Compilation of First Hungarian Network-Level Pavement Management System

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The first Hungarian network-level pavement management system relies on Markov transition probability matrices. A combined condition parameter is applied taking into consideration the bearing capacity, the unevenness, and the surface quality scores. The matrix variables are pavement type, traffic volume, and intervention variants. The system can be used to calculate the funds needed for highways at various condition levels, for the regional distribution of given amounts of money at a minimum cost to the national economy, and for the determination of the economic and technical consequences of subsequent modifications in funds distribution. Several trial runs have proved the practicability of the system.

All over the world the financial means available for highways lag more and more behind the actual needs. Although a growing share of these funds is used for maintenance and preservation tasks, the financial means even for these tasks decrease continually in several countries; among others, this has been the case in Hungary. This naturally influences the actual national roads policy, and the aim can only be at slowing down the general deterioration.

That is why the optimal distribution and allocation of rather limited financial means have become even more important than before. In recent years a significant development in the actual method of the allocation of highway funds between counties (highway directorates) has been seen. The former simple procedure that relied on normative values that were functions of road length, pavement type, and to a small extent traffic size were gradually substituted by methods that used information about the actual pavement condition. Recently, the need has emerged to transform this funds allocation so that it is as objective and reliable as possible. The objective preconditions of this development are the availability of the necessary data (insufficient quantity and accuracy) and of the appropriate computer technical background necessary for data retrieval and processing and the elaboration of an allocation model.

Thus, the development of the first Hungarian network-level pavement management system (PMS) has been performed in light of the circumstances described.

SCOPE OF TASK AND NETWORK-LEVEL AND PROJECT-LEVEL PMSs

The research presented here is aimed at the compilation of a mathematical model of the first Hungarian network-level PMS (*1*), more precisely, the establishment of the first version of the Hungarian network-level PMS.

The model relies on, for example, the available highway network, traffic, pavement structure, and cost information. The main technical-economic factors influencing the model were realistically considered, and at the same time, the limitations of available information were also taken into account. Compared with the preceding methods, the establishment of an optimization system can be considered a significant step forward, although several areas that need to be developed in the future can already be pointed out.

The model has the following main functions: determination of the necessary amount of funds required to ensure a given pavement condition in the future and a reliable regional allocation with certain limitations of the available financial means. When establishing the model the eventual controversial requirements of a high level of scientific accuracy and easy practicability were also considered and had a direct effect on the complexity and the size of the mathematical model and on the actual approximations applied.

In 1988 an expert team investigated the preconditions for the development of the first Hungarian PMS. It was concluded that to work out the first working version of the project-level PMS in Hungary several years of intensive research activities were still needed, whereas the elaboration of the network-level PMS appeared to be realistic in 1 to 2 years.

The network-level system should be established before the project-level one not only because the distribution of the financial means between various regions (counties) precedes even logically the optimal ranking of actual condition-improving interventions from a technical-economic point of view—that is, the elaboration of a project-level PMS—but also because

- Deficiencies and eventual limited reliability of the existing relevant data do not hinder the elaboration of the network-level PMS as much as they do the project-level PMS because in the former case mean values and only partly homogeneous data sets can be used,
- For the creation of the network-level PMS there is an existing method that can serve as a starting point for the new system, and
- The first version of the project-level PMS can be properly operated only if major organizational changes relating to several institutions (e.g., highway directorates and design and construction firms) are made, whereas this time-consuming and complex series of measures is not needed for the compilation of the network-level variant.

Thus, the Hungarian Institute for Transport Sciences (KTI) elaborated the mathematical model for the first Hungarian network-level PMS in 1989 and 1990. The system that was developed deals only with the maintenance-operation funds (*2*). The computer and mathematical aspects are presented elsewhere (*1*).

SELECTION OF MODEL

Preliminary Investigations

Development of the network-level model requires various preliminary investigations.

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The decision about the pavement types to be applied in the system was considered one of the first tasks. For this purpose the distribution of the national highway network area was investigated according to pavement type.

For the model to be established three main intervention alternatives (routine maintenance, surface dressing, and asphalt overlay) were chosen. Note that the maximal number of parameters applied was strongly limited by the need for the matrix on which the model relies to be manageable.

Among the traffic parameters, average annual daily traffic (AADT) and daily number of 100-kN axle loads (*N*) were taken into consideration. Although the actual heavy axle load has a direct connection to the loss of bearing capacity of the pavement structure, the parameter AADT was preferred partly because it is more widespread than the other parameter and partly because some other pavement deterioration forms—not only the loss of bearing capacity—should be considered in this complex investigation.

