INFLUENCE OF FUNCTIONALLY OBSOLETE BRIDGES ON THE EFFICIENCY OF ROAD NETWORK. PART I: OBSOLESCENCE CHARACTERISTICS AND ASSESSMENT

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Abstract. Deterioration of road bridges is causing serious problems in many countries of the world. Extensive research is carried out on the structural deterioration and defects of bridges and considerably less attention is given for their functional obsolescence. Inadequate deck geometry and clearances of bridges due to the increasing traffic volumes lead to the traffic safety and economic problems and influence the efficiency of a whole road transportation system. Typical bridge obsolescence model is analysed. Classification of five obsolescence categories and the main factors showing the functional obsolescence of bridges is presented. They include the deck roadway geometry (width and alignment), safety measures (barriers and railings), vertical and horizontal clearances beneath the bridge, alignment of the approach roadway, and waterway adequacy. Parameters assessing the functional obsolescence of bridges and the additional owner's and user's costs are identified. Decision-making strategy for obsolete bridges is discussed.

Keywords: road bridges, functional obsolescence, obsolescence categories and criteria, cost-based assessment, obsolescence management.

1. Introduction

Many world countries undergoing rapid economic development are making major investments in efficient road network systems. Increased trade and travel links dictate the growth of motor vehicle industry, modernization and construction of new highways. In 2003, some 41 million passenger vehicles rolled of the world wide assembly lines, five times as in 1950. The global passenger car fleet now exceeds 750 million vehicles and may approach 5 billion by 2050 (Kawachi, Wamala 2006). The development over time appears exponential. The traffic on the European roads is expected to increase at a rate of 4–5% each year (Hong, Hastak 2007). Similar situation is observed in Lithuania. In 2010, the intensity of traffic on state roads was estimated more than 2 million vehicles, i.e. 260% higher as in 1995.

Bridges are critical links in the road network in which they are located as their condition or out-of-service causes great losses for users, bridge owners and a whole society. Special attention is therefore focused on maintaining them in service conditions to ensure that they are fit for their intended purpose. The problem is quite complicated as it is related to function of bridge age, variety of structural types, strategic importance of route, increasing volume and composition of traffic. One of the major problems facing

the transportation system's efficiency of every country today is the structural deficiency and functional obsolescence of road bridges, tunnels and overpasses.

Structural deficiency reflects a bridge's inability to bear loads for which it was originally designed and built. All elements of bridges deteriorate at a greater or lesser rate dependent on materials and methods of construction, environmental conditions and the use of the structure. Extensive research is carried out on the structural deterioration and damage of concrete and steel bridges and many publications are presented on this subject.

Bridges are considered functionally obsolete or deficient if they have deck geometry, clearances, approach roadway, waterway adequacy, or load capacity that no longer meet current design standards and anticipated traffic volumes and types. Bridges that are considered substandard for load are only classified in this study as structurally deficient. Normally, they are load posted and are not analyzed here. The fact that a bridge is classified as functionally obsolete does not imply that it is structurally unsafe. Bridges are built to conform to the standards at the time they are designed. Different bridge standards exist for the various roadway systems in the world countries. Over time, improvements are made to the design requirements. Therefore,

the time comes when even the best-built bridge becomes showing function-related problems generally because of changing traffic demands particularly in high-traffic area.

The multiple cases of functionally obsolete bridges were reported in US (El-Tawil *et al.* 2005; Farhney 2006; Retting *et al.* 2000), UK (Das, Gibbs 2001; Horberry *et al.* 2002; Martin, Mitchell 2004), France (Martin, Mitchell 2004), China (Xin-Zheng *et al.* 2007) and other countries. In all these cases traffic volumes exceeded the bridge capacity in terms of bridge geometry or safety regulations resulting to obsolescence problem. However, the phenomenon of functional obsolescence of bridges has found until now insufficient attention in the maintenance and past research. Unfortunately, the measures undertaken for functional improvement are often reactive conducted in response to emergencies. Neglecting this situation create serious problems, such as damaged structures and vehicles, loss of lives, increased risk of accidents, increased road user costs, environment pollution. Some results on this subject are found also in (Farhney 2006; Ghose 2009; Hai 2006; Kamaitis 1997; Patidar *et al.* 2007). Traffic safety problems on Lithuanian roads and city streets are analysed in (Čygas *et al.* 2009; Grigonis, Paliulis 2009; Jakimavičius, Burinskienė 2009; Ratkevičiūtė 2010). It was observed during bridge inspections that due to inadequate approach, street configuration and geometry many urban bridges experience traffic bottleneck congestion almost every day. Improper operation of bridges is treated as the certain form of functional inadequacy. To the author's knowledge, this question has not been treated in literature.

