Development and Implementation of Pontis-Based Hungarian Bridge Management System

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ABSTRACT

In the last few years a new period opened in Hungary not only in political, social and economic life, but also in bridge management. To support the development of the market economy and to improve internal and international traffic highway authorities have to make an effort to ensure financial resources (domestic and foreign), politicians have to be convinced of the efficiency of bridge projects. Bridge Management Systems (BMS) are intended to assist the bridge managers in cost-effectively addressing the bridge infrastructure needs.

In Hungary several elements of the bridge management have appeared in the last decades (e.g., bridge database, bridge inspection). On their bases a ranking program was developed at the beginning of the 1990's, and the implementation of the American Pontis system began. After examining several foreign systems, Hungarian experts decided to realize the Hungarian BMS on the basis of the American Pontis system. Hungarian experts become acquainted with Pontis in 1993. In 1995 Hungary received version 2.0 officially with the entire documentation.

The implementation of bridge elements in the MR&R module, their quantity and condition distribution, cost data and deterioration matrices were introduced step by step. After implementing the components, decision makers were convinced of the advantages of the system by continous test runnings. In 1997 the system of the Hungarian bridge elements, their condition language and the feasible action were prepared. After training bridge engineers for field inspections and preparing the necessary documentation, field inspections in accordance with the Pontis system have begun and are going to be finished in these days on the whole Hungarian bridge stock.

In 1998 Hungarian experts established the Project-Oriented BMS based on the implemented Pontis.

This paper briefly summarizes the results and draws up further steps.

INTRODUCTION

Efficient management of traffic infrastructure in any country can be performed exclusively by using a scientifically based up-to-date management system. Bridge maintenance, improvement and rehabilitation demands in Hungary exceed the available financial resources. Hungarian Transportation, Communication and Water Management recognized this fact and has made efforts to implement and operate a Bridge Management System.

Bridges are complex structures. The materials of bridges are very sensitive to environmental effects (e.g., air pollution, deicing systems). Bridges are the most dangerous parts of road networks, because of the growth of traffic (both number of vehicles and load axles). Simultaneously, bridge failure cause serious economic disadvantages for road users. Repairs or replacements require a lot of social expenditures. In order to assure the minimization of these social expenditures and the adequate level of service (which can be expected) maintenance, improvement and replacement of the bridge network, as well as planning of budgeting (which is usually not sufficient), are required. Assistance in allocating funds and sufficiency analysis are also neccessary. To solve this complex technical-economic optimization task (and the analysis of possible alternatives) more and more countries apply Bridge Management Systems.

There are 6000 bridges in the Hungarian National Road Network. The length of bridges is more than 93 km and the surface of all bridges is 980,000 square meters. There are 23,000 culverts (span length is less than 2 meters). The gross value of bridges (actual price in 1998) is estimated to be 263 billion HUF (1.2 million US$). The average age of the bridges is 46 years. Considering bridge surface, the division of the superstructure of the bridges according to the used material is the following: 74% reinforced concrete and stressed concrete (half of it poststressed beam), 24% steel and 2% concrete or stone and brick.

During the annual inspection of public bridges, a bridge engineer describes the present state of the bridges with the so called "condition marks" ranging from 1 to 5 relating to the 22 structural elements and 5 main groups of structural elements (substructure, superstructure, bridge deck, bridge accessories and bridge enviroment), where number 1 marks the best and number 5 marks the worst state. The condition of the main bridge-structure element groups is shown on Figure 1.

The condition state of the bridges in public highways in the country is graded 4 or 5, which means that nearly 10% of the surface must be repaired within 1–2 years. Bridges having marks 3-4-5 (meaning 30% of the total surface) must be repaired within the next 5–10 years.

Taking appraisal of deck width and load capacity into consideration the rate of the unsatisfactory bridges—concerning load capacity—is 19.6%, the rate of the unsatisfactory bridges—concerning the clear deck width—is 12.8% and the rate of the bridges meeting at least one requirement is 26.1%. The division of national bridges according to suitability criteria is shown on Figure 2.

The funds available for bridges—exclusive of building new bridges—in the last decades show great fluctuation. During the last 30 years, the 0.61% of total gross bridge-value was spent on the maintenance of bridges on average, on modernization 1.1%; 1.71% total was spent, as shown in Figure 3. According to foreign experience, it is advisable to spend 0.5–2% of gross bridge-value to ensure a constant bridge condition level.

