# Maintenance and Rehabilitation Systems of Infrastructures Management

**András Bakó, Kornélia Ambrus-Somogyi**

Budapest Tech
Doberdó út 6, H-1034 Budapest, Hungary
bako@bmf.hu, a_somogyi.kornelia@nik.bmf.hu

*Abstract: The road network is one the most important element of the infrastructure system. The available budget for the rehabilitation and maintenance usually not enough for holding the system in a certain condition level its whole lifetime.*
*The paper briefly discusses some elements (monitoring of trial sections, asset value calculation) and several models (urban and motorway PMS, network level, multi-stage highway PMS, BMS). The formal construction of a combined PMS-BMS system is also presented where Markovian type deterioration process is supported and can be solved by Linear Programming.*

*Keywords: management system, infrastructure management, BMS, PMS, combined optimization model*

## 1 Introduction

The solution of the theoretical and practical problems of Maintenance and Rehabilitation Systems of infrastructure management, as well as the establishment of working systems seem to be an up-to-date task in our age. Several publications were made also in the field of transportation engineering.

In Hungary, the ministry responsible for highway transportation has revealed the importance of the completion of a Transport Asset Management System, and initiated the establishment of several system elements and models in infrastructure management.

The paper briefly discusses some elements (monitoring of trial sections, asset value calculation) and several models (urban and motorway PMS, network level, multi-stage highway PMS, BMS). The theoretical background of a combined PMS-BMS model, as well some basic information of Asset Management is also presented.

# 2 Analysis of the Condition Monitoring Data of Trial Sections

Although the systematic (yearly) sufficiency rating provides a kind of information about the performance of our national highway network of 30 000 km total length, it can not result in reliable performance models due to the relative infrequency of the measurement of some condition parameters (bearing capacity, unevenness etc). That is why, in 1991 some 60 trial (experimental) sections of 500 m length each were selected of the national highway network. They represent the typical (flexible, superflexible-macadam type, semi rigid) pavement structure types, the characteristic (0-1500, 1501-3000, min. 3001 vehicle unit/day) traffic volumes and typical (max 3%, 4-5% and min. 6%) subgrade CBR-values. The trial sections were classified into 14 road section categories. Four condition parameters (bearing capacity, surface defects, unevenness, rut depth) are yearly monitored. The time-series data of the trial sections within a road section category are used to determine the relevant performance models. The regression functions best fitted to the measuring points constitute the performance models (the generalised deterioration curves) for each road section category and condition parameter. The performance models can be the function of pavement age (since the construction or the past rehabilitation) or the traffic passed on the section [5,6].

The already 12-year monitoring of trial sections allowed evaluating the actual condition improving effect of various road maintenance techniques (e.g. pavement strengthening, thin asphalt laying, surface dressing). More importantly, the life cycle after intervention is also investigated to compare its performance with that of the earlier life cycle immediately after the new construction.

All of the information gained during trial section monitoring are used to the establishment of more and more reliable PMS models [4].

# 3 Asset Value Calculation of the Road Network

An asset management system badly needs reliable information about the asset value. That is why, in Hungary the systematic evaluation of the gross and the net values of the whole national highway network has been performed since 1981. The gross value means the value of a new facility (reproduction value), while the net value is the difference between the gross value and the depreciation meanwhile that is the actual asset value.

The Hungarian asset value calculation method considers physical wear (condition worsening) and economic depreciation (due to the continuous technical development).

The following average life times were taken into account in the net value calculation:

- earthworks (subgrades) 90 years,
- pavement structure 36 years,
- other road elements 45 years,
- bridges 60 years.

The residual asset value was considered as 10% of gross value for each road element.

The so-called net factor of pavement structure can be calculated in accordance with Table 1 using the 5-grade notes of various condition parameters. (Note 1 is the best condition level, while note 5 the worst one).

| Condition parameter notes | Net factors for | | | | |
|---|---|---|---|---|---|
| | bearing capacity | surface defects | unevenness | rut depth | surface texture |
| 1 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |
| 2 | 0,89 | 0,94 | 0,88 | 0,96 | 0,98 |
| 3 | 0,78 | 0,87 | 0,75 | 0,92 | 0,96 |
| 4 | 0,66 | 0,80 | 0,50 | 0,87 | 0,94 |
| 5 | 0,53 | 0,72 | 0,43 | 0,81 | 0,91 |

Table 1

Net factors of various condition parameter notes

It can be seen from the above table that the following weights were applied for the condition parameters: unevenness: bearing capacity: surface defects: rut depth: texture = 6 : 5 : 3 : 2 : 1.

The net factors for earthworks and other road elements can be deducted from that of pavement structure [5].

