Life-Cycle-Cost-Based Bridge Management in the Netherlands

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ABSTRACT: The main reason for the existence of transportation systems is public interest. From this point of view, any road program should be driven by various societal aspects. In this paper societal aspects are schematized into two categories, public and politics. The position of the engineer responsible for bridge management within the road agency is described in general and elaborated for two fields important for bridge management: 'reliability and structural safety' and 'maintenance'. The paper gives an overview of the discussion on these fields in the Netherlands. Key objectives are to establish open communication and to place this in a life-cycle perspective. The role of the managing authority is to create a coherent system having an interface to the societal domain.

1 INTRODUCTION

Transportation systems generally serve public interests such as the personal and business needs to travel. The national motorway network forms the backbone of the transportation system in the Netherlands. The performance and further development of this system is discussed in public and political circles. A tendency to restrict this discussion to one aspect only is often observed. Such a restriction can be due to either economic requirements—when discussing the development of the network—or technical requirements—when maintenance of the network is the subject. Such a restricted approach often leads to conflicts between the road agency and either politics or public, or sometimes both. The classical role of the road agency—legitimated by expert knowledge—is no longer accepted and has to be redefined. An effective incorporation of societal aspects in both policy objectives and operational procedures is necessary. Hence, conflicting interests have to be met somehow. A life-cycle approach can play a role in putting different aspects into a clear perspective to enable transparent decision making.

This paper discusses the societal dilemmas encountered and gives examples of incorporating societal aspects in decision making, using a life-cycle approach in the Netherlands. The items have not been elaborated in depth. Neither have all items mentioned been integrated into a comprehensive approach. The paper can best be regarded as a sort of discussion paper on what could be items for discussion on societal aspects and what could be the role of the engineer or the road agency in this discussion, illustrated with some background material.

2 CHALLENGES FOR THE DUTCH ROAD AUTHORITY

Bridges in the Dutch road network are ageing. Replacement of structures is no longer just a theoretical consideration within the scope of design, but is becoming reality in the near future. The use of existing infrastructure increases rapidly, partly due to the lack of space for new infrastructure. Safety for users must be ensured, while many structures come close to critical design limits. Management of infrastructure has developed from a purely technical approach into a performance-based network approach. At the same time, economic considerations are becoming increasingly important for business practices of the managing authority, the Netherlands Directorate-General for Public Works and Water Management. The Directorate-General will further be referred to as the ‘Agency’.

3 SOCIETAL DOMAIN

The main reason for the existence of transportation systems is public interest. From this point of view, any road program should be driven by societal aspects. The question to be answered is: What are these aspects and how can they be taken into account? A quick literature scan using the National Transportation Library from the U.S. Department of Transportation show two main fields of interest: public involvement and safety related aspects. Public involvement is mainly related to the design and implementation of transportation projects; for example, the construction of a new highway. Safety aspects are mostly related to traffic safety, aimed at reducing the negative effects of transportation.

In dealing with societal aspects, engineers are confronted with two societal forces: public and politics. The engineer is subjected to these societal forces him- or herself, by being a member of the ‘public’ and often working for the ‘politics’. The engineer has to be aware of the line between the policy makers and the professional staff (Gayle, 2001).

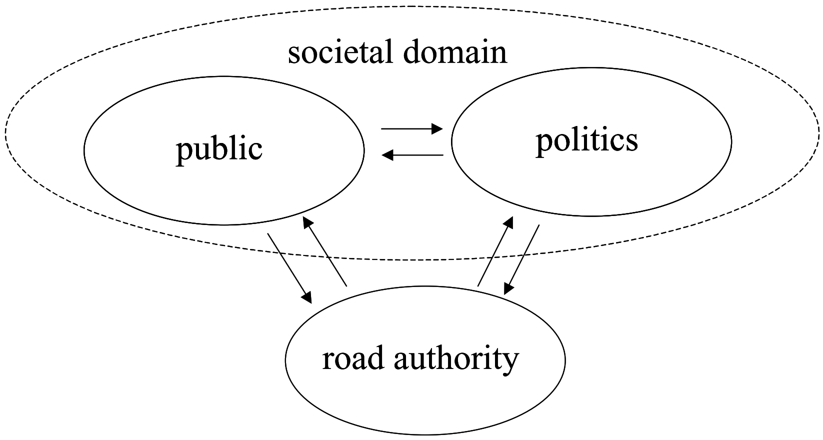

Figure 1. Schematic position of a road authority.

