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Rational approach for the management of a medium size bridge stock

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ABSTRACT: Infrastructure managers of medium size bridge stocks are being faced with the task of approximating short, mid to long term financial needs for their infrastructure. This task is particularly demanding due to the lack of relevant information, in particular in forecasting bridge condition and intervention costs. It can, therefore, be beneficial to make cost estimations based on structure types and present condition evaluation.

In this article a rational approach for the management of the medium size bridge stock including 654 bridges of a regional road network is presented. The basic methodology is given and it is described how this methodology is adopted considering the available information (data base) on the bridge stock on the structures level. The use of age equivalents is suggested to describe bridge condition and to link directly intervention cost to condition

1 INTRODUCTION

Most infrastructure management systems are designed for dealing with a large number of structures, typically more than 5’000, treating information on the element level. In Switzerland, such infrastructure management systems exist for the structures of the Swiss Federal Railways and the National Roads (Hajdin, 2006). Application of these infrastructure management systems requires advanced knowledge and a certain effort in personnel.

Many infrastructure managers (of public agencies) are dealing with medium size stocks typically with less than 1’000 structures, and rather crude information on the structures level is available only. Such stocks typically exist on the regional or community (town) level. Infrastructure managers have the task to approximate short, mid to long term financial needs for the maintenance of their infrastructure. (*Maintenance* here includes all the activities undertaken to ensure the continued existence of a structure, including preservation of its material and cultural values.) In order to solve this task, a rational approach is needed which is just precise enough in order to justify allocation of funds for infrastructure maintenance.

Approximating financial needs for the maintenance of a stock of structures depends on the availability and quality of relevant information and data on the current condition of the structures. Also, condition evolution needs to be forecasted and the corresponding intervention costs estimated.

This paper presents first results of an ongoing project to establish a rational approach for the management of a medium size bridge stock. In the first part of the paper, existing data is edited to deduce the most relevant characteristics in terms of the nature and condition of the bridges. The basic methodology to make cost estimations for the maintenance of the bridge stock based on present bridge condition evaluation is outlined in the second part of the paper.

2 PRESENTATION OF BRIDGE STOCK

The bridge stock of the road network of a Canton (region) in Switzerland is investigated. This canton has a 2’126 km long road network comprising 667 bridges. This bridge stock can be subdivided into four major groups depending on the construction type and construction material as follows (Table 1):

Figure 1. a) Masonry bridge, b) Masonry–concrete bridge, c) reinforced concrete bridge, d) steel bridge.

- *Masonry bridges* (Fig. 1a) have been mostly built until the middle of the 20th Century using natural stones (mostly limestone and granite). They represent 22% of all bridges, and 80% of them are single span arch structures with an arch opening of maximum 5m. These structures don’t have any waterproofing and water is percolating through the structure.
- *Masonry–concrete bridges* are originally masonry bridges which have been widened by adding a longitudinal beam and a concrete slab to cover the whole structure (Fig. 1b). These bridges represent 37% of all structures. Like for the masonry bridges, most of them (67%) are short span structures with a single span of maximum 5m. In some cases, only a slab has been placed on the original masonry structure to allow for placing a waterproofing membrane to protect the masonry.
- *Concrete bridges* (Fig. 1c) are constructed mostly in reinforced concrete and for longer spans (>20m) in prestressed concrete. They represent 38% of all bridges, and most of them (75%) have been built over the last 60 years. Over the last 20 years, code provisions prescribe measures to improve durability of concrete structures, and it is assumed that a waterproofing membrane has been placed systematically on concrete deck slabs since 1975.

- *Steel bridges* comprise steel structures with a deck to accommodate the roadway as well as steel–concrete composite bridges (where the deck slab is rigidly connected to the longitudinal steel beams). They are relatively small in number (3% of the total bridge stock), and they have medium or long spans (Fig. 1d), f.ex. to cross a river.

