



## EVALUATION OF ATTEMPTS FOR EFFICIENT ROAD MAINTENANCE – KNOWLEDGE COMPILATION

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**Abstract.** The objective of this study was to compile experiences regarding efforts by road authorities to satisfy the needs for efficient maintenance and the results of such efforts. The extent to which maintenance aspects are considered during road planning and design, as a potential for improvement of maintenance efficiency is studied. The study shows that such efforts have in many cases resulted in reduced maintenance costs. However, there are also indications that maintenance standards in some cases have declined, as the focus has been on reduction of the rate of recurring maintenance activities and prioritisation of some maintenance measures, e.g. winter maintenance, over other maintenance measures, e.g. pavement maintenance. The study also shows that efforts towards increased maintenance efficiency have one thing in common – namely that the main focus has been on improving operating practices and maintenance procedures. Road authorities have mostly ignored the improvement potentials that exist during the planning and design process through consideration of the interrelationship between geometrical road design and maintenance.

**Keywords:** efficient highway maintenance, road design for lower maintenance, life-cycle cost analysis for roads.

### 1. Introduction

Road maintenance includes activities carried out with the intention of maintaining the functions for which the road was designed. In some countries, e.g. Sweden, road maintenance is divided into operation and maintenance activities. Operation means short-term measures which primary purpose is to keep a road open for traffic, e.g. winter maintenance, grass mowing and cleaning of reflectors. Maintenance relates to longer-term measures ensuring durability of the road network, e.g. paving works and bridge repairs. Road maintenance has traditionally been funded by tax revenues or road usage fees.

As road infrastructure funding sources are less and less sufficient to insure implementation of new projects and maintenance of existing roads, road authorities worldwide are forced to increase efficiency and reduce costs (Parche 2007). Because maintenance costs constitute a large portion of the annual expenditure on road infrastructures, road authorities are continuously trying to increase road maintenance efficiency and reduce its related costs. Consequently, different strategies and contract forms have been used, such as outsourcing of maintenance in competitive markets and development of life cycle

cost models and new funding and subsidiary forms. Even if these efforts have reduced maintenance costs considerably, the general opinion is that some of the efforts have resulted in reduced maintenance standards and impaired road conditions, as focus mostly has been on reduction of the rate of recurring maintenance activities.

The aim of this study was to:

- compile experiences regarding efforts made by road authorities to satisfy the needs for efficient maintenance and the results of these efforts;
- evaluate the extent to which maintenance aspects are considered during road planning and design as an improvement potential for maintenance efficiency.

The study started by reviewing the funding challenges faced by road authorities, which underlay the need for efficient road maintenance. A compilation of international literature and road authorities' practical attempts towards efficient road maintenance was conducted. Interrelationship between geometrical road design and maintenance was analysed. A particular focus was on Swedish conditions, as the study is a part of a research project financed by the Swedish Road Administration (SRA).

## 2. Background

As funding resources for road infrastructure seldom are sufficient (Table 1), road authorities are facing the following challenges:

- insufficient funding sources to face the increased need for new road infrastructure;
- insufficient funding to face the increased demand for proper management of both newly constructed and existing roads;
- increased needs for funding to face the increased maintenance backlogs;
- increased demands for safety, accessibility and use of advanced traffic management systems to reduce socio-economical costs in terms of reduced maintenance-related environmental impacts, traffic disturbance and fatalities.

Demands for new road infrastructures are increasing around the world. At the same time, needs for road maintenance is constantly increasing. An example is given in (Table 2).

Funding the maintenance backlog is another challenge, which is faced by the road authorities (Table 3). Maintenance backlog is generally defined as the estimated cumulative cost of raising the condition of all roads in a system up to a level defined, typically by the concerned road authority, as an acceptable min (Lemer 2004). According to Gahm (2008), the underlying factors for maintenance backlog are:

- high prioritized new road investments compared to road maintenance;
- high prioritized other society sectors compared to the road infrastructure sector;
- high prioritized winter maintenance, cleaning and grass mowing measures compared to other maintenance measures such as road paving;
- poor communication between road authorities and politicians;
- complicated decision-making bases;
- the road structure lacks are invisible for road users;
- poorly founded technical-economical analyses.

