Adaptation of Pontis Prediction Model to Hungarian Conditions

László Gáspár
Institute for Transportation Sciences, Ltd., Budapest, Hungary
László Lublóy
Széchenyi István College, Györ, Hungary

ABSTRACT

Between 1955 and 1994, various successful development activities were carried out in Hungary in order to create several elements of a future bridge management system. In 1995 it was decided to adapt the American PONTIS bridge management system among Hungarian conditions. As an integral part of these adaptation activities also, the deterioration and the condition improvement matrices (Markov transition probability matrices) had to be tranformed. When carrying out this adaptation, Hungarian time data series, Hungarian expert elicitation and the original American PONTIS matrices were utilized. Since the bridge elements in both countries are not identical, special rules had to be followed when the "do nothing" type matrix elements of various sources were combined. The creation of "do something" type matrix elements for the PONTIS-H (Hungarian) system was performed in a similar way. Although the limited experience of Hungarian bridge specialists in the large variety of bridge intervention technique types caused some difficulties here. The term "environment" is interpreted more widely in the PONTIS-H than in the original version. This first approximation of the PONTIS-H deterioration and condition improvement matrix elements will be developed further in the future by comparing the actual and the long term condition distribution of bridge elements, as well as by the sensitivity analysis of deterioration matrix elements.

INTRODUCTION

In our world under globalisation, the development of transport sector and the attaining of the needed service level of transport facilities can be considered as an important national economy's interest. In this task, the maintenance of the bridge stock has a significant importance due to its high value and dominant network role. The macroeconomical analyses have lately comprised the establishment of maintenance strategies acceptable for the community and financeable from the social resources. Strategies meeting the relevant technical-economic requirements can and should be developed by harmonizing the maintenance needs and the economic possibilities. The minimization of social expenditures and, simultaneously, the provision of the service level expectable among the given social-economic conditions require—from a technical point of view—the appropriate maintenance, eventual rehabilitation and regular replacement of the bridge stock, as well as—from an economic point of view—the planning, the optimal distribution and the efficiency analysis of the use of (always very limited) financial resources. To solve the above complex technical-economic optimization task and to analyse the effects of possible strategies, bridge management systems are applied in more and more countries.

Two basic requirements can be formulated towards these strategic decision supporting and assisting management systems:

- they should determine reliably the optimal maintenance strategy of the stock to be managed and analyse the effects of non-optimum strategies in order to introduce the technical-economic consequences of a decision for the decision makers and to reach social expenditures matched to social needs,
- the managers could supply the optimum maintenance strategy of various structures (structural elements) to the operators to assist the optimum distribution of the funds available.

DEVELOPMENT OF HUNGARIAN BRIDGE MANAGEMENT SYSTEM

The detailed and uniform manual bridge registration was introduced in Hungary in 1955, then the computerized data registration started in 1965. In the 70's, bridge condition data sheets were introduced and computerised data storage was initiated. The National Road Data Bank has also been created which has stored also bridge data. Computerized data registration allows quick and multicriterial data analysis for reliable data support. During bridge inspection, the bridge engineer evaluates the present condition by giving notes in a 1–5 scale for 22 structural elements and 5 element groups (substructure, superstructure, deck, bridge accessories, bridge environment). No. 1 characterizes the best (almost new) condition state. From 1991 on the technical data have been complemented by economic data allowing a technical-economic analysis on the whole national highway network. The Hungarian bridge management system launched in 1995 is actually the adaptation of the American PONTIS BMS to local conditions. The data collection of the first survey cycle will be soon terminated. Utilizing the former development experiences, based on PONTIS data and results, a Project-oriented Bridge Management System was compiled in 1998 which modifies the PONTIS network results with project-level bridge information allowing also project-type analyses.

FORMER RESEARCH WORKS ON BRIDGE ELEMENT PERFORMANCE

The investigation of the bridge and bridge element performance (deterioration) has been received a significant professional interest from the early 90's, before the introduction of PONTIS to Hungary. Two research projects will be mentioned here; their results can be considered forerunners of the PONTIS deterioration (condition evolution) matrices and their experiences have contributed to the Hungarian expertise in bridge deterioration.

When calculating the net and the gross values of Hungarian bridges in 1992, KTI (Institute for Transport Sciences) Budapest, divided the stock into seven main bridge types. Their life expectancies were determined and typical deterioration models were taken as a function of time based on engineering judgement (*1*). For the sake of simplicity, the parabole type functions of net/gross value ratio (%) were substituted by polynoms. Figure 1 presents the life expectancies and the expected performances of various bridge type groups.