Selected Methodology

For the solution of the task outlined here, a methodology that took into account both the possibilities and the constraints had to be chosen.

The following existing possibilities for use in the establishment of the model are outlined:

- Available road data mass,
- Former fund distribution possibilities,
- Knowledge of similar foreign systems,
- Set of mathematical means for the treatment of this problem, and
- Goal-oriented expert team, including experienced highway engineers and mathematicians.

The following were objective difficulties and constraints in the establishment of the model:

- Limited time available for the elaboration of the model,
- Only a part of the huge mass of information on the countrywide sufficiency rating initiated in 1979 was available for data processing before the compilation of the model,
- Some available data are not sufficiently accurate because, for example, the existing data base does not contain the consequences of the recent changes in the numbers of kilometers of highways,
- Use of the time series is disadvantageously influenced because the condition parameters were often evaluated at various time points by different methods, and in some cases, the results of these procedures have no correlation between each other, and
- No domestic relationships are available between pavement condition and vehicle operating costs that would definitely help in the determination of well-founded optimum criteria.

Taking into account all of these aspects, the one that uses Markov-type transition probability matrices was chosen among several methods published in the literature. One reason was that it is clear and it does not need a longer time series as a precondition. For practicability, only limited numbers of condition variations, pavement types, traffic sizes, and intervention variants were taken for the establishment of the model.

MARKOV-TYPE TRANSISTION PROBABILITY MATRIX

The Markov-type transition probability matrix—in the case of a certain pavement type, traffic volume, and intervention strategy—supplies in the model the distribution of the probabilities of a given condition variant transitioning to another condition variant or of its remaining in the same condition variant during a certain period (e.g., 1 year).

Matrix Variables

The following are the matrix variables: pavement type, traffic size, and intervention variant.

Asphalt concrete and asphalt macadam pavements were chosen as pavement types. (In the first group all pavements were of the rolled asphalt type, whereas in the second group coated chippings and mixed and penetration asphalt macadams were included.) The rest of the highway network—rigid and unpaved sections of very limited lengths—has deterioration characteristics different from those of the selected flexible pavement groups.

For the characterization of low, medium, and high traffic, the following classes were chosen for the present study: 0 to 3,000 pcu/day, 3,001 to 8,000 pcu/day, and more than 8,001 pcu/day, respectively. The following three intervention variants were preferred: routine maintenance, surface dressing, and asphalt overlay. (Note that several foreign PMSs also apply the "do-nothing" variant. It was decided, however, to apply only the "routine maintenance" variant to the Hungarian System, even in the case of the slightest-intervention variant, when the necessary routine maintenance activities must be performed after the initiation of the first cracks and potholes. The possibility that the pavement would be left alone without any maintenance was unacceptable.

Taking into account the aforementioned facts, theoretically $2 \times 3 \times 3 = 18$ matrices should be made; two of them (surface dressing above 8,000 pcu/day for both pavement types), however, were excluded for technological reasons. So, the aim was the elaboration of 16 matrices.

Determination of Condition Variants in Matrix

The rows and the columns of Markov transition probability matrices are formed by pavement condition variants. On one hand the condition scores supplied by the countrywide highway suitability surveys are used for this calculation, for which sufficient data were available, with eventual time series, on the other hand, being considered of basic importance from the viewpoint of the deterioration process. The following pavement condition parameters were therefore selected:

- Pavement structure-bearing capacity score,
- Longitudinal unevenness (roughness) score, and
- Pavement surface quality score.

The ranking of these condition parameters into five quality classes appeared to provide sufficient accuracy for the intervention decisions.

For the longitudinal unevenness the following quality levels were applied:

With a Bump Integrator	*By Visual Evaluation*
1. good; maximum, 150 cm/km	1. good
2. sufficient; 151–225 cm/km	
3. fair; 226–275 cm/km	3. fair
4. insufficient; 276–350 cm/km	
5. unbearable; minimum 351 cm/km	5. poor

For the sake of the uniformity, a three-grade evaluation was selected for the longitudinal unevenness of the pavement. So, theoretically, 5 × 5 × 3 = 75 condition variants would be available. To solve the problem mathematically, however, the number of condition variants had to be reduced.

