Economic benefit calculation of quality improvements in road construction

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ABSTRACT: The Norwegian Public Road Administration (NPRA) R&D-program "Durable Roads" focused on quality improvements in road construction. Better quality, e.g. in materials, frost protection and compaction, will contribute to reduced deterioration of the pavement and increased service life. To show the value of constructing roads with better quality and to do R&D, future benefits of the program were estimated. No standardized method regarding estimation of benefits of R&D-projects was found in literature. A generic method for calculation of benefits was therefore developed. The method is used to estimate benefits of improved quality in construction of new roads, strengthening of roads and pavement maintenance. The result is presented as cost savings for the road owner per kilometer two-lane road and as the cost savings for the road network managed by the NPRA. After 15-20 years, annual savings for the NPRA corresponds to about 30 % of their annual cost of asphalt paving.

1 INTRODUCTION

In the period 2011 – 2015 the Norwegian Public Roads Administration (NPRA) conducted the research and development (R&D) program "Durable Roads" (NPRA 2016). The program focused on better quality in various topics for road construction with an aim to increase the service life of the pavement in general and especially for the surface layer.

The request from the Program Board was to estimate future benefits for the road owner of the R&D-results including implementation with respect to the importance and usefulness of building roads with better quality according to results from the program Durable Roads (Johansen & Granden 2015).

The objective of this work includes the development of methods which can have a more general use in estimating the benefit of R&D-results and even more general estimating the benefit of quality improvements measures.

2 METHOD

2.1 *Literature study*

A literature study regarding estimation of benefits of R&D-projects was conducted before estimating future benefits of Durable Roads. The study included which measures that are used as indicators for benefits of R&D-activity, methods for benefit calculation and problems that often occur when calculating benefits of R&D-activity.

In addition, literature closely related to estimation of benefits of R&D-projects were studied, like criteria for project selection, assessment of benefits for specific measures and profit realization.

No standardized generic method for estimation of benefits of R&D-projects was identified. Common problems for estimation of benefits included:

- Difficult to find a suitable indicator for benefit.
- Lack of information regarding the situation both before and after the R&D-project.
- Lack of a public known consistent method for estimation of benefit.
- Difficult to isolate the effect of the R&D-project from effects of other activities.
- The uncertainty related to the process of implementation which often lasts long after the R&D-project

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is finished and is depending of many conditions outside the R&D-project.

2.2 *Generic method*

Since no standardized method was available in international literature, a generic method for estimation of benefits of R&D-projects was developed.

This method is based on identifying the explicit results of the R&D-project, expressed in a way that facilitates the description of the appurtenant benefits. At the time of the estimation of benefits of the R&D-program Durable Roads, the results and proposals from the program was considered known, and the process of implementation was already started in the program. The actions that comes later in the process of implementation, must be considered unknown. The estimated potential benefits will therefore depend on that all necessary implementations are conducted and are successful.

The resulting benefits must therefore be seen in context with drivers and barriers for the actions of implementation. Promotion of the potential benefits to the general academic and especially to the management of road agencies, and likewise the public interest, are drivers that could be important for the success of the process of implementation. The organization of relevant activities and the focus on building costs versus long-term costs are examples of possible barriers that could affect the implementation in a negative way.

Interacting factors and activities that could modify the results from the R&D-project, needs also to be considered. At the same time as a R&D-project is carried out, there will often be other activities or projects which have an influence on some of the same topics. This kind of activities could also contribute to increased quality and it is not easy to separate the effects on quality from each specific activity.

The generic method for estimation of benefits can be summed up as follows. To each specific result or each quality improvement the following processes should be conducted in order to estimate the benefits:

1. Describe the quality improvements in concrete terms for the results which is assumed to give high values of benefit.
2. Determine the benefit effects for the quality improvements and the likelihood for them to succeed.
3. Determine the influence areas of the benefit effects. Describe which areas and actors are affected, and to what extent.
4. Determine the method and model for estimation of benefit, and decide the indicator for benefits. Estimate the potential benefits (maximum benefit with full implementation) based on the information from the past steps.
5. Consider methods for implementation and determine the resulting degree of implementation based on the assumed accumulated effect from relevant drivers and barriers.
6. Estimate probable benefits as a product of potential benefits and degree of implementation.