Due to the accumulated nationwide bridge maintenance and rehabilitation backlogs till the late 80's, the Hungarian Ministry of Transport commissioned Szechenyi Istvan College, Gyor, to compile a medium-term bridge maintenance and rehabilitation program in order to estimate the 8-year maintenance and rehabilitation need. Also the condition and the cost analysis of bridge population was carried out, and the priority ranking of bridges determined.

The main experience obtained during condition inspection was that—in accordance with the bridge operation practice of previous years—the average deterioration for substructure and superstructure happens in 40–50 years, for deck and bridge accessories in 20–25 years, while for bridge environment in 10–15 years. After it the condition remains more or less stable (unchanged) in a state defined by the actual bridge maintenance expenditures (see Figure 2). This very fact proves—from a technical viewpoint—the reality of the term "steady state" in PONTIS (*2*).

DETERIORATION MATRICES OF PONTIS-H (HUNGARY) FOR THE "DO NOTHING" CASE

When making the preparatory activities for the use of PONTIS among 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". Eighty-five bridge elements were selected. In the "do nothing"

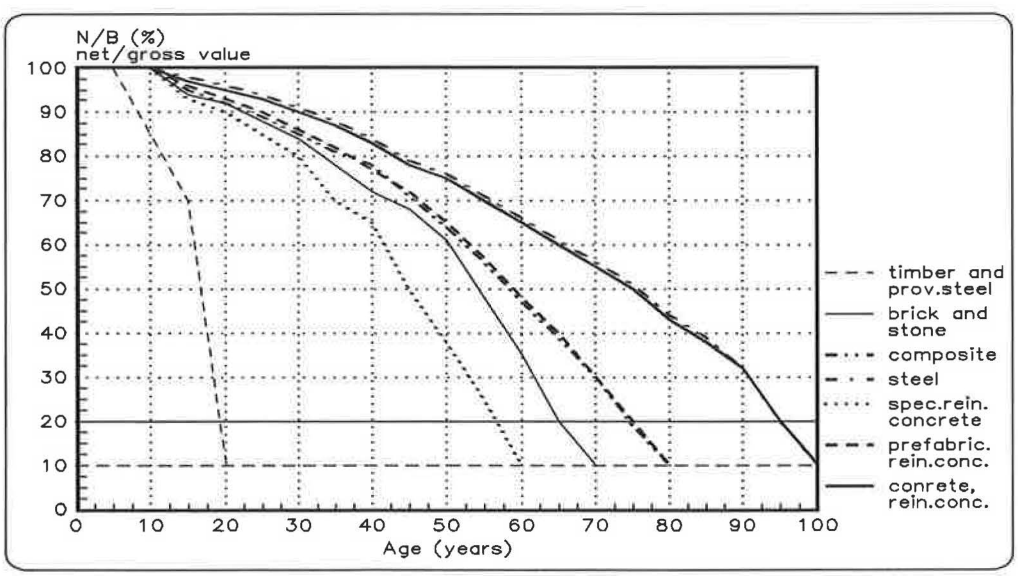


Figure 1: Performance models of various bridge types.