The relatively rare condition variants (maximum 10 km in the whole network) were not considered separately but were united with the similar (sufficiently widespread) condition variants. Following this procedure, the 41 condition variants presented in Table 1 were considered in the model.

Calculation of Matrix Elements

Each element of the matrix—that is, the decimal probability of the transition of a certain condition variant to another one in 1 year in case of a given pavement type, traffic volume, and intervention strategy—was calculated on the basis of the results obtained by processing actual domestic data or, when they were lacking, by interpolation.

The available highway network and pavement structural data set was processed by the following method. First, the changing condition variants in 1984 and 1989 were determined for some 2,500 road sections of various lengths on which no overlay or surface dressing was applied during the investigation period. This process, which took into consideration the pavement and traffic categories mentioned, supplied the distribution of condition variants (in percent) after 5 years. For example, in the case of asphalt concrete pave-

TABLE 1 Condition Variant Groups of Markov-Type Transition Matrices

Number	Condition variants
1.	111
2.	112
3.	113+114+115
4.	131+132+151
5.	133+152
6.	134+135
7.	153+154+155
8.	211
9.	212
10.	213
11.	231+251
12.	232+252
13.	233+214
14.	234+215+235+253+254+255
15.	311
16.	312+331
17.	313+314
18.	332+351
19.	333+352+353
20.	334+315+335
21.	355+354
22.	411

(*continued on next page*)

TABLE 1 *(continued)*

Number	Condition variants
23.	412
24.	423+414
25.	432+431
26.	433
27.	434+415+435
28.	452+451
29.	453
30.	454
31.	455
32.	511
33.	512
34.	513
35.	514+515
36.	532+531+551
37.	533+552
38.	534+535
39.	553
40.	554
41.	555

Legend:

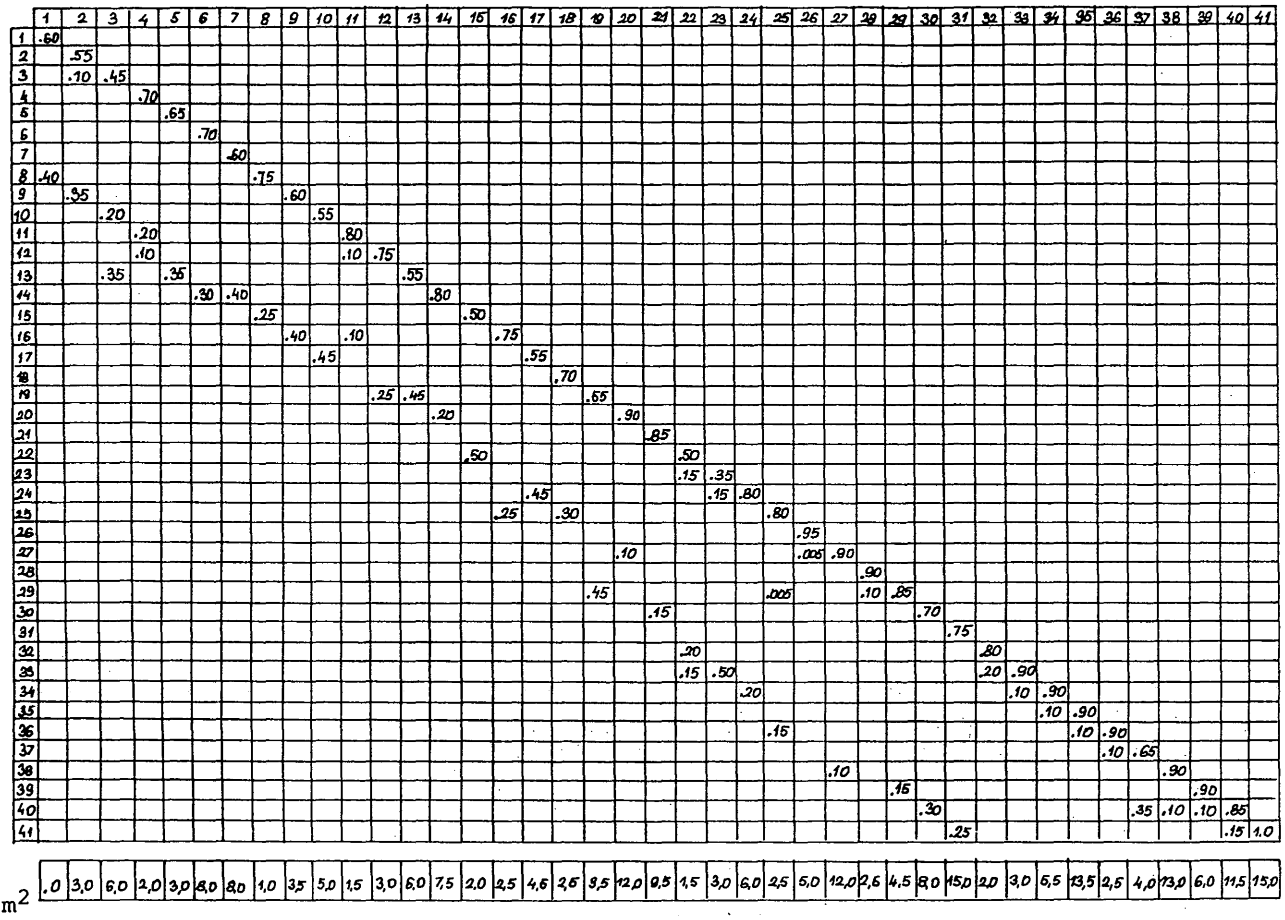
135 condition variant of a pavement with bearing capacity score 1 + pavement unevenness score 3 + surface quality score 5

