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FIBRA

Fostering the implementation of fibre-reinforced asphalt mixtures by ensuring its safe, optimized and cost-efficient use

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Deliverable 5.2 – Assessment of the economic feasibility of Fiber-reinforced Asphalt Pavements

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Author(s) this deliverable:

Irune Indacoechea Vega, University of Cantabria, GITECO, Spain

Pedro Lastra González, University of Cantabria, GITECO, Spain

Rien Huurman, BAM, the Netherlands (data provider and review).

Jian Qiu, BAM, the Netherlands (data provider and review).

Bjorn Ove Lerfald, VEIDEKKE, Norway (data provider and review).

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Executive summary

This report presents the methodology and main results of the LCCA performed to road pavements that include fibre reinforced asphalt mixtures (FRAMs). The main objective of this research is the long-term economic efficiency between conventional asphalt pavements, with Penetration grade bitumen (Pen) or polymer-modified bitumen (PMB), and those that include FRAMs.

In this report, the LCCA methodology is applied to two case studies. The first one corresponds to the pilot section built in the Netherlands as part of the FIBRA project. In this section, the type of mixture used was a 2 layer porous asphalt (2L-PA). The second one corresponds to the pilot section build in Norway, where asphalt concrete (AC) mixtures were implemented. When possible, the specificities of each section (type of mixture, thickness, length, distances, under layers, etc.) are taken into account.

For the conditions analysed in this study, and assuming the same service life, similar life cycle costs are obtained for all the alternatives evaluated in each case study. To consider FRAMs as an economically feasible alternative, a similar durability needs to be achieved in the case of case study 1 and a slightly higher durability needs to be achieved (around 10%) in case study n2.

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1 Introduction

FIBRA project

Existing transport infrastructures are facing important challenges to maintain a reliable performance of the road network, which is being threatened by the increase of heavy traffic, the opening of new freight corridors and the effect of climate change, among others. Maintaining a satisfactory service level currently implies frequent roadworks that generate environmental, economic and societal impacts, reducing at the same time mobility and reliability of the road network and increasing the travel time. Therefore, fostering the implementation of innovative solutions, like the addition of fibres in asphalt mixtures that improve their mechanical performance and durability and consequently the service life of the whole pavement is indispensable.

Despite the promising results achieved in previous research works and the availability of commercial fibres whose providers ensure a pavement life extension of at least a 50% and asphalt mixture life extension of around 200% (depending on the type of fibre and provider), the use of reinforced-asphalt mixtures is not as widespread as could be expected. This is principally due to the existence of gaps in the state of the knowledge that make National Road Administrations be reluctant to their incorporation.

In order to promote its utilization, the objective of the FIBRA project is to overcome the technical barriers for the safe and cost-efficient implementation of fibre-reinforced asphalt mixtures (FRAM) by NRAs with which an increase in the asphalt pavements durability could be achieved. In order to achieve this objective several activities were proposed and developed. Among these activities, a Life Cycle Cost Analysis (LCCA) was planned. The objective of the LCCA was to evaluate the long-term economic efficiency between FRAM and competing alternatives such as PMB or Pen bitumen.

The LCCA is an analysis technique used to evaluate and compare the cost of a number of asphalt pavement alternatives over their life cycle and over an analysis period. To carry out this analysis, all the significant present and future costs (agency, user and other costs) are calculated over the life of the pavement and expressing them in present value.

CEDR Transnational Research Programme

The CEDR Transnational Research Programme was launched by the Conference of European Directors of Roads (CEDR). CEDR is the Road Directors' platform for cooperation and promotion of improvements to the road system and its infrastructure, as an integral part of a sustainable transport system in Europe. Its members represent their respective National Road Authorities (NRA) or equivalents and provide support and advice on decisions concerning the road transport system that are taken at national or international level.

The participating NRAs in the **CEDR Call 2017: New Materials** are **Austria, Belgium-Flanders, Denmark, Germany, Netherlands, Norway, Slovenia, Sweden** and the **United Kingdom**. As in previous collaborative research programmes, the participating members have established a Programme Executive Board (PEB) made up of experts in the topics to be covered. The research budget is jointly provided by the NRAs as listed above.

2 LCCA methodology

2.1 General approach

LCCA is an analysis technique used to evaluate and compare the cost of a number of asphalt pavement alternatives over their life cycle and over an analysis period. To carry out this analysis, all the significant present and future costs (agency, user and other costs) are calculated over the life of the pavement and expressing them in present value.

In the FIBRA project, the purpose of applying the LCCA is to evaluate the economic feasibility of using FRAMs as an alternative to more conventional porous asphalt (PA) and asphalt concrete (AC) mixtures.

