Comparison of Road Pavement Performance Modeling of India and Hungary

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Abstract: The pace of growth of road infrastructure in India and Hungary is not commensurate with the traffic. As a result, the highway system is short of its functional/structural capacity. The current maintenance practices are ad-hoc and subjective in nature. Maintaining the road infrastructure at high level of serviceability with limited budget is a challenge for many transportation agencies, among others, in India and Hungary. Pavement performance models have an important role in the scientifically based support of road maintenance, rehabilitation and management decisions. The development of these models usually needs the monitoring of selected trial sections, the performance of which can be generalized for the creation of pavement performance models as a function of time (pavement age) or the axle load passed. In both countries, pavement performance models have been developed. The techniques applied and the main results are briefly shown and compared. 60 trial sections of the Hungarian national road network have been systematically (yearly) monitored since 1991. The time series date of several condition parameters obtained from the test sections, made it possible to create highway performance models for several structural, traffic and environmental variants. The performance of Indian highway pavements are evaluated considering bearing capacity, area of rut depth, cracking, raveling and bleeding. Hungarian performance prediction models were developed for surface defects, unevenness, rut depth, micro

texture and macro texture as a function of age or traffic passed.
The Indian deflection progression equation includes initial deflection when the road is opened to traffic, cumulative standard axle load repetitions and pavement age. Crack and raveling initiation and progression models were also developed in India.
The effect of rehabilitation techniques on pavement performance was evaluated in Hungary. Indian methodology is presented for the selection of maintenance alternatives and their optimum timing for the use of PPP concessionaires.

Keywords: pavement performance models, pavement deterioration, pavement maintenance, road infrastructure, Indian road performance

1. Introduction

1.1. Background

The pace of growth of road infrastructure in India and Hungary is not commensurate with the traffic growth. As a result, the existing highway system is greatly short of its functional/structural capacity to sustain high magnitude of stresses imposed by heavier axle loads and ultimately premature failure of road pavements. Heavy investments are needed for restoring the road network to a desired serviceability level. In addition, the maintenance grants allocated for upkeep of the system have been continuously shrinking. Unfortunately, the current maintenance practices are ad-hoc and subjective in nature. Due to the above reasons, maintaining the road infrastructure at high level of serviceability with limited budget is a challenge for many transportation agencies. Judicious and rational decisions are to be made for maintenance of the highways and it is essential that the highway professionals are provided with scientific tools to enable them to arrive at optimal solutions with the overall goal of utilizing the limited resources efficiently.

Pavement performance models have an important role in the scientifically based support of road maintenance, rehabilitation and management decisions. The development of these models usually needs the monitoring of selected trial sections, the performance of which can be generalized for the creation of pavement performance models as a function of time (pavement age) or the axle load passed. Every important pavement performance parameter should have a separate performance prediction model. In India and in Hungary, pavement performance models have been developed. The techniques applied and the main results will be briefly shown and compared.

1.2. Need for the present study

The present road network requires adequate structural capacity to meet the anticipated high traffic volumes and heavy axle loads. The pavement deteriorates due the combined effect of traffic, and environmental factors. Huge funding is needed to keep the highway system at or above the desired level of serviceability, to meet the needs of road users but the possibility of the huge funds needed for improvements/upgradings is not likely under the present economic scenario. In view of the funds constraints and the need for judicious spending of available resources, the maintenance planning and budgeting are required to be done based on scientific methods. The present work is to demonstrate the application of performance prediction models in maintenance planning and budgeting.

1.3. Objectives of the study

The main objectives of the present study are:

1. To evaluate the structural and functional condition of typical national highway pavement sections in Hungary and India.
2. To develop performance prediction models.
3. Compare the performance prediction model outputs developed in India and Hungary.
4. To demonstrate the application of performance prediction models in pavement management.

2. Pavement performance modeling

Any road management system needs information not only on the present, but also the (forecasted) future condition of the road network considered. Empirical-mechanistic pavement performance models were developed in Washington State from PMS database [9]. Prozzi et al. created pavement performance models by combining experimental and field data [10]. In the first step a riding quality model based on serviceability consideration is developed. Then the original model parameters are re-estimated by applying joint estimation with the incorporation of field data set. Pavement performance prediction models and decision trees for various families of pavements were developed based on Cincinnati's pavement inventory database [7]. A methodology was created to improve further the accuracy of the models in the future by updating the database.

The condition evaluation of a road section provides the necessary data for the present level of major condition parameters as an important precondition of the efficient planning of maintenance strategies. Since the sophisticated management systems seek long-term optimum, as much as possible reliable knowledge is needed about the future condition of various highway sections. The most wide-spread tool for creating performance models is the long-term monitoring of trial sections selected of highway network, and the generalization of their deterioration curves [2]. During a relatively long investigation period some of the sections were surface dressed, resurfaced or overlaid. The continuation of monitoring allows to determine the actual condition improving effect of various major maintenance techniques. The same goal can be attained when the condition parameter levels before and after the interventions on other – not trial – sections of highway network are collected and analyzed. Another "added value" of this kind of investigation is the knowledge on the actual condition levels of sections at the time of major maintenance works. A further research aim can be the evaluation of the trend of new deterioration cycles (after the intervention) compared to the preceding ones [5].