**Table 3.** Maintenance backlog in Nordic countries in relation to annual maintenance funding during 2005 (Gahm 2008)

Country	Maintenance backlog/annual maintenance funding
Denmark	1.4
Finland	2.8
Norway	2.2
Sweden	2.6

Many road authorities have been forced to postpone investment projects and reduce investment expenditures in order to cover maintenance expenditures. Accord-

**Table 1.** Infrastructure funding gaps around the world (Parche 2007)

Country	Infrastructure gap
Canada	Closing Canada's infrastructure gap requires an investment of six to ten times the current annual government infrastructure spending. Canada's local governments face an annual infrastructure deficit of \$ 60 billion.
USA	The US infrastructure deficit totals about \$ 40 billion a year in the road sector alone. The total US infrastructure investment need over the next five years is estimated to be up to \$ 1.6 trillion.
Europe	The infrastructure need for the EU is estimated to be significantly higher than \$ 1 trillion. Germany alone requires infrastructure investments of about \$ 90 billion each year.
East Asia	The developing countries in East Asia need to invest about \$ 165 billion per year over the next five years. China is estimated to account for up to 80% of all regional infrastructure expenditures.
South Asia	India is estimated to need about \$ 250 billion to infrastructure investment over the next five years.
South Pacific	Australia's infrastructure deficit is estimated to be about \$ 19 billion. New Zealand has an infrastructure gap of about \$ 4 billion.

**Table 2.** Annual road construction and maintenance expenditure forecast for USA and Canada as examples of increased demands for road infrastructure funding, US \$ billion (Parche 2007)

Annual forecast	Country	2000	2000–2010	2010–2020	2020–2030
Construction expenditure	USA	105.2	124.8	131.2	138.6
	Canada	9	14.8	15.4	16.2
	Combined	114.2	139.6	146.6	154.8
Maintenance expenditure	USA	89.5	106.1	111.5	117.8
	Canada	7.6	12.6	13.1	13.8
	Combined	97.1	118.7	124.6	131.6

ing to SRA Report 2008:39 “Pocket Fact”, in Sweden the winter maintenance expenditures, which concerns more than 25% of the annual maintenance expenditures, have risen continually since 2003. Demands for increased safety, accessibility and use of advanced traffic management systems have resulted in increased maintenance costs. As the infrastructure funding has not kept pace with increased investment and maintenance demands, according to SRA Report 2009:10 “Annual Report” investment expenditures has decreased by approx 30 mln EUR between 2003 and 2008 in order to cover maintenance expenditures. For example, according to *The Budget Statement 2007: Economic and Budget Policy Guidelines*, the Swedish government decided to increase the road maintenance funds by 10 mln EUR at the expense of road investments. This decision was necessary since the condition of the road infrastructure deteriorated during 2005. In addition, SRA have prioritized maintenance measures, e.g. winter maintenance, at the expense of other measures, e.g. pavement and bridge maintenance, to face the increased demands for maintenance funding.

Due to the mentioned funding challenges, road authorities are facing a great need for increased efficiency and reduced expenditures. Focus is on efficient road maintenance, as maintenance costs constitute approximately 50% of the annual road infrastructure financing (Parche 2007). World Bank Report “Road Maintenance” in 2001 notes, that improper maintenance also leads to increased socio-economic costs as a result of deteriorated road transportation quality and impaired environment. Maintenance activities have to be efficient as they can result in safety hazards for road users and maintenance staff. During the last five years, approximately 600 maintenance-related traffic accidents have occurred in Sweden. These accidents have resulted in 20 fatalities (Liljegren 2008).

### 3. Attempts to increase maintenance efficiency

Funding challenges creates a pressure to continuously increase maintenance efficiency. Some efforts made by road authorities are presented in this section.

#### 3.1. Outsourcing of maintenance activities

Outsourcing of maintenance activities in a competitive market has been used as an option to increase maintenance efficiency and reduce costs. A study of maintenance outsourcing in Sweden between 1992 and 2001 indicated that transaction costs for maintenance contracts for the outsourced maintenance areas, e.g. bid preparation and contract monitoring and evaluation, were estimated to be at least 5% lower than for the non-outsourced maintenance areas (Liljegren 2003). A study, which aimed to determine price development in relation to the maintenance outsourcing in Sweden, indicated that outsourcing of several maintenance areas in a competitive market during the first year reduced bid prices on average with 22–27% compares to in-house maintenance costs (Arnek 2002). These cost reductions are often attributed to reorganisation and

reduction of personal rather than to technical progress in machinery and methods (Stenbeck 2006).

Such reforms have also been used by the Swedish government as an incentive to cut grants of road maintenance. However, these reforms have negatively affected road maintenance, primarily pavement and bridge maintenance, as short-terms maintenance measures, as winter maintenance, cleaning and grass mowing, have been prioritised. The situation is the same in all Nordic countries (Fig. 1). Investigations of road user opinions have indicated increased dissatisfaction regarding road maintenance, which in turn indicates that the maintenance standards in Sweden have decreased after the reforms, primarily on roads in sparsely populated areas (Österberg 2003).