The basic statistical data on the bridge stock shows that almost 60% of all bridges are originally masonry bridges, most of them (about 75%) were built in the 19th Century. A second important roadway and bridge construction phase was in the years from 1950 to 1980 using almost exclusively reinforced and prestressed concrete. Steel bridges have been built in the 19th Century and until today in singular cases and when particular conditions are given.

3 CLASSIFICATION OF BRIDGES

The basic statistical data has been analysed further and classified as given in Table 1, considering the following two parameters which are believed to influence significantly *bridge deterioration*: 1) exposure, and 2) existence of waterproofing (see below).

Moreover and in view of maintenance intervention causing also user costs, the whole road network has been subdivided into roadways with high and low *priority* depending on traffic volume and strategic significance of the roadway with respect to networks of a higher level like highways or access roads to towns.

Table 1. Classification of the bridges as a function of deterioration relevant parameters

Classification						
Construction material	Total number	Number according to road priority	Exposure		Waterproofing	
			normal	severe	yes	no
Masonry	143	High: 99	66		0	66
				33	0	33
		Low: 44	29		0	29
				15	0	15
Masonry–concrete	240	High: 139	83		16	67
				56	10	46
		Low: 101	60		10	50
				41	6	35
Concrete	251	High: 190	124		44	80
				66	31	35
		Low: 61	41		20	21
				20	6	14
Steel	20	High: 12	7		3	4
				5	4	1
		Low: 8	7		2	5
				1	0	1
Total:	654	High: 440 Low: 214	417	237	152	502

Exposure: The investigated road network comprises both areas in the plains and close to a large lake with a rather moderate climate (at 400 to 500 m altitude) as well as mountainous areas at up to 2000 m altitude exposed to rather severe climatic conditions in particular in winter. The bridge stock has thus been subdivided depending on whether the bridge is located at an altitude above or below 700 m altitude. At altitudes of more than 700m above sea level, severe climatic conditions in winter lead to an extensive use of deicing salts on bridges. Consequently, chloride induced corrosion of steel reinforcement in concrete elements of concrete and masonry-concrete bridges is significantly more likely to occur at altitudes above 700m. Bridges located at altitudes below 700m are considered to be subjected to normal exposure.

Waterproofing membrane: Since about 1975 or for more than 30 years, water proofing membranes are systematically mounted on the deck slabs of new bridges and existing bridges undergoing rehabilitation. Waterproofing membranes largely prevent water and chloride ingress into concrete, and thus chloride induced corrosion and other concrete deterioration are significantly less likely to occur. In the case of masonry–concrete bridges the waterproofing also stops water percolation through masonry structures; in this way, it is prevented that mortar joints are washed out or the masonry structure is subjected to moist conditions.

The classification of the bridge stock according to Table 1 allows to deduce the following characteristics:

– 2/3 of all bridges are on roadways of high priority. As a consequence, a rational planning of maintenance interventions is very important in view of limiting user costs.
– 36% of all bridges are exposed to severe environmental conditions, i.e. these bridges are subjected to a substantial amount of deicing salts and the likelihood of steel rebar corrosion in reinforced concrete and corrosion of structural steel is increased.
– Only 23% of all bridge decks are equipped with a waterproofing membrane. While respectively 40% and 18% of all concrete bridges and masonry–concrete bridges have a waterproofing membrane, there is no waterproofing on all masonry bridges.
– There is no particular characteristic that would apply to the steel bridges which are limited in number. This means that steel bridges require specific considerations, and they could also be excluded from generalising considerations.

4 ACTUAL BRIDGE CONDITION RATINGS

All bridges are systematically inspected, in 75% of all cases by the roadway maintenance personnel of the agency and in 25% of cases by consulting bridge engineers mandated by the agency. The overall result of a bridge inspection is expressed by a bridge condition rating on the structures level in terms of 1:good – 2:acceptable – 3:deteriorated – 4:bad – 5:alarming. Table 2 gives an overview of the actual bridge condition ratings for the whole bridge stock.

