TØI report 957/2008
Authors: Harald Minken
Geir Dahl
Christian Steinsland
Oslo 2008, 48 pages Norwegian language

Summary:

Cost-benefit analysis of road maintenance and standard improvement strategies for the road network

The general problem of finding an optimal rehabilitation strategy when the objects have different initial states, different rates of degradation, and a shared annual budget, is an extremely complex one. In this report, a problem formulation and an algorithm to solve the problem is offered. Our heuristic algorithm is embedded in software that has been programmed for the road rehabilitation case and is shown to produce solutions, complete with upper and lower bounds, in a few seconds' computer time. As a by-product, our algorithm provides a method to measure the economic costs and benefits of allocating more funds to maintenance.

Introduction and overview

There is a growing awareness in Norway that for a long time, the funds allocated to transport infrastructure maintenance and rehabilitation have been insufficient, creating a maintenance backlog and imposing unnecessary high costs on users. The maintenance backlog on national roads has been estimated to NOK 11 billion (SVV 2003), i.e. more than US $ 2 billion. In addition, there is a backlog of similar size on regional roads (SVV 2005). More recently, a wave of small incidents with large consequences for users has pointed to a similar problem in the railway sector. Some immediate measures have been taken, and proposals have been made, in the coming National Transport Plan, for a major shift of focus and funds from new infrastructure building to maintenance and rehabilitation.

It may rather safely be assumed that increasing the maintenance budgets is a policy with a positive benefit-cost ratio, but by how much should they be increased? What is the economically efficient level of maintenance? What is the optimal pace of reducing the maintenance backlog? And what is the economically efficient long term level of service of the different infrastructure links?

The Institute of Transport Economics has been commissioned by the Norwegian Ministry of Transport and Communications to provide *methods* to answer these questions. This is the Final Report of the project. Chapter 2 provides principles and develops formulas that may be used to characterise optimal maintenance and assess maintenance policies under simplified assumptions. Under much the same simplified assumptions, we also develop formulas to assess the size of the

The report can be ordered from:
Institute of Transport Economics, Gaustadalléen 21, NO 0349 Oslo
Telephone: +47 22 57 38 00   Telefax: +47 22 60 92 00

backlog, to do cost-benefit analysis of improving the road standard, and to find economically efficient road standards.

In chapter 3 we drop the simplifying assumptions – in particular, the assumption that initially, all objects are in the best possible condition, and that the only possible rehabilitation measure is to restore the objects to their initial conditions at fixed intervals. The ensuing general problem to find an optimal rehabilitation strategy when the objects have different initial states, different rates of degradation etc., is inherently extremely complex. A problem formulation and an algorithm to solve the problem are formulated in Dahl and Minken (2008), which must be considered the main output of the project. The heuristic algorithm is embedded in software that has been programmed for the road rehabilitation case, and is shown in the article to produce solutions, complete with upper and lower bounds, in a few seconds. Chapter 3 explains the principles of the problem formulation and the algorithm and provides an example of a solution.

We need to solve the problem of finding optimal rehabilitation strategies to provide a solid foundation for cost-benefit analysis of transferring marginally more funds to maintenance. This is obvious: To compute the benefits, we need to know how the funds are going to be spent, and what better assumption to make than that they are spent in the best possible way? Once we are able to solve the rehabilitation problem, however, we are also in a position to answer the other questions posed in the project, such as the optimal pace of reducing a backlog, the benefits of improving the road standards (the level of service), and the problem of economically optimal standards.

Having formulated theoretically sound methods, both under the simplifying assumptions of chapter 2 and the more general assumptions of chapter 3, we are in a better position to see the shortcomings of current practice. Thus chapter 3 also contains an assessment of the strengths and weaknesses of the optimisation and cost-benefit modules of some of the commercially available maintenance planning tools, while chapter 2 pinpoints the assumptions behind the calculations of the road maintenance backlog (referred to above) that are arbitrary or unwarranted from an economic point of view.

In particular, the “road capital” approach to maintenance planning is singled out for criticism, in chapter 2 as well as in a chapter of its own, chapter 4. It is shown that a concept of road capital based on historic cost or current investment cost has no economic sense. The only sensible definition of road capital is the prospective definition, i.e., the net present value of future benefits derived from the road, or the net present value of future losses if it were to be closed. However, as shown by our formulas, not even road capital in the prospective sense has any role to play in the formulation of optimal maintenance strategies. On the contrary, a maintenance strategy aiming at upholding the capital value of the road, however defined, may be seriously misleading. In the case of a cost-based concept of capital, this is obvious: If the investment was a bad one, relating the amount of maintenance to the investment cost may be throwing good money after bad. In the case of a prospective concept of road capital, the argument is slightly more complex: In this case, the capital value will be proportional to the traffic flow, which in turn obviously has a close relationship to the wear and tear of the road. However, this latter relationship is not linear. Furthermore, the prospective capital value depends on the availability of alternative routes that are not actually used by the traffic on the road in question unless it closes down. Thus a maintenance policy based on the prospective capital value will probably mean too low a level of maintenance in districts with a dense road network.

On the other hand, chapter 4 also shows that, even if other indicators exist, the prospective capital value of a road may be a good indicator of the vulnerability of the road network with respect to incidents that close this road. Thus the prospective capital value may be a guide to the allocation of forms of maintenance (such as snow clearance) or incident management that keeps the road from closing down altogether.

The rest of this summary is devoted to a closer look at the contents of chapter 3, which contains the main results of the project.

New software to find optimal rehabilitation strategies

Consider a set of infrastructure objects that will have to share the same annual maintenance budgets. Their rates of deterioration may differ. Their initial states may be anything between the best possible and the worst possible. The worse the state, the higher the user costs. The agency in charge has at its disposal a number of rehabilitation activities of different intensity and cost. A rehabilitation strategy consists in the allocation of rehabilitation activities to the different objects for a number of future years, subject to annual budgets. The problem is to find a rehabilitation strategy which minimises the sum of user costs and agency cost subject to the budget constraints and constraints on end states.

If this problem – applied to road pavements – could be solved efficiently, a limited number of experiments with the annual budgets and other parameters could establish the benefit-cost ratio of allocating more money to maintenance, the best time profile for the budgets as well as the long-run average states to be aimed at for the different classes of road.

All practical strategic road maintenance systems at present fail to solve this problem. The Finnish HIPS is probably the best, as it solves correctly the problem of finding welfare optimal pavement rehabilitation strategies for a set of roads when there are no annual budget constraints. Unfortunately, annual budget constraints do exist and are known to make the problem extremely complex. Therefore, simple but incorrect methods are often offered instead, in the hope of not getting too far off the mark. A few articles in the academic literature solve versions of the rehabilitation strategy problem, but we do not know if they have been put to practical use.

In a recent article in the journal Computers & Operations Research (Dahl and Minken 2008), we study the rehabilitation strategy problem and model it as an integer programming problem with underlying dynamic programming structure. A heuristic algorithm with upper and lower bounds for the solution is proposed. The algorithm has been programmed for the road pavement application and applied to what we thought were realistic cases with respect to deterioration rates and costs. The results are promising and indicate that the model might indeed be applied to find optimal pavement rehabilitation strategies and do cost-benefit analysis of maintenance budget changes.

For practical applications we still need to validate our functions and parameters. Suggestions from other researchers and practitioners are welcomed. We also need to test the software on a wider range of cases. A wider choice of functional forms and applications to other types of infrastructure will require some reprogramming, which we hope to be able to do in the future.