devices and to complete the survey of the whole network over a period of 4 years. Measurements have been carried out at 100 m intervals on right wheel path. In addition to collecting the data of the various FWD displacement sensors pavement and air temperature measurements were also carried out. The temperature of the pavement was measured at a depth of 16 cm below the surface at the start of every session of tests and every 2 hours. Additionally the temperatures of the air and of the pavement surface were measured in continuous with two temperature sensors positioned near the load plate. The layer structure of the pavements has been defined by means of coring at 1 km intervals. With the last survey campaign (September/October 2004) almost the whole network has been analysed.

Figure 4: Bearing capacity survey on the main network of the Province of Milano

3.3 Evaluation of bearing capacity in terms of deflection values

For the further use of the FWD data within the PMS implementation a decision was made to use equivalent Benkelman beam deflections for a standard load of 50 kN at a reference temperature of 20° C. To this purpose it was necessary to conduct the following transformations:

- Determine FWD deflections for a standard load of 50 kN and a reference temperature of 20° C
- Transformation of FWD deflections to equivalent Benkelman beam deflections

The maximum deflections have been standardized (to a normalized 50 kN load at the temperature of 20°C) through a standard formulation using a linear correction according to the practice of various FWD survey providers:

$$D_R = \left(\frac{D_0}{Press} \cdot \frac{707}{10} \right) \cdot (20 - Temp)$$

Where:

- D_R = Reference FWD deflection, converted to a load of 50 kN and a temperature of 20°C [mm/100]
- D_0 = Central FWD deflection measured [mm/1000]
- Press = load on the plate [kPa] (707 kPa for 50kN)
- Temp = Temperature at the measurement points [°C]

Every correct FWD deflection was transformed to equivalent Benkelman beam deflections (50 kN, 10 t load over the rear axle) by means of the following equation (COST 324 1997):

$$D_R = 9.505 \cdot D_B^{0.58}$$

Where:

- D_R = Reference FWD deflection, converted to a load of 50 kN and a temperature of 20°C [mm/100]
- D_B = Benkelman deflection (50 kN, 10 t load over the back axle) [mm/100]

3.4 Evaluation of residual pavement life

One of the key elements for the determination of residual pavement life is a correct evaluation of the traffic loads. From the traffic data collected every hour and day by means of inductive loops, length classes have been transformed to weight classes through the combination of vehicle groupings according to Italian laws (Nuovo Codice 1999) and tables of axle distribution present in the Italian pavement catalogue (CNR 1993). Using the AASHTO relationships, the conversion factor necessary to transform the daily truck traffic to the 8,2 ton equivalent single axle loads has been computed. From this study the average conversion factor necessary to transform the daily truck traffic to the 8,2 ton equivalent single axle loads is 2.26 for the whole network.

The second key element for the determination of residual pavement life is the finding of a relationship between the current traffic load, the deflections and the residual pavement life. Such a relationship is provided by a graph taken from the Switzerland standard specification (SN 640733b 1997) that gives reinforcement thickness versus deflection and traffic. Knowing the traffic a relationship allows calculating the residual life (in years) of the pavement in a good state of efficiency, not needing structural repair (overlay thickness ≥4 cm).

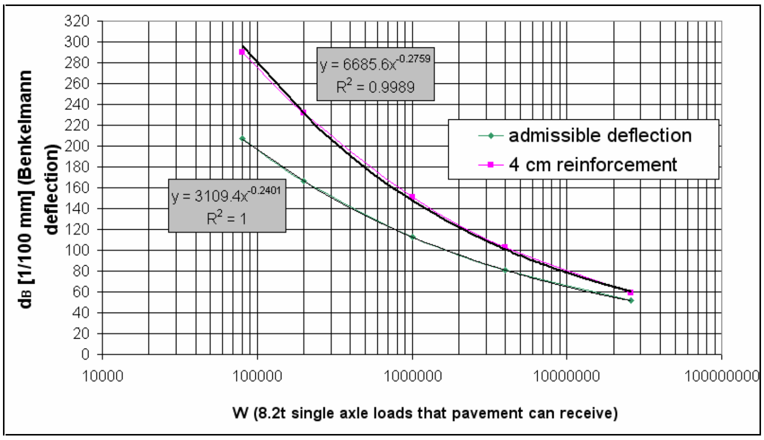

Figure 5: Graph of Switzerland standard SN 640733b (with related formulas).

3.5 Bearing capacity of the network

The application of the rules indicated in previous chapters for determining deflection and traffic values and their introduction into the graph of Swiss standard SN 640733b allowed to determine residual pavement life for each section of the network. as indicated in Figure 6. The results, showing a residual pavement life of ≤ 5 years for almost 50% of the network, shows quite well the structural deficiencies of the network and this highly supports the decision to take bearing capacity into account in the concept of the pavement management system.