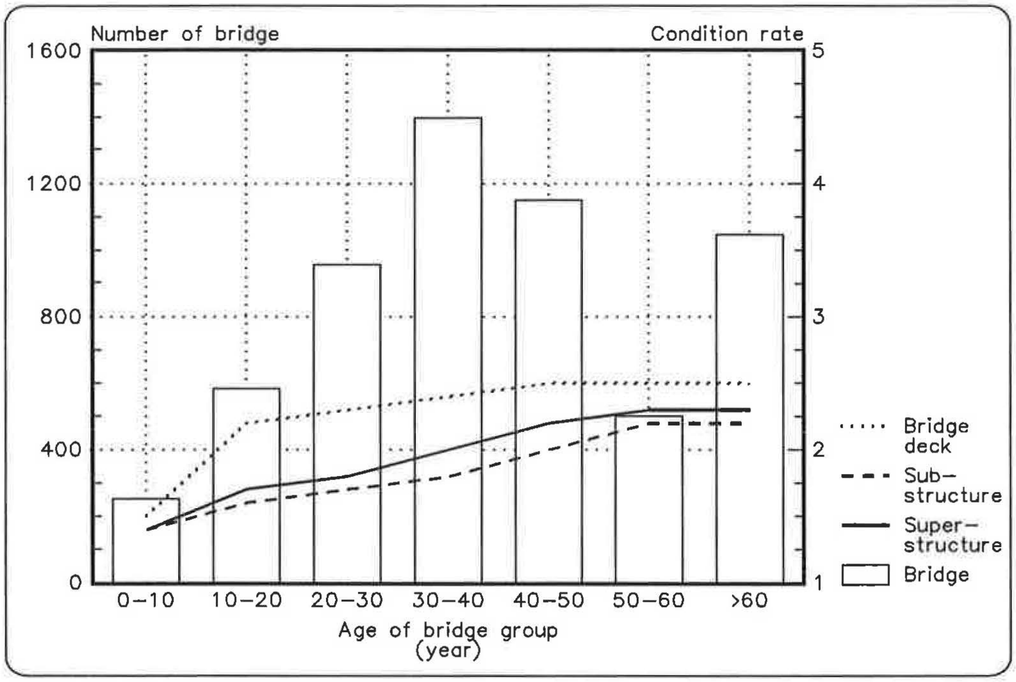


Figure 2: Deterioration of major bridge structural elements.

case, every deterioration matrix had to be calculated in the 4 environments. So, the size of these probability matrices is 5x5.

An element a_{ij} of the deterioration matrix gives the probability of the event that the condition of a bridge element having a condition state *i* at the beginning of the investigation cycle (2 years) will change to the condition state *j* till the cycle end.

PONTIS allows the creation of these matrix elements using condition state time series but also expert elicitation can be considered in the lack of time data series. The system can even accept the simultaneous treatment of both inputs with changing weighing factors as a function of the reliability of time data series.

Although the Hungarian computerized data registration has been applied for more than a decade, the detailed time data series needed by PONTIS were not available.

During the adaptation process, several information sources were used:

- Expert interpolation or (eventual) extrapolation of the data of the time series available,
- Expert elicitation of Hungarian practitioners and theoretical bridge engineers,
- American PONTIS expert elicitation,
- Comparative analysis of the above data.

The process of the creation of deterioration matrices will be shown as an example in the case of reinforced concrete slabs (moderate environment) because this element is highly represented in the Hungarian bridge stock and it has a significant financial implication.

Original PONTIS Expert Elicitation

When creating the first generation of deterioration matrices, the unchanged use of original American matrices seemed to be an option, although then the deterioration matrices could not have reflected the Hungarian specialities in bridge elements, condition states and environments, the experiences coming from Hungarian data and the results of Hungarian expert elicitation.

Consequently it was decided by the Hungarian adaptation team to apply the American matrices only if lacking of domestic information (*3*).

As an example the original PONTIS deterioration matrix of reinforced concrete slab is presented in Table 1.

Time Data Series of Hungarian Data Bank

When using the time data series, the main bridge condition notes stored in the National Road Data Bank were taken and the transition probability matrix elements of "Do Nothing" type activities were created supposing no intervention was done meanwhile (*3*). The screening of the bridges with recent intervention will be done in the near future in order to increase the accuracy of the results obtained.

Hungarian Expert Elicitation

Twice (in 1996 and 1998) an expert team of practitioners and theoretical bridge engineers was asked for the expert elicitation of the deterioration of major bridge elements. Only 10–10 bridge elements or bridge element groups were included in the evaluation in order to avoid the overburden of the experts participating in the elicitation. The following "deterministic" question had to be answered: in how many years do you expect the deterioration of 50% of a bridge element by one condition state? The replies could be used in the calculation of the relevant probability matrix elements.

In the first expert elicitation, the idea of the selection of the bridge elements was to include all significant elements which behave differently according to its material and/or structure. The elicitation comprised the following elements: reinforced concrete abutment, stone and brick arch, steel rolled girder, steel riveted or welded girder, reinforced concrete girder, prestressed reinforced concrete girder, reinforced concrete slab and girder, waterproofing, asphalt deck, waterproof joint (*3*). Table 2

Table 1: Original (American) Pontis Deterioration Matrix (PU)

Condition state	1	2	3	4	5	Life cycle (year)
1	82	18	0	0	0	7
2	0	84	16	0	0	8
3	0	0	94	6	0	22
4	0	0	0	88	12	11
5	0	0	0	0	88	11
Failed					12	59

Table 2: Version 1 of Hungarian Pontis-H Deterioration Matrix (PHSI)

Condition state	1	2	3	4	5	Life cycle (year)
1	84	16	0	0	0	8
2	0	93	7	0	0	17
3	0	0	91	9	0	14
4	0	0	0	88	12	11
5	0	0	0	0	84	8
Failed					16	58

shows the deterioration matrix of reinforced concrete slab based on the elicitation of 20 experts.