The various requirements for the predictive models to be relevant for these various applications are as follows [13].

[i] Mathematical models are needed to predict the trend in road condition over time, viz. both the short and long term effects of maintenance, so that reasonable estimates can be made regarding the likely timing and costs of future maintenance on a road and of the resultant quality of the service of the road to the road user.

[ii] The quality of service and the trend in road condition over time must be quantified so that they relate directly the factors influencing the engineering decision for maintenance intervention and to the factors influencing the economic benefits.

[iii] The predictive model must utilize only parameters, which can be measured physically and obtained within the budget of agencies, for their implementation within a management system to be feasible.

[iv] The predictive models must permit discrimination of the marginal effects of the various primary factors affecting the rate of deterioration, such as vehicle loading configurations, pavement strength, environment and so forth, for decisions concerning the price of road use and the allocation of costs amongst users.

[v] The reliability predictions is dependent on two sources of variation: the stochastic behavior of materials under natural conditions, and the inability of parameters in a model to fully represent all factors influencing.

Sood et al. collected performance data on existing pavement sections over a period of about six years for expeditious development of approximate pavement deterioration models [13]. They also did the study on specially designed and constructed pavement sections for providing more accurate data generation over a period of about ten years.

Reddy and Veeraragavan studied the applicability of different deterioration models and developed predictive models for structural and functional condition deterioration based on empirical modeling of performance data [12]. Mechanistic-empirical models for rut depth, crack area and unevenness of in-service flexible pavements were developed based on past performance data collected over a period of ten years. Allowable traffic loads for critical value of rut depth, crack area and unevenness based on deflection criteria were determined.

2.1. Discussions

Pavement performance models are needed to plan and schedule maintenance treatments. Limited performance models are available. In order to estimate the optimal timing for maintenance so as to minimize the agency costs as well as the road user costs, appropriate performance model are to the developed.

There is a need to compare to performance prediction models developed by different countries, so that based on each others experience, better planning and scheduling of maintenance treatment can be attempted.

3. Trial section monitoring

3.1. Performance evaluation of Hungarian road network

In Hungary, 60 sections of the national road network of normal traffic have been systematically (yearly) monitored since 1991. The time series data of several condition parameters obtained from the test sections, made it possible to create highway performance models for several pavement structural, traffic and environmental variants. Semi rigid, flexible and super flexible (unbound base) structure categories, three traffic categories (max 1500 pcu/day, 1501-3000 pcu/day, min 3001 pcu/day) and three environmental (sub-soil bearing capacity) classes were considered. The realistic variants (combinations) of the parameters mentioned were represented by 3-4 test sections. The following condition parameters of the trial sections of 500 m length have been evaluated and analyzed:

- unevenness (IRI in m/km, using laser RST),
- rut depth (in mm, using laser RST),
- macro texture (using laser RST, unitless parameter)
- micro texture (using laser RST, unitless parameter),
- bearing capacity (using KUAB falling weight deflectometer),
- surface defects (visual evaluation aided by a keyboard apparatus).

Besides, the traffic parameters and the eventual major maintenance actions on every section have been collected.

The major goal of trial section monitoring is the development of pavement performance models and the average (typical) deterioration curves. The performance models of the road categories can be attained by developing appropriate regression curves on the points representing condition parameter levels as a function of time. (Similar curves are determined as a function of the traffic passed).

3.2. Performance evaluation of Indian highway network

In India, the performance of the highway pavements are evaluated considering the following parameters:

- bearing capacity (in mm, using Benkelman beam),
- rut depth (in mm, using straight edge),
- cracking (in sq.m, visual assessment),
- raveling (in sq.m, visual assessment),
- bleeding (in sq.m, visual assessment).

In addition, the traffic volume in terms of commercial vehicles per day and the axle load spectrum are collected periodically. These data are used to compute the cumulative standard axle load repetitions passed.

3.3. Discussions on performance parameters

It can be seen that Hungary has a rich data base on pavement performance whereas periodical pavement performance data collection is in the stages of infancy in India. However, the data collected from semi-rigid, flexible and super flexible pavement sections have not been analyzed for each pavement type in Hungary.

The structural condition of the pavement is evaluated using falling weight deflectometers in Hungary whereas Benkelman beam has been used in India. Considering thick bituminous layers that are generally provided currently to meet the increased magnitude of wheel loads and repetitions, it will be more appropriate to use falling weight deflectometer so that the deflection bowl data can be analyzed to back-calculate the pavement component layer moduli values. However, structural condition data evaluated using falling weight deflectometer have not been effectively applied in performance prediction models, in Hungary due to wide variation in deflection bowl values. This may be because of the reason that the effect of commercial traffic has not bean considered in Hungary. Pavements will have different structural capacity after different traffic load repetitions and hence varying bowl values.

Hungary has been collecting details of surface texture using laser RST. Surface texture plays an important role on the skid resistance. However, India has not been collecting pavement surface texture data which are very essential to ensure safety or high speed corridors.

Thus it can be seen that both different countries measure different parameters to quantify the performance. For network level pavement management decisions, data on roughness, rutting and surface distresses are required whereas for project level maintenance decisions, in addition to the above information the structural condition data is essential.