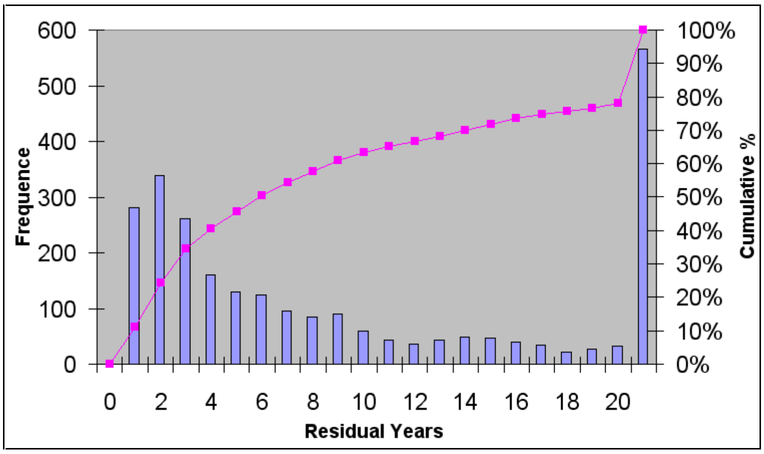

Figure 6: Histogram of residual life on every section of the network

3.6 Implementation of bearing capacity into the PMS concept

Of the two indicators of bearing capacity, deflection and residual pavement life, it is the latter that goes directly into the modelling of the system. The value of deflection, adjusted to Benkelman beam deflections under a 100 kN axle, is used as one of the influencing parameters, together with traffic loads, for the determination of residual pavement life.

A direct application of the graph of Swiss standard SN 640733b to the choice of treatments (definition of triggers) would already suggest the application of the following rules:

Table 2: Residual years (bearing capacity) and treatments' types

Residual Years	Enabled treatments
0 ÷ 5	Only rehabilitation
5 ÷ 12	Allow every treatment
12 ÷ 20	Only maintenance

The insertion of these rules into the rules defined in the previous version of the PMS system leads to the following revised trigger conditions:

Table 3: Examples of treatment types and revised triggers

	Condition parameter						
Treatment type	Residual Years		$SFC_{60km/h}$		IRI		%Cracking
Surface dressing	> 5	and	< 40	and	< 1,8	and	20 < < 50
or			-	-	< 1,5	and	20 < < 80
Mill and replace surface layer, 5cm	< 12	and	< 40	and	1,5 < < 2,5	and	< 60
or			-	-	1,5 < < 2,5	and	> 50

While the revised trigger conditions indicated above are the obvious primary and direct result of the implementation of considering bearing capacity in the PMS decision process other aspects are also taken into consideration, in particular the influence of bearing capacity on the deterioration of pavement roughness (measured by IRI in the Province of Milano).

As commonly known the evolution of roughness after a treatment depends also on the structural contribution of the treatment to the pavement. For this reason pavements and treatments were characterised by means of a structural number, commonly referred to as SN-value. This leads to the adoption of the following hypothesis: a larger structural contribution of a treatment (in terms of increase of the overall SN-value) will warrant a longer life of the pavements and consequently to a reduced progressive decrease of the IRI value (reduced annual deterioration rate).

In order to determine the Structural Number for the existing pavement before the application of a treatment (SNbefore) different formulas derived from literature research have been used (AASHTO 1993), that lead to define structural coefficients a_i for each layer from its elastic modulus. In order to evaluate the SN value after the application of a treatment (SNafter) also the negative influence of milled off materials have been considered. For each rehabilitation treatment the contribution to the SN-value has been calculated depending from the thickness of the layer:

$$SN_i = a_i \cdot s_i$$

Where:

- ai = coefficient for material
- si = thickness of the layer

The ratio between SNbefore and SNafter was calculated for each section where the thickness of black layers, foundation and their elastic modulus were known. The ratio (SNbefore/SNafter) is a number that shows the performance at structural level of each rehabilitation treatment.

The initial performance curve for IRI was:

$$IRI_{anno_i} = IRI_{anno_{i+1}} + (0.17 \cdot year_i)$$

The algorithm that describes the different performance curves is:

$$IRI_{anno_i} = IRI_{anno_{i+1}} + (0.17 \cdot year_i \cdot k)$$

Where: k=SNbefore/SNafter for the considered treatment (1 for superficial treatments).

The following table describe the annual deterioration rate for each treatment:

Table 4: IRI annual deterioration rate for some treatments

Treatment	IRI annual deterioration rate after treatment [m/km*year]
Crack sealing, Surface dressing and very thin layer	0.17
Mill and replace surface layer – ordinary bitumen	0.151
Partial reconstruction – ordinary bitumen	0.134

4 CONCLUSIONS

Currently all the processes described in the paper are being implemented into the Pavement Management System. The modified IRI performance curves have already implemented and the trigger condition are being updated. The new approach in the modelling of the decision making process with a direct link to bearing capacity is expected to provide a more accurate and reliable selection of maintenance or rehabilitation treatments and will thus modify the distribution of resources to maintenance or rehabilitation options in comparison to the previous PMS concept without consideration of bearing capacity.

ACRONYMS

IRI	International Roughness Index
ARAN	Automatic Road Analyzer
SFC	Sideways Force Coefficient
SCRIM	Sideway Force Coefficient Routine Investigation Machine
FWD	Falling Weight Deflectometer
PMS	Pavement Management System
ANAS	Azienda Nazionale Autonoma delle Strade (Italian National Road Agency)
IQS	Indice di Qualità della Strada (Road Qualità Index)

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