ments with AADTs of 3,000 to 8,000 pcu/day and with condition variant 111, 89 percent remained in the same category, 6 percent deteriorated to Category 112, and 5 percent deteriorated to Category 211 after 5 years. These changes in percentages were divided by 5 to relate them to 1 year. The calculation was made for each variant if a minimum of 5 km of total length was available. After dividing by 100 and rounding off, these percentage distributions became the matrix elements. When no actual data were available interpolation (or sometimes extrapolation) was performed. In cases of applications of surface dressings and asphalt overlays the condition scores before and after the intervention were compared to obtain information about the typical change in condition.

A row-vector situated under the matrix is connected with it. Every element of this vector indicates the unit cost for 1 m^2 for the given intervention type performed on the section that has a condition variant specified above the appropriate column of the matrix. This unit cost is identical for a given variant in the whole country.

Interpretation of Matrix

Any of the 16 matrices has a size of 41 × 41. According to the condition variants presented in Figure 1, using their numbering, the matrix has the following structure. (The horizontal axis indicates the condition variants in the first year—the basic situation—whereas the vertical axis indicates the expected condition variant distribution in the second year.) For example, the symbol a_{23} in the matrix means the probability of the transition of a pavement with Condi-



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	.60																																								
2		.55																																							
3		.10	.45																																						
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40																														.30							.35	.10	.10	.85	
41																															.25									.15	1.0
Unit cost, HUF/m2	.0	3,0	6,0	2,0	3,0	8,0	8,0	1,0	3,5	5,0	1,5	3,0	6,0	7,5	2,0	2,5	4,6	2,6	3,5	12,0	9,5	1,5	3,0	6,0	2,5	5,0	12,0	2,6	4,5	8,0	15,0	2,0	3,0	5,5	13,5	2,5	4,0	13,0	6,0	11,5	15,0

FIGURE 1 Markov-type transition probability matrices of asphalt concrete pavements with minimum traffic volume of 8,001 pcu/day for routine maintenance only.

tion variant 2 to Condition variant 3 in the next year (at the pavement type, the traffic volume, and the intervention strategy of the matrix in question). If the probability is 20 percent the value for a_{23} is 0.20.

The sum of each column in Figure 1 is 1.0 because 100 percent of the sections characterized by any condition variant will be in one of the condition variants in the next year.

After only routine maintenance the matrix elements can be found along or under the diagonal, according to the general deterioration. At the same time, surface dressing, especially asphalt overlay, pushes the elements that are different from 0 into the upper part of the matrix as a consequence of the general improvement in condition. (Some elements can be found along the diagonal for this case as well.)

Figure 1 presents, as an example, a matrix used for asphalt concrete pavements.

Unit Costs of Interventions

The unit costs of various interventions (routine maintenance only, surface dressing, asphalt overlay), which can be found as row vectors under the matrices, constitute an important part of the model.

Two questions arise in relation to this problem: What is the actual series value of intervention costs belonging to a given matrix and its 41 starting condition variants? Should costs unified countrywide or regional costs be used?

For the first question, it is evident that the interventions needed to repair the various condition variants have different costs:

- In the case of routine maintenance activities (it includes fixing potholes, crack filling, fine patching, and repairs on a large area) it can gradually increase from 0 to 10 t/km,
- In the case of surface dressing a double dressing is considered if the original condition is relatively poor (between condition variants of about 25 and 41), and
- Thickness of new overlay increases from a minimum of 3 cm up to 10 cm together with the condition deterioration.

