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A MODEL FOR ASSESSING THE PRIORITY OF THE BRIDGES WITHIN THEIR REPAIR STRATEGY

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Abstract

The efficiency of the road network operation significantly depends on ensuring the durability and operational reliability of road bridges. To prevent accidents on bridges, ensure their reliability and durability, it is necessary to perform a set of measures, including the following: inspection of bridges, determination of their operational condition, calculation of residual life, development of recommendations for their further operation, and performance of operational measures. Considering the significant quantity of bridges in Ukraine, most of these activities have to be performed using modern information technology. Therefore, an Analytical Expert Bridge Management System Software Complex (AESUM) for bridges of Ukraine on public roads was developed and implemented. An important component of this software complex is the procedures for development of a strategy of repairs in the system of road bridges operation. One of the components of the mathematical model, which is the basis for justifying the repairing strategy, is a system of priorities for bridges repairs, taking into account their importance. This scientific paper considers the current system of priority, which takes into account the technical and operational condition of bridges and the category of roads on which they are located. A new model for evaluation of the priorities of repairs is proposed which takes into account such factors as importance of the bridge, technical and operational condition of the bridge, traffic capacity of the bridge and the cost-effectiveness of repairs. The factors mentioned above consist of a set of sub-factors. For example, the bridge importance factor consists of such sub-factors as the average daily traffic volume, the bypass influence, the bridge's affiliation with international transport corridors, etc.

Keywords: road bridge, AESUM, bridges repairs strategy, bridges repairs priorities

1 Introduction

The maintenance service has an influence on the bridges condition and the amount of costs by choosing a certain sequence, nature and scope of repairs over time - the strategy of operation of the bridges. There is a big number of options for such strategies, so the issue of choosing the best strategy for one or more criteria is of the highest importance in justifying the strategy of bridges operation.

Providing the coordination of the degradation process and the rehabilitation process in space and time (rehabilitation strategy) under certain constraints is the content of the tasks (functions) of planning, organization, motivation and control of bridges conditions. Limitations in these tasks are the limit parameters of the degradation process and limitations on the resources (financial, labor, logistical, informational, etc.) (the principle of consistency).

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It is impossible to provide the optimal solution for one bridge without simultaneous consideration of other bridges on a certain network of roads, therefore, it is a question not only of the project of operation of an individal bridge, but, mainly, of the bridges operation program (principle of network level dominance). An important principle of rationale for the strategy of the technical bridges conditions rehabilitation is to take into account the external effects of of the bridge existence itself, i.e. its usefulness for consumers (consumer qualities) which can be assessed by traffic speed, permissible traffic loads and vehicles dimensions, safety and riding comfort, losses from closing the bridge for reconstruction, repair or replacement with a new bridge, etc. This principle should be called (utility principle). During implementation of this principle, the bridges are considered as integral parts of the road network, therefore, the deterioration of bridges causes inefficiency of the road network. Negative consequences include the cost of repair and reconstruction of bridges and increased costs for bridge users. Therefore, it is necessary to maintain bridges for securing their satisfactory values in their useful lifetime individually or as part of a road network [1]

2 One-level prioritization model

Bridges on the road network have different significance. Firstly, their significance is assessed by their operational conditions; secondly - by the impact on economic efficiency of transportation and traffic safety; thirdly, by the economic and social conditions of the adjacent region. So, they may have different priority (principle of priority) depending on a number of factors [2]. The list of factors can be quite wide, the main thing is to have access to information to calculate each of them, and that they meet the requirements for the expected result of their application. For example:

- average daily traffic volume;
- percentage of trucks in traffic;
- administrative importance of the road;
- category of the road;
- the nature of the bridge location;
- possible bypasses, length, traffic composition limitation;
- importance for defense;
- historical importance;
- compliance of the bridge dimensions with the traffic requirements.

The importance factor (priority) of the i-th bridge (Π_i), is determined by the formula:

$$\Pi_i = \sum_{k=1}^{m} w_k \cdot f_{ik} \tag{1}$$

where

w_k – specific weight of k-th factor $\sum_{k=1}^{m} w_k = 1$

f_{ik} – the dimensionless importance of the k-th factor of the i-th bridge takes values from 0 to 1.

During implementation of this principle, bridges are considered as integral parts of the road network, so the deterioration of bridges, in addition to safety issues, causes some inefficiency of the road network. This inefficiency can lead to significant negative economic consequences which include additional costs for repair and reconstruction of bridges and increased costs for bridge users. Therefore, it is necessary to maintain bridges for securing their satisfactory values individually or as part of the network [4].

Table 1 Samples of the score factors

Components of the importance factor	Score
Operational state of bridge	0.18
Daily traffic volume	0.15
Administrative importance of the road	0.12
Road category	0.11
The length of bypass when closing the bridge	0.10
Compliance of the bridge dimensions with the traffic requirements	0.14
Aggressiveness of the environment	0.05
Defense importance	0.10
Historical importance	0.05
Total	1.00

3 Two-level model of bridge prioritization

The proposed two-level model of bridge prioritization is based on the approaches presented in [5, 6]. According to these approaches, the priority of the bridge is a weighted indicator of five factors that are measured: the importance of the bridge, technical condition of the bridge, the design redundancy, the structure capacity and cost-effectiveness. The dimensionless value of each of these factors is multiplied by the score coefficient. The general form of the equation of priority П is:

$$П = a \cdot КВ + b \cdot РС + c \cdot КП + d \cdot КЗ + e \cdot КЕ \quad (2)$$

Where

a, b, c, d, e - score coefficients, a + b + c + d + e = 1.0;

КВ - coefficient of importance of the structure (Bridge Importance Factor) - the relative importance of the bridge in a particular network of roads;

РС (Condition State Factor) - a condition rating factor that characterizes the overall physical condition of the bridge based on the condition of each individual element;

КП (Design Redundancy Factor) - coefficient of adaptation (redundancy) - a measure of risk in the analysis of four important limit states: brittle fracture, emergency erosion, emergency destruction due to fatigue, destruction due to earthquake;

КЗ (Structure Capacity Factor) - traffic capacity of the bridge - the ability of the bridge to pass traffic, including the effect of restrictions on weight, bridge clearance and width dimensions;

КЕ (Cost-Effectiveness Factor) - cost-effectiveness factor characterizes the cost-effectiveness of a rehabilitation measure.

