Development of methodology of alternative rationale for financial ensuring of bridges building

Igor Britchenko [1]; Maksym Bezpartochnyi [2]; Yaroslava Levchenko [3]

Received: March 3, 2020 | Revised: March 28, 2020 | Accepted: March 31, 2020

JEL Classification: D61, E22, H54, R42, R53

Abstract

The purpose of the article is to develop a methodology for alternative substantiation of financial support for bridge construction. To achieve the purpose, the following general scientific and special methods and techniques of research were used: “golden ratio” rule; systematization and generalization; generalization of the results of the analysis and the logical generation of conclusions. Initially, the article analyzed the state of bridge structures in Europe and Ukraine. Based on the analysis, a disappointing situation has been identified, namely that a significant ratio of bridges number require major overhaul or are in critical condition. During the research, the following tasks were solved, namely: physical wear of the bridge as a failure was considered; the feasibility of investing in reconstruction or new bridge construction was determined.

For the purpose of rational use of financial resources, which are limited in the age of economic challenges, and on the basis of the rule of “golden proportion”, the maximum percentage of investment in reconstruction is determined. If the limit is exceeded, it is decided to build a new bridge. This result allows making an economically sound decision and evaluating the effectiveness of the invested resources. It is proved that if the wear index of the overhaul bridge construction is higher than the wear rate of the new bridge construction by λ_2 / λ_1, and the amount of funds for overhaul reaches 70% of the funds needed to build a new one, it is better to build a new bridge.

Keywords: financial support for bridge construction, physical wear, failure, economically sound decision, effectiveness of the invested resources.

Introduction

Transport and its infrastructure are an important factor determining the development and security of each country. Its stable, uninterrupted and efficient functioning is the key to successful interaction of all sectors of the economy, improving the welfare of the population, as well as ensuring the defense capability of the state and its interests (Yavuz, Attanayake, Aktan, 2017).

As part of the European integration, an effective platform for cooperation at the regional level within the framework of the Eastern Partnership Transport Panel has been formed, the main purpose of which is to help improve transport links between the EU and its closest neighbors (Ministry, 2019). Transport networks and services ensure a key role in improving the quality of citizens’ life of the country and in increasing the opportunities for industrial development. Therefore, transport is one of the key areas of cooperation between the EU and Ukraine, and in accordance with Article 368 of the Association Agreement between Ukraine and the EU, the main purpose of such cooperation is to facilitate the restructuring and updating of the transport sector of Ukraine and the gradual

[1] State Higher Vocational School Memorial of Prof. Stanislaw Tarnowski in Tarnobrzeg, Poland, Faculty of Technical and Economic Sciences, Doctor of Economics, Professor, e-mail: ibritchenko@gmail.com, ORCiD: 0000-0002-9196-8740

[2] National Aerospace University named after N. Zhukovsky “Kharkiv Aviation Institute”, Ukraine, Faculty of Soft Engineering and Business, Doctor of Economics, Professor, e-mail: confer.piel@gmail.com, ORCiD: 0000-0003-3765-7594

[3] Kharkiv National Automobile and Highway University, Faculty of management and business, Ukraine, e-mail: slavalevcenko1984@gmail.com, ORCiD: 0000-0002-4979-1101

harmonization of existing standards and policies with those in the EU (European integration, 2019).

Inspections of bridges in Italy witnessed disappointing conclusions: 300 bridges in the country are in disrepair and may collapse at any time. And not far from the Sicilian town of Agrigento, traffic on the bridge has already been blocked. The reason for this is structural damage to the supports. Most of the bridges and roads in Italy were built in the 50-60s of the last century and are in poor condition. The shelf life of the concrete from which they are made, depending on the grades, is the same 50-60 years (Ministry, 2019).