The position of the road authority is defined outside the societal domain (Figure 1). Within the societal domain ‘public’ and ‘politics’ can be regarded as two interacting entities both interacting with the road authority. This interaction consists of formal procedures, like the national budget planning process, and informal procedures, like media attention. The public cares more about how the transportation system performs in relation to their travel needs and less about how it is constructed or financed. Construction is regulated by construction codes and legislation is based on general public interest, such as safety levels. Financial means are provided by government funds coming directly from the public as tax payer. Decisions upon these two are made by political bodies. In theory this all matches, but in practice the staff of the road authority can find herself caught between diverse public demands, technical codes based on sometimes outdated legislation and short-term interested elected officials. A way to deal with these dilemmas is the subject for the next sections.

4 LIFE-CYCLE APPROACH

In this paper, a solution to deal with conflicting aspects of transportation infrastructures is a system approach based on life-cycle considerations. The engineer is not able to reconcile all parties. His role is to give the parties involved feedback on their demands, using his professional judgment. His attitude should be independent, communicable, flexible and striving for continuity. He must assure that legislation and codes are currently met and that they are frequently modernized to a change in needs and standards. Specific for bridge management, a framework within road management is set up to deal with cross-cutting issues such as safety, mobility and quality of life.

Two fields important for bridge management are discussed in the next sections: reliability and structural safety and maintenance. In dealing with reliability and safety, the engineer can easily close the discussion by pointing at enforcing regulations. These regulations originate from an aversion of risk from 'man made' disasters, but are not understood by the public and politics. In this respect, a strategy of trying to establish open communication and to put demands in a lifetime perspective is chosen in the Netherlands. To a high extent, maintenance is governed by decisions in the past. At the same time, present decisions on maintenance spending determine future behavior and related costs with a considerable time lag. A life-cycle approach puts today's problems in historical perspective and future prediction is used to deal with these problems in the Netherlands.

5 RELIABILITY AND STRUCTURAL SAFETY

The subject of reliability and structural safety is dominated by the professional opinion of the engineers. The managing authority will be held responsible in case of a disaster. Although the role of the engineering staff is clear, the question is how this role must be played. It is important to try to establish open communication with the public and politics, to develop options on the basis of the best available data and to communicate these efforts. A further discussion on aspects of reliability and structural safety is given next.

One of the leading principles for structural integrity management is that there should be a sufficient degree of reliability against partial or total collapse throughout the entire lifetime. The question of reliability may be put forward explicitly on a number of occasions. First of all, when damage is observed like serious corrosion, spalling of concrete, cracks, leakage, heavy settlements, and so on, a structural appraisal is usually carried out. The damage should be fully understood and the effects on the load bearing capacity should be assessed. Apart from "obvious damage" there may also be a "suspicion of damage" after the occurrence of some extreme load event as for instance truck or ship impact, earth quake or fire. In those cases there might be reasons for further investigation, even if this particular structure does not show any visible damage at first sight. Another important reason for a safety evaluation can be that structures in the course of time are confronted with much heavier loads than anticipated during design. Both with respect to ultimate load capacity as to fatigue resistance, this may cause concern. This is an actual problem in many countries as far as bridges are concerned (Turkstra, 1990; Moses and Verna, 1987; Allen, 1991). In the Netherlands for example there are requests to use the bridge shoulders as part of an extra lane during rush hour. These shoulders have not been dimensioned on the full traffic load in the past, because they only had to serve as an emergency lane.