4. Performance prediction models

4.1. Importance

The condition of a pavement changes with passage of time due to the combined effects of its structural adequacy, volume, composition and loading characteristics of traffic, environment and the maintenance inputs provided. The failure of a pavement structure is not abrupt like collapse of any other structure. The failure occurs due to internal damage caused by traffic loads over a period of time. The process of accumulation of damage is called deterioration. It is very essential to predict the deterioration of distresses in order to estimate the remaining service life of the pavement which in turn is helpful for suggesting maintenance options.

4.2. Hungarian performance prediction models

The function types applied in the development of the HDM-III model organised by the World Bank [11] were selected for the condition parameters. (Exponential functions were chosen for unevenness and rut depth, while linear functions for other condition parameters monitored).

The performance models of each road category and each condition parameter have been determined, every year, utilising also the latest condition information (Table 1).

Box-Whiskers test is applied to select and to exclude the outliers of the data series analysed [3].

No determined trends could be found yet for bearing capacity parameters (deflection value or stiffness modulus) as a function of time or traffic passed. The seasonal und the yearly fluctuations due to environmental reasons seem to be more pronounced than the fatigue of the pavement structures.

Table 1. Example for the performance models of a "road section type". Road section 5 (flexible pavement, AADT = 1501-3000 vehicle unit/day, max 7 % sub-grade CBR)

Condition parameter	Pavement performance model as a function of	
	age (AGE)	traffic passed (TRAF)
Surface defect (SD)	SD= 1.72+0.12 AGE	SD=1.44+0.12 TRAF
Unevenness (IRI)	IRI = 1.57 exp (0.09 AGE)	IRI = 1.69 exp (0.10 TRAF)
Rut depth (RD)	RD = 2.27 exp (0.07 AGE)	RD=2.21 exp (0.08 TRAF)
Micro texture (MIC)	MIC = 0.32–0.009 AGE	MIC = 0.25–0.007 TRAF
Macro texture (MAC)	MAC = 0.69–0.016 AGE	MAC = 0.66–0.019 TRAF

The performance models are used, among others, for the Hungarian PMS [1].

4.3. Indian performance prediction models

Deflection and roughness progression models developed considering current condition, traffic, structural condition and age of the pavement are as follows:

Deflection progression equation is

$Def_t = 0.006\ \mathrm{Exp}\ (i\,Def) + 0.153 csa^{0.317} + 0.171 age,$ (N=90; R^2 =0.841; S.E=0.24)

where

Deft - deflection at any time t, mm,

iDef - initial deflection, mm,

csa - cumulative standard axles (million),

age - age of pavement from the time of construction, years.

Roughness progression equation is

$UI_t = UI_0 + 9.09 csa^{iDef} + 15.575 age^{2.244}$, (N=90; R^2 =0.81; SE=0.237)

where

UI_t is the roughness at any time t, mm/km,

UI_0 is the initial roughness, mm/km,

csa is cumulative standard axles (million), age is age of pavement from the time of construction, years.

Validation of the models

Deflection/roughness values in the year 2008 are predicted using developed deflection/roughness models developed using the data obtained during 2006 and 2007. The predicted values are compared with observed deflection/roughness values in 2008. Chi-square test was done to check the goodness of fit between both observed and predicted values.

Crack initiation

The crack in the bituminous surfacing occurs due to combined action of traffic loading and the environment. The cracking initiation model [13] is as follows:

$AGECRIN=4Exp\,(-1.09CSALYR/MSN^2)$, (N=20; R^2 =0.45; SE=0.43)

where

AGECRIN=Age of the pavement at the time of cracking initiation, years

CSALYR= Cumulative standard axles per year (million)

MSN=Modified structural number

Crack progression

$CRt=4.26(CSALYR/MSN)^{0.56}\ SCR_i^{\ 0.32}$, (N=124; R^2 =0.25; SE=1.14)

where

CRt = Percentage of cracking at the time t,

SCR_i = initial cracking percentage.

Raveling initiation

Raveling occurs either due to loss of fines/stone particles from the surfacing and/or due to loss of adhesion / bonding between binder and aggregates. The general form of ravelling initiation model [13] is as follows:

$AGERVIN=3.18AXLEYR^{-0.138}(CQ+1)^{-0.38}$, (N=26; R^2 =0.43; SE=0.38)

where

AGERVIN=Age of pavement at the time of raveling initiation, years

CQ is construction quality (CQ=0, good quality; CQ=1, poor quality)

Raveling progression

$RV_t=3.94AXLEYR^{0.32}SRVi^{0.46}$, (N=82; R^2 =0.43; SE=0.38)

where

RV_t= Raveling at time t, %

AXLEYR=Number of vehicle axle per year (million)

SRV_i= Initial raveling, %

4.4. Comparison of models from both countries and lessons learnt

It can be seen that the Hungarian models consider only age or traffic as influencing parameters to predict the various distresses, like surface distress, unevenness and texture. The traffic is represented in terms of Annual Average Daily Traffic (AADT). However, the Indian models consider the structural condition of the pavement as an influencing parameter in performance prediction. The structural condition of the pavement plays an important role on the performance. The performance two pavements carrying the similar traffic load may be quite different at a given age, depending on the structural condition of the pavement. The traffic in Indian model is represented in terms of commercial vehicle volume considering the axle loads and are quantified as cumulative standard axle load repetitions. The damage to the pavement is caused by commercial vehicles and hence it is more appropriate to consider commercial vehicle load repetitions as a significant parameter instead of AADT. An ideal structural condition prediction model should have variables like age, traffic and a structural condition indicator say, structural number or deflection. However, functional condition prediction model say, texture prediction model may contain parameters like age and/ or traffic as they are directly influenced by traffic alone and not by the structural condition the pavement. Thus performance prediction models play a significant role in pavement maintenance decisions.