ESTABLISHMENT OF THE HUNGARIAN BRIDGE MANAGEMENT SYSTEM

The basis of all kinds of maintenance and improvement work is bridge registration and inspection. Computer based bridge registration was introduced in Hungary in 1965. In the

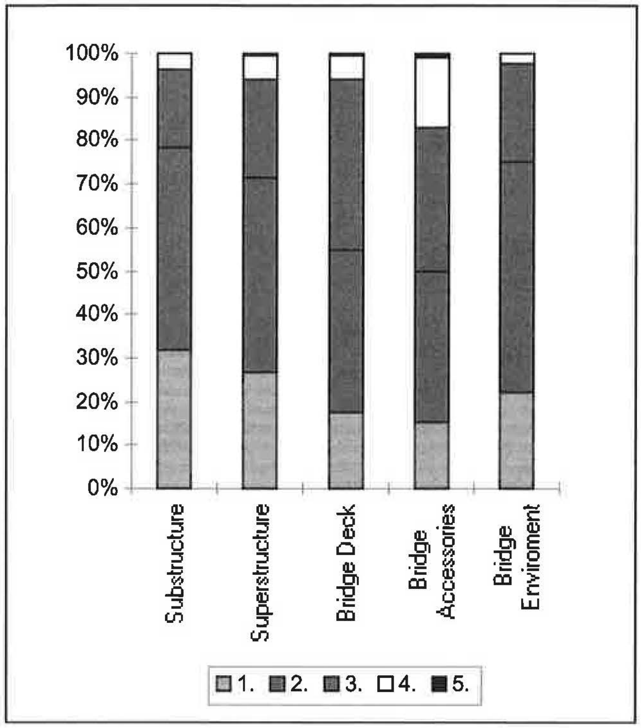

Figure 1: Condition distribution of main elements of Hungarian bridges.

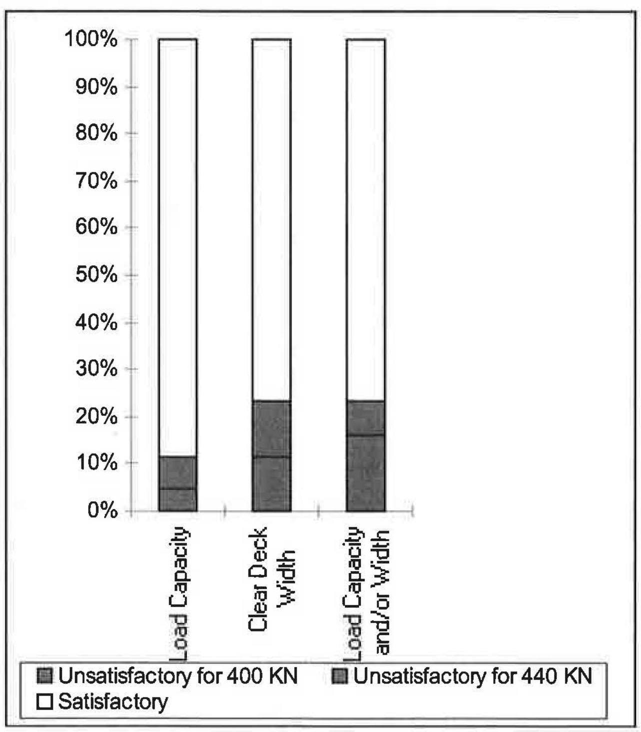

Figure 2: Appraisal of the load capacity and clear deck width of Hungarian bridges.