The requirement of sufficient reliability can be taken into consideration in a Life-Cycle Costing (LCC) analysis in two ways: (1) by incorporating the risk (failure probability times consequence) explicitly in the cost optimization procedure and (2) by requiring that the failure probability is smaller than some target value. The latter requirement may be translated into standard code formulations using the following set of formulas (JCSS, 1996):

$$\gamma = 1 + \alpha\beta V,$$

$$\beta = \Phi^{-1}(P_{target}),$$

where γ is the partial factor for the load or property under consideration, α is the standardized FORM influence factor, β is the reliability index, Φ is the standard normal distribution function, P_{target} the target failure probability and V the coefficient of variation. The formulas hold for the normal distribution and for nominal values equal to the mean. For all other cases corrections may be necessary. Method (1) is the most correct one from the decision theoretical point of view, but Method (2) is usually adopted in practice.

One basic question is whether the required level of reliability P_{target} should be the same for the design situation as for the assessment situation (Ditlevsen, 1986). In the design situation, the engineer has many degrees of freedom to adapt the structural dimensions or even the concept of the structural system. If necessary he can, without much additional costs, strengthen a structure which does not fulfill the requirements. This situation, however, changes fundamentally once the structure has been build. Compare for example the possibility to add a single reinforcement bar to a concrete beam in the design stage to the same modification in an existing structure. In the first situation the additional costs are very small, in the second case they may prove to be prohibitive. This may lead to the acceptance of a lower safety level on economic grounds. If an assessment is based on partial factors this will also lead to a lower value.

Flexibility and dedication to the problem are the key words. Open communication leads to understanding by the societal parties and possibly to a broader perspective of the engineer.

The advantage of existing structures compared to structures to be designed is the possibility to measure their properties: one can measure the geometrical dimensions, the material properties, some of the loads and loading parameters, the structural behavior and response, it's degree of deterioration, and so on. In practice these possibilities of course are limited, because of the costs involved. But even visual inspection or the observation that a structure has survived some heavy load situations without any damage, may help to get a better view on the properties of the structure than is possible in the design stage.

Inspections can be of various types: visual, direct measurement, non destructive testing, response measurements or even a proof load (CEB, 1989). In principle one should combine all information: visual observations, performance in the past, measurements of various kinds and so on. Probabilistic methods like Bayesian Updating (Madsen, 1987; Diamantidis, 1986; JCSS, 2001) offer an ideal framework for such a procedure (Figure 2).

The use of additional information, ‘the best data available’ is the key issue here. Again communication on this is essential.

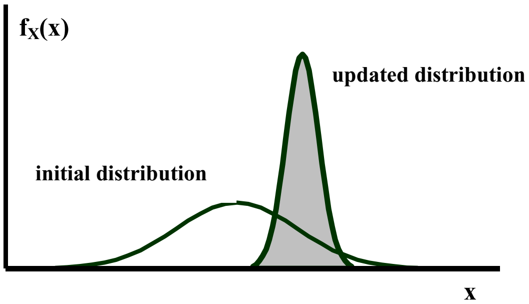

Figure 2. Initial and updated probability density function for an inspected variable x.

Assuming that all efforts to prove the structure safe for purpose do fail, a number of measures are possible: a first option is to reduce the loads on the bridge by closing it for certain types of vehicles. The second option is to repair or strengthen the structure and the third option is to build a new one. Again a cost evaluation should decide on this issue. In the case of reduced use the user cost should not be forgotten. The most difficult parameter to assess is probably the lifetime of the repair or strengthening measure.

Here we strike a difficult point. Reducing the lifetime of an element of a bridge or even the structure itself, is often welcomed as an attractive strategy that avoids costly repair, renovation or strengthening. The big question with such a strategy is whether we move to a realistic scenario. Will the funds be available when measures are inevitable? Or do we really know how to determine the end of lifetime and do we have realistic options for replacement? Academic answers on these questions are not enough.