In France, roads are in “critical condition” too: about 50% of the road surface is in need of repair, every tenth bridge is in poor condition. A recent government check showed that one third of the bridges need urgent repairs, and 841 of them are at risk of collapse. In her report, the Minister of Transport of France, Elizabeth Bourne, said that one third of the 12 thousand French bridges need cosmetic repairs in order to exclude structural changes. In 7% of cases, the damage is quite serious. They can lead to collapse. It is necessary to close these bridges for heavy vehicles, and maybe for all cars (Bridges, 2020).

In Germany, a similar study last year was carried out by the Federal Research Institute of Roads. The result is also alarming: the state of 12.4% of German bridges inspires serious concern, only 12.5% of German bridges are in absolutely good condition, that is, every eighth one. Many bridges were built in the 60-70s of the last century and are not designed for the so intensive traffic of our days. By the way, thanks to the renovation program adopted after the reunification of the two Germanys, the condition of the bridges in the east of the country is better than in the west, where heavy vehicles are already prohibited on a number of bridges, including the Leverkusen bridge across the Rhine north of Cologne (Bridges, 2020; Agócs, Vanko, 2016).

In the Netherlands, federal bridges are doing relatively well, but the bridges operated by cities and provinces are alarming: only in the province of North Holland are 14 bridges in disrepair (Ministry, 2019).

The Bulgarian government in 2018 announced plans to repair more than 200 bridges, most of which were built 35-40 years ago. Bulgaria is considered the poorest country in the European Union, so the modernization of transport infrastructure will take place at the expense of EU funds (Levchenko, 2020).

According data of the association “Bridges of Ukraine” 80% of structures are in need of repair (Bodnar, Panibratets, Zavgorodnii, Chursin, 2016).

Table 1. – Ranking of road bridges by age

	Bridge age					**Total, %**
	1-20	**21-40**	**41-60**	**61-80**	**80 and more**	
%	3,39	21,24	52,97	12,07	10,33	100
Number of bridges	549	3438	8574	1954	1672	16187

Source: formed by the authors on the basis of data (Bodnar, Panibratets, Zavgorodnii, Chursin, 2016)

According to the observation (Koshchenko, 2017), the average service life of Ukraine’s bridges is 47-50 years, which is almost two times lower than the regulated one.

However, at present, the transport industry is only meeting the current needs of both population and economy in quantitative terms (Levchenko, 2019). And the most common reason for this is the lack of funds (Bezpartochnyi, Britchenko, Jarosz, 2018). Sometimes the need to be guided by the saying: "We are not rich enough to pay twice" (Smyrnov, Borysenko, Trunova, Levchenko, Marchenko, 2020). Therefore, the ***purpose*** of this study is to develop a methodology of alternative rationale for financial ensuring of bridges building. To achieve this purpose, the following *tasks* were set:

- To prove that physical wear of the bridge is a failure;
- To determine the feasibility of investing in reconstruction or new bridge construction.

Bridges, traditionally, are the most expensive infrastructure projects. They are built slowly and require billions UAH. Neither the central nor the local authorities are in a hurry to invest in projects that will last for years (A bridge to concession, 2019). Therefore, in the first place, the most emergency overpasses are being repaired. Today, logistics, the number of cars, freight transport, passengers transport has grown so much that without bridges the economy of entire regions suffocates (Yavuz, Attanayake, Aktan, 2017; Faoziyah, 2016).

Here the question arises as follows:

When, and is it worth it at all, to spend money on the reconstruction of the bridge?

Maybe is need to build a new one?

The authors of this study offer the following answer to this question.

Material and methods

To achieve the purpose, the following general scientific and special methods and techniques of research were used: «golden ratio» rule; systematization and generalization; generalization of the results of the analysis and the logical generation of conclusions.

Numerous studies have established that harmonization processes proceed according to the rule of the "golden ratio". The structure of many well-known self-organizing structures is subject to this rule. In such systems, the ratio of the whole and its parts is in accordance with the rule of the “golden ratio”. The number 1,618 is called the "golden ratio", and the division of the segment in the indicated ratio is called the “golden ratio”.