The level of economic depreciation is characterised by the actual traffic safety situation of the road section during the past 3 years, the capacity factors and the actual vehicle operating costs compared to the optimum one.

The net factor for bridges depends on the following factors: bridge age, traffic volume, and use of ice-melting salt, technical condition level and economic depreciation. Linear yearly depreciation factors (%) are applied.

Table II shows the changing of the %-ratios of gross and net asset values between 1981 and 2001. The values for roads, bridges and the whole road network are presented separately.

| Year | Roads | | | Bridges | | | Road network | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gross (G) | Net (N) | N/G | Gross (G) | Net (N) | N/G | Gross (G) | Net (N) | N/G |
| | value ($10^9$ HUF) | | (%) | value ($10^9$ HUF) | | (%) | value ($10^9$ HUF) | | (%) |
| 1981 | 195.9 | 130.6 | 66.7 | 16.8 | 12.7 | 75.6 | 212.7 | 143.3 | 67.4 |
| 1986 | 279.8 | 172.7 | 61.7 | 25.8 | 18.2 | 70.5 | 305.6 | 190.9 | 62.5 |
| 1990 | 1535.7 | 922.7 | 60.1 | 131.3 | 74.7 | 56.9 | 1667.0 | 997.4 | 59.8 |
| 2000 | 5802.0 | 3623.6 | 62.5 | 300.8 | 173.9 | 55.8 | 6113.8 | 3797.5 | 62.1 |
| 2002 | 6412.3 | 3984.6 | 62.1 | 331.3 | 180.9 | 546 | 6743.6 | 4165.6 | 61.8 |

Table 2

Asset values of Hungarian roads and bridges between 1981 and 2002

The time-series data of N/G (%) asset value ratios proves that the financial means available between 1981 and 1990 were much below the level needed for the asset preservation of the national road network. While the funds for road construction, rehabilitation and maintenance during the period between 1990 and 2000 permitted a slight improvement of N/G (%), although it did not attain the 1981-level yet. Lately, the worsening of this ratio has been registered again.

# 4 Urban Road PMS Model

A project level Pavement Management System was developed in Hungary for urban road networks in the 90’s [3]. The following tasks were aimed to be solved:

- optimum scheduling of highway maintenance activities,
- selection of the optimum maintenance techniques for certain highway sections,
- project ranking in a certain funds limit.

An analysis period of 10 years was selected, using rolling-type planning technique.

The main part of the model is the ranking subsystem, which produces a priority list for the interventions based on the results of cost-benefit analysis. In order to estimate the costs, performance models and optimum intervention techniques were determined for each condition variant. Three grades of the following condition parameters were applied: bearing capacity, unevenness, surface defects. Various performance models (deterioration processes) were selected as a function of initial condition, traffic size and pavement type. Also the yearly condition grades are forecasted for the 10-year investigation period if the optimum intervention is performed. Similar condition grades are forecasted for the patching needs for the period if only local interventions are performed. Using these kinds of information, the total costs of optimum and non-optimum variants for every section can be calculated. The benefits of the interventions are considered by the help of the changing in the vehicle operating costs (actually its main element the fuel consumption cost). Finnish measurement results [7, 8] were utilized in the estimation of fuel consumption cost reduction. The idea of efficiency calculation is that the costs of optimum interventions are compared to the extra vehicle operating costs due to the postponement of this optimum technique. The resulting cost/benefit ratios of various projects supply the intervention ranking order.

# 5 Motorway Pavement Management Model

In 1995-96, the model of a special Motorway Pavement Management System (APMS) was developed in Hungary [2].

The APMS has the following main tasks: determination of the rehabilitation activities and costs on the Hungarian motorway (expressway) system,

- priority ranking of interventions on a basis of the national economy in case of limited funds,
- pavement performance prediction at a given funds level.

A priority ranking type model was selected which can be used for both network level and project level cases. Three pavement types, three-five condition parameters (depending on the pavement type), four intervention types, two traffic categories were applied. An investigation period of 25 years was chosen.

Expert elicitation was used to determine the most important technical, economic and organizational parameters.

Two main strategies are considered. One systematically selects the recommended type of intervention, and the other exclusively applies routine maintenance. Their long-term consequences are compared, and the results supply the basis for project ranking.

Deterioration tables, intervention tables, intervention cost tables and user cost tables were compiled and used.

The optimum criterion is the lowest national economy cost (agency + user costs) during the whole investigation period.

The output of the system is a list of expressway sections where repair is recommended, together with the types of intervention ranked in a descending order of benefit/cost parameters. It permits every action where the benefit expressed in net present value exceeds its costs.

The model can be used for the estimation of the required funds, for funds split (distribution) and for the calculation of economic loss due to the delay of economically efficient projects.