3 BENEFITS OF QUALITY

3.1 *General benefits of quality*

In this chapter the main monetized benefits for quality improvements in road construction are estimated with the method described in chapter 2. As a measure for monetized benefit cost saving for the road owner is used.

The quality improvements will also have several positive environmental effects linked to longer service life of the pavement like less use of road building resources, reduced emissions and waste in the production and reduced exposure for the workers. Increased service life of the pavement will also give less roadwork over the time. This contributes to reduction of negative environmental effects linked to reduced traffic disturbance. These non-monetized benefits are not discussed in this paper.

Annual cost for the surface layer is used as indicator for the monetized benefits, this is the production cost for the surface layer divided by the service life of the surface layer. For simplicity reasons, these calculations are carried out with fixed price level and no regulation by the discount rate. This simplified calculation is adopted also because it contributes to direct comparison with agency budget levels.

In the next sections benefits of better quality in construction of new roads, strengthening of roads and pavement maintenance are estimated.

3.2 *Construction of new roads*

The most important areas where quality improvements from the Durable Roads program will contribute to extended service life for a new road are investigation of the subgrade condition, use of materials in the base course and the subbase layers, frost protection, compaction of granulated materials, pavement design and materials, production, transport and laying of the surface layer.

Improved quality in these areas will contribute to a correct road construction with reduced deterioration of the road and increased service life.

When the road is built with the identified quality improvements it is likely that the service life for the wearing course will extend 20-30 % which corresponds to 3-4.5 years.

Given a typical wearing course on a new 2-lane road with production cost about 127,000 euro per kilometer (based on a road width of 9.5 m, asphalt thickness of 5 cm and an asphalt cost of 107 euro/ton) and a normal service life on 15 years before it needs to be

resurfaced (NPRA 2014), the benefits of quality improvement can be estimated.

Table 1 shows the annual cost of the surface layer for new roads built with current construction methods and for roads which are built with two different levels of quality.

Table 1. Annual costs of a surface layer on a road built with current construction methods and alternatively built with new construction methods which improves the service life of the surface layer.

	Annual cost euro/km
Current methods (15 years)	8500
New methods, 20 % (18 years)	7000
New methods, 30 % (19.5 years)	6500

Previously the pavement design and/or the construction of the road was not good enough to achieve the expected result with regards to the service life of the surface layer. Even with the new construction methods it is not likely to achieve maximum of the quality improvement in all new roads. If it is assumed possible to get the maximum increase of surface layer service life in 65-85 % of the new roads, or in general an improvement of 65-85 %, this will give a saving of 950-1700 euro per kilometer. This corresponds to 10-20 % reduction of the annual cost for the surface layer compared to a new road built with current methods.

3.3 *Strengthening of existing roads*

For strengthening of existing roads, the same main factors in quality improvements are important to achieve increased service life of the pavement as for construction of new roads. In addition, it is essential to identify the road sections with strengthening needs and to choose the right methods for strengthening.

A typical road that needs strengthening is narrower than a new road. The cost of a new wearing course on that type of road will therefore be about 107,000 euro per kilometer (based on a road width of 8.0 m, asphalt thickness of 5 cm and an asphalt cost of 107 euro/ton). On roads which needs strengthening the typical factor of service life (the ratio between actual and normalized service life) is about 0.5-0.7 which corresponds to about 7 years for a typical rural road with low traffic volume (NPRA 2014). After a successful strengthening the factor of service life should be raised to 1.8-2.2 or a pavement service life of ca. 20 years. The factor of service life after strengthening should be aimed as high as almost 2 because the normalized service life is based on existing roads most of which are not built according to design criteria of today. A newly strengthened road section should at least obtain a surface layer service life twice an old road.

