# Life Cycle of Road Structures in Road Construction in Practice

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## Summary

The life cycle concept in road management is aimed to discover the overall costs, long-term performance and other impacts of road projects which extend on the entire service life of the road. Thus, a longer period can be covered by this kind of analysis than by applying traditional methods. With relevant case examples, this paper will outline the current state of life cycle analysis in road management in Finland.

## 1. Introduction

At the moment the development of lifetime-oriented road management proceeds rapidly in Finland. This development can be divided in two sectors. Firstly, some significant contributions to the research and development of long-term pavement performance have been made during the past decade. The models depicting long-term performance are naturally never complete, but a sufficient amount of new knowledge has been obtained to create new models and parameters. Secondly, procurement methods are now going through profound changes. In investment projects this means that the maintenance responsibility after investment is included in the contract. The daily maintenance contracts will therefore be covering larger geographical areas with longer contract periods. These two main sectors have now made lifetime-oriented road management into a very topical issue in Finland.

## 2. Current situation in Finland

### 2.1 Research

The Road Structures Research Programme (TPPT) was carried out in 1994-2001 by the Finnish Road Administration. The objective of the results obtained from the TPPT project was to be able to construct new roads and repair old paved roads more durable while reducing the annual cost of the road. The results of the TPPT project were compiled into a design system, which includes e.g. a procedure for estimating the life cycle costs of alternative pavement structures [1].

The focal point of research in the TPPT project was on the pavement solutions and the design of new high-volume roads. A separate project concentrating on thinly-paved roads was also conducted alongside the TPPT project [1].

Moreover, Finnish researchers have been involved in several international, mainly EU –funded, research programmes, e.g. [2]. Plenty of knowledge about long term pavement performance has been gained as a result of this research and development work.

### 2.2 Development of procurement methods

In the beginning of 2001 the Finnish Road Administration was divided into two organisations. Since then the Finnish Road Administration (Finnra) has been responsible for maintaining public roads and bridges. The other organisation, the Finnish Road Enterprise, is now a state-owned enterprise which provides engineering, construction and maintenance and related products and services within the civil engineering sector.

The organisational changes have enabled the introduction of new procurement methods. The Finnish Road Administration has issued the following guidelines for this development:

- Service packages will be extended in terms of duration, geographical area and contents of procurement.
- Alongside with the separate procurement and consultation contracts, the new contract types, which include sequential execution phases, will be introduced.
- Incentives and bonus systems will be developed.
- Quality specifications will be changed from technical input specifications to those highlighting the functionality output.

As a result of this development work the contractors and consultants need to expand their competence, encourage new ways of co-operation in their field and negotiate mutual agreements with their partners. Service producers also need to consider adopting new strategies for life cycle planning with regard to new funding methods. The life cycle maintenance costs will be decreased and more efficiency will be attained by implementing new methods.

### 2.3 Development of funding methods

As new procurement methods are created, it is important to introduce new funding methods as well. In the beginning of 2003 the Finnish Road Administration launched a new life cycle model for large-scale road investments. The leading idea of this method is to form a service concept that makes it possible to minimize the costs of investments and maintenance for a long service period, as well as enhance a customer-oriented approach and provide the prerequisites for the innovations made by the service producer. The financing of the life cycle model can be based on direct government payments as the work proceeds, or on the financial responsibility of the party implementing the project. In the latter case, the client organisation is to pay an annual service fee as soon as the service becomes available. Using producer’s financing based on risk management means that more efficient production may be provided [3].

## 3. Life cycle of pavement

The life cycle of pavement depends on the frost susceptibility and the bearing capacity of the road structure. Nowadays these factors are satisfactorily taken account of as to the main roads. As for the secondary roads, the threshold values allow greater variation. As a result an increasing number of maintenance measures are required during life cycle.

A typical defect which requires measures on the Finnish main roads is rutting that is mainly caused by studded tyres. The maintenance and rehabilitation costs of main roads generally consist of the costs of repaving and pavement re-mixing. There are only local needs for improving the bearing capacity of road structure or subsoil and reducing frost susceptibility.

The secondary roads suffer from different kind of defects. In this case rutting is caused by the deformation of unbound layers. Also unevenness occurs widely. Many combinations of rehabilitation measures may have to be taken to maintain the pavement within acceptable threshold values. Rapid deterioration and severe unevenness require heavy rehabilitation strategies. Minor measures for improvement are taken on the slowly damaging roads and in the cases where the deterioration is caused by the upper layers of road structure.

The selection of rehabilitation methods depends on the factors which cause defects, rutting or unevenness. The environmental aspects should always be considered. For example, the recycling possibilities of road structure materials are nowadays taken extensively into account.

In the following, two different example cases will be presented.

# 4. Example Case: Main Road 9 Orivesi – Jämsä

## 4.1 Introduction

Main Road 9 is an important route for heavy transport. The average daily traffic is about 6 000 vehicles, with an annual increase of 3 % in average. The increasing volume of traffic and the low level of road geometry had decreased the road safety. The road was constructed mainly as new road, but there were few short sections where the old road was improved. Many passing lanes were also added in order to improve traffic safety. The length of the road section was 46 km and it included several bridges. The project was managed by the Finnish Road Enterprise for the client, the Finnish Road Administration, and it was carried out in 2002-2003.