# 6 Network Level Multi-Stage PMS-Model

The first single-stage network level optimisation model was developed in Hungary in the late 1980's. Its multi-stage version, the PMMS, was created in 1991.

In spite of its mathematical "elegance", the model had several "infantile disorders" which resulted from the number of intervention types, which was too low (only 3), and from some problems related to the deterioration and the cost model.

The road administration needed quick and practical results. That is why the Finnish HIPS model (see Männistö) was chosen, because the experiences gained over several years were available.

The recently developed HUPMS-model [3] has been created using the optimisation procedure of MPMS and the model structure of HIPS [1], which forms one component of the combined pavement/bridge model.

The main features of the model are:

- several (a maximum of 10) time periods (stages);
- 2 pavement types (asphalt concrete and asphalt macadam);
- 3 traffic categories;
- 4 condition parameters (unevenness, bearing capacity, rut depth, surface defects);
- combined target function;
- a maximum of 8 intervention types.

In the long-term model, the optimum solution is sought for the distribution of pavement condition in the network which can be attained after the optimum interventions; it is the Markov-stable condition. The target function is the minimum of the sum of agency and user costs (i.e. social total optimum).

For asphalt concrete roads the following traffic categories were chosen: 0-1500; 1501-6000; min 6001 pcu/day. The traffic categories for asphalt macadam roads were: 0-500; 501-1000; min 1001 pcu/day.

Interventions possible for asphalt concrete roads are: routine maintenance, patching, rut repair, surface dressing, thin asphalt layers, asphalt overlay, and reconstruction. The interventions for asphalt macadam roads are: routine maintenance, patching, surface dressing, profile repair, asphalt overlay, reconstruction.

The Markov transition probability matrices are used for determine the deterioration processes. The mathematical model contains of several conditions which are related to the Markov stability, the initial and latter years condition state distribution, proportions of the different condition states, cost bounds etc.

In the case of the multi-stage model, one of the objectives could be to reach a stable model result by means of an approximation over a period of several years. The number of time periods is generally 10, and the model gives the necessary interventions in each period. The same designations are applied in the mathematical formulation of the multi-stage model as were selected for the single-stage model, except for the additional period index t, with values 1,2-10. The objective is the weighted combination of the intervention and the user cost.

# 7 Bridge Management Systems

Several elements of a bridge management system had been developed and implemented in Hungary already in the 70's and 80's, but it was only in 1993 that the Ministry of Transport decided to adapt the American PONTIS bridge management system to Hungarian conditions. Since then, the Bridge Management Task Group has investigated the original model and agreed to adapt it (bridge elements, actions, unit costs, deterioration matrices etc). Several trial runs have taken place using the PONTIS-H(ungary) models, the results of which could be utilized by the decision makers in several bridge management problems. The first PONTIS-type inspection of the whole bridge stock (some 6000 projects) was completed in 1999. Control surveys were done and are planned for the future to enhance the reliability of this activity. Several further development activities of the system are planned.

- it can manage the whole country-wide bridge stock using comprehensive, uniform and reliable data base,
- it is a valuable decision-supporting tool at network level, although the system has several project features, as well,
- it covers not only the MR&R needs but also the reconstruction ones,
- the PONTIS-type bridge inspection provides detailed and reliable information about the condition state distribution of the bridge stock,
- the bridge deterioration is treated on a high mathematical level,
- its optimisation procedure is based on the analysis of actions, costs and environments,

- its outputs are clear and readily utilizable by the user.

At the same time, Hungary seemed to be appropriate for the PONTIS adaptation due to

- the bridge management elements already available,
- detailed inspection methodology applied,
- need of and decision about the clearance of MR&R backlog,

reliable bridge data bank.

When making the preparatory activities for the use of PONTIS under Hungarian conditions – after having decided about the bridge elements, the condition states and the environment – the transition probability matrices related to the partly new bridge elements had to be developed. These matrix elements reflect the deterioration of the elements in the case of “do nothing” and the improvement of the bridge element in the case of “do something”.

In addition to the actual adaptation activities, the members of Hungarian Bridge management Committee have revealed several limitations and drawbacks of the American PONTIS, and the possibility of their solution is considered when developing the new PONTIS-H model. These problems are as follows:

- Reduction of bridge element number (rare or low cost elements)
- Managing of interconnected bridge elements (bridge deck – waterproofing – slab; main girder - open expansion joint – bearing – abutment; bridge footpath structural elements – footpath surfacing).
- Managing of standard bridge spans. A model containing standardized bridge spans is much more realistic than the traditional one with separate bridge elements. In the Hungarian model, bridges are described using standard bridge spans. The network-level optimisation utilizes these spans, the actions are given as a function of condition state for the bridge spans over a period of 30 years for the model.
- Total optimisation (HUBMS) model. The original American PONTIS optimises each bridge element separately. It is evident mathematically that the optimum for each element and the optimum when all bridge elements are optimised in a single model provides different results with the same constraints. Since the model has common constraints (e.g., cost constraint) – excluding the Markov-stable model – in the model the total optimum should be aimed at. The HUBMS (Hungarian Bridge Management System) optimises all the “simple” and interrelated bridge elements simultaneously for a 30-year period.