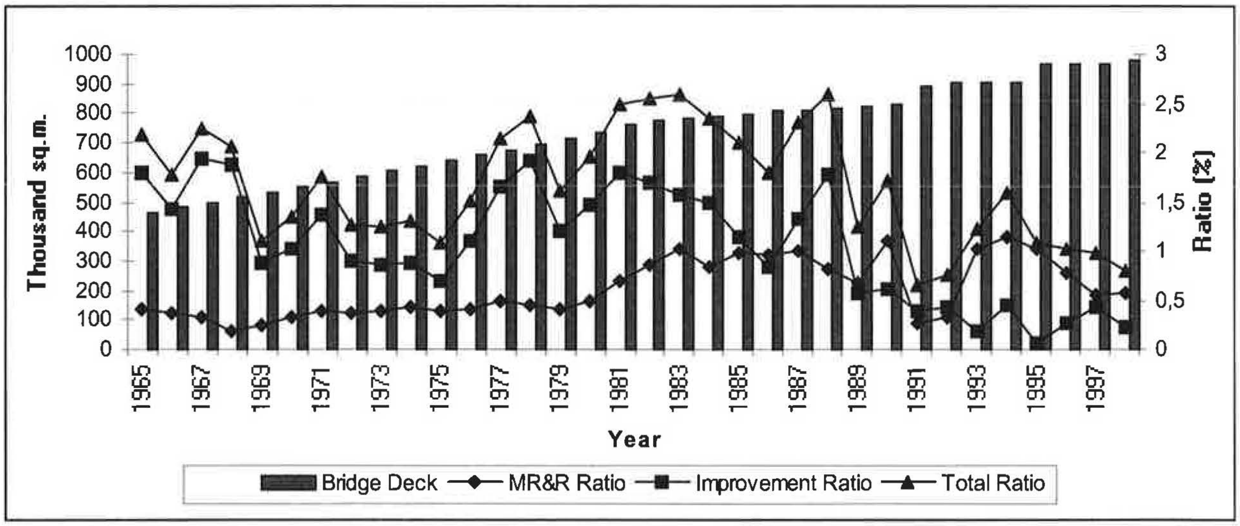

Figure 3: Trend of the annual MR&R and Improvement Ratio.

1980s the Hungarian National Road Data Bank was established, which recorded bridge data. The other base of bridge management is bridge inspection, which is done by a bridge engineer on every bridge at least once a year according to the Hungarian rules valid since 1956. The evaluation by condition state results of the inspections has nearly a 10-year history in Hungary.

The most important decision and steps in the introduction of the Hungarian BMS were made in the 1990's, and there were 2 programmes:

- Middle-Term Bridge Maintenance and Improvement Program for the Years 1992–2000;
- Implementation of Pontis Bridge Management System (network optimization system for bridge improvements and maintenance). Pontis is an outgrowth of Federal Highway Administration Demonstration Project 71, USA.

THE PONTIS-H BRIDGE MANAGEMENT SYSTEM

The Hungarian Bridge Management Task Group dealing with the Hungarian BMS suggested the introducion of the American Pontis system (developed by the Federal Highway Administration) in 1994. Version 1.0 was recognized by the experts in 1993. To search for and find possibilities of the program we have made serious efforts, and due to these results Hungary acquired the 2.0 version of the program together with full documentation in 1995.

Basically Pontis is a network-level BMS, giving project-level results. Pontis connects to MR&R module, which is based on probability (a long-term steady-state condition distribution) and the optimum long-term maintenance cost. The improvement module which ranks on road user benefits, is regulated by a sufficiency and serviceability criterion system. The integration module ranking is on the basis of cost-benefit ratio.

The First Step of Implementation

First we examined the possibilities of applicability in Hungary. We concluded that the flexibility of the system makes the application possible in Hungary in spite of the fact that the Hungarian bridge stock differs from the American bridge stock and we do not have any data regarding deterioration. During the adaptation of Pontis at "minimum level" we applied the basic principle that the bridge data necessary for the running of the MR&R module was converted from the current Hungarian bridge database without local inspection. For the system of bridge elements, deterioration and cost data we applied the American method. According to our investigations American cost data exceeded Hungarian cost data only by 20–30% and the deterioration of different elements belonging to the "moderate" environmental factors were the same.

Pontis was planned so that it can import data from several sources. Pontis sources its data from the American National Bridge Inventory; that is why we had to know the data structure of the National Bridge Inventory, as well as the code of each data field and description. We had to convert 123 different data fields.

We produced bridge elements according to Pontis rules from the Hungarian database by matching them up to the National Road Data Bank-Pontis data. In those cases where it could not be applied, we used computer techniques and engineering algorithms. The most complex work was to make the bridge element types of superstructure correspond, because 101 types of Hungarian superstructure elements had to be matched up with Pontis bridge elements. Table 1 shows the correspondence of Bridge Footing elements.