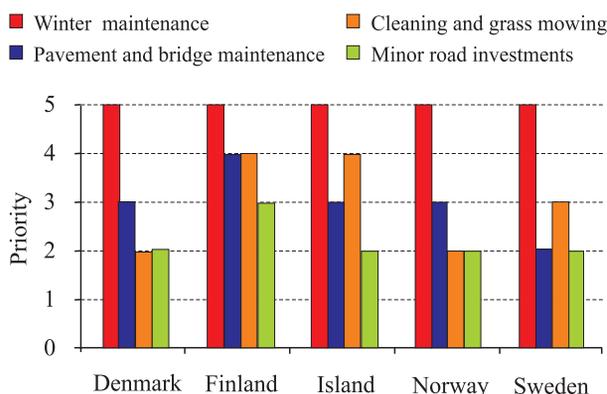


Fig. 1. Priority of the maintenance measures in case of maintenance funding gap in the Nordic countries (Gahm 2008)

By outsourcing maintenance activities, SRA tried to encourage contractors to develop technical improvements. Unfortunately, studies show that the effects of outsourcing on innovation have been limited (Stenbeck 2007; Thorsman, Magnusson 2004). The interest of development among contractors has been low because development costs are often high compared to the benefits obtained. In addition, contractors have often refused to share knowledge with others in order to maintain competitiveness. As a result, Stenbeck (2007) claimed that long-term technical developments in Sweden have decreased. He raised the question: “if the substance in organisation reforms only is cutting costs and making personnel and equipment work harder, should that really be considered as technical development in the true sense of the word?”. He also mentioned that the maintenance costs for outsourced contracts in Canada were 26% higher than for in-house contracts. The quality and technical development were neither noticeably higher nor lower in the outsourced contracts compared to in-house contracts.

#### 3.2. Consideration of maintenance aspects during the road planning and design process

Problems faced during conducting maintenance activities often trigger debates on road planning and design as a crucial underlying factor. According to Freer-Hewish (1990),

the cost of a road project over its service life is, among other things, a function of design standards, construction quality, maintenance strategies and maintenance operation. These aspects control the rate of road deterioration and dictate the maintenance workload throughout the life of the road (Fig. 2). However, very few studies considered interrelationships between the components.

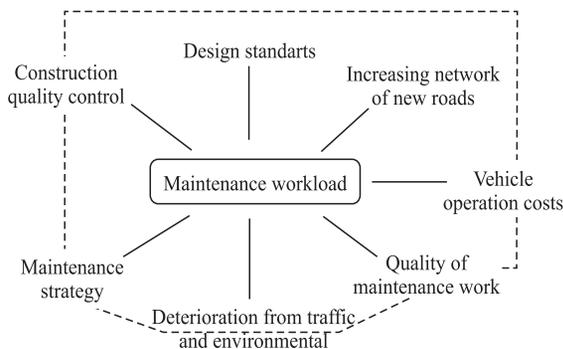


Fig. 2. Development of maintenance workload (Freer-Hewish 1990)

Thorsman and Magnusson (2004) have studied road maintenance costs for three or four lane roads with barriers separating opposing traffic. Insufficient consideration of maintenance aspects as well as inadequate support for the designers during the planning and design process are two major factors underlying high maintenance costs. The study suggests following improvements:

- improvement of methods and technologies to reduce the maintenance costs through reduction in intervention time and use of efficient tools;
- creation of functions to support designers and coordinate maintenance-related consulting between involved parties;
- improvement of the coordination and information sharing between contractors.

In another study, factors in road design which contribute to decreased needs for future road maintenance are compiled (Gaffeny, Gane 1970). Based on experience from the United States, some general advices are listed concerning the design of cuttings, embankments, bridges, bridge abutments, steelworks, street lighting, pavement types, pavement thicknesses and surface types. Regrettably, calculations for quantifying the positive effects are not performed.

Olsson (1983) describes a new method for road construction design using annual cost calculations. The major factors which prevent consideration of road management and maintenance costs, during road design are difficulties in quantifying administration costs, time shortage and improper experience of the road designers regarding road maintenance. A model for road design is recommended consisting of the following three steps:

- study different design alternatives and calculate annual costs, including investment and maintenance costs, to choose an optimal design;

- clarify the calculation presuppositions to offer enough information for decision makers concerning calculations and included cost items;
- estimate calculation accuracy statically or based on practical experiences.

Other studies concerning design of pavements, bridges and specific roadside components have also indirectly considered maintenance aspects. A study made by Neuzil and Peet (1970) examined the fill height of embankments, whereby flattening of slopes proved to be cheaper than installation of guardrails. Based on cost-benefit analysis, maintenance costs have been considered in simplified graphs to determine needs for road barrier installations (Wolford, Sicking 1997). They compared different road barrier end-terminals in order to identify the most profitable in order to decrease future maintenance needs (Mattingly, Ma 2002). The study was based on practical experiences and did not include analyses of life-cycle costs or any evaluation of how factors, such as traffic volume and road design, would affect the maintenance costs of the end-terminals.