Three main reasons explained the decision to apply unified average unit costs countrywide:

- Regional unit costs are influenced by several parameters that should not be included in the system,
- Realistic regional unit costs would be disadvantageous in the funds distribution for the highway directorates that maintain their networks economically, and
- Use of several unit costs would complicate considerably the "funds needed determination" part of the model.

APPLICATION AREAS

The network-level PMS model can be used primarily for the solution of three tasks

- Determination of the necessary funds needed to ensure a given condition level at a certain optimum criteria,
- Regional and functional distribution of a certain amount of money under constraints and given optimum criteria, and
- Evaluation of the technical and economic effects of subsequent funds distribution modifications.

DETERMINATION OF NECESSARY FUNDS

Basic Principles

The maintenance funds needed can also be determined with the help of 16 Markov-type transition probability matrices and the connected unit costs of the intervention.

Evidently, the actual funds needed relate to a desired condition level. In practice it usually means one of the following:

- Shares of some "good" condition variants are minimized,
- Shares of some "poor" condition variants are maximized,
- Former condition distribution is also required in the future, or
- Various constraints are selected for certain pavement types and traffic alternatives.

In general, the shares of condition variants can be maximized, minimized, fixed, or not regulated at all.

Some Trial Runs

The practicabilities of the principles mentioned were investigated by performing several trial runs and evaluating their results.

In a trial run the following constraints were assumed as future conditions: the areas of sections of poor condition variants—6, 14, 20, 21, 27–41 (Table 1)—should not decrease after the intervention. The areas of the rest of the condition variants were not limited at all. Because of the relatively few condition constraints the total funds needed were only 2.08×10^9 Hungarian forints (HUFt), of which 610 million HUFt was for routine maintenance, 646 million HUFt was for surface dressing, and 826 million HUFt was for asphalt overlay (US\$1 = 100 HUFt). If the shares of areas undergoing an intervention are considered, the following results can be obtained: new asphalt overlay on 1.2 percent surface dressing on 11.0 percent, and routine maintenance (mainly patching) on 87.8 percent.

Another trial run was then performed when the influence of the increase in constraints on the funds needed and the actual funds needed was investigated. In this case, besides the constraints mentioned before (upper limitation of poor condition variants), it was also specified that the area of good condition variants—variants 1, 2, 4, and 8 according to Table 1—should not decrease.

The following area resulted: 111.7 million m^2 (73.0 percent) of routine maintenance, 8.2 million m^2 (5.4 percent) of surface dressing, and 32.8 million m^2 (21.5 percent) of asphalt overlay, (total of 152.7 million m^2).

The following cost resulted: 422 million HUFt (2.8 percent) for routine maintenance, 264 million HUFt (1.7 percent for surface dressing, and 14,410 million HUFt (95.5 percent) for asphalt overlay, (total of 15,096 million HUFt).

When evaluating these results it is striking that the attempt to preserve the sections in almost perfect condition required a high extra cost. The former 2,000 million HUFt increased here by 650 percent. It is interesting to observe that the share of asphalt overlay grew considerably. In the first version only 1.2 percent of the total area needed an overlay, whereas it grew to 21.6 percent after the increase in constraints.

Another trial run was carried out to investigate the shares of various intervention techniques (maintenance strategies) when a funds need determination for several years was performed by using the same overall condition requirements. Figure 2 shows that

- Funds needed each year increase slightly, with some fluctuation,
- Financial means used for routine maintenance gradually decrease during the 6-year period,
- More and more funds are destined for surface dressings, and
- Overlay needs grow rapidly until the fourth year, and then a little decrease can be observed.

FUNDS DISTRIBUTION

Basic Principles

In practice certain financial means are frequently divided for various purposes and regions. In this case the minimization of a value proportional to the vehicle operating costs is considered the objective function, whereas the traffic and pavement type constraints are also taken into account. It is correct to ask why the sum of the vehicle operating costs and the intervention costs—which is approximately the related national economic expenditures—is not maximized. At present this aim cannot be attained because information about the actual vehicle operating costs is not available and these absolute data would be needed to accomplish the summation with the absolute values of intervention costs. As long as only relative values connected with the vehicle operating costs (*3*) are used because of the lack of more accurate data, only the minimization of one of these parameters can be selected as an objective function. For this purpose the vehicle operating costs are chosen as being more significant on a national economic level.