6 MAINTENANCE

Today's maintenance of bridges is governed to a large extent by yesterday's decisions on investments, choice of materials, design procedures, construction methods, and so on. Present maintenance practice will determine tomorrows needs. The time lag between the decision taken and its effects is often large. In dealing with a time lag of years or even decades, a life-cycle based management practice is used in the Netherlands. Societal aspects are considered by means of user-driven requirements, politics-set budget schemes, et cetera. The role of the managing authority is to create an interlocking system having an interface to the societal domain. The methodology will be described next and it will be illustrated with some results. Next, some current items will be discussed (such as the backlog of maintenance and service levels).

6.1 *Bridge management*

Maintenance strategies are drawn up for frequently used elements such as concrete elements, preserved steel, extension joints, and bearings. Such strategies require a description of the minimal acceptable quality or condition, or a description of acceptable defects. Once the strategies are outlined, they can be applied to the stock of structures for the formulation of operational programmes and they can be used to estimate the total maintenance costs. The estimation of the maintenance intervals and the costs of standardized measures is an essential, but difficult part of the methodology. This information has to be extracted from maintenance experts, since registered data is not yet available. In this process, subjective—and often conflicting—expert opinions have to be combined to reach a sort of consensus (Ministry of Transport, 2003).

For each structure, the maintenance costs are estimated using the corresponding maintenance intervals and cost indicators. The results of this cost analysis can be updated by assessing the actual state of the structure by means of inspections. In addition to the costs of maintenance, the costs of replacing a structure should be estimated as well. Future costs of maintenance measures and maintenance intervals are uncertain. These uncertainties result in a spread out of the costs computed for the bridge stock in time. Therefore, Van Noortwijk and Klatter (2004) propose to incorporate the uncertainties in the times of maintenance and replacement. After aggregation of the maintenance plans of the entire stock of structures and prioritization of the available budgets, this process leads eventually to operational maintenance programmes. The prognosis of the maintenance costs for structural elements can be used to estimate the maintenance costs for groups of structures. By combining the maintenance costs of these groups of structures and their asset sizes, the maintenance costs on a network level can be determined.

6.2 *Example life cycle cost bridge stock*

Possible maintenance actions are routine maintenance, repairs and replacements of the bridge elements. To a large extent, these actions determine the technical lifetime (distribution) of a bridge. Three types of concrete viaducts and bridges have been identified: (i) concrete viaducts over the highway, (ii) concrete viaducts in the highway and concrete bridges shorter than 200 m, and (iii) concrete bridges longer than 200 m. For all three types of concrete viaducts and bridges, the stock and the average costs of replacement of a single bridge can be found in Van Noortwijk and Klatter (2004).

To include maintenance measures into the life-cycle cost analysis, the costs of repair and replacement have been quantified for the following bridge elements: kerbs; bridge deck and pavement; piers, abutments and main carrying element; railing and guard rail; asphalt top layer (i.e., pavement maintenance); joints; and bearings. For all concrete viaducts and bridges, inspections are performed every ten years and routine maintenance every year. Using renewal theory, the expected costs of maintenance are computed as a function of time for all the three types of concrete viaducts and bridges. For these maintenance actions, renewals can be interpreted as repairs, replacements, inspections and routine maintenance of the bridge elements. For details, see Van Noortwijk and Klatter (2004).