Several methods are used to evaluate functionally deficient infrastructures. De Brito and Branco (1998) introduced the notion of bridge functional failure costs. They are divided in three categories, namely: traffic delays caused by the slowing down of the traffic crossing the bridge, detours of traffic, and detours of heavy traffic. Functional deficiencies related to the roadway width, clearances, and waterway adequacy are included in Pontis bridge management system employed in the U.S. (Patidar *et al.* 2007). Geometric ratings using a 0–9 scale are used to assess the bridge geometry that are key determinants of traffic safety
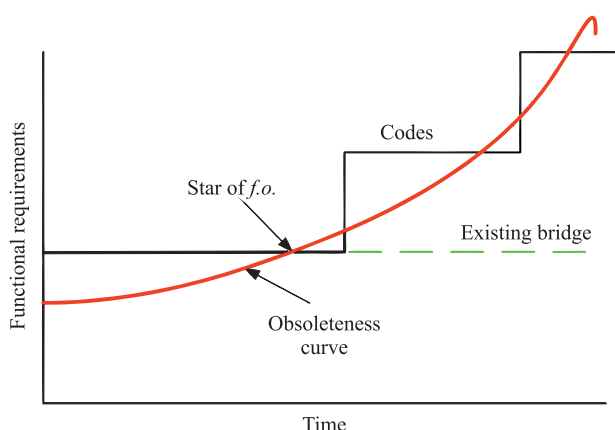
and serviceability. Bridges with appraisal rating 3 or less are considered as functionally obsolete. Benefits of functional improvements are assessed in terms of user cost savings. The user cost model estimates accident costs, delay costs or vehicle operating costs. The bridge user costs, when a bridge becomes unusable due to accident or rehabilitation works, are also analyzed in (Kamaitis 2001; Lee *et al.* 2004; Singh, Tiong 2005; Sugimoto *et al.* 2002). It was demonstrated that these costs may considerably exceed the direct rehabilitation work costs and have considerable effect on maintenance/management of bridges. It was also proposed (e.g., Kamaitis 2001; Sugimoto *et al.* 2002) that along with the user's costs, the socio-economic losses should be also accounted for. However, there are not sufficient research on the functional deterioration of bridges and the actual degree of its effect on transportation system's efficiency of a district or a whole country. The indirect costs deserve further study.

The objective of the Part I of this study was to identify the criteria of functional obsolete bridges, to break down deficiencies into categories and to assess deficient structures using cost-based approach. In this paper cost analysis based on bridge owners, users and social losses has been employed.

2. Functional obsolescence of bridges

2.1. Obsolescence model

The technological, social and market changes are the main causes having a profound effect on the economic life and value of industrial facilities, personal property as well as transportation systems. These influences are generally called as functional obsolescence.

Consider a typical bridge obsolescence model depicted in Fig. 1. Obsolescence is related to the utility of a bridge as a critical link of a given transportation system. Obsolescence is a relative decline in bridge utility, i.e., its inability to serve the user's current needs. Obsolescence refers to road bridges that become obsolete at a certain time because of changes in traffic intensity or composition. The functionality of older bridges relative to its intended purpose is reducing. Functional obsolescence affects the level of service and the development of substandard conditions for bridge users as well as traffic flow safety and capacity. Traffic over or under bridges should be kept to a minimum and, where it is essential, appropriate restrictions of the access to the bridge must be provided.