When comparing the matrices of Tables 1 and 2, the following modification %-values (PUM1) are calculated for the elements in diagonal: +2, +11, –3, 0 and –5.

The second expert elicitation in 1998 partly checked the former survey results; partly it concentrated on the following elements which have the highest cost implications: reinforced concrete slab and girder, reinforced concrete girder, prestressed reinforced concrete girder, steel girder, waterproofing, asphalt deck, waterproof joint, complementary lane deck and surface protection, backfill, steel fencing (*4,5*). The deterioration matrix of the reinforced concrete slab based on the expert elicitation of 10 specialists can be seen in Table 3.

The main experiences gained in this field are as follows:

- the new expert elicitation can reduce the number of bridge elements which were forced into a single group (the same deterioration processes were assumed for them),
- the Hungarian expert elicitation in 1998 provided results closer to the original American values than in 1996; this fact can be interpreted as the increase of carefulness in the expert elicitation.

During the further data processing, the mean values of both expert elicitations were utilized as most reliable possible data. Table 4 illustrates this expert deterioration matrix for the reinforced concrete slab. When comparing the matrices of Tables 1 and 4, the following modification %-values (PUM) are calculated for the elements in diagonal: +6, +12, –1, +3 and 0. As a summary of the results obtained using expert elicitation, it can be stated that

Table 3: Version 2 of Hungarian Pontis-H Deterioration Matrix (PHST)

Condition state	1	2	3	4	5	Life cycle (year)
1	91	9	0	0	0	14
2	0	95	5	0	0	25
3	0	0	94	6	0	22
4	0	0	0	93	7	17
5	0	0	0	0	92	16
Failed					8	94

Table 4: Pontis-H Deterioration Expert Matrix (PHS)

Condition state	1	2	3	4	5	Life cycle (year)
1	87	13	0	0	0	10
2	0	94	6	0	0	22
3	0	0	93	7	0	17
4	0	0	0	91	9	14
5	0	0	0	0	88	11
Failed					12	74

they can be readily evaluated although they do not always supply results close to the time data series and the original American PONTIS expert elicitation.

Weighing the Data Bank Information and Expert Elicitation Results

When producing the transition probability matrices for Hungarian use, the results of domestic expert elicitation were "mixed" by data bank time series results. The following weighing factors were chosen (*3*):

- 1000 for expert elicitation results,
- the number of bridges actually considered for data bank information.

The weighed expert and data bank deterioration matrix (PHSA) for reinforced concrete slab can be seen in Table 5. When comparing the matrices of Tables 1 and 5, the following modification %-values (PM) were calculated for the diagonal elements: –20, +5, +1, +11 and +9. It was decided to limit the modification in ± 25%. After the investigation of the deterioration matrices obtained using the above criteria, the following statements can be made:

- when increasing the original American matrix elements by +5, +10 or +15%, in some condition states and environments, the maximal possible 99% probability value was reached (or an even higher one would have been needed),
- inside some environments, the differences and the tendencies of the matrix elements on various condition states became illogical or unexplicable,

Table 5: Pontis-H Weighed Expert and Data Bank Deterioration Matrix (PHSA)

Condition state	1	2	3	4	5	Life cycle (year)
1	66	34	0	0	0	3
2	0	88	12	0	0	11
3	0	0	95	5	0	25
4	0	0	0	98	2	65
5	0	0	0	0	96	34
Failed					4	138

- due to the modifications by −5, −10 and −15%, too large differences presented themselves between the matrix elements on various condition states in a given environment.

Because of these facts, a decision was made to apply only the modifications based on Hungarian expert elicitation, because it is much closer to the original American matrix elements.

Deterioration Matrices in PONTIS-H

The principles of the creation of the transition probability matrices in PONTIS-H are as follows:

- For the bridge elements which had Hungarian expert elicitation and which can be found in the original American system, the modifying "matrix" (PUM) can be used. The following rules were followed when calculating PUM:
  - The Hungarian 5-note system was reached by modifying the eventually 3 or 4-note American matrix elements using a special method,
  - Due to the statistical evaluation of results, difference ranges instead of actual differences were suggested to use, keeping the ± 15% limit,
  - The modification is done for diagonal elements; other matrix elements are calculated accordingly (not the classical rules of matrix multiplication were applied).
- For the bridge elements which had no Hungarian expert elicitation but the deterioration can be taken nearly identical with an evaluated element, this latter's modifying matrix was used.
- For the bridge elements which had no Hungarian expert elicitation, which can be found in the American system and the deterioration of which can be considered similar to that of an American-Hungarian element pair, the modifying matrix of this bridge element pair was applied.
- For the bridge elements where this kind of similarity can not be found the original American matrix elements were provisionally taken.
- For the bridge elements which have no equivalent in the original system but which had expert elicitation, the results of this latter were accepted.
- For the bridge elements without Hungarian expert elicitation and American equivalent, the known deterioration characteristics of a similar element were chosen.
- The comparison, that is the calculation of modifying values was carried out in a moderate environment. Special technique was applied for the determination of the matrix elements in other (benign, low and severe) environments (*3*).