The system analyses the condition distribution of the inspected bridge stock in more detail than the Hungarian practice, considering the distribution of the quantity of the different bridge element types in different condition states. Concerning this we got approximate data from the extended range of the Middle-Term Bridge Maintenance and Improvement Program for the Years 1992–2000. Figure 4 shows the condition distribution of substructure-type bridge elements.

It caused us a problem that in Hungary we apply 1-5 condition states in case of every main structure part, but in Pontis it can be in 1-3, 1-4, 1-5 depending on the bridge

Table 1: Correspondence of Bridge Footing Elements

National Road Databank		**PONTIS**	
Code	*Name*	*Code*	*Name*
1	Footing (Brick, Stone)	220	Submerged Pile Cap /Footing, Reinforced Concrete
2	Footing (Concrete)	220	Submerged Pile Cap /Footing, Reinforced Concrete
3	Footing (by Sheet-Piling)	220	Submerged Pile Cap /Footing, Reinforced Concrete
4	Cylinder or Caisson	220	Submerged Pile Cap /Footing, Reinforced Concrete
5	Timber Pile	228	Submerged Pile/Timber
6	Steel Pile	225	Submerged Pile/Steel No Paint
7	Pile with Small Diameter	227	Submerged Pile/Reinforced Concrete
8	Pile with Large Diameter	227	Submerged Pile/Reinforced Concrete
9	Other (e.g. Cast in-situ Diaphragm Footing)	220	Submerged Pile Cap /Footing, Reinforced Concrete
N	None	None	

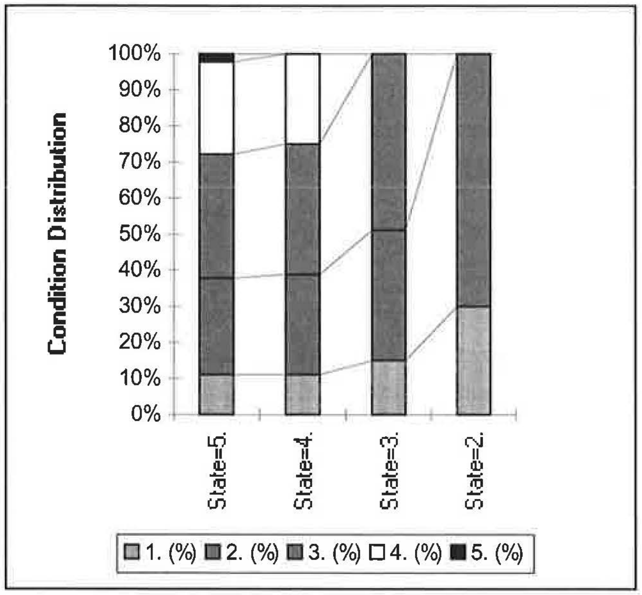

Figure 4: Condition distribution of substructure-type bridge elements from Middle-Term Maintenance and Improvement Program.

element. In cases that differed from the Hungarian practice we merged the Hungarian 1-2 and 4-5 condition states together (see Table 2).

During the analysis of the system we experienced that the "moderate" environmental factor corresponds to the Hungarian conditions; that is why we made the first test runnings with it.

The first results of the program showed similarity with our earlier examinations. The system convinced the decision makers about the advantages of BMS, and that is why the Ministry decided to implement the whole system.

Complete Implementation of Pontis

Utilizing the flexibility of the original system we developed a bridge element system which depends on structural function and material and is guided by the Hungarian features. We determined the definitions of the elements' condition states, the feasible actions and the costs of each action. Because of Hungary's small territory and its uniform climate no remarkable difference can be expected in the enviromental factor according to environmental (climate) grouping. That is why we changed this modificational possibility for considering traffic load, age of structure, influence of cooperative structure elements,

Table 2: Hungarian and Pontis Condition States

Hungarian Practice	1	2	3	4	5
PONTIS	1		2	3	4
	1		2	3	

level of operation and efficiency of the protective system (the Hungarian name is "endangering" factor).

To keep it distinct from the American version, we named the system Pontis-H.

Bridge Elements, Condition States and Environmental Factors

According to Pontis rules, bridges are composed of elements (max. 160 elements), each element representing a particular type of member made of a particular material (e.g., Steel Thru Truss, Reinforced Concrete Deck). A bridge can be divided into 15–20 elements; 5–10 elements influence the maintenance or improvement cost effectiveness of the bridge management program. Bridge elements can be determined by preference in the program.