Functional obsolescence in many cases is a gradual process: it begins very slowly and gradually accelerates with later increasing or decreasing increments over time. The growing traffic intensity requires regulatory changes that impose new requirements on bridges in the codes. Experience shows that the functional requirements in the codes are subject to change over time.

The rate of functional obsolescence is estimated through identification on its impacts on economic values. Let's consider the benefits (or utility) and costs to the

Fig. 1. Typical bridge obsolescence model

community of the operating bridge over its lifetime. These benefits B and life cycle costs C_{LCC}, expressed in terms of money, will appear over time and are presented as the functions $B(t)$ and $C_{LCC}(t)$, respectively. In general, the bridge benefit increases with time at an increasing number of bridge users. After some time, the benefits slow down due to the traffic not increasing, or they decrease achieving the limit traffic capacity of a bridge. Then, the economic efficiency or the bridge utility function is expressed as follows:

$$U(t) = B(t) - C_{LCC}(t). \qquad (1)$$

Life cycle costs of operating bridge involve not only the bridge initial cost C_0, but also the discounted maintenance costs C_M (including repair or rehabilitation costs), as well as additional economic losses C_{FO} due to changes in the functional characteristics of the bridge and its role on the network. Then, Eq (1) become

$$U(t) = B(t) - C_0(t) - C_M(t) - C_{FO}(t - t_{f.o.}). \qquad (2)$$

This model is illustrated in Fig. 2. The problem is to be able to assess the economic losses C_{FO} for a particular bridge. These losses in monetary expression include time losses, increase in accidents, more emissions, and additional travel expenses. It is evident, that the bridges with different levels of functional obsolescence and intensity of traffic flow would exhibit different values of the economic efficiency.

Problem of functionally obsolete bridges is related with the following three main questions that have to be considered:

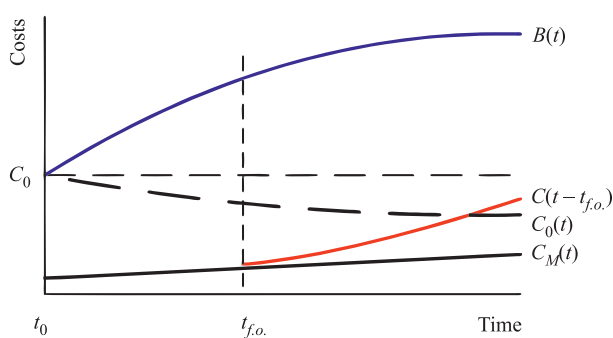– how to determine which bridge is functionally obsolete;

Fig. 2. Benefits and life cycle costs associated with a bridge in service

– how to assess the impact of obsolete bridge on the efficiency of present transportation system;
– which functional obsolete bridges are eligible for signing, rehabilitation or replacement.

2.2. Obsolescence classification and criteria

Specifications on the basic geometry of bridge structures normally are included in the codes of each country. Dimensional requirements for bridge deck widths, bridge openings and bridge railings normally are given. These requirements are governed by requirements of traffic safety and considerations of economy. The functionally obsolete bridges have older design parameters and while they are unsafe for all vehicles, they are not able to safely accommodate current traffic volumes, vehicle sizes and weights.

In order to determine if a bridge is functionally obsolete the evaluation in this study includes five categories of the bridge parameters (Table 1). Note, that some bridges are functionally obsolete in several categories.

The principal criteria justifying functional obsolescence of existing roadway bridges are divided in five groups:

Table 1. Categories and factors of functionally obsolete bridges

	Categories	Obsolescence factors	Possible obsolescence consequences
I	Deck roadway geometry (width and alignment)	Inadequate number of travel lanes for the traffic volumes Lanes narrower than required for actual truck size Lack of breakdown shoulders	Reduced traffic safety Increased collision risk, bridge strikes Limit of speed, traffic jam, loss of travel time Presence of road detours Overtopping of an urban area, roadway approaches or bridge deck Additional cost of traffic management Cost of goods increased Environmental pollution
II	Safety railings (vehicular and pedestrian)	Lack or insufficient height or crash resistance of security barriers	
III	Clearances (horizontal and vertical) beneath the bridge	Inadequate vertical or horizontal clearances under bridges	
IV	Horizontal and vertical alignment of the approach roadway	The number or width of lanes don't correspond with those of the approach roadway Inadequate sight distances because of excessive vertical or horizontal curvature of approach road Short diverge and merge lanes Pedestrian sidewalks are not accessible to pedestrians with mobility impairments	
V	Waterway adequacy	Restricted bridge opening Tidal waters	