As for new roads, it is not possible to obtain 100 % effect of all quality improvements for every strengthening project. Table 2 shows the annual surface layer cost for a road that needs strengthening, given for a road after a successful (100 %) strengthening, a road that is strengthened by current methods and for two typical rates of success with new methods of strengthening.

Table 2. Annual costs of a surface layer on a road with strengthening needs, before strengthening (with 7 years service life of the surface layer), after a successful strengthening (with 20 years service life of the surface layer) and for typical rates of success with current strengthening methods and new strengthening methods.

	Annual cost euro/km
Before strengthening (7 years)	15,500
After, 100 % successful (20 years)	5500
Current methods, 30 % success	12,500
New methods, 50 % success	10,500
New methods, 70 % success	8500

Today only about 30 % of maximum improvement for service life of the surface layer is reached in strengthening projects. With methods of strengthening with better quality it is likely to achieve 50-70 % of the improvements for service life of the surface layer. With these rates of success, the new methods for strengthening of roads will contribute to 2000-4000 euro per kilometer in savings per year. That corresponds to 15-30 % of the annual cost for surface layer on a road that is strengthened by current methods.

3.4 *Pavement maintenance - resurfacing*

For resurfacing of pavements the quality improvements in materials, production, transport and laying introduced in the R&D-program are most important. In addition, quality improvements in methods, plans and competence in control of asphalt laying are important factors for achieving long service life of the surface layer.

Better competence and quality control of the resurfacing process contributes to discover poor design, mistakes or poor workmanship early in the production process. This makes it possible to change and correct the production process.

A typical 2-lane paved road is about 7 m wide. The costs of resurfacing are about 84,000 euro per kilometer (based on a road width of 7.5 m, asphalt thickness of 4.5 cm and an asphalt cost of 107 euro/ton), and the new asphalt surfacing has an average service life of 15 years before it needs to be resurfaced (NPRA 2014).

The quality improvements will generally increase the service life of the surface layer. In addition, quality improvements will reduce the number of road sections with abnormal short service life of the surface layer due to local defects. In average, it can be assumed that the quality improvements will increase the service life with 1-3 years.

Table 3 shows the annual cost for resurfacing of a road with current methods, and a low and a high estimate for a road resurfaced with quality improved methods.

Table 3. Annual costs of resurfacing with current methods and with a low and a high estimate for quality improved methods.

	Annual cost euro/km
Current methods (15 years)	5600
New methods, low estimate (16 years)	5300
New methods, high estimate (18 years)	4700

Annual benefit of this new methods is 300-900 euro per kilometer 2-lane paved road which corresponds to a 5-15 % reduction of the current annual cost.

In addition to the reduction of the costs for normal resurfacing, the need for asphalt patching will be reduced because of the quality improvements of the surface layer.

4 QUANTIFYING BENEFITS FOR NATIONAL AND COUNTY ROADS IN NORWAY

4.1 *Quality improvements in Norway*

In the R&D-program Durable Roads there was conducted an evaluation of benefits for the national and county roads in Norway. The NPRA is road agency for these roads. The work consists only of a direct benefit estimation, not a complete cost-benefit analysis.

There is about 10,500 km national highways and 44,500 km county roads in Norway. Annual production of asphalt mixtures in Norway is about 6500,000 tons, and about 2250,000 tons are consumed by the NPRA.

Many of the roads which are constructed in Norway experience damage and other problems much earlier than they should. To prevent this in the future new or revised requirements has been implemented in road construction and maintenance by the R&D-program Durable Roads.

Previously there was generally too little investigation of the subgrade condition and too few measurements and samples in areas with difficult subgrade, that lead to incorrect classification of the subgrade. This often resulted in wrong pavement design. The new requirements are more based on use of Quaternary geological maps and the road alignment so that more resources can be used in the critical areas.