# 8 Combined PMS-BMS Model

In the majority of countries – including Hungary – the PMS (Pavement Management System) and BMS (Bridge Management System) operate independently. However, their interdependence is obvious since the bridge surfacing constitutes part of the road pavement. Very often their financial sources are also identical (e.g. Road Funds) contributing to the need for more or less common management. Both PMS and BMS apply the same concept and application of system technology and require a system output function that can be optimised in relation to the benefits and costs.

In Hungary, both the adapted PONTIS-H Bridge management System and the HIPS-HUPMS network level Pavement Management System are based on the use of Markov transition probability matrices. As a result, their identical structure allows the joint optimisation of both systems. This activity is especially important when the aim is the distribution of the funds available between the two infrastructure elements (road pavements and bridges).

The mathematical-engineering model of this BMS-PMS(PBMS), [2] common model has already been completed. Its implementation is planned for the near future.

| | | |
|---|---|---|
| P1 Markov matrices for road pavements | | BOUNDARIES |
| | B1 Markov matrices for bridges | |
| P2 Conditions for road pavements | | |
| | B2 Conditions for bridges | |
| P3+B3 Conditions common to road pavements and bridges | | |

Target functions

| | | |
|---|---|---|
| P4+B4 | User costs | MIN! |
| P5+B5 | Intervention costs | MIN! |
| P6+B6 | Weighted intervention and user costs | MIN! |

Figure 1

Combined model of management of road pavement and bridges

The structure of this model is presented in Figure 1. It has two columns. The first one (P1 and P2) contains the elements of the HUPMS model. In the right-hand column the relevant BMS conditions can be seen (B1 and B2). The PBMS model can also have common conditions, for example relating to the annual sum, which is commonly available (P3 and B3).

The objective is the sum of the object functions of pavement and bridge models. The object can be here the minimisation of the intervention costs (P4 + B4), the minimisation of user costs (P5+B5) or the weighted sum of these costs (P6 + B6). By varying the weight of the parts, any arbitrary combination of the target function can be produced, for example, the minimisation of the sum of road (pavement) user costs and bridge intervention costs.

# 9 The Basic of Asset Management System

The PMS, BMS and its combination lead the way for Asset Management System (AMS).

It has several definitions, one of the best is that of FHWA [9]:

Asset Management (AM) is a business process and a decision-making framework that covers an extended time horizon, draw from economics as well as engineering, and considers a broad range assets. The AM approach incorporates the economic assessment of trade-offs among alternative investment options and uses this information to help make cost-effective investment decisions. Thus, asset management provides a framework for handling both short -and long-range planning.

The main elements of highway AM are: pavements, bridges, tunnels, guardrail, signs, barriers, lighting, other equipments and facilities ([9]).

Some other elements could be contacted to the system: equipments, vehicles, materials, human resources, and buildings. The municipal AM contains of several other elements which are related to mostly the infrastructure: sewer, emergency services, electricity, water, garbage collection, recycling, drainage, park facilities, traffic signals, signs, and markings, buildings, refineries, parks and recreation arias, airport.

The realisation of AM needs several subsystems:

- monitoring of subsystems,
- life-cycle cost analysis,
- asset value,
- analysis of maintenance and rehabilitation actions,
- information system management,

- condition assessment and performance modelling,
- optimisation methods (max. benefits min. cost),
- economic analysis (costs and benefits),
- others.

The main questions which arise at different administrative levels of technical and economic decision making are as follows:

- how much money is required for AM elements pavement maintenance and rehabilitation?
- which AM elements condition distribution would be expected if the sum mentioned above were to be available?
- what consequences would be expected if this sum were not available?
- what consequences would be expected if the maintenance expenditures were significantly increased?
- what are the optimum times for maintenance actions?
- what consequences would be expected from the delay of necessary actions?
- who benefits and who loses, to what extent, etc?

## Conclusions

As mentioned earlier, several subsystems exist already in Hungary in the field of Transport Asset management. The systematic monitoring has begun more than a decade ago. The asset value calculation related to bridges and roads is also performed regularly. We have urban, motorway and highway PMS systems, as well.

A combined PMS-BMS model is also completed. The generalization of this model system is under development.

The first version of the model family consist of the following parts:

- the exact mathematical model (e.g. BMS + PMS),
- normative model for some other elements,
- cost/benefit types models.

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