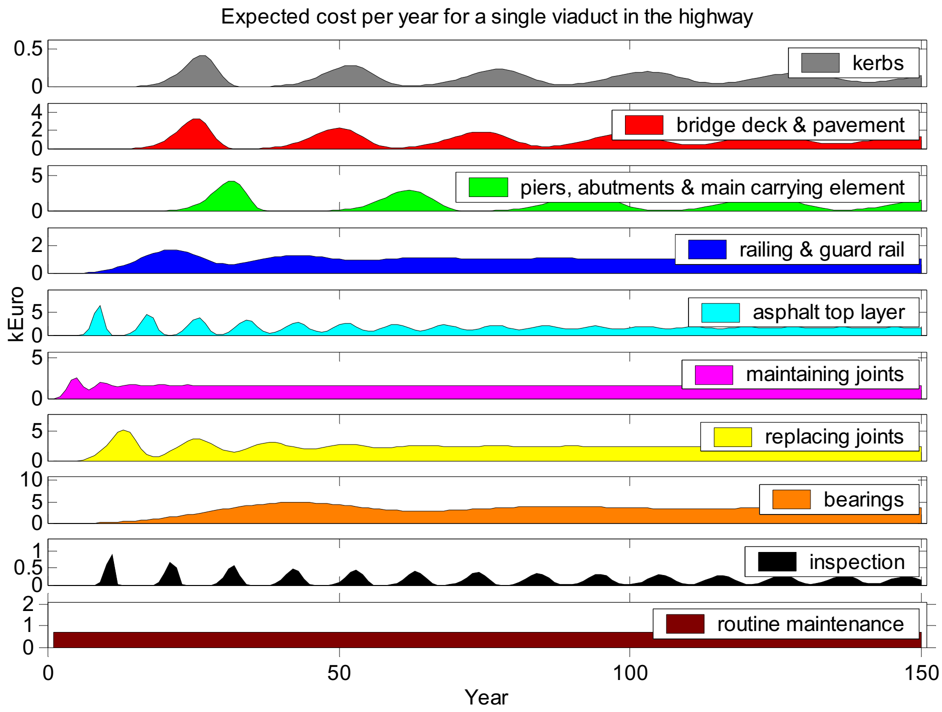

Figure 3. Expected cost per year for a single viaduct in the highway.

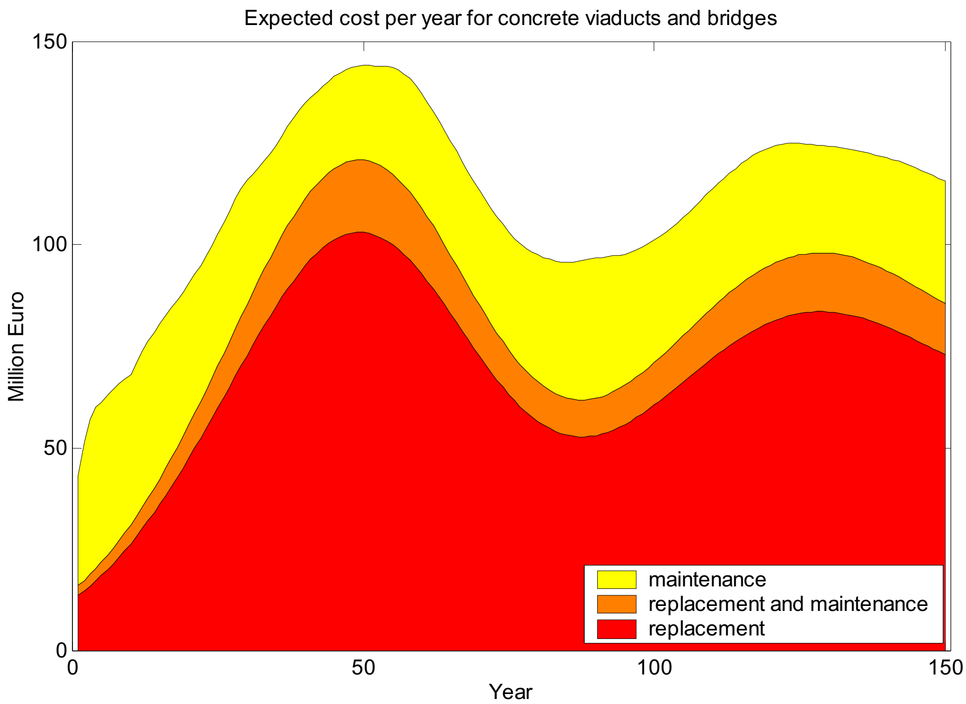

Figure 4. Expected cost of maintenance and replacement per year for the bridge stock.