Denote:

Vp – bridge reconstruction costs;

Vн – new bridge construction costs.

Then we have income *Vн – Vp*.

According to the “golden ratio” rule, we get:

$$\frac{V_н - V_p}{V_p} = \frac{V_p}{V_н} = 0{,}618$$

$$V_p = 0{,}618 \cdot V_н \qquad .$$

$$V_н - V_p = 0{,}382$$

In our case (70% for reconstruction), we get:

$$V_н - V_p = 1 - 0{,}7 = 0{,}3 .$$

$$0{,}382 > 0{,}3.$$

The percentage of income under the “golden ratio” rule is greater than the percentage of income with 70% of reconstruction costs.

It can be concluded that if the funds for the reconstruction of the bridge are large from 61.8% of the cost of building a new bridge, the reconstruction is economically disadvantageous.

Further calculations also confirm these considerations. To do this, we will conduct additional research.

Failure – one of the main terms of the theory of reliability, means a violation of the health of the object, in which the system or its element ceases to fulfill its functions in whole or in part, otherwise a malfunction of the device, system, part.

Consider *the physical deterioration* of the bridge structure *as a failure*.

The proportion of physical wear of the bridge structure is determined by the formula:

$$U(t) = e^{\lambda(t-T)} - 1, \qquad (1)$$

Where: *U* (*t*) – physical wear rate at the time *t*;

λ – indicator of the wear rate of the structure (located in the tables in accordance with the material of which the bridge is made);

t – current time from the start of operation in years;

T – initial period of operation, at which wear does not occur yet.

The wear index of the design of the new bridge λ_1 will be equal to 0.009. Taking into account the fact that old elements remain during the reconstruction of the bridge, we will take the wear indicator of the bridge after reconstruction λ_2 higher and equal to 0.012.

If the wear rate of the structure is 0.7, then the structure is subject to demolition, or is it still reconstruction? In our case, we will not take into account bridges of historical value.

Calculations of the share of wear are presented in table 2.

Table 2. – Calculation of the share of wear

Of the year	New bridge	Overhaul
	λ_1 = 0,009	λ_2=0,012
20	9,42%	27,12%
25	14,45%	34,99%
30	19,72%	43,33%
35	25,23%	52,20%
40	31,00%	61,61%
45	37,03%	**71,60%**
50	43,33%	
55	49,93%	
60	56,83%	
65	64,05%	
70	**71,60%**	

Source: calculated by the authors

For the adopted parameters, the new bridge will serve approximately 70 years, and the bridge after overhaul – 45 years. In time, we have a gain of 70 - 45 = 25 years.

The efficiency of the service life is 25/70 = 0.3571 or 35.71%.

The effectiveness of the invested funds (building a new bridge – *Q* UAH., reconstruction of the bridge – 0.7 · *Q* UAH.) is (1-0.7)/1 = 0.3 or 30%.

The conclusion can be drawn as follows: with this ratio of funds needed for the construction or reconstruction of the bridge, the decision made in favor of the construction of the new bridge will be more effective.

Results and discussion

Let's will carry out the calculation for other indicators and the generalization results will be presented in table 3.

In the authors` opinions of this work, it all depends on the assessment of the physical condition of the bridge. If its condition does not require volumetric reconstruction, then the following indicators can be selected and calculated (then, accordingly, the gap between the wear indicators is small). This is evidenced in table 4.

According to the interest received, we have the volume of funds for reconstruction (Graph 1).

So, let λ_1 is the wear rate of the new bridge structure, and let λ_2 is the wear rate of the bridge structure after reconstruction. Considering that after reconstruction of the bridge old elements remain, the rate of wear of the wear rate of the bridge should be higher. We accept that $\lambda_2 = \lambda_1 + \Delta$.