DETERIORATION MATRICES OF PONTIS-H FOR THE "DO SOMETHING" CASE

The calculation of the condition improvement matrices was considerably more difficult than that of deterioration matrices without intervention. Also in this case the following information sources were available: data bank time series, Hungarian expert elicitation and American PONTIS matrix elements (expert elicitation).

Original (American) Expert Elicitation

When creating the condition improvement matrices for various interventions, the adaptation of original American matrices presented itself as an option. However this possibility was rejected by the Hungarian development team for allowing the consideration of Hungarian experiences and specialities.

In order to ensure thair comparability with the Hungarian data, the American intervention matrices of 3 or 4 condition states had to be transformed into 5-state variants (*3*).

As an example, Table 6 shows the original intervention matrices of the reinforced concrete slabs in cases of 2 intervention types for every condition state.

Processing Data Bank Information

No utilizable information was available in the data bank; only the code and the repaired main structural element of the bridge under intervention can be found in the Hungarian data registration. The type of intervention can be more or less identified but no statistical analysis was possible due to the very small number of cases (*3*).

Hungarian Expert Elicitation

Similar difficulties came up when the Hungarian expert elicitation results were analysed. While the bridge engineers and the experts have more or less statistically identical opinions about the deterioration process without intervention, significant standard deviation presented itself in the estimation of the expected condition distribution after intervention. This situation can be explained by the fact that even the experienced bridge engineers have not often encountered major rehabilitation projects of every bridge type and they have not had to evaluate the deterioration process of various bridge elements before. As another significant problem, it can be mentioned that the intervention types in the American and the Hungarian systems are not identical, and in such a way several compromises had to be made.

Table 6: American Pontis Expert Intervention Matrices (PU)

Intervention 1 (PU1)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	48	48	4	0	0
3	19	48	31	2	0
4	28	28	28	12	4
5	63	33	4	0	0

Intervention 2 (PU 2)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	-	-	-	-	-
3	19	48	31	2	0
4	63	33	4	0	0
5	63	33	4	0	0

For the improvement evaluation of some intervention types of major Hungarian bridge elements, two expert elicitations were organized.

In the first elicitation in 1996, the following 7 important bridge elements were chosen: reinforced concrete abutment, steel girder, reinforced concrete girder, timber girder, waterproofing, asphalt bridge deck, waterproof joint (*3*). After the statistical analysis of the elicitation of 20 experts the condition improvement matrices shown in Table 7 were given in cases of 2 intervention types of reinforced concrete slab chosen for each condition state.

The second elicitation in 1998 dealt with the improvement characteristics of 10 major bridge elements after intervention (*4,5*).

The condition improvement matrices obtained were a bit different from the former ones. Table 8 shows the matrices of reinforced concrete slab.

The mean values of the two expert elicitation results (PHS) were applied in the further analysis.

Condition Improvement Matrices in PONTIS-H

The condition improvement matrices (PH) to be applied in PONTIS-H were calculated as a mean value of original American probability matrices (PU) and Hungarian expert elicitation matrices (PHS) in case of interventions. The principles applied were similar to those described in subchapter 3.5 for the "do nothing" case.

When analyzing the matrices obtained, it was suggested to investigate the possibility of the use of the same condition improvement matrix for each environment (*3*).

The resulting PONTIS-H improvement matrices are illustrated in Table 9.

Figure 3 illustrates the probability of various condition states after an intervention in condition state 5. It can be seen that the PONTIS-H matrix is the closest one to the original American matrix.