### 3.3. Life-cycle cost analyses

It has been a well-known fact that although about only 20% of the costs is actually incurred in activities prior production; these activities actually commit 80% of the costs. The production costs, however, incur 80% of the costs, but production improvement efforts impact only about 20% of the cost commitment (Emblemsvåg 2003). Due to similar understanding concerning weapon systems, the life-cycle costing approach came about in the early 1960s in the US Dept of Defence.

Life-cycle cost (LCC) of road objects are considered more important than investment costs (Bajaj *et al.* 2002), and consequently road authorities are encouraged to overweight LCC analysis and provide calculation methods (Gransberg, Molenaar 2004). Thus, there is also a trend to work with the influence of roads on the whole society. The road planning and design process should be based on LCC analyses, including costs for both road authorities and society (Huvstvig 1999). Road authority costs consist of costs for planning, design, construction, maintenance and rehabilitation. These costs are usually covered by governments using the tax revenue. Society costs include:

- road users costs, such as vehicle operation costs, and costs for time people spend on the road;
- accident costs, paid by individuals, insurance companies and society in form of tax covered health care;
- environmental costs, which also are covered by the society.

The average cost per service year life is suggested as a parameter, when selecting road designs or evaluating bids (Adams, Kang 2006; Stenbeck 2004). Many road authorities have developed models for LCC analyses with the intention to reduce total costs for the road infrastruc-

ture and maximize the socio-economical benefits. Some models are simple and includes only road authority costs. Other models are very complex including calculation of society costs and models for prediction of road deterioration. The Nordic Road Forum (NVF) has studied the use of life-cycle assessments, annual costs and LCC calculations in road construction in Nordic countries (Holmviik, Wallin 2007). The study showed that models developed for analyses of LCC often consider the road authority's costs, such as investment costs, maintenance costs and sometimes, to some extent, user and environmental costs. Still none of the models can be used as a standard model without considerable improvements, since they are developed for particular road projects. The disadvantages of the studied models also include use of roughly calculated maintenance costs and insufficient consideration of how design influence on maintenance costs. Huvstig (1998) has studied several models for calculation of LCC made by road authorities as, COMPARE in Great Britain, QU-EWZ in Australia, Whole Life Costing System in USA and Highway Design and Management Model (HDM I to IV) developed by The World Bank. These models have mainly been used for selection of road construction types or pavement types.

Unfortunately, LCC analyses are still of less important in bid evaluations due to, among other things, difficulties related to absence of reliable data and methods for calculation of LCC of road objects (Karim, Magnusson 2008). Lack in maintenance and investment related data is due to the fact that most road authorities do not have systematic data registration or follow-up procedures regarding planning, design, construction and maintenance (Karim 2008). Absence of reliable LCC methods is due to lack of accurate road deterioration models as well as models for calculation of society costs. Current deterioration models are based on experiences and empirical models (Huvstig 2004). Such models can give acceptable results, if the historical circumstances are similar to the future circumstances. However, such circumstances seldom exist for a road construction due to, among others, traffic development, use of heavier vehicles and super single tyres.

LCC analyses may in some cases result in higher investment costs. The lowest possible yearly life-cycle cost is currently tested as an award criterion by SRA (Stenbeck 2007). This has resulted in higher investment costs, causing budgetary problems. An explanation could be that after decades of short-term thinking, transition to life-cycle cost will be painful. A more conspiratorial explanation, according to the same study, is that the contractors are taking advantage of the situation, trying to sell expensive solutions with long-term speculative promises that can't be verified and corrected until too late.

It is worth noting that the above mentioned LCC models are established for structural road design as a tool to selection most economic solution for investment and maintenance. While, the geometrical road design is igno-

red in almost all the models despite the fact that geometrical road design, such as road alignment and road restrain systems, affects the costs during the road life cycle (Freer-Hewish 1990).

### 3.4. Public-private partnership projects

The road authorities aspire to develop new funding forms to bridge the infrastructure funding gaps. Public-Private Partnership (PPP) project is a new funding form used to deal with the increasing demands for new road infrastructures (Arnek *et al.* 2007). In PPP projects, governments or another public sector assign the obligation to finance, design, build, operate, maintain and rehabilitate an infrastructure project to a private-sector partner (the concessionaire). The concession duration is usually 5 to 30 years. The archetypal PPP project is a build–operate–transfer project (Queiroz 2007). Other forms of contract are also possible, such as operation-maintenance. The concessionaire collects revenue from users in form of road tolls, while the balance of the revenues comes from government, either in form of an up-front payment, or as a recurrent shadow toll. When the volume of traffic, combined with the agreed toll, do not generate sufficient revenues to cover all costs, governments have to accept shared costs.