Table 3. – Calculation of effectiveness (E) for other indicators

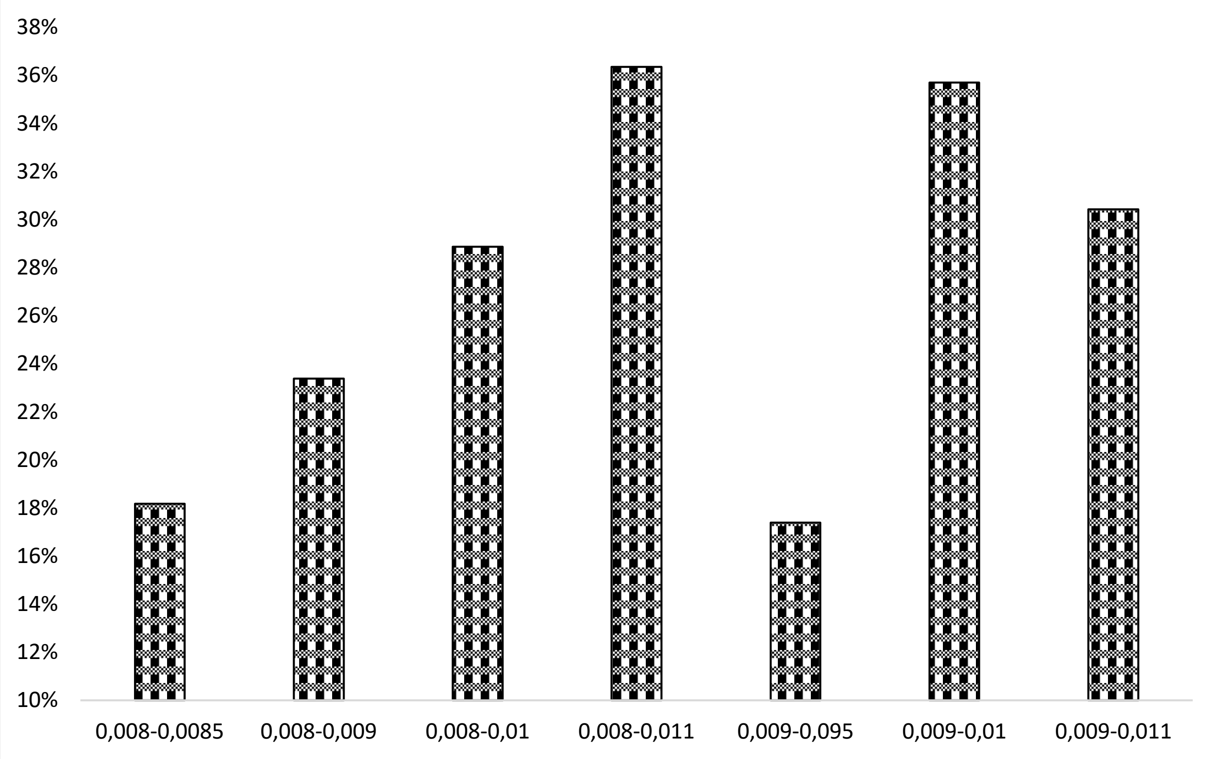
Of the year	**λ1**	**λ2**	**Of the year**	**λ1**	**λ2**	**Of the year**	**λ1**	**λ2**
	0,008	0,01		0,008	0,011		0,009	0,011
20	0,0833	0,2214	20	0,0833	0,2461	20	0,0942	0,2461
22	0,1008	0,2461	22	0,1008	0,2738	22	0,1140	0,2738
24	0,1185	0,2712	24	0,1185	0,3021	24	0,1343	0,3021
26	0,1366	0,2969	26	0,1366	0,3311	26	0,1549	0,3311
28	0,1549	0,3231	28	0,1549	0,3607	28	0,1759	0,3607
30	0,1735	0,3499	30	0,1735	0,3910	30	0,1972	0,3910
32	0,1924	0,3771	32	0,1924	0,4219	32	0,2190	0,4219
34	0,2117	0,4049	34	0,2117	0,4535	34	0,2411	0,4535
36	0,2312	0,4333	36	0,2312	0,4859	36	0,2636	0,4859
38	0,2511	0,4623	38	0,2511	0,5189	38	0,2866	0,5189
40	0,2712	0,4918	40	0,2712	0,5527	40	0,3100	0,5527
42	0,2918	0,5220	42	0,2918	0,5872	42	0,3338	0,5872
44	0,3126	0,5527	44	0,3126	0,6226	44	0,3580	0,6226
46	0,3338	0,5841	46	0,3338	0,6586	46	0,3826	0,6586
48	0,3553	0,6161	48	0,3553	0,6955	**48**	0,4078	**0,6955**
50	0,3771	0,6487	**50**	0,3662	**0,7143**	49	0,4205	
52	0,3993	0,6820	52	0,3882		51	0,4463	
54	0,4219	**0,7160**	54	0,4106		53	0,4726	
56	0,4448		56	0,4333		55	0,4993	
58	0,4681		58	0,4564		57	0,5265	
60	0,4918		60	0,4799		59	0,5543	
62	0,5159		62	0,5038		61	0,5825	
64	0,5403		64	0,5281		63	0,6112	
66	0,5652		66	0,5527		65	0,6405	
68	0,5904		68	0,5778		67	0,6703	
70	0,6161		70	0,6032		**69**	**0,7006**	
72	0,6421		72	0,6291				
74	0,6686		74	0,6553				
76	0,6955		76	0,6820				
77	**0,7092**		**77**	**0,7092**				
E = (77-54)/77 = 29,87%			E = (77-49)/77 = 36,36%			E = (69-48)/69 = 30,43%		