The system of Hungarian bridge elements closely follows the bridge elements used since the end of the 1980's for condition state recording, but they are distinguished from the structural function according to their material (stone-brick, concrete, reinforced concrete, stressed reinforced concrete, steel, others—wood). There are five main structural element groups according to the function (superstructure, substructure, deck, bridge accessories, bridge enviroment). Within a main structural element group there are 4-6 structural elements. For example within the substructure there is foundation, abutment, pier, bearing and hinger. The units of bridge elements were recorded in connection with the disintegration of bridge elements. Altogether 85 bridge elements were defined. The measurements of different elements were also recorded.

Each bridge element is rated by dividing them into 5 condition states. The description of condition states were determined. The deterioration of each bridge element over time is influenced by several effects. To capture these effects, each element of each bridge is placed in one of the four "endangering" (e.g., deck distress caused by waterproofing failure) factors (benign-low-moderate-severe). We can consider here the interrelations among elements, too.

The above definitions were recorded in a detailed user manual, in which several examples can be found for the disintegration of the bridge elements.

MR&R Unit Costs and Deterioration Matrices

Pontis adds three feasible actions to each element which can be performed in four "endangering" factors and five condition states. The first action is the "do-nothing." A separate module contains the unit costs of all possible MR&R actions for each element. The costs were determined by detailed unit price analysis.

The future-year conditions of elements are described by transition matrices. Four "endangering" factors of each element belong to transition (deterioration condition for "do-nothing" and improvement condition for other actions) matrices.

We used three data sources to determine transition matrices: bridge inventory, Hungarian and American expert elicitations. In the case of do-nothing data bank information were important, and also the estimations of Hungarian experts gave consistent results. So the original American deterioration matrices were modified. But it was very difficult to make new probability matrices valid for actions. There was not useable information in the data bank and the opinions of the Hungarian experts were quite diverse.

Element-Level Inspection

Bridge elements are the units of Pontis. Each bridge element may have five condition states and it can be found in more condition states. During bridge inspection, detailed quantity recording is done concerning bridge elements and condition states. It can be supplied in percentage or in absolute units of measurement. To do this, the whole quantity of bridge elements should be determined (but only the first time). A detailed guide, explanatory figures, and training helped the work of bridge engineers who recorded the condition and the quantity of disintegration on the spot.

Results of the Application of Pontis-H

To test the Pontis-H program we made a test database of Hungarian bridges at the beginning of 1997 by converting data of the National Road Databank, since data recording by Pontis can begin only after completion of the program development. This test database can describe the real situation of the bridge elements only inaccurately (the condition of certain bridge elements cannot be determined from data in the National Road Data Bank). The condition state of bridge elements (we considered the condition state of bridge elements homogenous), quantity (quantities could be estimated only according to the data of the National Road Data Bank), and the "endangering" category (we grouped every bridge element into the "moderate" category), were recorded.

After the first runs of the program we can define the length and type of maintenance cost when maintenance backlog grows, stagnates, reduces or disappears. See Figure 5, which shows the summarized results.

We tested the established system, then we made the first version of the condition state and the final quantity recording system in accordance with Pontis-H by analysing the summarized experiences. In 1997 condition state examinations started in accordance with Pontis-H. By the end of 1998, about 36.7% of the stock was in the Pontis database.

