

The impact of different maintenance policies on owners costs: Case Studies from Croatia and the Netherlands

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Abstract. Optimisation of maintenance planning is an important part of bridge management. The efficiency of condition assessment process is directly influencing the choice of repair and maintenance technique, i.e. measures which have to be undertaken. This paper examines the effect of two opposing maintenance strategies, corrective and preventive maintenance. The condition rating and planned maintenance costs for structural elements of bridges at different ages are compared. In case studies from Croatia and the Netherlands, data from previously performed inspections was compiled in order to correlate age, condition and costs for structural elements. The case studies have been used to assess the impact of different maintenance policies (corrective vs. preventive) on the occurred maintenance costs.

Keywords: bridge management system, condition assessment, maintenance options, corrective vs. preventive approach, costs.

1 Introduction

Functional and serviceable road infrastructure presents one of the most important predispositions for economic growth of countries around the world. One of the most important and critical parts of road infrastructure are bridges which present a vital link in any roadway network. It is estimated that the ratio of expenses per route km of bridges is 10 times the average expense per route km of roads. The length of bridges compared to the whole length of road networks is only approximately 2% but at the same time they present 30% value of the whole network (PIARC, 1999). During the last decade a new network management philosophy, Asset Management has emerged, which puts the customer - the traffic user - into the centre, and, at the same time, methods to allocate the socio-economic optimal amount of money to each specific asset (roads, bridges, tunnels, lighting, signs, guard rails, etc.). When these developments and statistics are taken into consideration it is easy to understand why, in the past few decades, an increasing number of Bridge Management Systems (BMS) and life cycle maintenance models were developed like for example Branco & Brito, Frangopol's and Rijkswaterstaat's model (Kaneuji et al. 2006, Airaksinen 2006, Astudillo Pastor et al. 2000, Noortwijk J.M. et al. 2004).

A Bridge Management System (BMS) is defined as a rational and systematic approach to organizing and carrying out all the activities related to managing a network of bridges, including optimizing the selection of maintenance, repair and rehabilitation actions in order to maximize the benefits while minimizing life cycle costs (Hudson et al., 1992). Mainly there are three aspects addressed by BMSs found in literature: condition assessment, modelling future degradation and optimisation of maintenance, repair and rehabilitation decisions and actions. The heart of a BMS however is a database derived from the regular inspection and maintenance activities. The integrity of a BMS is directly related to the quality and accuracy of the bridge inventory and physical condition data obtained through inspections (AASHTO, 1994). Additional information such as the bridge name, location, and construction date are stored in the system.

The BMS can be used as a tool to allow bridge managers to be fully informed about the bridge stock under their control so that they can make informed and optimal decisions about future maintenance and repair activities.

2 Maintenance strategies and maintenance planning

Any BMS is used as a tool as part of a broader bridge management strategy. Depending on the bridge inventory, constraints and societal demands, a road agency will lay out a strategy aiming to achieve optimal results within the limitations posed by the constraints.

Maintenance decisions are based on the deterioration level of an object. Degradation or deterioration of infrastructure is one of the main factor that triggers maintenance. With regard to maintenance planning, two approaches may be applied, a corrective versus a preventive maintenance strategy. In a corrective strategy, maintenance is planned after a certain amount of damage has occurred, whereas a preventive approach aims to plan maintenance so as to prevent unaccepted damages from occurring. In practice, often a combination of both strategies is followed, aiming for an optimal balance between costs and performance, see Figure 1. A good understanding of bridge condition and future degradation is necessary for this optimisation.