Source: calculated by the authors

Table 4. –Calculation of the effectiveness of the options

	Option 1	**Option 2**	**Option 3**	**Option 4**
λ_1	0,008	0,009	0,009	0,008
λ_2	0,009	0,1	0,095	0,0085
E_t	23,38%	23,19%	17,39%	18,18%

Source: calculated by the authors



Graph 1. – Boundary amounts of funds for reconstruction

Source: formed by the authors based on own calculations

Then the difference between the share of physical wear of the bridge structure after reconstruction and the new one will be:

$$U_P(t) - U_H(t) = e^{(\lambda_1+\Delta)(t-T)} - 1 - e^{\lambda_1(t-T)} + +1 = e^{(\lambda_1+\Delta)(t-T)} - e^{\lambda_1(t-T)} =, \quad t - T = k = e^{(\lambda_1+\Delta)k} - e^{\lambda_1 k} = e^{\lambda_1 k}\left(e^{\Delta k} - 1\right)$$

We compose the following proportion:

$$U_H(t) - \qquad 1$$
$$U_P(t) - U_H(t) - \quad x$$

From the proportion we have:

$$x = \frac{U_P(t) - U_H(t)}{U_H(t)} = \frac{e^{\lambda_1 k}(e^{\Delta k} - 1)}{e^{\lambda_1 k}} = = e^{\Delta k} - 1$$

$$e^{\Delta k} - 1 = 0{,}3$$

$$e^{\Delta k} = 1{,}3$$

$$ln(e^{\Delta k}) = ln(1{,}3)$$

$$\Delta \cdot k = 0{,}2624$$

$$\Delta = \frac{0{,}2624}{k}$$

Table 5. – Summary table

Bridge constructions	T_{kp}-T	λ_1	λ_2	λ_2 / λ_1
Wooden bridge	42	0,015	0,024	1,6
Reinforced concrete and stone bridge	70	0,0125	0,02214	1,58
Metal bridge	85	0,009	0,0135	1,5

If the wear indicator of the overhaul bridge construction is higher than the wear indicator of the new bridge construction by λ_2 / λ_1, and the amount of funds for overhaul reaches 70% of the funds needed to build a new one, it is better to build a new bridge.