Table 7: Version 1 of Hungarian Pontis-H Expert Elicitation Matrices (PHSI)

Intervention 1 (PHSI 1)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	79	21	0	0	0
3	59	29	12	0	0
4	49	25	17	9	0
5	49	25	14	7	5

Intervention 2 (PHSI 2)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	-	-	-	-	-
3	56	33	11	0	0
4	57	25	11	7	0
5	49	25	14	7	5

Table 8: Version 2 of Hungarian Pontis-H Expert Elicitation Matrices (PHSII)

Intervention 1 (PHSII 1)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	79	21	0	0	0
3	59	29	12	0	0
4	23	48	23	5	1
5	37	45	14	3	1

Intervention 2 (PHSII 2)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	-	-	-	-	-
3	21	60	18	1	0
4	37	45	14	3	1
5	37	45	14	3	1

Table 9: Hungarian Pontis-H Intervention Matrices (PH1 and PH2)

Intervention 1 (PH1)

Condition state	1	2	3	4	5
1	-	-	-	-	-
2	64	34	2	0	0
3	39	38	22	1	0
4	32	33	24	9	2
5	53	34	9	3	1

Intervention 2 (PH2)

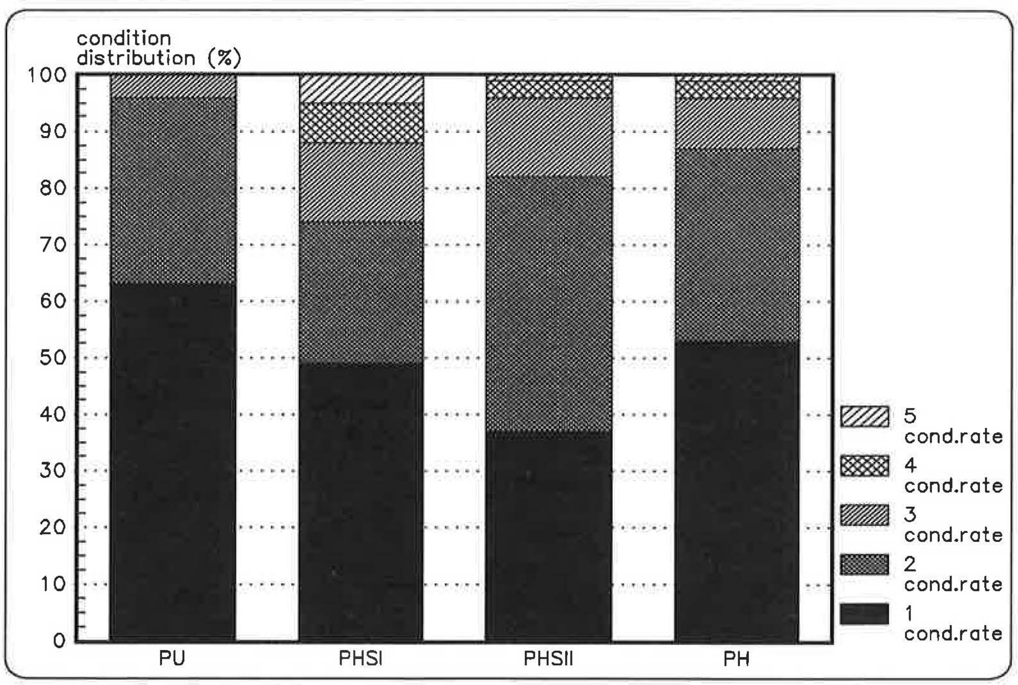
Condition state	1	2	3	4	5
1	-	-	-	-	-
2	-	-	-	-	-
3	29	47	23	1	0
4	55	34	8	3	0
5	53	34	9	3	1

ENVIRONMENT INTERPRETATION FOR THE MATRICES

In PONTIS every deterioration or improvement matrix is to be determined in four environments. This latter means actually a deterioration speed.

In the Hungarian PONTIS-H, environments are interpreted more widely than in the original PONTIS since the former considers:

- traffic parameters,
- endangering parameters (age, salting, superstructure material, etc),
- importance (road category, deck surface, structural length, span, etc),
- incidental traffic effects (overloading, crash, high dynamic load),



PU	Original American matrix
PHSI	Version 1 of Hungarian expert matrix
PHSII	Version 2 of Hungarian expert matrix
PH	Hungarian PONTIS-H matrix

Figure 3: Condition distributions after Intervention 1 done in condition state 1.

- bridge construction and maintenance parameters (design and construction failures, efficiency of maintenance, operation and protective systems),
- structural interrelationships,
- superstructure without waterproofing, etc.

The basic value of environment is determined using data bank information. It can be modified by one value at the maximum during the bridge site inspection.

SOME CONCLUDING REMARKS

The deterioration and condition improvement matrices determined for PONTIS-H can be considered as first approximations. Their further development and finetuning are planned in the future. Two relevant projects have already had remarkable results:

- comparison of the actual and the long term condition distribution of bridge elements,
- sensitivity analysis of deterioration matrix elements.