5. Effect of rehabilitation techniques on pavement performance

5.1. Hungarian experience

During this 18-year period of monitoring in Hungary, the majority of the sections deteriorated to such an extent that surface dressing, resurfacing or strengthening was needed. Then, the question arose, whether their monitoring should be discontinued or not. It was decided to go on with the regular condition evaluation since the additional survey could provide other kinds of useful information. The condition parameter levels in the years before and after the intervention can be utilized for the determination of the actual condition improving effect of various major maintenance techniques. Furthermore, the continuation of trial section monitoring for several more years can provide information about the deterioration trends after the intervention which can be compared to the tendencies during the former life-cycle.

Between 1991 and 2008 56 major interventions were undertaken on 83 % of the 60 trial sections (multiple interventions on several trial sections). Altogether 33 strengthening activities, 3 thin asphalt layers and 20 surface dressings were built.

The overlaying above 40 mm asphalt layer thickness is taken into consideration as pavement strengthening. The effects of strengthening on surface defects, unevenness, rut depth, macro texture and micro texture are analyzed.

In the group “resurfacing using thin asphalt layers”, the consequences of the various condition parameters are evaluated as in pavement strengthening group.

Before and after surface dressing, all of the condition parameters already mentioned are collected and evaluated. The changing of texture parameters is considered of high importance [2].

Figure 1 shows the effect of pavement strengthening on the visual condition state which characterizes surface defects. It can be seen that the originally medium-poor condition level (states 3-5) changes into excellent (state 1) or good (state 2) one. The five points in Figure 1 actually represent information about 16 sections, since the variant 4→1 occurs seven times, and 5→1 three times, while the variants 4→2, 3→1 and 5→2 twice. So, the results are close to the expected ones: 75% state 1 and 25% state 2. (The not fully perfect condition state, a single year after the construction, refers to some quality problem during the construction).

The influence of pavement strengthening on the unevenness was characterized by IRI (International Roughness Index). The surface irregularities even before intervention were not high (in the range of 1.4-2.7 m/km). Consequently, the improvement of unevenness due to pavement strengthening, is minor or moderate.

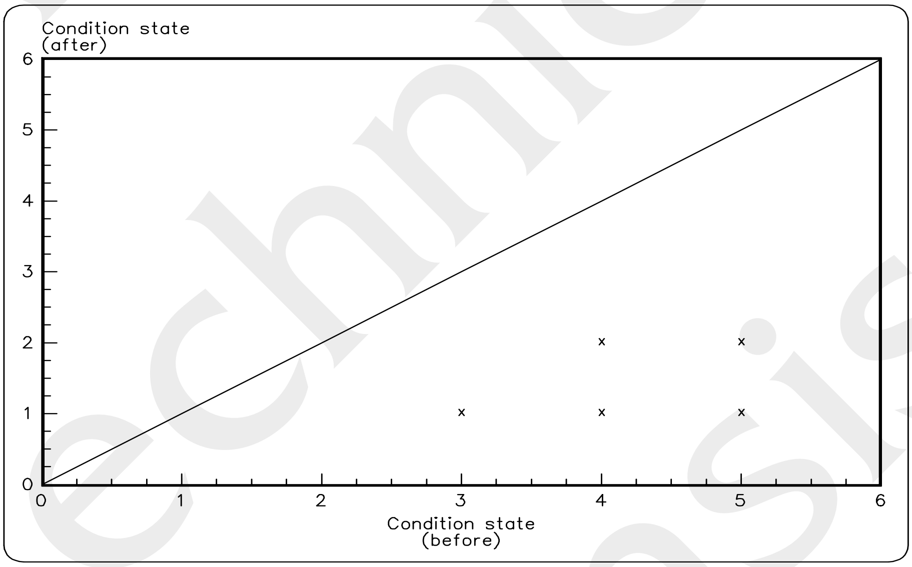

Figure 1. Effect of strengthening on surface defects (visual condition state)

The deterioration curves of the trial sections before and after strengthening were also determined for IRI and rut depth. As an example, Fig 2 shows the deterioration trends in both life cycles (before and after intervention). Based on the analysis of the curves, the following remarks can be made:

- the unevenness during the period investigated generally changed only slightly proving that this condition parameter is not critical among present Hungarian conditions,
- if relatively uneven section is overlaid, the improving effect is much more pronounced, however, a quick deterioration is to be expected,
- the trends of rutting process can be different for various pavement sections,
- the typical rut depth before intervention is in the region of 6-10 mm,

- 2-4 mm rut depth can be expected after pavement strengthening,
- a slight increase of rut depth is typical after the intervention, however, relatively quick deterioration can be also observed,
- the unevenness and the rut depth data series obtained during the investigation period do not show yet any sign of basically different life cycle trend from the preceding one.