– *Reduced speed of traffic.* This forces the driver to break, slow down or travel to extremely low speeds, causing the traffic delay, increasing feelings insecurity among drivers.

– *Detour roads.* This forces drivers to choose another way and to travel additional distance if the bridge is restricted or closed for particularly type of vehicles.

– *Reduced traffic safety.* This is potential occurrence of traffic accidents/collisions over or under the bridge, on approach roadway or detour road (if any), influencing user's safety and bridge structures strikes probability. Bridge should be considered functionally obsolete if a higher accident/collision risk than the bridges without traffic restriction exist.

– *Impacts on environment.* This criterion takes into account environmental pollution by vehicles (CO_2 emissions from gas, noise) and different disturbance minimization measures.

– *Traffic management.* This criterion is related with extra traffic management to bridge owner. Excessive wear of road surface as a result of braking or acceleration of vehicles in bridge area could be also taken into consideration.

Obsolete bridges are often hazardous locations. It is necessary to distinguish between the scenarios occurring at the intersections on main route (including bridge), on detours or on/under the bridge itself. Main route is the part of approach route located within the influence zone of the beginning and end of a bridge. Detour route is the route to be used in the event of a temporary or long-term closure of bridge traffic lanes or a whole bridge for a particular type of vehicles as well as during accidents, bridge repair/replacement works. Note, that on detours due to longer routes and increased number of vehicles, traffic delay and increased rate of accidents are expected. It should be stressed that slower speeds, longer trip times, traffic jams, and increased accident rates in the bridge area inevitable affect road network's capacity.

Traffic delay during time period of assessment (t_{fo}, t) is determined according to the well-known expression as the difference between the vehicle-hours travelled at reduced speed v and the free flow speed v_0 where there is no congestion

$$D(t_{fo}, t) = Lt \sum_j N_j \left(\frac{1}{v} - \frac{1}{v_0} \right), \qquad (3)$$

where L – the length, km, of road segment with the limited speed v, km/h; N_j – the total number of vehicles of type j (cars, passenger vehicles, small and large trucks, etc.).

Accidents happen on bridges or on the roadway section. With increasing traffic volume flows on the road network an increase in the number of overweight truck collisions with highway or railway bridges are observed. Accidents/collisions due to obsolete bridges (including approaches) are characterized by the occurrence of an additional number, rate, or severity of accidents over a given period of time. Thus, the total number or the frequency of expected accidents/collisions over a given time period (typically one year) are determined as follows:

$$N_{\frac{acd}{col}} = \sum_j N_j p_j + \sum_{j.col} N_{j.col} p_{col}, \qquad (4)$$

where p_j – the probability of vehicle to vehicle accidents; p_{col} – the probability of vehicle collision with bridge members; $N_{j.col}$ – the number of vehicles type j which can possibly strike bridge piers by aberrant vehicles or superstructure by abnormal height vehicles.

The probability of vehicle collision with bridge is determined as follows:

$$p_{col} = p_0 p_g p(H \geq R), \qquad (5)$$

where p_0 – probability of vehicle aberrancy, i.e. when vehicle has lost control; p_g – geometric probability of a collision between vehicle and bridge piers (in the case of aberrant vehicle) and superstructure (in the case of abnormal height vehicle); $p(H \geq R)$ – probability of bridge damage (or collapse) due to collision; H – impact load; R – resistance of a given element.