It can be stated that the overall “health” condition of the bridge stock is rather satisfactory since 80% of all bridges are in good or acceptable condition. Yet, there are 18% or 119 bridges in deteriorated condition requiring rehabilitation in the coming years; almost half of them are masonry-concrete bridges. The 10 bridges in bad condition are all short span structures with rather low consequences in case of failure, and thus, the risk of bridge collapse has been evaluated as being acceptable over the remaining time period until intervention. There is no bridge in “alarming” condition (meaning that it would need to be closed for traffic use).

Table 2. Actual bridge condition ratings of all bridges of the bridge stock

Condition :	Bridge type (construction material)				Total :
	masonry	masonry-concrete	concrete	steel	
good	38	79	102	7	226
acceptable	79	105	104	11	299
deteriorated	26	53	38	2	119
bad	0	3	7	0	10
	143	240	251	20	654

The existence of a significant part of bridges in “deteriorated” condition indicates that it is no longer possible to allocate only minimal resources to maintain the bridge stock. This situation has occurred due to insufficient funding in the past to levels below that required for optimal long term maintenance of the bridges. Consequently, a period of time with additional resources will be needed to catch-up. Obviously, the longer the additional funding is delayed the greater the resources that will be required to catch-up.

5 METHODOLOGY FOR MAINTENANCE COST ESTIMATION

In cases of advanced management systems with adequate amounts of data, the optimal intervention strategies can be predicted using structural element level data. In the present case, this capacity does not exist, since the implementation and support of an advanced management system and the collection of the required data require a significant effort maybe disproportionate with respect to the task. An own methodology is needed to estimate overall maintenance cost using the information gained from the basic bridge stock data and from bridge condition ratings.

The basic idea of the suggested methodology presented graphically in figure 1, consists in constructing for each of the four construction types a dependency between the bridge condition and the intervention cost (Adey et al., 2006a & b):

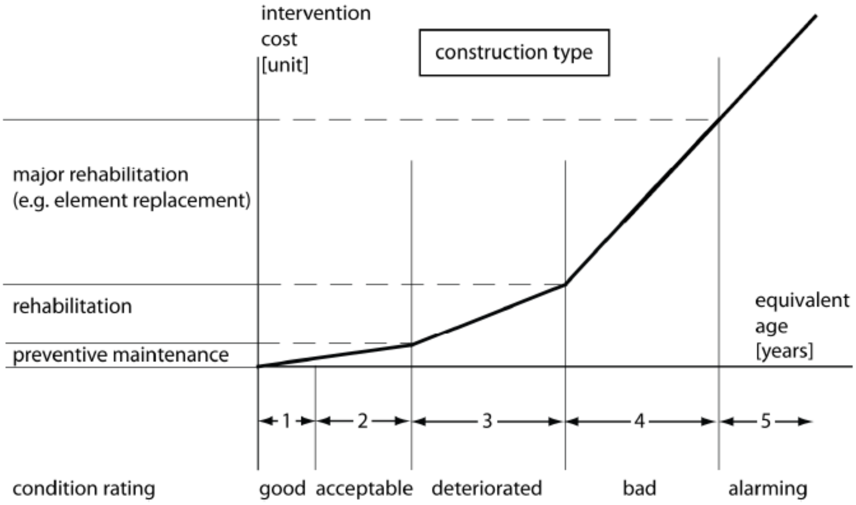

Fig. 1. Dependency between equivalent age (bridge condition) and intervention cost.

The *bridge condition* is described by the overall condition rating for each bridge as obtained from inspection. This rating is then transposed to an "equivalent age" (Adey et al., 2006a). The notion of "equivalent age" of an existing bridge describes the actual age in terms of bridge condition. For example, after an intervention the bridge condition is improved to reach the condition similar to a newly built bridge; the equivalent age is then equal to 0 years (irrespective of the physical age). The "equivalent age" is equal to the physical age of a bridge in case no intervention has been performed.