Conclusions

Representation of the physical wear of the bridge as a failure made it possible to determine the proportion of the physical wear of the bridge structure. Further, on the basis of the "golden ratio" rule, the efficiency of the service life and the effectiveness of the invested funds were determined. All information was compiled and a summary table on the types of bridge structures was presented.

References

A bridge to concession: why does road workers need a public-private partnership? And how to improve the condition of Ukrainian bridge infrastructure. Available at: https://mind.ua/ru/openmind/20189923-most-v-koncessiyu-zachem-dorozhnikam-gosudarstvenno-chastnoe-partnerstvo

Agócs, Z., Vanko, M. (2016). Preparation of the Reconstruction of the Old Bridge over the Danube in Bratislava. *Procedia Engineering,* 156, 8-15. doi: 10.1016/j.proeng. 2016.08.261.

Bezpartochnyi, M., Britchenko, I., Jarosz, P. (2018). Reengineering business processes as a modern innovation of development wholesale enterprises region. Management of innovative development the economic entities: collective monograph. *Higher School of Social and Economic*, (1), 10–24.

Bodnar, L., Panibratets, L., Zavgorodnii, S., Chursin, O. (2016). Modern Bridge Management Tool. *Road industry of Ukraine*, 4, 46-51.

Bodnar, L., Stepanov, S., Koval, P., Stabrovskii, O. (2016). Determining the estimated cost of bridges repair using the Bridges analytical expert system. *Roads and bridges*, 16, 28-36

Bridges. How would we live without them? Available at: https://wol.jw.org/uk/wol/d/r15/lp-k/101998804

European integration. Available at: https://mtu.gov.ua/timeline/Evrointegraciya.html

Faoziyah, U. (2016). Who Benefits? The Case of the Suramadu Bridge Construction. *Procedia – Social and Behavioral Sciences*, 227, 60-69. doi: 10.1016/j.sbspro. 2016.06.043

Kim, M., McGovern, S., Belsky, M., Middleton, C., Brilakis, I. (2016). A Suitability Analysis of Precast Components for Standardized Bridge Construction in the United Kingdom. *Procedia Engineering*, 164, 188-195. doi: 10.1016/j.proeng.2016.11.609

Koshchenko, O. (2017). Unite the shores. Available at: http://www.silskivisti.kiev.ua/19475/Sonjashnik.php?n=35320

Levchenko, Ya. (2019). Bridges building in Ukraine: the importance of public-private partnership for its development. *Problems and prospects of entrepreneurship development*: Collection of scientific works of Kharkiv national automobile and highway university, 2 (23), 118-129. doi: 10.30977/PPB.2226-8820.2019.23.0.118.

Levchenko, Ya. (2019). On the way to European integration. How and to whom to invest in the construction and reconstruction of bridges in Ukraine? *Eastern Europe: Economy, Business and Management*, 6 (23), 152-157.

Levchenko, Ya. (2020). *Theoretical and methodological foundations of financial ensuring for bridges` building in Ukraine in the framework of public-private partnership: monograph*. Sofia. VUZF. 272 p.

Mehrotra, A., Glisic, B. (2015). Reconstruction of the appearance and structural system of Trajan's Bridge. *Journal of Cultural Heritage*, 16, 65-72. doi:10.1016/j.culher.2014.01.005.

Ministry of Infrastructure of Ukraine. Road industry 2019. Available at: https://mtu.gov.ua/timeline/Dorozhne-gospodarstvo.html

Smyrnov, O., Borysenko, A., Trunova, I., Levchenko, I., Marchenko, A. (2020). Determining the technical and economic parameters for designing hybrid power units for the budget segment. *Eastern-european journal of enterprise technologies, 1*(8(103)), 43-49. doi: 10.15587/1729-4061.2020. 194642

Yavuz, F., Attanayake, U., Aktan, H. (2017). Economic Impact on Surrounding Businesses due to Bridge Construction. *Procedia Computer Science,* 109, 108-115. doi: 10.1016/j.procs.2017.05.301.