In hazardous bridges (particularly railway and pedestrian) the collision probability p_f accounting users (vehicles, trains, passengers, pedestrians) being on a bridge probability p_u during the collision should be included and is determined as follows:

$$p_f = p_{col} p_u. \qquad (6)$$

It should be stressed that road accidents are rare, random, multifactor events. Normally, several-year data is required from which annual accident rate taking into consideration the effect of traffic volume is calculated. For intersections, this would be in terms of average numbers of accidents per million vehicles entering the intersection per annum. For road sections it would be in terms of average accidents per million vehicle-km per annum.

Thus, accident average rate per million vehicle-km for road segment L (km) or accidents per million vehicles for intersections ($L = 1$) is calculated as follows:

$$A_{acd} = \frac{\sum_j N_j p_j}{AADT 365 L} 10^6. \qquad (7)$$

Collision average rate per million vehicles per intersection (bridge) is determined as follows:

$$A_{col} = \frac{\sum_{j.col} N_{j.col} p_{col}}{AADT 365} 10^6, \qquad (8)$$

where $AADT$ – the average annual daily traffic for the year analyzed.

One of the important questions is to gather accident statistics to see whether any of these deficiency categories

are causing additional road accidents. To data, there is no sufficient data for collision rates. Some estimates of p_{col} based on collision statistics are presented in (Trouillet 2001; Calgaro, Gulvanessian 2001; Vrouwenvekder *et al.* 2001). For example, (Trouillet 2001) estimated p_{col} value of 8.5×10^{-3} for bridge piers.

The factors, such as daily traffic volume, public and cargo transport, commercial motor vehicles, large trucks influence considerably the expected consequences of functional obsolescence.

3. Economic assessment of functional obsolescence

The criteria of functionally obsolescence of bridges which provide service to entire road network are traffic capacity, safety and cost that are paid by bridge owners, users and a whole society. To quantify functional obsolescence of bridges the time dependent cost-based approach was used. The functionally obsolescence of a bridge expressed as a total expected cost during time period of assessment $C_{FO}(t_0, t)$ is considered assessing bridge owner $C_{OW}(t)$, bridge user $C_{US}(t)$, and indirect social $C_{SOC}(t)$ costs discounted over the considered period t of the structure. The total cost is

$$C_{FO}(t_0, t) = [C_{OW}(t) + C_{US}(t) + C_{SOC}(t)] \frac{1}{(1+r)^t}, \quad (9)$$

where r – discount rate.

3.1. Owner's costs

Owner's costs $C_{OW}(t)$ include improved maintenance of risky structures (more frequent inspections, repair of road surface within bridge influence zone due to excessive wear of road surface as a result of braking/acceleration of vehicles with stop-and-go operations), traffic regulation and bridge protection measures ΔC_M, as well as post-accident (if any) repair work (materials, labour, equipment) C_{col}. Total owner's costs are

$$C_{OW}(t) = \Delta C_M(t) + C_{col}. \quad (10)$$

Additional cost of improved maintenance is normally included in the annual maintenance budget of the bridge stock. The renewal costs are easily predicted on current construction or maintenance costs.

3.2. Road user's costs

Road user's costs are the costs associated with transport operating over or under the bridge, on approach way or detour routes and are one of the favourite subjects because they may sometimes considerably exceed the owner's costs. User's costs are mainly attributed to the functional deficiency of a bridge such as load posting, clearance restriction, posted traffic speed or partial or total closure of the bridge. The user's costs due to traffic delays or rerouting caused by bridge restrictions during ordinary or post-accident (if any) time are estimated on the basis of traffic data and economic indicators. Although the assessment of

economic indicators which include unit costs per km or per hour for different vehicle types and time periods remains speculative, introducing their effect is indispensable when determining the relevant management strategy for a bridge in question.

In general, road user's costs consist of three major costs items. They are expressed as follows:

$$C_{US} = C_{VO} + C_{TD} + C_F, \quad (11)$$

where the costs associated with: C_{VO} – increased vehicle operating; C_{TD} – delay or loss of travel time; C_F – risk of additional accidents on main route (within bridge area) and detours.