Before the optimization the calculation already mentioned should be done according to which of the shares of necessary interventions on asphalt concrete and asphalt macadam pavements—separately for surface dressings and asphalt overlays—is given as a preliminary constraint.

The first step of the distribution of funds is the countrywide distribution of available financial means according to intervention categories, pavement types, condition variants, and traffic sizes.

After this optimization is done from the point of view of traffic operating costs, the regional distribution follows. This time no more weighting is needed; the distribution is made simply according to the area shares of sections with given characteristics (AADT, pavement type, condition variant) in various counties.

The selected objective function is the minimization of the following sum:

$$\sum_{i=1} A_i \cdot \mathrm{AADT}_i^a \cdot H_i, \qquad (1)$$

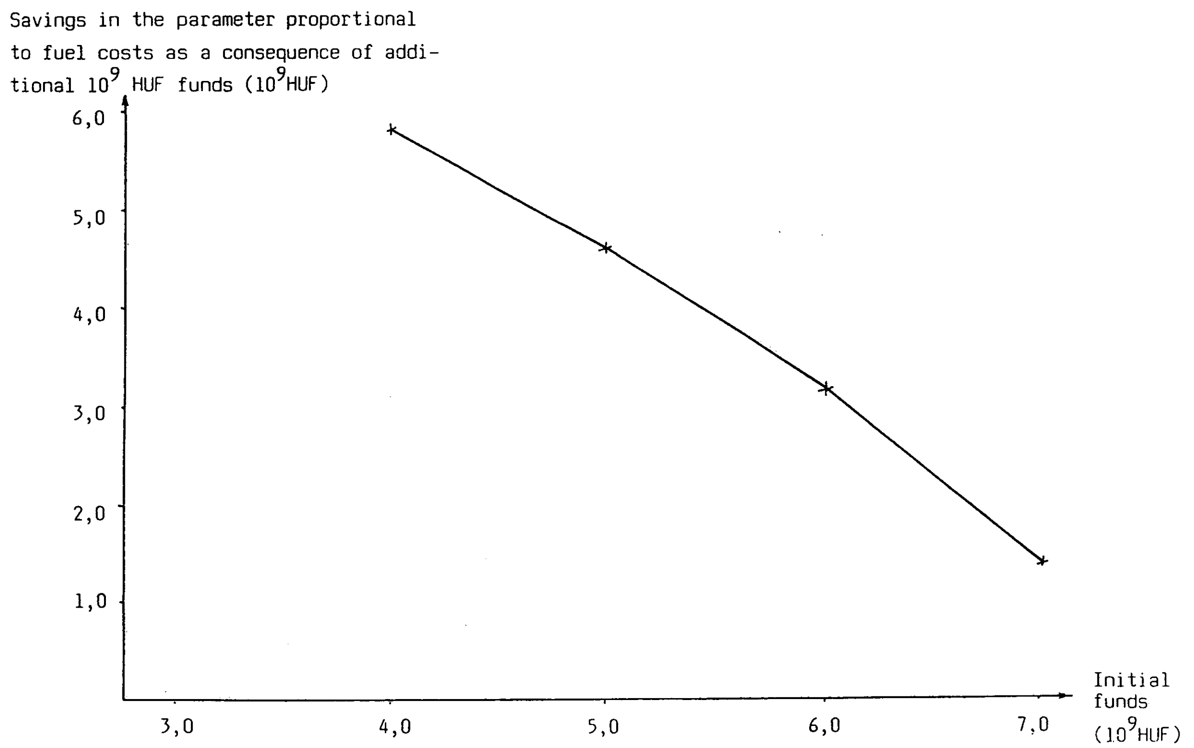

FIGURE 2 **Expenditures for various intervention techniques required to ensure a given condition for 6 years.**

where

A_i = specific vehicle operating cost parameter as a function of *i*th condition variant and the relative share of the heavy traffic (Figure 3).

AADT$_i^a$ = AADT weighed by the road area of *i*th condition variant (pcu/day), and

H_i = total length of sections in *i*th condition variant.

This sum of products can also be calculated before the intervention, so the effects of various condition-improving intervention strategies on vehicle operating costs can be evaluated (i.e., increase? decrease? to what extent?).