The deterioration trends of two trial sections before and after their resurfacing by thin asphalt layers (thickness does not exceed 40 mm) were also tested. It could be seen that this thin layers are unable to improve the rutted pavement surface totally; they can just reduce the rut depth by 5-8 mm. The rutting process after thin asphalt layers seems to be relatively quick showing the minor effect of resurfacing to the deformation resistance of pavement.

The changing of micro texture due to resurfacing by a thin asphalt layer was also evaluated. It could be seen that this condition parameter improved in every case investigated. The micro texture parameter, characterised by the Swedish laser RST, can be considered appropriate, if it exceeds 0,20. This level was surpassed in 4 of the sections in question [2].

The analysis of the test sections already surface dressed shows that – not surprisingly – this type of intervention does not actually influence unevenness and rut depth. That is why, texture parameters were concentrated on. The macro texture value characterised by laser RST is improved significantly by the intervention. The macro texture of the other sections investigated became just slightly higher after surface dressing. The typical improvement in micro texture value is 0.2-0.3 depending also on the initial value.

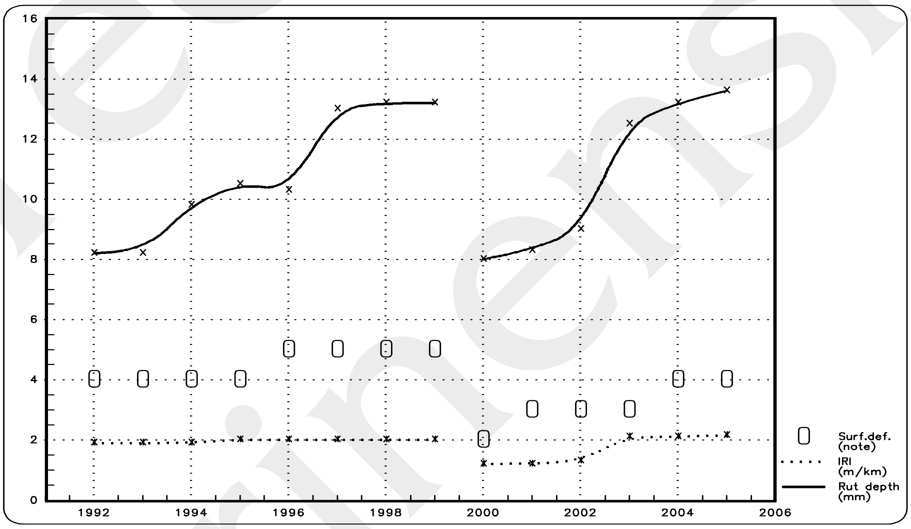

Figure 2. Effect of Strengthening on Pavement Condition Parameters

5.2. Indian experience

5.2.1. Selection of maintenance alternatives

Pothole patching and crack sealing options are considered as routine maintenance options. 25 mm Semi Dense Asphalt Concrete (SDAC25), 20mm Mix Seal Surfacing and two coat surface dressing are considered as preventive maintenance options to improve the functional condition of the pavement. 40 mm asphalt concrete overlay (BC40) and two different structural asphalt concrete overlays, 85 mm and 110 mm are considered as corrective maintenance options.

Table 2. Performance Results Comparison between BC40 and Routine Maintenance

	Deflection, mm		**Roughness, mm/km**		**Crack,%**		Treatment
year	**Routine maintenance**	**BC40**	**Routine maintenance**	**BC40**	**Routine maintenance**	**BC40**	
2008	0.97	0.97	1867	1867	0	0	
2009	1.22	**0.73**	2097	**1500**	0	0	**overlay**
2010	1.44	0.59	2391	1601	1	0	
2011	1.65	0.80	2752	1681	8	1	
2012	1.86	0.96	3183	1812	15	9	
2013	2.06	**0.75**	3685	**1500**	20	0	**overlay**
2014	2.27	0.73	4262	1701	22	0	
2015	2.46	0.93	4915	1783	23	1	
2016	2.66	**0.70**	5646	**1500**	25	0	**overlay**
2017	2.86	0.81	6456	1722	26	0	
2018	3.06	0.97	7348	1798	27	1	
2019	3.25	**0.75**	8323	**1500**	28	0	**overlay**
2020	3.45	0.86	9381	1849	29	1	
2021	3.64	**0.64**	10525	**1500**	30	0	**overlay**
2022	3.83	0.93	11756	1739	33	0	

The performance parameters such as deflection, roughness and cracking values are predicted for the design period of 15 years using appropriate deterioration models. Table 2 and Figs 3 to 5 show the performance of typical pavement for two cases, viz.,“do nothing” strategy and thin overlay.