These factors indicate the relative importance of the structure (in the range from 0 to 1.0). For example, a structure with a score of 0.62 is more significant than a structure with a score of 0.43 for this.

The normalized score coefficients, a + b + c + d + e = 1.0, were selected for prioritization using the method of hierarchy analysis proposed by T. Saati [7].

The coefficients a, b, c, d, e for including five factors given in formula (2) are calculated using the so-called matrix of advantages (or comparisons) and the following formula is obtained:

$$П = 0.30 \cdot КВ + 0.25 \cdot РС + 0.15 \cdot КП + 0.10 \cdot КЗ + 0.20 \cdot КЕ \tag{3}$$

Table 2 Matrix of advantages for five factors (criteria)

	КВ	РС	КП	КЗ	КЕ	$\prod_{j=1}^{n} w_{i,j}$	$v_i = \left(\prod_{j=1}^{n} w_{i,j}\right)^{\frac{1}{n}}$	$v_i = \frac{v_i}{\sum_{1}^{n} v_j}$
КВ	1,00	3,00	2,00	2,00	1,00	12,0000	1,64	a=0,30
РС	1/3	1,00	2,00	4,00	4,00	10,6667	1,40	b=0,25
КП	1/2	1/2	1,00	1,00	1,00	0,2500	0,82	c=0,15
КЗ	1/2	1/4	1,00	1,00	1/9	0,0139	0,54	d=0,10
КЕ	1,00	1/4	1,00	9,00	1,00	2,2500	1,12	e=0,20
							Σ = 5,53	Σ=1,00

Importance of the bridge:

$$КВ=0,30 \cdot V_A+0,10 \cdot V_B+0,15 \cdot V_C+0,20 \cdot V_D+ 0,05 \tag{4}$$

Where
V_A - average daily traffic volume, car / day per traffic lane;
V_C - the same is for trucks, car / day per traffic the lane;
V_B - future average daily traffic volume, car / day per traffic lane, which is calculated taking into account increment rate of traffic volume;
V_D - the effect of bypassing the bridge;
$V_{Ед}$ - belonging of the bridge to the network of roads of state importance (yes - 1, no - 0);
V_F - belonging of the bridge to the transport corridor (yes - 1, no - 0).

Condition rating factor:

$$РС = 1.00-E / 100, \tag{5}$$

where E is the rating of the bridge (0 - 100)

Bridge traffic capacity:

$$КЗ=1,00-(0,35 \cdot ЗВ+0,50 \cdot ПГ+0,15 \cdot ШМ) \tag{6}$$

ЗВ - score reduction (from 0 to 1) - score characteristics of the structure relative to trucks;
ПГ - bridge clearance (from 0 to 1);
ШМ - correspondence of the width of the bridge to the width of the entrances of the highway ШМ (from 0 to 1).

Indices ЗВ, ПГ and ШМ in the absence of violations of technical parameters take the value of 1.0.

Cost-effectiveness factor

$$КЕ=С_з/С_{нм} \quad (7)$$

Where

$С_з$ - the cost of the operational measure

$С_{НМ}$ - the cost of a new bridge, UAH.

4 Application of priorities

Ranking and optimization are the two most widely used methods in selecting the repair project for the repair strategy. However, the concepts of these two approaches are very different. Rating methods assess simultaneously several related project factors and quantify the rating based on the assessment of these factors; therefore, all considered projects are evaluated according to their rating values.

Ranking methods do not necessarily give the optimal solution. Nevertheless, the rating approach is easy to use and provides a relative order of importance for different projects. It is most often used for short-term (annual) planning (distribution, prioritization) of repair works during the operation of bridges. In this case, the calculated priority of the building is included in the group of key indicators that determine an orderly list of solutions based on the rating indicators of the project.

On the other hand, optimization methods provide an “optimal” solution, where projects are selected subject to certain constraints. The optimal solution can be obtained by providing the maximum benefit from the bridge for the road network. Unlike ranking methods, optimization methods do not follow the rule of “selection of projects with the worst conditions”; instead of this, optimization methods identify the projects that best suit the entire road network, because all the constraints of the model are met simultaneously.

The optimization model for long-term planning uses a direct representation of the evaluation criteria determined by the target functions. The following indicators are used in AESUM: the cost of planned repairs and / or the weighted average level of degradation in terms of area and priority of bridges. In this optimization model, the priorities of bridges are not determining factors of calculation. However, they have a certain influence due to the influence on the amount of “fines” in determining the cost, and in the case of determining the weighted average degradation level it is included in the formula along with the structure area.

5 Conclusions

The proposed two-level model of prioritization of bridges on the road network has a number of advantages. Firstly, with a significant number of factors involved, their arrangement by groups allows for more influential control over defined impact factors and analyzes the results in their adjustment. Secondly, by implementing the mentioned model in the AESUM PC, it is possible to obtain a mechanism for tracking the influence of both individual factors and groups of factors on the results of calculations. The model of prioritization allows streamlining the consideration of bridges in the process of rehabilitation their technical condition and possible replacement in accordance with the priorities of bridges.

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