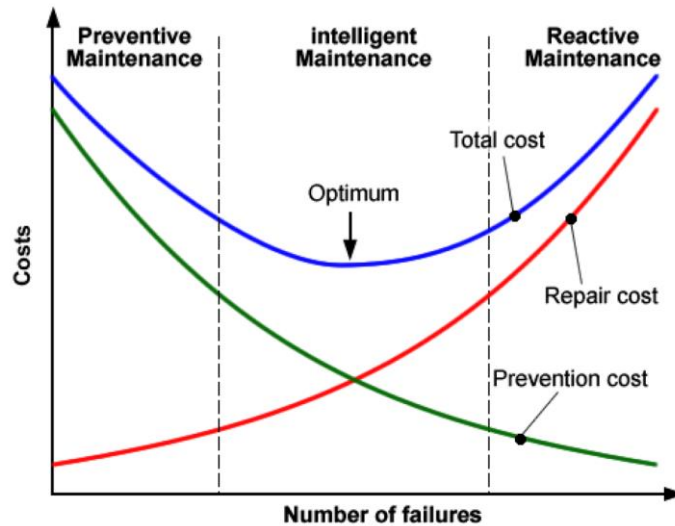


Figure 1: Optimization of Maintenance Costs

Much literature can be found related to condition assessment and modelling future degradation but only few studies have been directed at optimizing the decisions to the maintenance or repair of bridges, especially on the material level (Elbehairy 2007). Frangopol et al. (2001) stated that additional research is required in order to develop a better life cycle so that the costs and benefits can be quantified. Moreover, costs and effects of the interventions should be assessed more accurately based on real data (Bocchini et al., 2010). Best practices call for including all costs incurring through the life of a bridge.

2.1 Maintenance plan

A maintenance plan should be based on a decision making system which enables choosing the best repair option considering multiple performance aspects, for example safety, durability, functionality and economy. A first maintenance plan could be made up based on the design of the structure and be periodically updated during the service life based on inspection and maintenance data. Figure 2 presents a general framework for the life cycle of concrete structures, where the strategy of interventions (maintenance, repair, rehabilitation) is consisting of:

1. Defining the set of requirements to be fulfilled by the structure;
2. Performing a technical and economical analysis through the use of requirements and performance indicators, for example by a life-cycle cost analysis (LCCA); and
3. Selecting among the options identified the optimal repair or strengthening method.

Finally, the repair has to be executed and the maintenance needs of the repaired structure have to be established. Although it seems that a life-cycle cost analysis, or LCCA, would be the most suitable methodology for comparing different repair options, a LCCA is very often not feasible because of lack of experience or of reliable data. (Andrade & Martinez, 2009; CONREPNET 2007, Andrade & Izquierdo 2005; Frangopol et al. 2001). The process of choosing the best repair option is often expert based.

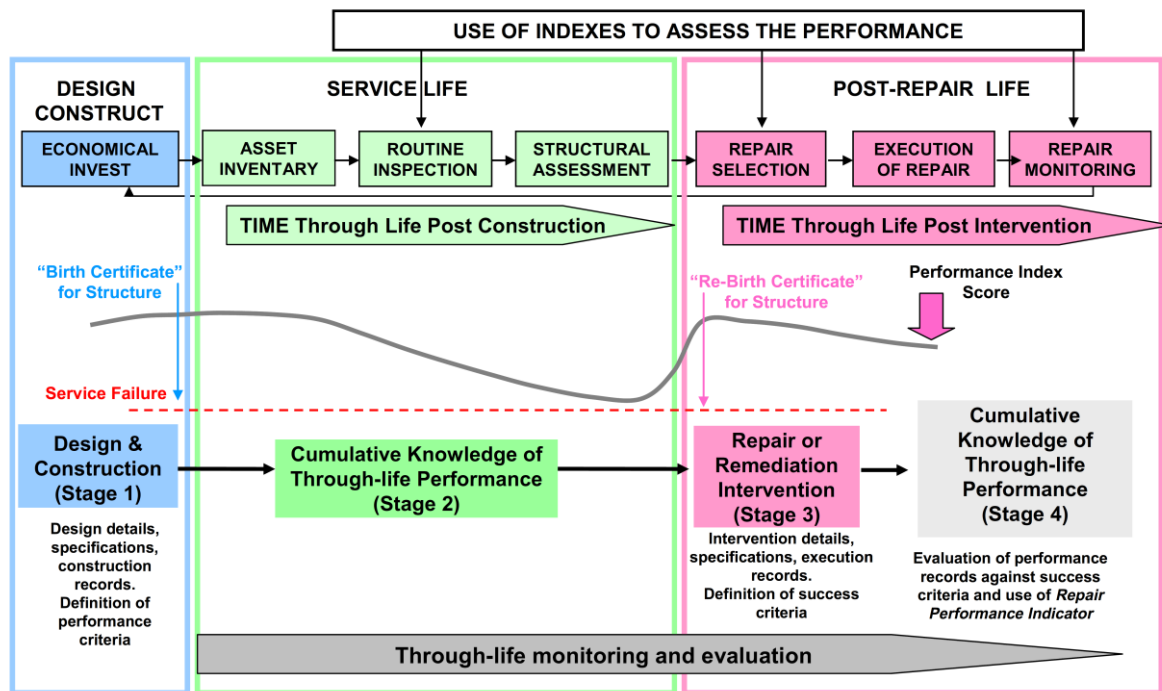


Figure 2: General framework for concrete structure maintenance (Andrade & Martinez, 2009)