Comparison of Actual and Long Term Condition Distribution

The MR&R module of PONTIS calculates the Long Term Steady State characterized by the minimum maintenance costs by optimizing every bridge element. The difference between the actual and the long-term optimum bridge condition distribution reflects the present maintenance backlog—that is the quantity and the costs of future interventions. This difference can be shown in Figure 4 for the reinforced concrete slab 5. It can be stated that

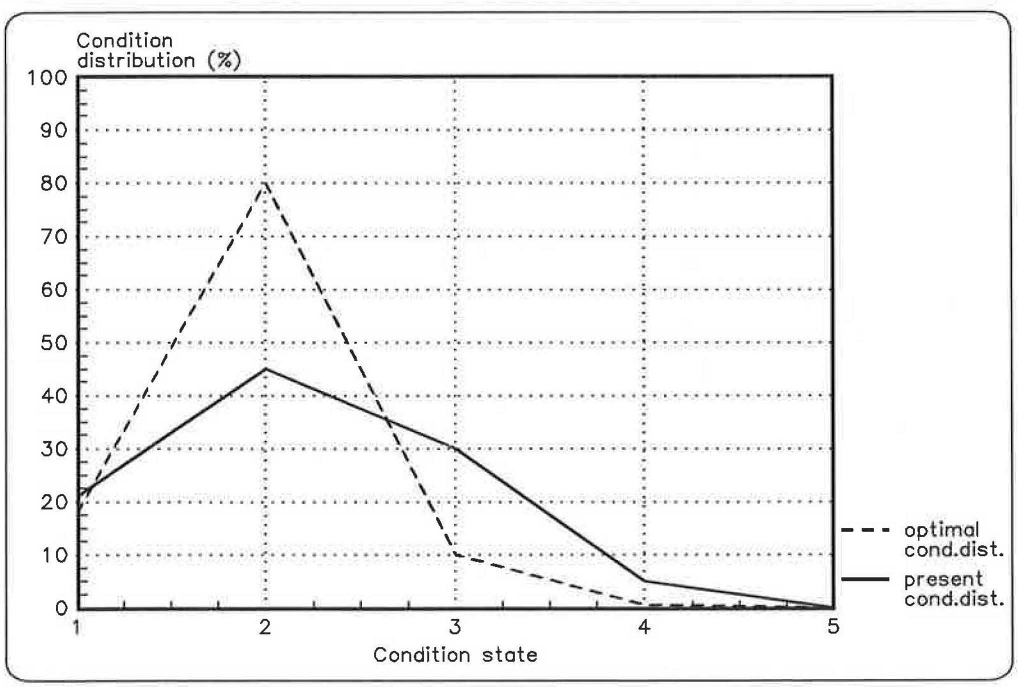


Figure 4: Optimal condition distribution of reinforced concrete slab (in accordance with Pontis).

the most efficient maintenance strategy can be performed if the majority of the slabs are already improved from the condition states 3 and 4 to the condition state 2 (*6*).

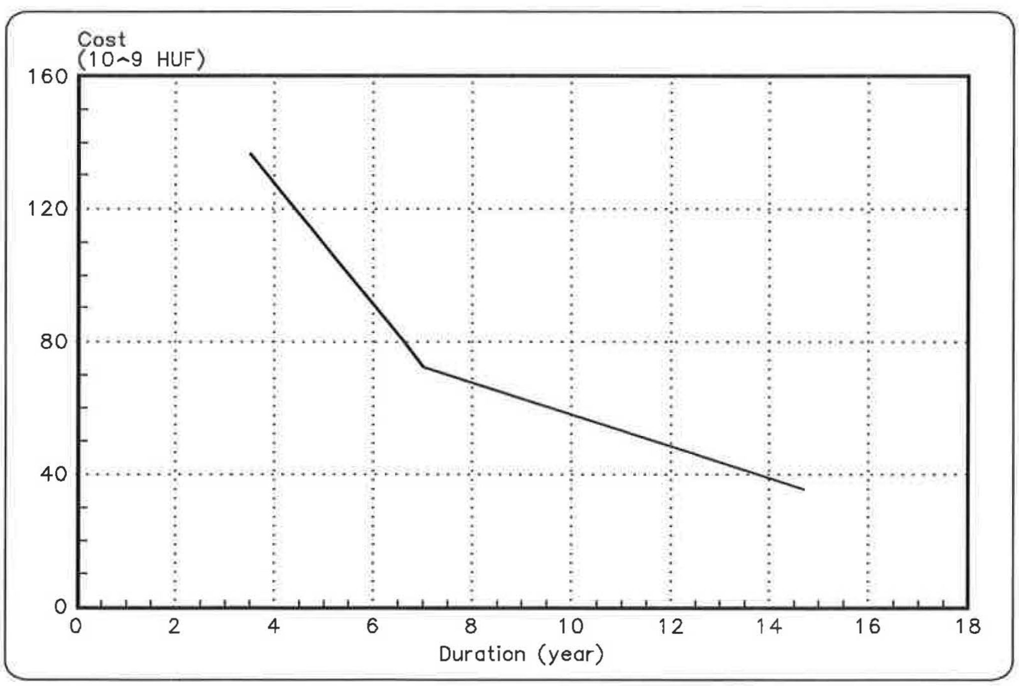
Sensitivity Analysis of Deterioration Matrices