For the purpose of illustration, the annual expected costs of maintaining the bridge elements of a single new concrete viaduct in the highway are shown in Figure 3. For this type of bridge, the predicted evolution of the maintenance costs over time is displayed. It can be seen that the more uncertain the times between identical maintenance actions, the faster the corresponding costs spread out. For example, compare the expected costs of maintaining the bearings to the expected costs of inspection. When the first time of maintenance is quite uncertain, the second time of maintenance is even more uncertain, et cetera. In the long run, the expected costs per year approaches the quotient of the expected cycle cost (cost of a single maintenance action) and the expected cycle length (length of the interval between two identical maintenance actions) (Ross, Chapter 3, 1970).

The expected costs of maintenance and replacement of the bridge stock is shown in Figure 4. Without taking account of bridge replacements, the long-term expected costs of maintenance per year is 42.7 million Euro. To avoid double counting of maintenance actions in the event of bridge replacement, the long-term expected costs of maintenance per year should be adjusted to 31.2 million Euro. This adjustment is based on subtracting the sum of all maintenance activities from the long-term expected average maintenance costs per year due to building a new bridge. In Figure 4, the expected costs of bridge replacement finds its first maximum after about fifty years counted from the year 2000. Due to the averaging over all bridges in the bridge stock as well as over all its bridge elements, the expected costs of bridge maintenance are close to a constant average value. Other reasons are that the maintenance intervals are relatively short and the uncertainties relatively large. The annual cost average can be used for reserving future maintenance budgets.

6.3 *Societal interaction, case backlog of maintenance*

Maintenance is hardly ever a hot political item. Increased budget needs for maintenance have to compete with new vital transportation links, high speed rail tracks, and such. In this climate a backlog of maintenance has been developed. The road agency was fruitless in its attempts to increase budgets until recently. Public rail transportation was hampered by frequent delays, caused by malfunctioning of trains and rail infrastructure a few years ago. This set off a public debate on maintenance backlog. This debate was used to place backlog of maintenance in a broader context. It resulted in additional funding for maintenance of the road infrastructure too. In this discussion the road agency used the results of the life-cycle approach as presented in the previous section and added actual information as was discussed in the media. This approach placed the public discussion on the effects of backlog in maintenance in a broader context and enabled us to move on from just solving the incidents to a more structural approach. Lessons learned are taking advantage of the momentum of the discussion as it emerges. To take this as a starting point for adapting criteria for prioritization and strategic planning to the political and public discussion points. And last but not least to establish an open communication.

7 CONCLUSIONS

The societal domain can be schematized into two interacting entities, the public and politics. In fulfilling the societal needs, the road agency should have an independent position. The question is not if it should participate in societal discussions, but how to participate. Public and political discussions are autonomous and dominate the ‘front office’ of the road authority. The use of life-cycle techniques in the ‘back office’ helps to develop consistent solutions. The staff of the road authority can find herself caught between diverse conflicting public demands, having limited budgets provided by the politics while having to maintain high standards for safety. Open communication on this leads to understanding by the societal parties and definitely to a broader perspective of the engineer.

In dealing with reliability and safety, the engineer has to develop realistic alternatives on the basis of the best available data and to communicate these efforts. Reducing the lifetime can only be accepted if a realistic scenario for replacement is available.

Discussion on maintenance of bridges benefits from having a life-cycle based approach as a reference. Discussion on societal aspects related to maintenance has its own dynamics. By interacting this with a life-cycle approach, discussion converges. Lessons learned are to take advantage of discussion as it emerges. Summarizing, life-cycle-cost based bridge management should connect this with strategic planning, transform political and public discussion points into criteria for prioritization, and last but not least establish an open communication.

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