2.2 Maintenance options

Common maintenance measures do not need structural design and are generic. They are correlated to the type of elements when these concern the bridge's equipment (eg. joints, bearings) or the type of material when these concern the other elements. More important maintenance measures, like external pre-stress, are correlated to the structural design of the bridge. The European standard EN 1504 gives guidelines for the choice of repair materials and systems that are appropriate for rehabilitation and maintenance of concrete structures. These standards describe the main points of rehabilitation of a damaged concrete structure:

- Assessment of the registered state of a concrete structure
- Determination of the courses of damage
- Determination of the objective of the rehabilitation of a damaged concrete structure
- Choice of relevant principles for rehabilitation of a damaged concrete structure
- Choice of methods for rehabilitation of a damaged concrete structure
- Definition of the properties for repair materials and systems for rehabilitation of a damaged concrete structure or its members
- Specification of requirements for the maintenance that should always follow rehabilitation of a damaged concrete structure or its members.

Table 1: Maintenance strategies

No	Options for protection and repair
1	Do nothing for a certain time Postpone the repair work, but monitor the degradation process
2	Re-analysis of structural capacity, possibly leading to downgrading of the function of the concrete structure
3	Prevention or reduction of further deterioration, without improvement of the concrete structure
4	Improvement, strengthening or refurbishment of all or part of the concrete structure
5	Reconstruction of part or all of the concrete structure
6	Demolition of all or part of the concrete structure

According to EN1504-9, six different maintenance strategies are possible. Table 1 indicates the strategies that should be evaluated to decide upon the right maintenance for the structure. It should be emphasised that more than one strategy may be relevant and also that each structural part should be given a separate evaluation. Selection of right maintenance strategy and repair method should at least be based on owners requirements, as built documentation, evaluation of the bearing capacity, cost benefit analyses and a detailed condition assessment.

3 Case study – Croatia

Croatia has started implementing a bridge management system at Croatian Roads and Highway agency about 20 years ago. Input data for bridge condition are based on visual inspections conducted by specially trained engineers, using procedures and aids defined in the management system, HRMOS (Tenzera et al., 2012). Bridge condition is rated through interpretation of damages that have been identified and registered, then these ratings are combined into a single rating valid for the entire structure. Bridge maintenance activities and costs should be planned by setting priorities and anticipating the future life of the structure. Unfortunately, the introduction of HRMOS did not ensure that the activities related to bridge maintenance are carried out regularly, but on an ‘as-needed’ basis with inspection and testing undertaken only when structural damage becomes self-evident. This is an example of corrective maintenance policy. To illustrate the grave consequences of neglecting bridge maintenance activities, several cases in the past have shown that if we choose to act only when damage of a bridge structure becomes self-evident, the repairs are not only expensive but very difficult to perform. (Radic et al. 2007, Stipanovic et al. 2008).

In Figure 3 a relation has been established between degradation category and direct cost of repair method, based on the historical data from Croatian case studies (Skaric Palic et al. 2008, Stipanovic Oslakovic et al. 2008). For example cost for category IV and V is the same but risks are different because category V means that stability of element or the whole structure is endangered. The methods and principles used are some of repair methods from standard EN 1504-9:2001. Direct costs included in the analysis present current costs on Croatian market and were collected directly from manufacturers and contractors.