## 4.2 Topography and subsoil

The topography was varied, with moraine and rock hills as typical features of the landscape. The valleys on the other hand consisted of soft clay and organic soil. Due to the highly varied altitudes of the landscape many rock and soil cuts were needed, just as high embankments usually on soft soil were necessary at other points. Soft soil was generally replaced by blasted rock or by constructing a temporary surcharge.

## 4.3 Design of road structures

The bottom layers of a road embankment was made of granitic blasted rock and moraine. The filter layer, the sub base was constructed by using blasted rock and crushed rock. The minimum thickness of the frost resistant layer was determined by calculating frost heaves. In practice the calculated frost heaves tend to be small enough to avoid significant frost damages.

The bearing capacity of road structures was calculated for a service life of 20 years. The base courses were made of crushed rock and crushed recycled asphalt, which was stabilized with foam bitumen. The thickness of the layer was 12 cm. Hot mix asphalt was used as base course in the sections where the old road was rehabilitated. The thickness of the asphalt layer was 6 cm. Hot mix asphalt layers also proved practical in the places which had to carry heavy traffic during the construction. The layer stabilized with foam bitumen and the hot mix base course were covered with a hot mix asphalt layer as a wearing course. The minimum thickness of the asphalt layer was 4 cm. A good wearing resistance was achieved by using high quality rock. Plans were made to apply a new hot mix asphalt wearing course after 4...6 years. After that the bearing capacity will be sufficient for the targeted 20 years.

## 4.4 Life cycle of road

The life cycle of these structures depends on the quality of layer materials and on subsoil settlement. Theoretically, unbound materials like granitic blasted rock are permanent, but in practice there are some local risks for frost action and minor movements caused by heavy traffic. These factors may cause deformation and unevenness of road surface. The difficulties in replacing the soft soil tend to bring about the risk of uneven settlement, which usually occurs within 1...5 years. The rutting of foam bitumen stabilized layers normally happens within 2...5 years, but it will also achieve its maximum strength and stiffness in that time. Therefore, it is practical to prepare for the repair of these kinds of settlements, unevenness and rutting, if we use stage paving. Prior to the construction of the final bituminous wearing course, the dimensioning and condition of the various road structures should be checked carefully.

Where the bearing capacity of the road structures is sufficient, it is possible to use remixed wearing courses with rather small addition of new bituminous material. Locally there is still need for preparations with mill and fill -methods. The remixing of pavement can be repeated 2 or 3 times. On Highway 9 the life cycle of 20 years can be easily achieved. After twenty years it will become necessary to check the bearing capacity and to decide for the next step - whether to add a new bituminous layer or recover the old bituminous structures by mixing a new binder.

### 4.5 Life cycle costs

In cases like this the required construction investments are very large in comparison with the life cycle maintenance costs. Efforts have been made to reduce the amount of investments by planning alternative pavement structures. The bituminous materials of old roads have been efficiently utilized in new structures. The need for bringing in materials from outside the site has been minimized. The transportation distances of road materials have also been kept very short. The construction and maintenance of temporary roads for traffic during the projects was both difficult and expensive. Therefore, it is necessary to consider these matters at an early stage of planning, when the road designers are choosing routes.

The estimated life cycle costs (20 years) of this project are presented in table 1.

*Table 1. Life cycle costs of main road 9 –project.*

| Year of action | Type of action | Cost (MEUR) | Present value factor | Discounted cost (MEUR) |
|---|---|---|---|---|
| 0 | Construction | 30,0 | 1 | 30,0 |
| 4 | New pavement | 3,2 | 0,855 | 2,6 |
| 12 | Remixing wearing course with preparation works | 1,7 | 0,625 | 1,1 |
| 18 | Remixing wearing course with preparation works | 1,9 | 0,494 | 0,9 |
| | | | **LIFE CYCLE COSTS:** | **34,6** |

The 4 % interest rate have been used to calculate discounted costs. According the calculation, the maintenance costs covers 13 % of life cycle costs, which is typical figure for this kind of main roads.

There is no general way to calculate residual value for road structures. However, in this case the residual value after 20 years have been estimated. The estimation based on assumption that construction of the road (30 MEUR) and new pavement (3,2 MEUR) is calculated as such in the residual value. Remixing of wearing course does not increase the residual value, but the preparation works including remixing (0,3 MEUR) does. On the other hand, the residual value decreases (6,0 MEUR) because of deterioration of pavement and decreasing of riginity of bituminous layers. Thus, the discounted residual value is estimated as 27,0 MEUR in this case.