Daily vehicle operating and loss of travel time costs are calculated by the following expressions:

$$C_{VO} = L_0 \frac{v_0 - v}{v_0 v} \sum_j N_{0j} c_{tj} +$$
$$L_d \frac{v_{0d} - v_d}{v_{0d} v_d} \left(\sum_j N_{dj} c_{dj} + \alpha \sum_j N'_{dj} c_{tj} \right); \quad (12)$$

$$C_{TD} = L_0 c_{pas} \frac{v_0 - v}{v_0 v} \sum_j N_{oj} w_j +$$
$$L_d c_{pas} \left(\frac{v_{0d} - v_d}{v_{0d} v_d} \sum_j N_{dj} w_j + \frac{\alpha N'_{dj} w_j}{v_d} \right), \quad (13)$$

where L_o and L_d – the length of original route in bridge area (including bridge) and of detour route in km, respectively; N_{0j}, N_{dj}, N'_{dj} – the number of vehicles of type j existing on the original route, detour route, and detoured from original route, respectively; c_{tj} and c_{pas} – the average operating cost for each type of vehicle, and average delay time value of passenger, respectively; v_0, v, v_{0d}, v_d – the free speed and reduced speed on original and detour road, respectively; w_j – number of passengers in vehicle j.

Note, that negative impacts of vehicle operating and time delay should also include increased fuel use and additional maintenance of vehicles.

Additional risk of vehicle accidents on main and detour routes as well as vehicle collisions with bridges are evaluated using the failure cost

$$C_F = (L_0 \sum_j N_{0j} \Delta A_{acd.0} + L_d \sum_j N_{dj} \Delta A_{acd.d}) c_{ac} 10^{-6} +$$
$$\sum_{j.col} N_{j.col} n_{col} c_{col}, \quad (14)$$

where $\Delta A_{acs.0}$ and $\Delta A_{acs.d}$ – additional number of accidents per million vehicle-km with traffic congestion compared to the normal conditions on the main rout and detours, respectively; n_{col} – a number of vehicle collisions with a bridge for the year analyzed; c_{ac} and c_{col} – an average losses of accident and collision, respectively.

In the calculation of C_{VO}, C_{TD} and C_F, location and importance of a bridge, traffic type and volume, number and distance of alternative routes/bridges as detour routes, number and type of vehicles detoured, existing traffic on the detour route affected, accident/collision risk statistics, and average operating and travel or failure costs should be considered and are obtained from traffic network analysis and current cost data.

Note, that additional accident costs are composed of direct failure costs including damaged structures and vehicles, fatality and injury losses and indirect costs, such, for example, as environmental pollution and other indirect impacts (the cost of public litigation, adverse public opinion, etc). Fatality and injury losses are evaluated in a monetary expression on the traffic accident cost data. Frequently, accident costs are not included in analysis due to insufficient statistical data. The determination of vehicle accident costs are found in numerous publications (e.g. Wong *et al.* 2005).

3.3. Indirect social costs

Social costs are attributed to the consequences of bridge functional deficiencies to society. Increased time spent to travel leads to loss of employee's productivity, increased work accident risk, decreased rest time, increased environmental pollution (ground-level ozone pollution, vehicle emissions, noise, etc.). Delayed time of emergency and fire-fighter vehicles have catastrophic consequences for population. In some situations of economic losses C_{FO} related with damage of vehicles, fatalities and injuries are also important for community. Social costs (including environmental impact) are difficult to quantify. It is expected that they are related to the average daily traffic volume. The higher this indicator the higher social and economic importance of the bridge. Social costs are considered by the individual bridge administration in a simplified way for each bridge, for example, as a percentage of road user's costs. In the reference (Le *et al.* 2006) it is reported that socio-economic losses range approx from 50% to 150% of user's costs.

4. Obsolescence management

The management of bridge stock must consider operational risks over the life time of a bridge associated with obsolescence. Specifically it must address the issues such as:

Which bridges on the road network are showing deterioration signs and what kind of obsolescence is identified?

What would be the impact of bridge being obsolete on the functionality of road system that is the part?

What would be the impact of bridge being obsolete on the bridge owner, users, and a whole society?