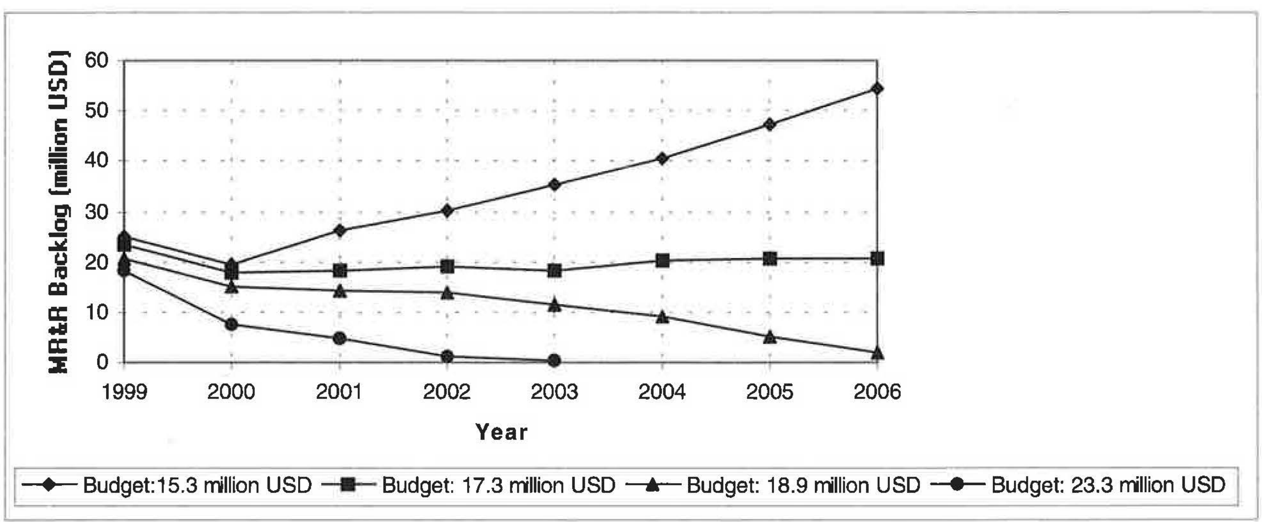

Figure 5: MR&R backlog at various annual budgets, results of Pontis-H.

Results for the whole bridge stock are

Steady-state MR&R needs:	2.78 billion HUF (12.6 million USD)
MR&R backlog:	6.99 billion HUF (31.8 million USD)

The aim of bridge management is to look after the optimal (minimum cost) maintenance solution. The program makes cost optimization and explains its results for the whole stock. Pontis also obtains partial results in which certain bridge owners are interested: for example about the optimal condition state of a bridge element, or the different characters of the current condition state. A typical condition state type is shown on Figure 6 in the case of Reinforced Abutment.

HUNGARIAN PROJECT LEVEL MODEL

A Project-Oriented BMS was developed (so called PBMS) in the last year in Hungary. This model is based on the Pontis-H model. The planning process of this model consists of two steps:

a) running the Pontis-H model
b) running the PBMS model

The input of the Pontis-H is the usual Pontis input format. The PBMS model uses the output of the Pontis-H model as a part of the input. The other part of the input comes from the National Road Data Bank. The data from the Pontis-H are:

- MR&R Cost/Benefit Ratio
- Improvement Cost/Benefit Ratio
- Total Cost/Benefit Ratio.

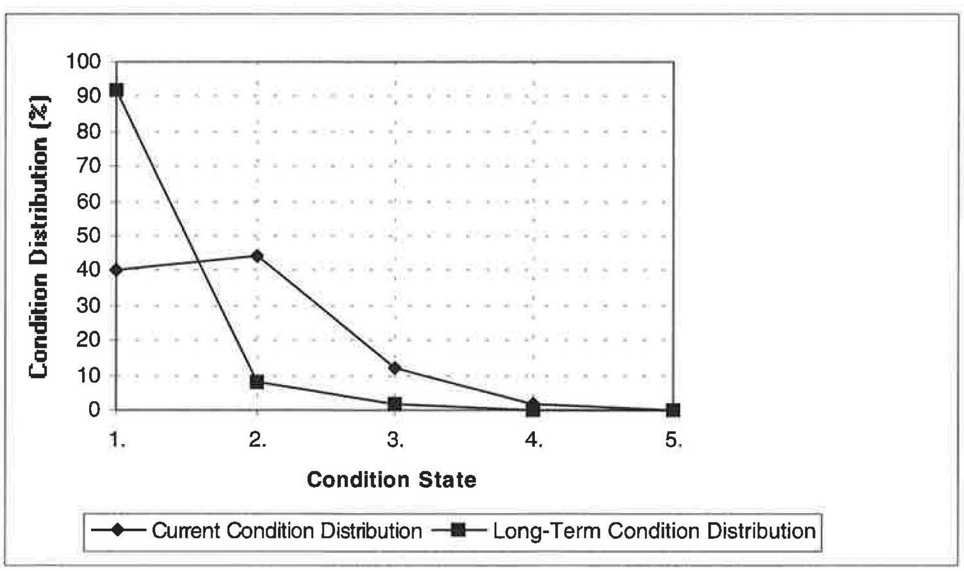

Figure 6: Condition distribution of the reinforced abutment from Pontis-H.