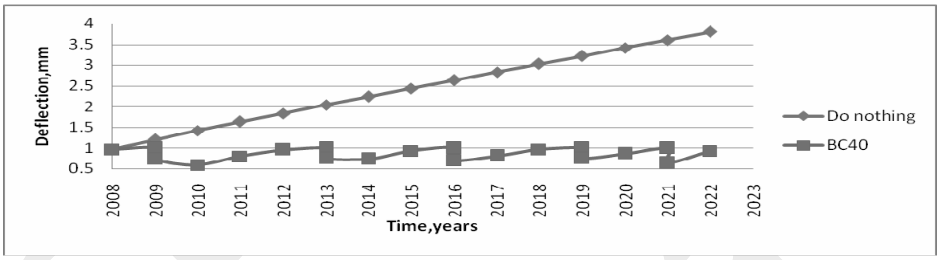

Figure 3. Comparison of deflection progression between Do-Nothing Strategy and Bituminous Concrete Overlay

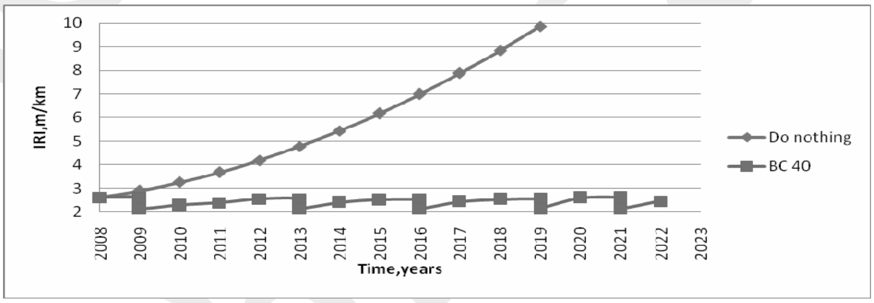

Figure 4. Comparison of Roughness Progression between Do-Nothing Strategy and Bituminous Concrete Overlay

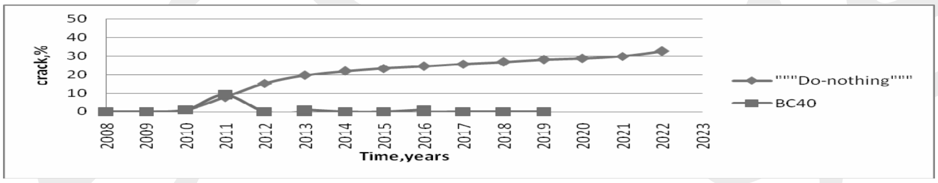

Figure 5. Comparison of cracking progression between Do-Nothing Strategy and Bituminous Concrete Overlay

The following observations are made:

- the percentage reduction in deflection is found to be dependant on the initial deflection value before strengthening as well as the type (of material) and the thickness of the strengthening treatment,
- the initial roughness value depends on the choice of treatment,
- structural overlay reduce the deflection, unevenness, cracking and rutting,
- thin surface treatments do not improve the strength of the pavement,
- the timing of maintenance interventions dictates the life of the pavement,
- the choice of appropriate maintenance intervention dictates the life cycle costs.

Optimal timing is 2009, 2013, 2016, 2019, 2021.

5.3. Comparison and discussion

The Indian efforts concentrated on the selection of various maintenance alternatives, the prediction of their pavement parameters and the optimal timing of maintenance treatments based on road user cost models. At the same time, Hungarian researchers investigated the actual condition improving effect of different road rehabilitation techniques considering, also the eventual differences between the deterioration characteristics before and after intervention. The results obtained in the two countries can compliment each other; the Hungarian performance information can (could) be readily utilized in the Indian selection and prediction process allowing room for the different pre-conditions (design, construction, quality management, traffic climate etc.) in the countries in question.

6. Findings

6.1. Hungarian experience

The main findings of data analysis are as follows:

- strengthening usually creates an excellent [1] visual condition state, although the good [2] state occurs in 30-35 % of the cases,
- strengthening improves unevenness slightly because this condition parameter was typically not in a critical state before intervention (Table 3)
- typically 6-10 mm rut depth reduction can be attained by pavement strengthening,
- relatively rapid deterioration of unevenness and rutting after strengthening was observed,
- the unevenness and rut depth time data series during the investigation period do not show any sign of significantly different life cycle trend from the preceding one,
- resurfacing by thin asphalt layers can reduce rut depth by 5-8 mm, followed by a rapid deterioration (Table 4)
- thin asphalt layers improved micro texture parameter in every case investigated,
- the macro and micro texture of surface dressed sections became slightly higher than before,
- the analysis of country-wide rehabilitation data showed that these sections were, on an average, more uneven and more rutted than the trial sections before intervention. Their improving effect seemed to be more pronounced,
- the majority of surface dressed pavement sections had poor visual condition state (Table 5) and, surprisingly, favorable macro and micro texture values before intervention,
- surface dressing improves average visual condition state by 2.5 in a 5-score scale,

- surface dressing did not change the average macro and micro texture parameter, although extremely unfavorable values were considerably improved by the intervention.