According World Bank Report “*Public-Private Partnership – a New Concept for Infrastructure Development*” in 1998, benefits of PPP projects includes increasing efficiency during the design, construction and operation phases of a project, enhancing implementation capacity, mobilizing financial resources and freeing scarce public funds for other uses.

World Bank in the Report “*Toolkit for Public-Private Partnership in Highways*” in 2002 notes, while PPP projects in the road sector have only recently been used in the United States and Europe, they are common in countries such as Chile, Argentina, South Korea, Malaysia, Chad and the Philippines. However, PPP projects are underutilized in transition countries due to relatively low traffic volumes, lack of appropriate legal frameworks, economic and political instability, and consequently high perception of risk.

World Bank Report “*Reducing the Economic Distance to Market: a Framework for the Development of the Transport System in South East Europe*” in 2004 inform, that an analysis of motorway development over the past 15 years in Poland, Hungary, the Czech Republic, Slovenia, Croatia, Romania, and Serbia showed that any successful PPP project requires strong government support and long-term political will and engagement. The analysis highlights the following key prerequisites for successful PPP projects:

- a strong political will, an appropriate and stable regulatory and legal framework, and a stable macro-economic environment;
- willingness of the public sector to provide contribution up to 40–60% of total project cost through the provision of existing assets as an in-kind contri-

bution, equity participation, sovereign guarantees, subsidies, etc.;

- sufficient traffic volumes to make it viable to the private sector. A new road is unlikely to be viable without a flow equal to, or exceeding, 15 000 vehicles per day, unless the respective national government offers an additional subsidy to the concessionaire. By contrast, rehabilitation of a road, particularly where there are no competing corridors, can be viable where the flow is just 6500 vehicles per day;
- a robust economic and financial appraisal of the project that asks, and endeavours to answer three questions; is the project beneficial for society, is it commercially viable for the potential concessionaire, and is the required public sector contribution justified in terms of the additional benefits engendered by that contribution?

According to Ward and Sussman (2006), toll road PPP programs should try to adhere to several principles:

- the institutional framework should be supportive and transparent. Concessionaires must know that the government will meet their obligations, and the public must be confident that the process has produced a fair outcome;
- risks should be allocated to the party best positioned to manage them;
- the government should not use subsidies unless it is the only way to build a needed road;
- toll road investment carries a risk that includes significant financial losses. A corollary is that the concessionaire should have opportunity to retain greater-than-expected returns;
- the public can impede a partnership if neither the public authorities nor the private sector involves them meaningfully in the process;
- the government should support innovation into the bid procedures, but it must be done with care to avoid the appearance of favouritism.

Queiroz (2007) identified six steps to implement PPP projects in the highway sector:

1. Define the priority projects for which the government envisages soliciting financing from private investors to cover all or part of the costs of the project.
2. Enact relevant legislation, for example concession and toll road laws.
3. Conduct feasibility studies of priority projects; employ reputable consultants, using well-prepared terms of reference; identify and quantify social and economic benefits; and conduct financial assessments to confirm the potential for attracting private capital.
4. Conduct environmental and social assessments, including development of a mitigation plan and land acquisition plan for the right of way.
5. Assess the willingness of users to pay; review tolling and payment options, for example actual tolls, shadow tolls, vignette systems and availability fees.

6. Define performance and service standards for the new investment during the operation period.

According to Queiroz (2007), risks associated with PPP projects need to be adequately managed. The main risks, in addition to changes in design during construction which can lead to significant cost increases, are risks that reflect uncertainty concerning predictability of future traffic volumes, willingness of road users to pay tolls and the possibility that predicted land-use patterns fail to materialize. A study of 67 toll road cases found that actual traffic was, on average, 70% of forecast volume, with a range of 18% to 146% (Bain, Wilkins 2002). For countries without tolling experience, the average actual traffic was only 56% of the forecast, compared to 87% for countries with previous experience.

According to Ward and Sussman (2006), the political risk, which covers issues as changes in regulations, governments and public opinion, may have significant impact on the performance of PPP projects. These risks must be balanced between the public and private sectors to provide the best social value (Ward, Sussman 2006). Indeed, the principle behind PPP projects is that they are a mechanism for equitably and effectively sharing risks. The government's goal should not be simply to transfer as much risk as possible to the private sector. The goal should be to create an arrangement that satisfies goals for public and private sector in such a way that both parties are better off with a PPP arrangement. This means that the government shoulders some risk to achieve goals beyond economic efficiency. Risks should be transferred to the private sector, but the government must remember that this must be accompanied by a commensurate possibility of reward. The ideal amount of risk transfer is difficult to determine, but some general rules apply. Ward and Sussman (2006) mention a PPP project in Malaysia as an example, where the low transparency and minimal public involvement throughout the process breed the belief that the concessions are awarded on basis of political connections rather than social benefit. Protests have occurred that forced the government to limit proposed toll rate increases and to renegotiate agreements with concessionaires.