For Figure 3 the classification of 41 condition variants into the five groups shown in Figure 3 is needed. The three condition note variations were put into the following classes:

Pavement condition and type					In case of "n"			
					0,10	0,15	0,20	0,25
very good	good	fair	poor	very poor	fuel cost factor			
AB					1,00	1,00	1,00	1,00
AM	AB				1,05	1,04	1,04	1,04
	AM	AB			1,08	1,06	1,06	1,04
		AM	AB		1,21	1,19	1,16	1,14
			AM	AB	1,26	1,24	1,21	1,19
				AM	1,40	1,37	1,35	1,32

Legend: n - the ratio of the heavy (min 30 kN) axle load vehicles and all vehicles on the section

AB - asphalt concrete

AM - asphalt macadam

FIGURE 3 **Extra fuel cost factors for roads with various pavement types and heavy traffic ratios.**

- *Very good condition* if the sum of three condition notes is a maximum of 6,
- *Good condition* if the sum of three condition notes is between 7 and 9 and none of them is note 5,
- *Medium condition* if the sum of three condition notes is between 10 and 12 and none of them is note 5,
- *Poor condition* if only one of the condition notes is 5, and
- *Very poor condition* if two or three of the condition notes are 5.

The value *n*, the ratio of vehicles with heavy axle loads and all motor vehicles, is calculated by putting into the numerator the sum of the numbers of camions, trailers, buses, and heavy trucks.

Taking into account the aforementioned facts, the product $A_i \cdot \text{AADT}_i^a \cdot L_i$ is calculated for each condition-pavement type-traffic variant. These products are summarized for every variant to obtain the parameter K_K of the initial condition of the network, which is proportional to the vehicle operating costs.

The areas of the various condition-pavement type-traffic variants change after the distribution of the available funds because a slight percentage of the network receives an overlay and a higher share receives a surface dressing, whereas routine maintenance only is carried out on the majority of the total area.

For a new condition distribution, the parameter K_i, which is proportional to the actual vehicle operating costs, can be calculated by following the same principles. (The first element of the product is unchanged, the second one can be considered constant, whereas the third one usually changes. As a consequence the total sum of products will also be different.)

As a part of this computerized model the optimal variant with the lowest K_i value (*1*) can be determined by using linear programming techniques.

The K_i value of the optimal variant can exceed the former K_K value, proving that the available financial means are not sufficient for the preservation of the original condition level. If K_i is below K_K, then a more favorable situation than the former one can be attained.

Afterward the regional (county) funds allocation requires only a simple proportioning in which the funds for various condition-pavement type-traffic variants are divided among the counties according to the shares of the total area of their highway sections among the entire national area with given parameters.

Experiences from Some Trial Runs

Because the value of the funds (7.0 × 10⁹ HUFt) assumed in the first trial run was greater than the presently realistic level, for the additional variants the funds assumed were gradually reduced; that is, 6 × 10⁹ HUFt, then 4 × 10⁹ HUFt, and finally, 3 × 10⁹ HUFt were distributed.

The main direction of the investigation was to determine how the actual funds level influences the shares of three intervention types. Figure 4 indicates changes in the shares used for routine maintenance, surface dressing, and new asphalt overlay in the allocation according to this model as a function of available funds.

The following main results were obtained:

- In the case of the allocation of 3.0 × 10⁹ HUFt, only one-third of the financial means was used for asphalt overlays; the highest share was spent for surface dressings;
- With an increase in funds, the financial means allocated to asphalt overlay grew considerably, whereas the shares for other two intervention types evidently decreased; and
- Among the areas of various intervention types, percent changes that were not as high could be observed since the unit costs of routine maintenance and surface dressing gradually decreased accordingly, because—together with the increase in total funds—asphalt overlay was applied on the worst sections that had earlier received only patching or surface dressing.