## 5. Example Case: Highway 338 Kaanaa-Jäminkipohja, Tampere & Ruovesi

### 5.1 Introduction

Highway 338 is a typical low traffic road in the countryside. The average daily traffic is about 960 vehicles, with an annual increase of 1 % in average. The condition of road was poor, due to different kinds of defects and unevenness. The combination of frost action and low bearing capacity had caused the rapid deterioration of bituminous pavement. Also local unevenness on some sections reduced traffic safety. The main goal was to remove the damaged sections and improve the bearing capacity by increasing the bound layers. As client, the Finnish Road Administration had set an investment limit for this project. As contractor, the Finnish Road Enterprise was in charge of planning and construction. The length of the road was 15,4 km. This project was carried out in the summer of 2001.

## 5.2 Topography and subsoil

The topography is varied and moraine and rock hills are typical for the landscape. There are many rock and soil cuts along the road. The ground also consists of soft clay and organic soil, which is generally very susceptible to frost. Frost action causes unevenness especially in soil cuts.

## 5.3 Design of road structures

The road structure design was based on various kinds of information. The information included traffic data, a condition databank, a road databank, a maintenance history and geological soil maps. Site investigations were accomplished by using falling weight deflectometer tests and georadar soundings including sampling. Defects and uneven sections were mapped during the spring. After the data analyses were complete, the road was divided in appropriate sections according to the selected rehabilitation method. The sections damaged by frost heave-related unevenness were repaired by using a thick frost-resistant pavement with transition structures. Reinforced structures were used in the sections which suffered from wide longitudinal cracks. The load-bearing capacity was improved by pre-mixing and stabilizing the existing pavement and the unbound road base. The mixture consisted of old bituminous pavement, unbound crushed gravel and foam bitumen. The thickness of stabilization varied between 15...20 cm. The wearing course was of soft asphalt (thickness 4 cm). The structures are calculated to endure a 20-year service life. Due to the investment limit set by the client all harmful defects could not be removed.

## 5.4 Life cycle of road

The life cycle of constructions depends on frost action. Even if the sections which suffer from unevenness were removed, some local frost action may still occur and cause longitudinal cracks and perhaps minor unevenness. Using flexible road structures reduces the cracking of soft asphalt pavement.

Where the load-bearing capacity of road structures is sufficient, it is possible to use remix wearing courses. Experience has shown that the typical life span of soft asphalt pavement is 12...15 years. When the pavement is renewed, it is possible to prepare for eventual frost damages and unevenness. This will help to achieve the desired life cycle of 20 years, after which time it will be necessary to check the bearing capacity. A possible method could be the rehabilitation of old bituminous structures.

## 5.5 Life cycle costs

In cases similar to this the amount of investment can be kept reasonable. Careful planning and co-operation between the designers and the contractor will lead to a good outcome. The materials reclaimed from old roads have been efficiently utilized in new structures, which has minimized the need for bringing in materials from outside the site. However, attention must be paid to risks and maintenance costs, since it is always difficult to predict the development of cracking and evenness. In these kinds of projects the stage rehabilitation of the road could prove most economical.

The estimated life cycle costs (20 years) of this project are presented in table 2.

*Table 2. Life cycle costs of Road 338 –project.*

| Year of action | Type of action | Cost (MEUR) | Present value factor | Discounted cost (MEUR) |
|---|---|---|---|---|
| 0 | Construction | 1,2 | 1 | 1,2 |
| 12 | Remixing wearing course with preparation works | 0,6 | 0,625 | 0,4 |
| | | | **LIFE CYCLE COSTS:** | **1,6** |

The 4 % interest rate have been used to calculate discounted costs. In this case, the maintenance costs covers 25 % of life cycle costs. The high proportion of maintenance costs is typical for low-volume road, which is constructed by taking advantage of old road structure.

In this case the estimated residual value is even greater than construction costs. This is caused by previously mentioned structures of the old road. The monetary value (1,5 MEUR) of these structures, that is embankments and pavement layers, can be calculated as such in the residual value. Construction costs (1,2 MEUR) of the new road can be added to residual value. The residual value decreases (0,1 MEUR) because deterioration of structures. Thus, the discounted residual value is estimated as 2,6 MEUR in this case.

## 6. Conclusion

The new procurement methods of the Finnish Road Administration demand the development of new competence and technical solutions. The contractors and consultants need to learn how to evaluate the life cycle and the life cycle costs of roads. Empirical knowledge, careful observation of existing structures and competence are the keys to success. New contracts will be designed to include the construction, rehabilitation and maintenance of large road networks for long periods of time. On its part, the client (the Finnish Road Administration) will be obliged to describe the targets and the desired level of quality clearly. The client will also be in charge of collecting preliminary data in order to ensure that tenders can be submitted without unnecessary risks.

It is important to study the use of new materials in road structures and aim at more efficient construction methods. The attention is now focused on design and quality control. There is a growing interest towards considering environmental aspects and sustainable solutions, and this means an end to wasteful construction. In practice all methods which incorporate recycling and energy saving into the production of road structures have usually proved profitable.

The life cycle concept is about to change our thinking and our way to act. The keywords to solving problems are co-operation, competence, research and environmental aspects.

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