In some cases, even 15–20% differences can be observed between the evalutions of different experts concerning various matrix elements and expected life times. In the sensitivity analysis performed, the goal was to evaluate the modification of the running results when changing matrix diagonal elements (life cycles in condition states (*4*).

The analysis was carried out using the deterioration matrix of reinforced concrete slabs in PONTIS-H obtained after the first expert elicitation for moderate environment (PHI). In this matrix the duration of the deterioration from condition state 1 to state 2 is 7.0 years.

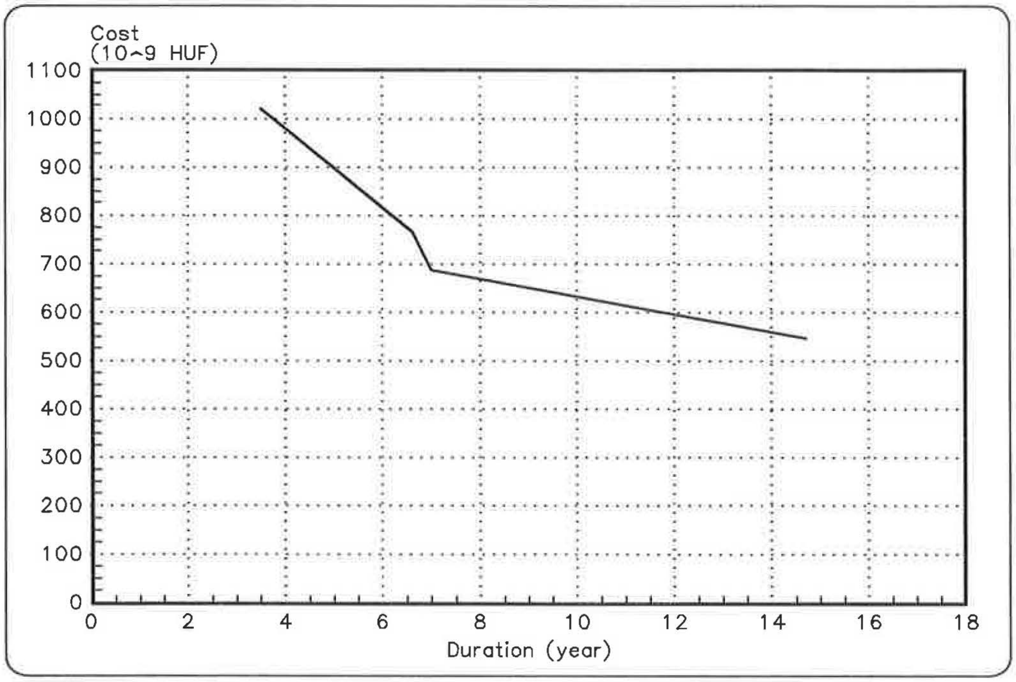
Trial runs were carried out for modifying this period to 3.5, 6.5 and 14.7 years (simultaneously several life cycles of other condition states have changed). The resulting Long Term Steady State costs and the total maintenance costs during a 30-year period (Figures 5 and 6) show the following trends:

- the slowing down of bridge element deterioration (longer life cycle) results in a significant saving in the 30-year maintenance costs,
- the slowing down of deterioration leads to the reduction of Long Term Steady State costs,



Note: 1 USD = 220 HUF

Figure 5: Changing of long term steady state cost need as a function of duration.



Note: 1 USD = 220 HUF

Figure 6: Changing of 30-year maintenance costs as a function of duration.

- the deterioration slowing above a given limit no longer has a remarkable effect on costs (hyperbolic relationship),
- already a slight (0.5 year) changing in life cycle causes relatively important cost modification, which attracts the attention to the necessity of increasing the accuracy of expert elicitation in the future.

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