A basic principal in PPP projects is consideration of maintenance aspects during planning and design, especially influence of road design on maintenance. This will lead to increased maintenance efficiency and reduced overall costs. As the contract is awarded to the concessionaire who provides the highest value, often the lowest cost over the term of the concession, the bidders strive to minimize the overall cost of the project, not only the initial cost for design and construction, but also the costs for operation, maintenance and rehabilitation. This leads to a solution that is not derived from the availability of funds, but is determined by what is most cost efficient (Parche 2007). However, review of guidelines developed by World Bank "Toolkit for Public-Private Partnership (PPP) in Highways" in 2002 and by European Commis-

sion “Resource Book on PPP Case Studies” in 2004 for PPP projects shows that consideration of maintenance aspects in the planning and design process is not prioritized. Experience from the Nordic countries and other European countries indicate that the influence of geometrical road design on road maintenance has been ignored in most of the PPP projects carried out up to now (Karim 2008).

### 3.5. Performance-based contracts

Performance-based contracting in the infrastructure sector means that public sector representatives and a commercial enterprise sign a contract on both construction and maintenance, or solely maintenance, of an infrastructure object. The contract terms are based on some specified services that must be given to future users, not on the fulfilment of technical specifications. It is the performance of the asset over the contracting period that matters (Nilsson *et al.* 2006). Performance-based contracts in the road sector were first introduced in 1893 in USA but increased in popularity during last three decades. So far performance-based contracts have mostly been used for road pavements with duration between 4 to 10 years. The main reasons of using performance-based contracts are to:

- maximize performance by allowing contractors to deliver the required service based on their own best practices and the customer’s desired outcome;
- maximize competition by encouraging innovation from the supplier by using performance requirements;
- minimize burdensome reporting requirements and reduce the use of contract provisions and requirements;
- shift risk to contractors so they are responsible for achieving the objectives through the use of their own best practices and processes; and
- achieve solutions which give optimal live cycle cost.

The most important characteristic of performance-based contracts is to give contractors freedom to decide the best methods and materials based on road authorities’ direction of road performance and schedules for construction activities. Performance-based road management and maintenance contracts preserve the road asset according to predefined performance standards on a long-term basis. The most challenging task is to develop performance-related specifications, which ensure that the objective is achieved as efficiently as possible. These performance-based specifications provide guidelines for the design and construction of the road project (Carpenter *et al.* 2003). Payments are based on how well the contractor manages to comply with the performance specifications defined in the contract, and not on the amount of works and services executed. According to Zietlow (2004), development of “right” performance specifications is a challenging task since they have to satisfy a set of goals such as:

- minimizing total system cost, including the long-term cost for preserving roads, bridges and traffic assets and costs for the road users;
- satisfy comfort and safety of road users.

To avoid ambiguity, performance indicators have to be clearly defined and objectively measurable. According to Zietlow (2004), typical performance indicators are:

- max International Roughness Index (IRI);
- absence of potholes, cracks and rutting;
- min amount of friction between tires and road surface;
- max amount of siltation or other obstruction of drainage systems;
- min retroreflexivity of road signs and markings.

According to Huvstig (1999), it is rather easy to measure actual values of the surface characteristics for different parts of a road, but it is problematic to predict the value in the future. To solve this problem, a reliable deterioration model is needed. Current deterioration models are mostly based on empirical knowledge and not on mechanistic calculations. This could be another reason for the limited use of performance-based contracts.

According to Carpenter *et al.* (2003), introduction of performance-based contracts in USA, Australian and New Zealand has resulted in cost reductions of between 10% and 20% compared to traditional contract forms. In Latin America, 40 000 km of the national roads are maintained under performance-based contracts. Rough estimates indicate that performance-based contracts in Latin America have resulted in cost-savings of around 10% compared to traditional unit price contracts (Zietlow 2008).

There are also examples of performance-based contracts that have turned out to be more expensive than traditional contracts. In a case study of four performance-based contracts, Stenbeck (2007) shows an increasing in costs between 10% and 50% compared to traditional contracts. The Ministry of Transport Infrastructure of Brazil cancelled a tender for a performance-based contract, as the prices offered were much higher than expected (Zietlow 2008). This decision was mainly due to the high risks perceived by the bidders that the government might not honor its payment commitments. Therefore, a balanced approach towards the distribution of risks is recommended. The party that controls the risks should also take the risks.