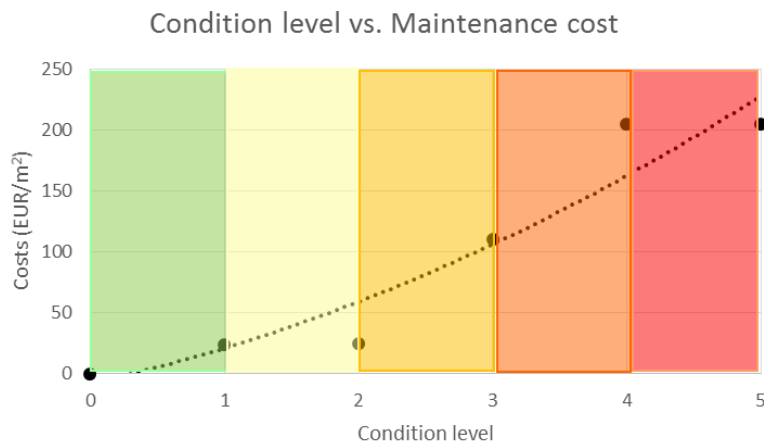


Figure 3: relation between degradation category and direct costs of the repair method

A case study was performed on 12 bridges (viaducts) inspected in 1998 and in 2010. The analysed viaducts are listed in Table 2. Only routine maintenance was performed on viaducts from the year of construction until the final inspection in year 2010. In 1998 and 2010 visual inspection were performed on all structural elements (bridge equipment, substructure and superstructure elements). All defects (delamination, spalling, segregation, corrosion of reinforcement, wet areas, mechanical defects, cracks) were recorded and categorized accordingly. Upon the performed condition assessment a list of repair works needed to bring the structural elements (substructure and superstructure in this analysis) back into their original condition (when constructed) was made with direct costs of all activities.

In Table 2 direct costs of repairs performed in 1998 and 2010 are presented. They are compared and also transformed into the unit value €/m². The averaged value of direct repair cost in relation to the age of the bridge is presented in Figure 4. It is obvious that after app. 17 years of usage direct repair costs enhance rapidly.

Table 2: Analysed viaducts from Croatian case study

No	Year of construction	Length (m)	Technical characteristics	Bridge area (m ²)	Total repair cost in year 1998 (€/m ²)	Total repair cost in year 2010 (€/m ²)
1	1988	186 (6 spans)	4 precast prestressed "T" girders (H=1,70m, L=29,85m) + continuity slab 24 cm (precast slabs 6 cm + in-situ concrete 18 cm) <ul style="list-style-type: none"> • Cantilever head beam • 2xO column • Precast curbs and cornices 	1971,6	3,7	149,0
2	1988	189 (6 spans)		2003,4	3,4	31,9
3	1988	186 (6 spans)		1971,6	3,2	68,0
4	1988	186 (6 spans)		1971,6	4,5	15,2
5	1988	127 (4 spans)		1346,2	3,4	16,0
6	1988	480 (16 spans)	4 precast prestressed "I" girders (H=1,70m, L=29,85m) + continuity slab 24 cm (precast slabs 6 cm + in-situ concrete 18 cm) <ul style="list-style-type: none"> • Cantilever head beam • □ column • Precast curbs and cornice 	5088,0	6,9	27,1
7	1981	377 (14 spans)	6 precast prestressed box girders (H=1,50m, L=29,10m) <ul style="list-style-type: none"> • Cantilever head beam • 2xO column 	4410,9	0,2	49,8
8	1981	74 (4 spans)	6 precast prestressed box girders (H=1,10m, L=17,30m) <ul style="list-style-type: none"> • Cantilever head beam • □ column 	843,6	0,5	37,8
9	1981	240 (8 spans)	4 precast prestressed "I" girders (H=1,86m, L=29,75m) + continuity precast slab 17 cm <ul style="list-style-type: none"> • Cantilever head beam • Octagonal column • Monolithic pedestrian ways 	2760,0	18,4	152,6
10	1981	122 (6 spans)	4 precast prestressed "I" girders + continuity precast slab <ul style="list-style-type: none"> • Cantilever head beam • 2x□ column • Precast curbs and cornices 	1725,0	2,1	19,6
11	1981	150 (5 spans)	4 precast prestressed "I" girders (H=1,86m, L=29,75m) + continuity precast slab 17 cm <ul style="list-style-type: none"> • Cantilever head beam • Octagonal column • Monolithic pedestrian ways 	1342	23,9	144,2
12	1981	50 (1 span)	4 precast prestressed "T" girders (H=1,70m, L=29,85m) + monolithic continuity slab 17 cm Monolithic pedestrian ways	575,0	24,3	159,3