Table 3. Effect of pavement strengthening to unevenness characterized by IRI (m/km) (679 sections with 477 km total length)

Statistical parameters	Unevenness, IRI (m/km)		
	Before	after	changing
Mean value	4.26	3.01	–1.25
Maximum	11.70	9.10	–2.60
Minimum	0.80	0.60	–0.20
Standard deviation	2.22	2.18	–0.04

Table 4. Effect of thin asphalt layer to rut depth (mm) (245 sections with 172 km total length)

Statistical parameters	Rut depth (mm)		
	before	after	changing
Mean value	6.38	4.12	–2.26
Maximum	21.30	17.80	–3.50
Minimum	1.60	1.10	–0.50
Standard deviation	4.23	4.06	–0.17

Table 5. Effect of surface dressing to visual pavement condition state note (643 sections with 451 km total length)

Statistical parameters	Visual condition state note		
	Before	after	changing
Mean value	4.17	1.65	–2.52
Maximum	5	2	–3
Minimum	1	1	0
Standard deviation	1.00	1.08	+0.08

A sensitivity analysis was carried out to reveal the influence of traffic volume, pavement structural type and initial condition level to the effect of rehabilitation performed [6].

a.) Traffic volume

The analysis concentrated on the eventual influence of traffic volume on the actual maintenance effect. The pavement sections rehabilitated were divided into three categories for their AADT: max 1500; 1501-3000 and min 3001 pcu/day. The influence of resurfacing by various rehabilitation techniques on visual condition state (level), IRI-value and rut depth were investigated in the three traffic categories. The following statements are made after the analysis of the results obtained:

- rehabilitation improved the average condition state,
- in 8 of the 9 categories tested, lightly trafficked highway sections improved above the average (it was close to the mean value in the ninth group),
- in 4 investigated categories, road sections with medium traffic volumes improved above average; in this traffic class, the texture of surface dressing actually worsened,
- the condition of highly trafficked sections improved above average in 5 categories,
- it can be stated with limited reliability that the condition of lightly trafficked roads can be improved more than that of the sections of higher traffic volume. A possible explanation is that the intervention levels of secondary roads are relatively low and the generally applied rehabilitation techniques have a more pronounced improving effect,
- consequently, the influence of initial condition level to the actual maintenance effect is worthwhile to investigate.

b.) Pavement structure type

The following analysis evaluated the eventual effect of pavement structure type to actual maintenance effect. Four pavement structure types were investigated i.e. super-flexible (macadam type), flexible, semi-rigid and rigid. The reliability of these statements is influenced by the very fact that various pavement structure types were represented by considerably different sample size: 671 super-flexible (macadam-type), 719 flexible, 147 semi-rigid and 30 rigid pavement structures. The following remarks are based on investigation results:

- the various maintenance techniques improved the condition parameters in each pavement structural category (there were just two exceptions),
- macadam type structures improved above average in 6 of the 9 cases. In 2 cases, it was only slightly below the mean value,
- improvement above average could be observed in 2 flexible, 6 semi-rigid and 5 rigid pavement structure categories. The very low sample size of rigid structures should be emphasized,
- the generally large condition improvement of macadam type structures can be explained by the fact that these lightly trafficked roads have generally a poor condition before intervention,
- the pronounced IRI-improvement of semi-rigid structures after strengthening needs further investigation,

- the visual condition state of rigid pavements improved after any intervention was much better than in the case of other pavement structure types. The quality of surface defects was the usual critical condition parameter of cement concrete pavements,
- the reduction of rut depths for flexible pavements after pavement strengthening was considerably above average, probably due to the relatively deep ruts of thick asphalt layers.

c.) Initial condition level

A further phase of analysis concentrated on the influence of initial condition level to actual maintenance effects. Some of the consequences of the complex investigation may be summarized as:

- Initial visual condition state does not influence the new condition state given after strengthening and resurfacing using thin asphalt layer.
- Initial IRI-value has an influence on new unevenness level after any rehabilitation technique applied. The more efficient IRI-reducing effect of strengthening compared to thin asphalt layers is evident above higher (4-5 m/km) initial IRI-values. Surface dressing can slightly decrease the unevenness if the initial IRI-value is medium or high (Figure 2). If the initial IRI does not exceed 3 m/km, in some cases, no leveling effect can be observed after any type of rehabilitation.
- Rut depth (mm) values after various initial unevenness levels were also investigated if thin asphalt layer is built or the pavement structure is strengthened. The new rut depth seemed to be the highest (around 10 mm) if the initial IRI-value was extreme (very low or very high). The observations with originally even pavement surfaces can not be explained readily. Further analysis is needed.
- The average IRI (m/km) values after various rehabilitation techniques were analyzed in case of different initial rut depth values; the expected trend – initially more rutted surface will be relatively uneven after maintenance – can be usually detected, just strengthening shows some uncertainties in this field.
- Figure 6 deals with the mean rut depth values after various rehabilitation techniques when initial rut depths are different. The normal tendency according to which the more rutted sections will have deeper ruts after any intervention can be seen; slightly surprisingly, new asphalt layers can reach an extra decrease of 1-3 mm in rut depth in comparison to surface dressing. The sample size of initial rut depth categories were as follows:

0-4 mm	330,
4-8 mm	678,
8-10 mm	203,
10-12 mm	129,
above 12 mm	227.