Regarding quality aspects, studies show also different results. In Denmark, a summary of the experience of six years of performance-based maintenance contracts of totally 300 km roads indicates that in the first year of the contracts, municipalities experienced a faster rate of surface renewal than the budget typically allows (Baltzer 2007). Experience from two performance-based contracts in Sweden shows a significant road quality improvement (Ydrevik 2009). However, Stenbeck (2007) presents an anonym case where a performance-based contract resulted in inferior quality. According to the

study, unsuccessful cases could be due to lack of experience in implementing long-term maintenance contracts in road projects and absence of sufficient follow-up procedures.

Despite many successful performance-based contracts, the acceptance for this kind of contracts is limited. According (Carpenter *et al.* 2003), the primary reason for this can be hypothesized as follows:

- lack of knowledge in implementing long-term maintenance contracts in the road construction sector;
- the extra work involved in developing specification for such projects;
- lack of research and evaluations comparing in-house maintenance and operation with outsourced maintenance;
- road authorities are not sure what type of projects benefit most from performance-based contracting;
- road authorities have concerns about the ability of the contractors to manage the road over long-term warranties;
- contractors are not willing to take great risks; and
- road authorities are concerned about losing knowledge.

The above presented studies of performances-based contracts show that the interrelationship between geometrical road design and future maintenance measures has been considered in a very limited extent.

### 3.6. Strategies to increase road maintenance efficiency

To deal with future funding challenges in Sweden, various strategies are stated in the strategic plan for 2007–2017 established by SRA to improve efficiency and reduce costs, including maintenance expenses. Strategies to improve efficiency of road maintenance are:

- development of new forms of cooperation and contracts as well as performance-based requirements to stimulate innovations and promote productivity growth within road infrastructure;
- exploit SRA's purchasing volume to guarantee a competitive market for road infrastructure;
- harmonisation of guidelines and requirements with adjacent countries in order to increase the number of international and domestic bidders;
- focus on applied research in order to improve road management efficiency;
- use LCC analyses to achieve optimal total cost;
- development of new funding forms, such as PPP projects, road usage fees or short-term loans, to increase flexibility and efficiency.

In SRA's plan, it is stated that the efficiency of maintenance and operation activities will be increased by 1% per year. It is also stated that the possibilities to make savings concerning operational activities are very limited. SRA will prioritise maintenance of road information systems, tunnels, bridges and road equipments before traffic safety. These statements indicate that efforts made by SRA to

increase maintenance efficiency are mainly cost-cutting efforts rather than stimulation of maintenance activities. Focus is on reduction of recurrence rate of maintenance activities and prioritisation of some activities before others. Many of these efforts might decline road maintenance standards. For example, the developmental project "Review of Maintenance Activities (GAD)" has been carried out by SRA with the intention to increase maintenance efficiency. GAD and other similar projects are expected to give SRA 70 mln SEK (7 mln EUR) per year in cost-savings, i.e. 1% of the annual maintenance budget. However, the consequences regarding maintenance standards and socio-economic costs are not considered. Some measures proposed by GAD have resulted in lower standards. For instance, visibility along roads has been decreased due to reduction of the mowing width from seven meters to three meters and reduced frequency of cleaning road reflectors. These kinds of cost-cuttings and negative consequences are not unique for Sweden. A study of maintenance costs in Newfoundland and Labrador in Eastern Canada showed that the maintenance budget was reduced by a third in three years (Stenbeck 2007). Several actions that have been undertaken to keep the budget in balance such as mixing salt with sand, reduction of sand quality, fewer depots for materials and equipments, giving up shoulders and change of double line marking to single line. According to the study, innovation has been interpreted as the capacity to cut quality without too much negative effects. In addition to the direct effects of the cuts, the study points out that productivity also may be reduced by displeased staff and more relocation time needed as a result of less equipment depots per area.

## 4. Discussion

Maintenance costs around the world are continually increasing while the funding gaps in road infrastructure are widening considerably. To face road infrastructure gaps, road authorities are continuously trying to increase efficiency, especially maintenance efficiency by attempts as:

- outsourcing of maintenance contracts;
- implementation of performance-based contracts;
- development and implantation of LCC models;
- implementation of new funding forms such as PPP projects.

Some of these efforts have resulted in reduced costs. However, in some cases, such as outsourcing of maintenance contracts, it seems that standards have deteriorated. Focus has been on cost-cutting through reduction of the recurrence rate of maintenance activities, prioritisation of some measures before others, e.g. prioritization of winter maintenance, cleaning and grass mowing before bridge and pavement maintenance. Road authorities should consider such efforts as cost-saving rather than efficiency increasing as the definition of efficiency is to get more value from the same resources or to get the same value from less resources. This might explain why some

efforts to increase maintenance efficiency have been less successful.