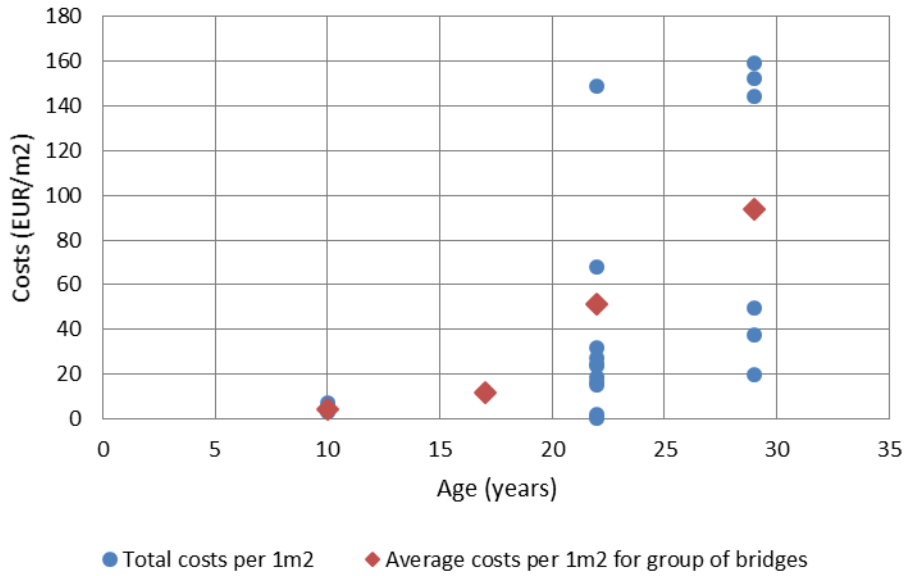


Figure 4: Direct costs established on a case study of 12 viaducts

4 Case study – the Netherlands

The maintenance strategy in the Netherlands can be described as a preventive approach. Bridges are inspected on a regular basis and based on the information collected a risks are assessed and maintenance tasks planned to manage and mitigate risks. Maintenance is planned so as to prevent the occurrence of unaccepted risks, the occurrence of unwanted situations is thus prevented. A description of the inspection practice can be found in Bakker et.al. (2012).

During inspections a maintenance strategy is used which states general requirements for different (structural) elements (eg. joints, superstructure, bearings) and materials (eg. concrete, steel). Suggested maintenance options and associated costs are also included in the maintenance strategy. The inspection process is further supported by the DISK Bridge Management System. To rate the condition of bridge elements, a 7 point scale is used (table 4). When an element reaches or approaches a condition rating of 3 a maintenance tasks is to be planned. Note that also at condition 3 requirements are still met. Maintenance tasks are aimed to be preventive.

Table 4. Condition rating in the Netherlands

Condition rating	Description
0	excellent, as new
1	very good
2	good
3	average, risk of meeting requirements
4	under average, requirements are not meet
5	poor
6	bad

As a case study, 24 randomly chosen bridges with different periods of construction were analysed (table 5), all part of the main highway network. For each bridge, the results of two inspections (with an interval of circa 6 years) were compared for the main structural elements, with the first inspection between 2008 and 2011 and the second inspection 2014 and 2016.

Table 5. Characteristics of the 24 bridges in the case study, incl. costs and condition rating for from two inspections