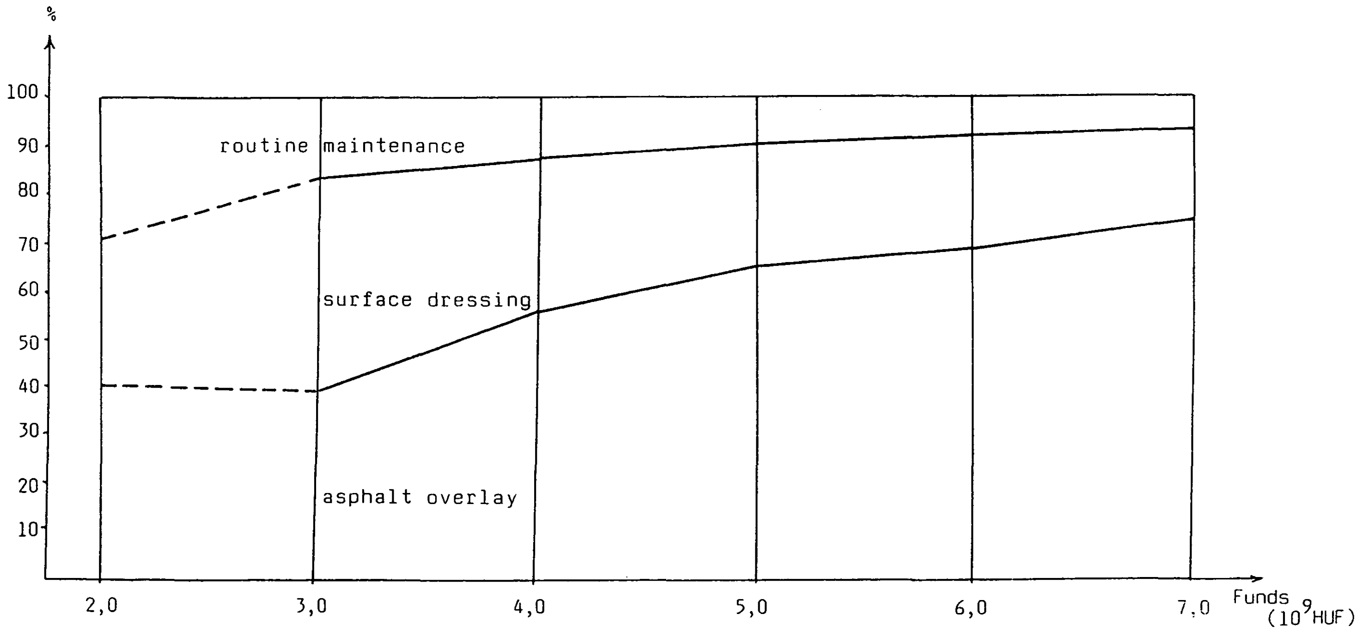

FIGURE 4 Relationship between funds and shares for various intervention types.

Figure 4 analyzes how the funds, which were increased by 1.0×10^9 HUFt, influenced the vehicle operating costs (or the parameter proportional to them). There was a definite tendency for the "savings" (reduced fuel costs) to be smaller and smaller as the total funds grew. This statement is not surprising because the extra funds allowed not only the very poor but also the less bad sections to be repaired. In the latter case a lower fuel cost reduction can evidently be attained by the interventions.

EVALUATION OF CONSEQUENCES OF SUBSEQUENT MODIFICATION IN FUNDS DISTRIBUTION

Frequently, (and presumably in the future as well) the optimum funds distribution is not implemented. The reasons, among others, can be consideration of local aspects, the need to concentrate financial means, and the necessity for an internal regrouping of money. It is appropriate to evaluate the technical and economic consequences of such modifications.

The technical consequence is the resulting condition distribution of the network concerned. It can easily be obtained by using the appropriate Markov transition probability matrices and forecasting the conditions in the following year according to the changed intervention spectrum.

The economic consequences can be evaluated by calculating total vehicle operating costs (or the parameter proportional to them). Determination of this sum of products, after the intervention alternative has been changed, makes it possible to estimate the losses in national economic costs as a result of the new decisions. (An improvement cannot be attained because the optimum variant was originally developed.)

CONCLUSIONS

The significance of the first Hungarian network-level PMS model can be summarized as follows:

- Determination and the distribution of maintenance-operation funds were carried out by considering several influencing factors,
- At the optimization, data on roadways not only in poor condition but also those of all conditions were taken into account,
- Distribution of funds is done by excluding the local subjective parameters,
- As a last step some other aspects can be applied in the system, and
- The system can readily be developed further.

REFERENCES

1. Bakó, A. Heuristic and Optimization Models for Solving the PMS. *Proc. PMS,* Budapest, Hungary, 1989.
2. Gáspár, L. Ein Netzbezogenes Managementsystem für die Strassenerhaltung in Ungarn. *Strasse + Autobahn,* Cologne, Germany, 1992, pp. 490–495.
3. Takács, F. A Practical Method for the Analysis of the Economical Effectiveness of Highway Investments (in Hungarian). KTI Publication 20. Közdok, Budapest, Hungary 1986.