The choice of material in the base course and the subbase layer is important for the long-term condition of the road. To ensure better results the requirements for the materials in these layers are developed to be more relevant and precise. The material requirements for the frost protection layer have been more relevant and precise and the design thickness has been raised. Compaction of the granulated materials is important to reach homogeneity in the pavement and evenness on the surface. Clearer requirements for method and amount of compaction are important improvements.

There has also been made some rearrangements in the design manuals in order to make it easier to have overview of all parts of the pavement design system and prevent parts of the requirements to be forgotten in the design process.

Changes in the design requirements are important to achieve better quality, but also for the production and workmanship there is a need for improvements. New and revised requirements for tack coat were implemented to ensure good bonding between asphalt layers and prevent slippage, cracking and potholes. For the joints there has also been new requirements regarding compaction and maximum void content to prevent early pavement distresses.

About 20 % of the asphalt mixtures laid in Norway are transported by boat. Better solutions for loading, unloading and temperature preservation during transportation is important to keep material performance and achieve a good asphalt layer on the construction site.

4.2 *Benefit estimation*

National plans for national and county roads shows that it is likely that there will be built about 250 km new roads per year in the coming years in Norway.

Over a period of 20 years the quality improvements will contribute to 47-85 mill. euro in cost savings or benefit for the NPRA.

There is no official list of how many kilometer road that is being strengthened per year in Norway. Questions to the regional units of the NPRA implies that in the last years about 650 km national and county roads have been strengthened. It is likely to believe that the same length of road will be strengthened during the next 10 years before the activity gradually will be reduced during the next 10 years after that. This gives 10,000 km strengthened roads in the 20-years period and about 250-500 mill. euro in cost savings or benefit.

Data from the last seven years show that about 3500 km paved road have been resurfaced each year in Norway. This corresponds to an average resurfacing interval of 15 years. The annual benefit for pavement maintenance, i.e. resurfacing, because of the quality improvements, will increase for each year until all roads have the new and better wearing coarse after about 15 years. Later the annual benefit will stay on the same level, about 10-30 mill. euro. In the 20-years period the quality improvements will contribute to 220-650 mill. euro in cost savings or benefit.

Figure 1 shows the area of annual benefit, or cost saving for the road owner, which is likely to be obtained in Norway if the quality improvements are implemented in road construction, strengthening of roads and pavement maintenance. The shape of the

area tells that the size of the annual benefit will increase significantly until all the paved road have been resurfaced and most of the roads with very short service life of the surface layer (low factor of service life) have been strengthened. Afterwards the annual benefit will remain on this high level, about 40-100 mill. euro. This corresponds to 18-40 % of NPRA's annual cost of asphalt paving.

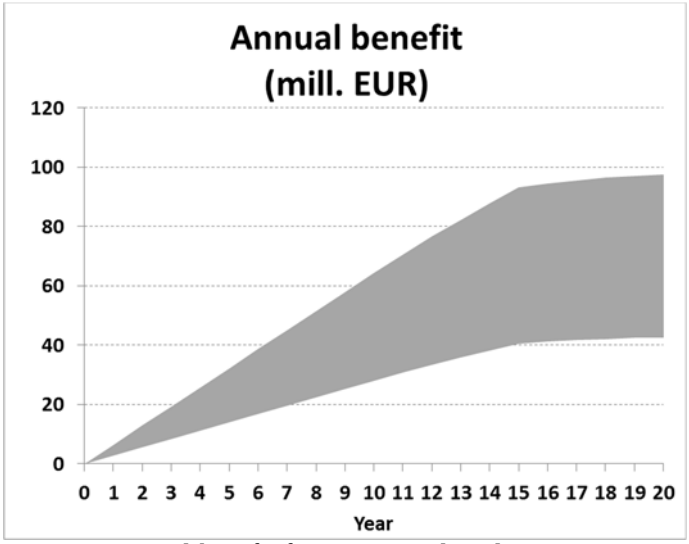

Figure 1. Annual benefit from improved quality in pavements for the Norwegian Public Roads Administration (construction of new roads, strengthening of roads, pavement maintenance).