Using the notion of *"equivalent age"* has the advantage that bridge condition degradation can be derived from the assigned equivalent age and intervention costs are directly linked to condition (see Table 3). Moreover, bridge history, which is often lacking, can be neglected, since all estimations depend alone on the present condition and the expected deterioration. It is not necessary to know the date of construction or the number or types of interventions that have been conducted on it in the past.

The *intervention cost* includes only the direct construction cost of the intervention, not considering indirect or user costs. It is expressed in terms of, for example, unit cost per m^2 of bridge deck surface or % of the actualized value of the bridge with an equivalent age of 0 years. The likely costs of intervention for the different construction types as a function of their "equivalent age" are estimated based on information about past intervention costs as known for the present bridge stock as well as expert opinion (COST, 2004). The intervention costs are approximated by determining three general condition states that are associated with three types of interventions, i.e. preventive maintenance (with/without repair), rehabilitation and major rehabilitation (including f.ex. element replacement). The likely time periods of these interventions and their respective costs are estimated for each construction type.

The dependency between “equivalent age” and “intervention cost” has to be established for each construction type. For the sake of illustration, Table 3 gives – for the example of concrete bridges – the tentative dependency between “condition rating” and “equivalent age” as well as between “equivalent age” and “intervention cost”.

Table 3. Example of dependency between equivalent age and intervention cost for concrete bridges (tentative, to be confirmed).

Condition description for concrete bridges:	Condition rating	Equivalent age [years]	Intervention cost [% of value]
Protection systems (f.ex. waterproofing membrane, cover concrete) function reliably; there is no indication of deterioration.	1: good	0 – 10	0 No intervention
Protection systems are no longer reliably effective (f.ex. initiation phase for steel rebar corrosion is complete, water proofing system is at the end of its service life).	2: satisfactory	11 – 25	1 – 10 Preventive maintenance and repair
Protection systems are largely defective; there are multiple indicators that deterioration is active (f.ex. cracking, spalling, etc..). Damage is visible but it is not yet much advanced, i.e. loss of material < 10%.	3: deteriorated	26 – 60	11 – 30 Rehabilitation
Deterioration is advanced; obvious damage with significant material loss, f.ex. steel rebar corrosion with an important reduction of the initial cross-sectional area; spalling and excessive cracking due to other deterioration phenomena like alkali-aggregate reaction.	4: bad	61 – 120	31 – 100 Major rehabilitation (f.ex. element replacement)
Advanced deterioration and obvious damage; structural safety is affected due to significant loss of resistance (typically more than 30%) and large deformations (accompanied by excessive cracking) of structural members.	5: alarming		

Using the dependency between “equivalent age” and “intervention cost”, as established for each construction type, the intervention cost is determined for each bridge of the bridge stock depending on its condition and when the intervention will be carried out. Intervention cost obviously increases the longer the intervention is postponed.

Intervention scenarios are then developed and investigated to determine the overall (yearly) cost for the maintenance of the bridge stock. Such scenarios could be, for example, (1) to carry out the interventions first on the bridges in the worst condition, (2) to improve the overall age equivalent of the bridges on high priority roads, (3) to determine evolution of the equivalent age of the bridge stock while maintaining a given budget, or (4) to optimize interventions such that maintenance costs will be minimal. Such scenarios have to respect budget constraints.

The sequence of interventions and the corresponding maintenance cost for the bridge stock is determined by minimizing all costs during the considered period while assuming that each bridge has only one planned intervention (i.e. those that can be accurately predicted based on the bridge condition) and budget constraints are respected [Adey et al. 2006a&b].

It is also assumed that safety problems only occur from exceptional actions due to natural and man-made hazards and that such problems will be solved by funds other than the ordinary maintenance budget.

Budget needs for the various strategic maintenance scenarios are finally obtained and used to justify short, mid and long term financial needs to maintain the bridge stock.