From the National Road Data Bank about 26 items of data are used in our model. These data are the following:

- bridge identification data;
- technical data (length, area, year built, etc.);
- traffic on the bridge;
- data of the span;
- others (e.g., detour etc.).

The optimization algorithm is based on ranking and use of the above mentioned data for this purpose.

The following formula is used for ranking the bridges:

MF = CI∗TI∗I∗A∗HI∗D

where:

MF = modification factor
CI = recent condition index of the bridge
TI = traffic index
I = index of importance
A = age factor of bridge
HI = Bridge Health Index combined by year built
D = length of detour.

The final rank is calculated by the following equation:

RI = TotalRatio∗MF

where:

MF = modification factor
TotalRatio = Total Ratio of Pontis-H.

The parts of the modification factor can be calculated according to the following:

Recent condition index of bridge:

CI = 1 + BHI/100 range: [1,00. .1,10]

where:

BHI = Bridge Health Index.

Traffic index:

TI = 1 + ADT/100000 + TRU/2500 range: [1,00. .1,20]

where:

ADT = Average Daily Traffic
TRU = number of Trucks.

Environment:

E = 1 + (((SAL – 1)/20) + (UND/20)) range: [1,00. .1,20]

where:

E = environment
SAL = salted or not salted bridge
UND = place under the bridge (e.g., river, railway, road).

Index of importance:

I = 1 + ((10 – FUR/90)) + (IM/10) + (1/(20*HIS)) + (TIR/10) range: [1,00. .1,35]

where:

FUR = functional classification of inventory route
IM = importance of bridges
HIS = historical significance
TIR = transit route for trucks.

Age factor of bridge:

A = 1 + (a – BU)1000 range: [1,00. .1,20]

where:

a = actual year
BU = year built.

Bridge Health Index combined by year built:

BI = 1 + BHI/(200*(a – BU)) range: [1,00. .1,10]

where:

BHI = Bridge Health Index
a = actual year
BU = year built.

Length of detour:

D = 1 + (DS/400) + (DL/800)) range: [1,00. .1,10]

where:

DS = length of detour for 20 ton trucks
DL = length of detour for 40 ton trucks.

The programming system was developed in Access 97, which is an easy to use, flexible, fourth generation language. The needed hardware configuration is equal to the configuration needed by Windows 95/98 (MS Office '97 contains this language). Table 3 shows the final report of PBMS.

Table 3: Final Report of Project-Oriented Hungarian BMS

BridgeID	TotalRatio	MODT	RANKING	TotalCost
2549	75019,45	1,931	144862,56	2973700
2099	24144,77	1,607	38800,65	19488800
1190	6782,44	1,88	12750,99	170100
5501	6782,44	1,569	10641,65	199800
5555	7542,33	1,32	9955,87	255800

FUTURE DEVELOPMENTS

Some future development is being planned in connection with the Hungarian BMS. One of them is connected to the deterioration processes (e.g., Markov matrices). Here we have much more exact data, which could be used to improve some of the Markov matrices.

The other modification is to change the optimization procedure. In the Pontis the optimization is made by each of the bridge elements individually. In order to get a total optimum using the optimization model each element has to optimize at the same time in one model instead of doing it by individual elements.

The other idea is to handle the correlated bridge elements in the model (e.g., waterproofing, bridge deck, slab).

The third generalization is toward the combined Infrastructure Management System. In the first step, a BMS/PMS model is planned. The mathematical model has been formalized, and the engineering part is already under development.

CONCLUSIONS

Our paper presented the problems related to bridges on the other side of the Atlantic Ocean. The major causes of deterioration are a shortage of funds for proper maintenance, leaking joints, and increase of traffic. To save money and to answer the questions, we have to use computerized BMS.

Hungary—using the existing parts of BMS—implemented Pontis succesfully. The system has exact engineering-mathematical models, is flexible and its documentations are clear. Hungary proved that this system can be applied in another country where the bridge stock and the practice are different from the American ones.

Future system improvement efforts will be in the following areas:

- Application of Pontis Version 3.2.
- Developing of Project-Oriented BMS.
- Advanced deterioration processes.
- Handling correlated bridge elements in model.
- Overall integration with other management system.

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