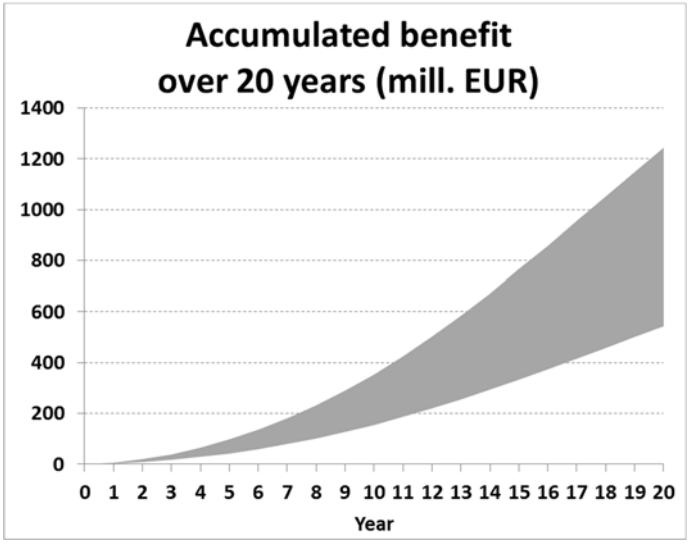

Figure 2. Accumulated benefit of quality improvements for the Norwegian Public Roads Administration over a 20-years period (construction of new roads, strengthening of roads, pavement maintenance).

In figure 2 the accumulated benefit of quality improvements for Norway over a 20-years period is showed. After 20 years, the accumulated benefit is about 550-1200 mill. euro.

The quality improvements could also be transmitted and give monetized benefits to other users of asphalt mixtures like municipalities, airports and private operators. It is likely that the degree of implementation will be less in these sectors than in the organization of the NPRA. The benefit measured as a percentage of annual consumption of asphalt mixtures will consequently be smaller than what is stated above for the NPRA.

5 CONCLUSIONS

Estimations in this paper shows that quality improvements in road construction will have considerable benefits. The numerical analysis is based on typical Norwegian situations and values. To which extent the results are representative to other countries will depend on several factors. National cost level and current quality level regarding asphalt material and work are some of the most important factors for the potential resulting benefits. Local weather condition and soil condition could also contribute to other levels of typical service life for the asphalt pavement and will lead to different resulting benefit levels.

For one kilometer of new road, built with the quality improvements, will the annual costs of the surface layer probably be reduced with 10-20 %, or 950-1700 euro per year.

The quality improvements for strengthening of roads will probably contribute to 2000-4000 euro per kilometer in cost savings per year, which corresponds to 15-30 % of the annual cost of a surface layer on a road that is strengthened by current construction methods.

For resurfacing, quality improvements will probably contribute to 300-900 euro per kilometer in benefit for a 2-lane paved road. This corresponds to a 5-15 % reduction of the current annual cost.

In Norway benefits of quality improvements in these three areas could in sum contribute to about 40-100 mill. euro in annual cost saving per year for the NPRA which corresponds to 18-40 % of their annual cost of asphalt paving. The total amount of savings for other countries will, in addition to several local factors, depend on the length of the paved road network and the plans for building new roads, strengthening of roads and resurfacing of roads.

Extended service life of the pavement and surface layer would also contribute to positive environmental effects like reduced use of building resources, reduced emissions and exposure for the workers in production and in reduced traffic disturbance.

The generic method developed and used for estimation of benefit of quality improvements in road construction and maintenance is not related to any special Norwegian conditions and will be applicable in other countries as well. The generic method can also be generalized and adjusted for use in estimating the benefit of R&D-results and even for more general estimation of benefits

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