6 IMPLEMENTATION OF THE METHODOLOGY AND EXPECTED RESULTS

This methodology is currently implemented as follows. Targeted condition surveys are conducted on 100 bridges (out of 654) to validate the methodology and to update the available data. In this way, an indication about the dependability of the available data is obtained. In the next step, the dependency between "equivalent age" and "intervention cost" (Table 3) is established for all four construction types. Various scenarios will then be analysed and optimized respecting given constraints. Finally, the budget needs for the optimal maintenance of the bridge stock will be determined.

The study most likely will bring forward the need to surmount a so-called "*catch-up period*" during which the overall bridge stock condition must be improved before optimal interventions (i.e. preventive maintenance (with/without minor repair)) are feasible (Fig. 3). Catch-up periods are the result of insufficient previous bridge maintenance. Once this occurred even the resumption of funding at an (initial) sufficient funding level is not effective and further bridge deterioration would result. Consequently, the longer the additional funding is delayed the greater the resources required for the catch-up period. The more additional funding is invested to surmount the "catch-up period" the shorter is the duration a (Fig. 3).

Beyond the "catch-up period" (after the year 2007 + a) only the financial resources equivalent to the minimal long term cost are allocated on a yearly basis while maintaining a constant collective condition of the bridges.

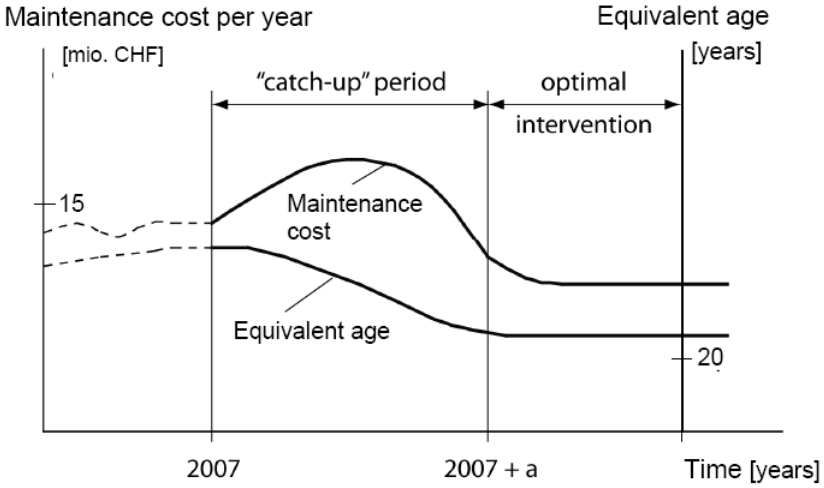

Fig. 3. Expected result: maintenance cost over the next years.

Moreover, it will be shown that it is optimal for each bridge type to ensure that it is continually protected against deterioration processes by applying preventive maintenance measures. The study may also show that if deterioration processes are allowed to attack bridges that there is a significant period of time in which deterioration may be tolerated to take place, as long as there are no safety problems, with little effect on the long term maintenance costs. The savings in the long term attained by pursuing an optimal intervention strategy for the bridge owner, however, will most likely be substantial.

7 CONCLUSIONS

A rational approach for the management of the medium size bridge stock including 654 bridges of a regional bridge agency in Switzerland is presented. This approach has been adopted by the directly involved managers considering their available information (data base).

The classification of the bridge stock according to deterioration relevant parameters shows that 36% of all bridges are exposed to severe environmental conditions and only 23% of all bridge decks are equipped with a waterproofing membrane.

The condition rating data shows that there are 20% of all bridges in deteriorated or bad condition requiring rehabilitation in the coming years. This indicates that it is no longer possible to allocate only minimal resources to maintain the bridge stock. Consequently, a period of time with additional resources is needed to catch-up.

The methodology outlined to approximate optimal intervention strategies and maintenance costs, is useful for agencies responsible for medium size bridge stocks.

The use of age equivalents is an efficient means to describe bridge condition and to link directly intervention cost to condition.

8 LITERATURE

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