Some remarks to the figure:

- below 3 mm initial rut depth, practically no improvement can be observed after the intervention,
- rut depth reducing effect is independent on the thickness of new asphalt layers,
- slightly astonishing, the improving effect of surface dressing was the most effective for the initial rut depth of 9 mm when a mean reduction of 4.5-5.5 mm could be attained,
- surface dressing can decrease rut depth by 2-3 mm.

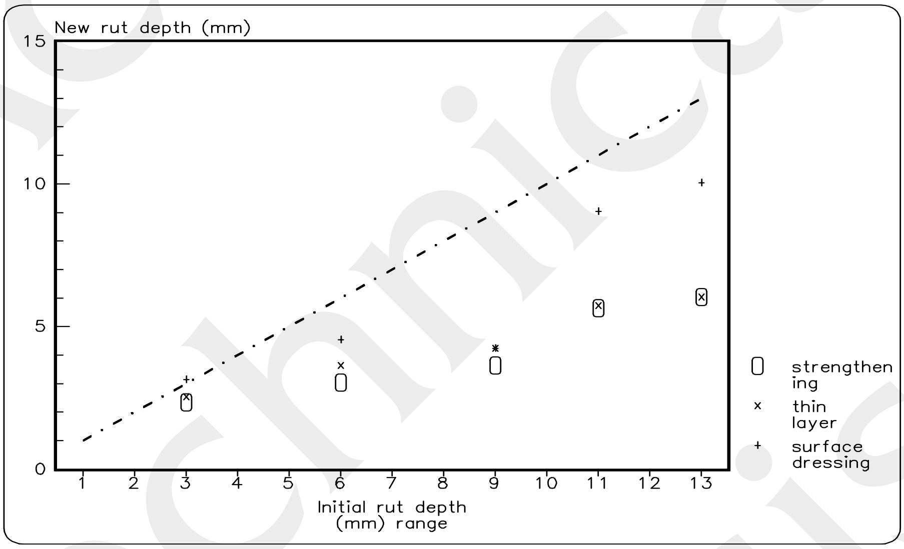

Figure 6 New rut depth (mm) values after various rehabilitation types as a function of initial rut depth (mm) ranges

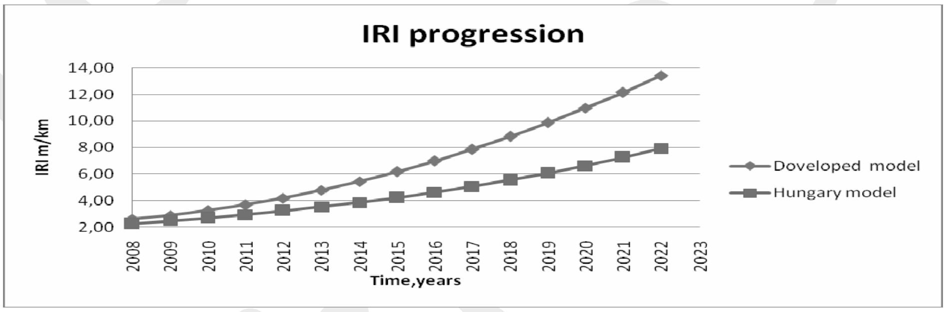

Figure 7. Unevenness Progression Model in Hungary and India

Comparison of Hungarian and Indian performance prediction models

The unevenness progression model developed in Hungary and India are compared and the result are shown is Table 6 and Fig. 7

Table 6. Comparison of Unevenness values

Year	IRI values from developed model, m/km	IRI values from Hungary model, m/km
2008	2.61	2.25
2009	2.89	2.46
2010	3.25	2.69
2011	3.69	2.95
2012	4.19	3.23
2013	4.78	3.53
2014	5.44	3.86
2015	6.17	4.23
2016	6.99	4.62
2017	7.87	5.06
2018	8.83	5.53
2019	9.87	6.06
2020	10.98	6.63
2021	12.16	7.25
2022	13.42	7.93

7. Conclusions

The recent research results on the theoretical and practical issues of road pavement performance models obtained in India and in Hungary were briefly presented. The Hungarian methodology based on the long-term monitoring of selected trial sections typical for the whole national highway network can be considered as a straightforward, "logical" approach to collect the necessary information for the creation of pavement performance models. However, it is a rather time-consuming procedure to attain reliable pavement performance models. The Indian approach is different. The pavement performance prediction models developed concentrated on the roughness (unevenness) and the bearing capacity (characterized by Benkelman beam deflection measurements), actually a combination of them. This is especially valuable allowing simultaneous consideration of both highly important condition parameters in the same model.

The Indian models for ravelling and cracking are more complicated.

As a summary, the Hungarian information on pavement performance models and the actual condition improving effect of maintenance (rehabilitation) actions rely on long and reliable data time series, but they are too "simple" being just a function of pavement age or traffic passed. Meanwhile, the Indian results are supposed to be an aid for Public-

Private-Partnership (PPP) concessionaires to carry out the most efficient and economic ("optimum") maintenance strategy during the concession period. Accordingly, their research efforts concentrated on the pavement parameters actually important for the concessionaire and the optimization of the selection of maintenance strategies and timing. The results obtained are a bit specific, the works in the field should continue in order to get more "general" results. The planned Indo-Hungarian professional co-operation in the topic can contribute considerably to the success of the research ambitions in both countries.

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