Bridge No.	Year of Construction	Length (m)	Width (m)	Deck area (m ²)	Object type	Inspection #1		Inspection #2	
						Costs (€/m ²)	Condition Rating	Costs (€/m ²)	Condition Rating
1	1967	49	15	732	Viaduct in motorway	0,97%	3	0,26%	3
2	1979	44	15	641	Viaduct in motorway	0,00%	2	0,00%	2
3	1979	47	15	692	Viaduct in motorway	0,00%	2	0,00%	2
4	1975	48	19	908	Viaduct in motorway	0,00%	2	0,08%	4
5	1975	99	15	1.496	Bridge	0,00%	2	0,00%	2
6	1987	40	15	623	Viaduct in motorway	0,00%	3	0,00%	2
7	1995	42	15	625	Viaduct in motorway	0,00%	2	0,00%	2
8	1987	76	27	2.009	Bridge	0,00%	2	0,00%	2
9	1987	119	14	1.637	Bridge	0,00%	2	0,00%	2
10	1979	29	18	535	Bridge	0,00%	2	0,00%	3
11	1979	66	20	1.344	Viaduct in motorway	0,00%	2	0,00%	2
12	1979	66	21	1.408	Bridge	0,00%	2	0,00%	2
13	1995	43	23	970	Viaduct in motorway	0,00%	2	0,33%	2
14	1995	166	14	2.403	Viaduct in motorway	0,00%	2	0,24%	2
15	1995	32	23	725	Bridge	0,00%	1	0,00%	2
16	1967	36	21	764	Viaduct in motorway	0,00%	2	0,06%	3
17	1979	22	23	502	Bridge	0,00%	3	0,11%	3
18	1967	37	17	611	Bridge	0,76%	2	0,38%	3
19	1967	112	18	1.988	Bridge	0,00%	2	0,00%	2
20	1967	49	13	653	Viaduct in motorway	0,00%	2	0,00%	2
21	1967	44	15	678	Viaduct in motorway	0,00%	2	1,13%	3
22	1967	66	17	1.093	Viaduct in motorway	0,00%	2	0,00%	2
23	1967	35	19	660	Viaduct in motorway		2	0,00%	2
24	1967	33	17	564	Viaduct in motorway		3	0,65%	3

First, the condition rating and costs for planned maintenance tasks for the main structural elements were compared for two inspections for each bridge. Note that for most bridges the condition indicated a rather good condition (rating of 1 or 2) in which cases no maintenance tasks were planned. For the last inspection, 8 out of 24 bridges showed a condition worse than 2, for 9 bridges maintenance tasks were planned (table 5).

Secondly, the relation between the age of the bridge at the moment of inspection and both condition and costs for maintenance was analysed. The age of the bridges at the moment of inspection ranged between 13 and 49 years. Most maintenance was planned for bridges constructed over 36 years before the moment of inspection. The exception being three bridges where maintenance was planned after 20 years.

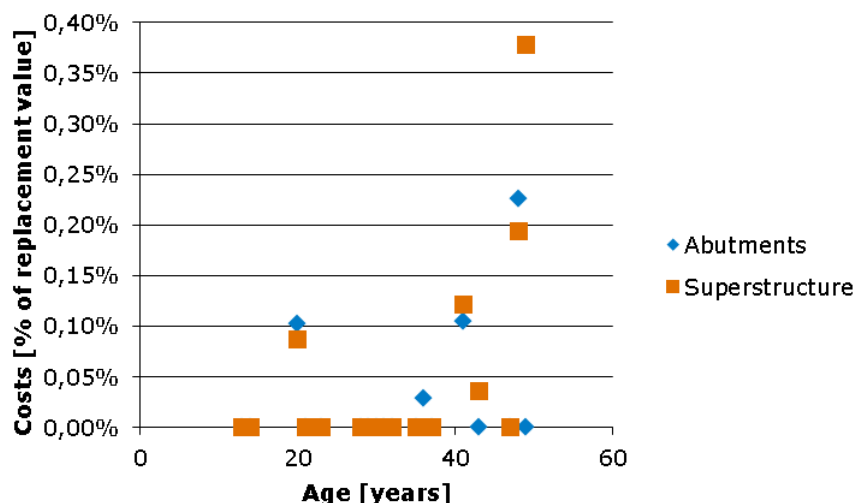


Figure 5. Costs of maintenance tasks relative to bridge age

5 Discussion and conclusion

The efficiency of condition assessment process is directly influencing the choice of repair and maintenance technique, i.e. measures which have to be undertaken. This paper examines the effect of two opposing maintenance strategies, corrective and preventive maintenance, from Croatia and the Netherlands respectively. The condition rating and planned maintenance costs for structural elements of bridges at different ages are compared. In case studies from Croatia and the Netherlands, data from previously performed inspections was compiled in order to correlate age, condition and costs for structural elements. Although both cases are limited to only a small number of bridges, it can be argued that there is a relation between the age of the structure and maintenance costs. Also, the increase in maintenance costs appears to be later in the case of the Netherlands than in the Croatian practice. Finally, based on these results it can be concluded that a preventive approach to maintenance planning supported by an inspection procedure will, in the longer term, be more efficient.

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