All maintenance efficiency efforts evaluated in this study have one thing in common – namely ignorance of the interrelationship between geometrical road design and maintenance as an efficient tool to increase maintenance efficiency. Focus has mainly been on improving operating practises and maintenance procedures.

The main underlying factors for ignorance of the interrelationship between geometrical road design and maintenance are (Karim, Magnusson 2008):

- absence of reliable models for analysis of the relationship between design and maintainability;
- insufficient registration of investment and maintenance related data;
- insufficient follow-up procedures for maintenance measures.

This in turn has prevented sufficient considerations of maintenance aspects during the road planning and design process. This might also explain why some efforts for increasing maintenance efficiency have been less successful. Ignorance of maintenance aspects during planning and design process is a well-known issue. However, there are very few studies published concerning the underlying factors (Freer-Hewish 1990), which is confirmed in this paper by the limited amount of literature found.

Implementation of performance-based contracts, PPP projects and LCC analyses are options to considered maintenance aspects during planning and design. However, in almost all the projects and literature evaluated in this study, focus has been on structural design, such as pavement design, rather than geometrical design. Guidelines for these types of contracts do not recommend analyses of how geometrical design affects maintenance. Fortunately, performance-based contracts and LCC analyses in many cases have resulted in reduced maintenance costs and improved road structure quality. However, these contract types and analyses are still uncommon in the road sector mainly due to lack of knowledge in implementing long-term maintenance contracts and poor follow-up procedures for these contracts. The bidders have perceived a higher risk and the contracts have been more expensive than traditional contract forms (Stenbeck 2007). There are also reasons to believe that road authorities in many cases have used performance-based contracts and PPP projects to transfer risk to the contractors and to obtain a financing partner.

One of the most important characteristics of performance-based contracts and PPP projects is to give the contractors freedom to decide the best design and construction method and material for the road project. In some cases, especially in PPP projects, this can be difficult since the concessionaires often are foreign companies with limited experiences of risks and conditions existing in the concerned countries. In these cases, contracts may become more expensive than traditional contract forms as the concessionaires are taking higher risks. In

addition, road authorities may lose valuable knowledge if contractors lead the technological development. This may in the long run also lead to poor competition in the infrastructure market, as only large actors will have the required knowledge and sources for these contract types. Consequently, road authorities are in great need for development of models to analyse the interrelationship between road design and maintenance workloads. This development has to be accomplished through implementation of systematic data collection and follow-up procedures for planning, design and maintenance of roads.

It is obvious that road authorities have most emphasized eliminating costs in the incurring stages, e.g. construction or maintenance stages, instead of commitment stages, e.g. design stages. According to Emblemsvåg (2003), such emphasis leads to a reactive cost management, as opposed to reducing costs before they are incurred, proactive cost management. Reactive cost management is insufficient as 80% of the costs for a product are committed in the activities prior production. Many organisations or companies realize this fact but still employ reactive cost management. Emblemsvåg (2003) claims that this might simply be a matter of bad habits or people dislike learning new things unless the consequences of not learning are worse than those of learning.

## 5. Conclusions and recommendations

From this study, the following conclusions can be drawn:

To manage costs road authorities have often focused on eliminating costs after they are incurred (i.e. reactive cost management) instead of eliminating costs in the commitment stages (i.e. proactive cost management).

The use of reactive cost managements, efforts to increase maintenance efficiency in many cases resulted in reduced maintenance costs, but have in other cases resulted in impaired maintenance standard and quality. This impairment is mainly due to focusing on reduction in personnel and the recurrence rate of maintenance activities as well as prioritisation of some maintenance measures before others. Due to this fact, these efforts should be considered as cost-cutting rather than efforts for increased maintenance efficiency.

In almost all efforts for efficient maintenance, road authorities have ignored the improvement potentials that exist during planning and design. This is one of the crucial factors underlying the failure of some efforts towards efficient maintenance.

Ignorance of the interrelationship between road geometrical characteristics and maintenance is mainly due to the fact that road authorities do not have a reliable model to analyse interrelationships, poorly established follow-up procedures for planning, design, and maintenance measures as well as insufficient registration of associated data.

Although insufficient consideration of maintenance aspects during road planning and design is a well-known issue for road authorities and other concerned actors,

the underlying causes and consequences have not been studied adequately. This fact is confirmed by the limited amount of literature on the subject found in this study.

For increased maintenance efficiency through successful implementation of PPP projects, performance-based contracts and LCC analyses, road authorities should develop reliable models to analyse the influence of geometrical and structural road design maintenance on maintenance. Such development includes systematic data collection and follow-up procedures for the planning, design, and maintenance processes. Such procedures are also important in preserving the road authorities' knowledge and to maintaining a competitive infrastructure market.

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