What will be the cost of bridge rehabilitation or other actions taken to eliminate obsolescence?

An assessment of above factors must be conducted from time to time in order to identify the most appropriate obsolescence management strategy. The major objective of obsolescence management is to ensure that this issue is addressed at the initial stages in order to minimize the risk for users and its costs and to ensure safe operation of a bridge with max benefit for society in accordance with national standards.

When identifying and assessing the functional obsolescence of any bridge the decision-making strategy in maintenance, rehabilitation or replacement on the individual bridges should be analyzed. This is divided in three types:

- do nothing now, only improved survey of condition state of a bridge and traffic circulation is carried out; this enables the obsolescence problem to be addressed before it affects the users operational effectiveness;
- identifying and assessing the obsolescence problem; the intensity of activity is determined by the identified risk and the measures is taken that the bridge is functional and signing (warning signs and markings) is appropriate;
- determining of obsolescence costs and make a reconstruction, bringing a bridge to the state meeting the current criteria for the transportation system for which the bridge is a part.

A functional aging evaluation should be carried out comparing different functional improvement measures deciding whether these rehabilitation actions are technically and economically reasonable. It is evident that in decision-making process the cost to be the most important factor. In order to determine the functionally obsolescence costs various risk and cost factors must be assessed and analyzed as was mentioned above.

The profit of functional improvements for each bridge is expressed taking into consideration impacts on bridge owner, users and society. Of course, road user costs are one of the favourite subjects. Constraints on available budget should be also included. The budget needs usually exceed the available funds. Thus, the prioritizing of improvement actions to be taken on the different bridges for the max benefit to society is modelled by

$$\max\left\{\sum_b C(t_0,t)\right\} =$$
$$\sum_b C_{FO}(t_0,t) - \min\left\{\sum_b C_R(s_i)\right\} > 0 \tag{15}$$

$$\text{subject to } \sum_b C_R(s_i) \le Bud(t_0), \tag{16}$$

where $C_{FO}(t_0,t)$ – the economic losses due to decline in bridge utility throughout the time period $[t,t_0]$, based on present value and prediction future costs and values; $C_R(s_i)$ – the total cost associated with i^{th} rehabilitation scenario s_i including rehabilitation work cost and all indirect costs; b – the bridge number; $Bud(t_0)$ – the budget in year t_0.

Estimation is made on individual bridges and also at the network level. This expression shows that the rehabilitation will be justified when its costs are outweighed by the expected economic losses of functional aging.

5. Conclusions

1. Bridges being critical elements of the transportation system have a significant direct and indirect influence on the efficiency of road network. Structural deficiency and functional obsolescence of road bridges are two major aspects facing the road system's efficiency of every country. Phenomenon of functional obsolescence of bridges has got until now insufficient attention and the measures undertaken for functional improvement are often conducted in response to emergencies. Neglecting this situation, the traffic flow and safety is negatively affected by deficient bridge condition and lead to economic losses for bridge users and a whole society.

2. Typical bridge obsolescence model is analysed. Due to changes in traffic intensity the utility of a bridge to the community is reducing with time. Classification of five obsolescence categories and the main factors showing the functional obsolescence of bridges is presented. They include the deck roadway geometry (width and alignment), safety measures (barriers and railings), vertical and horizontal clearances beneath the bridge, alignment of the approach roadway, and waterway adequacy.

3. The criteria justifying functional obsolescence of bridges are formulated. They include traffic delay, reduced traffic safety (potential accidents of vehicles or vehicles with bridges), as well as impacts on the environment or road/bridge maintenance.

4. To quantify functional obsolescence of bridges the time dependent cost-based approach is used. The functionally obsolescence of a bridge is considered by assessing bridge owner, bridge user, additional accidents/collisions, and indirect social costs.

5. Comprehensive bridge management system is of vital importance in the establishment of the quality of maintenance, repair or rehabilitation of deteriorating road bridges. Economic analysis based on benefit-cost ratio for functionally obsolete bridges should be the focus of the decision making process. The rehabilitation will be justified when its costs are outweighed by the expected losses of functional aging.

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