Various methods can be used for LCCA. Some of the more common economic analysis strategies include net present value (NPV), equivalent uniform annual costs (EUAC), rate of return (ROR), benefit-cost (B/C) ratios, and break-even analysis [1]. In the practice of LCCA of pavements, NPV is most commonly used economic indicator and the one calculated in this study [1-4].

The NPV is the net discounted monetary present value of future cost (i.e. maintenance or End-of-life) minus residual value (or salvage value). In order to compare different alternatives, NPV transforms future cash inflows and outflows to their present values, which are a common unit of measurement. To do so, a discount rate factor is applied to account for the time value of money.

Then, the present value (PV) of a future cash flow is calculated as follows:

$$PV = FC \times \left[\frac{1}{(1+r)^y}\right] \quad \text{eq. 1}$$

Where, *FC* is the future cash flow, *r* the real discount rate and *y* the year into the future in when the future cash flow occurs.

The LCCA in terms of the NPV is the sum of the initial costs and discounted future costs (i.e. maintenance and rehabilitation activities) minus the salvage value.

$$NPV = IC + \sum_{m=1}^{M} FC_m \left[\frac{1}{(1+r)^{y_m}}\right] - RV\left[\frac{1}{(1+r)^p}\right] \quad \text{eq. 2}$$

Where, IC is the initial cost of construction, FC_m the future cost of the maintenance (or other) activity m, RV the residual value of the pavement, r the discount rate, y_m the year when the future cash flow of activity m occurs, M the total number of activities and p the number of years in analysis period.

2.2 Case studies and design alternatives

The goal of this LCCA is to evaluate the feasibility of using fibres to extend the life service of asphalt mixes by comparing the costs over the life cycle of asphalt pavements that incorporate FRAMs with the costs of pavements built with other competing alternatives such as asphalt mixes with Penetration grade bitumen (Pen) and polymer-modified bitumen (PMB).

The LCCA is applied to two case studies, corresponding to the pilot sections implemented by BAM in the Netherlands (one FRAM and two references) and by VEIDEKKE in Norway (one FRAM and two references).

Case study 1 (PA) – The Netherlands (BAM)

As part of the FIBRA project, BAM and its NRA, Rijkswaterstaat (RWS), have built a road section with the following design alternatives:

- PA_PMB, reference, conventional 2L-PA 8 mixture with PMB.
- PA_PEN, reference, 2L-PA 8 with PEN (70/100).
- FRPA, 2L-PA 8 with PEN (70/100) and 0.05% aramid fibre.

This case study has the following characteristics:

- Average daily traffic of 50000 vehicles.
- Three asphalt layers: 2LPA in the wearing course 8 (7cm), asphalt concrete AC16 in the binder course (6cm) and AC22 (16cm) in the base course.
- 1km length, two lanes, one direction and 11m wide.

Case study 2 (AC) – Norway (VEIDEKKE)

VEIDEKKE and its NRA, Statens Vegvesen, agreed in the implementation of the following asphalt layers in the test section built in Norway:

- AC_PEN, binder 70/100, reference.
- FRAC, binder 70/100, PAN fibre.
- AC_PMB, binder PMB.

This case study has the following characteristics:

- Average daily traffic of 1300 vehicles.
- Three asphalt layers: AC11 in the wearing course (4cm), AC22 in the binder course (4cm) and AC22 in the base course (9cm).
- 1km length, one lane, two directions and 11m wide.

Initially, the same durability is considered for all the alternatives for each case study.

Concerning case study N1, the specifications for the design of Asphalt pavements issued by Rijkswaterstaat in 2016 [5] indicates an expected service life for 2L-PA (2L-ZOAB8) with PMB of 9 years on the right slow lane and 13 years on the other lane. Given these figures, the standard maintenance protocol that is proposed in this analysis is to mill and overlay (M&O) the top PA8 layer of the surface layer in the right lane after 9 years and M&O the complete 2LPA of both the left and right lanes in year 13. Afterwards, repeat the protocol at year 22 by M&O the left lane and in year 26 remove and reinstall the complete asphalt system (surface, binder and base course).

In Case Study N2, according to the Norwegian EPD Foundation [6], the Estimated Service Life (ESL) for the construction work is 40 years for roads and the default Reference Service Life for the asphalt replacement layer (RSL) is 15 for roads with an average daily traffic between 1500 and 3000 vehicles and that are produced with conventional Pen bitumen. According to these figures, the proposed maintenance protocol consists of conducting a M&O of the surface course at years 15 and 30 and the complete removal and reinstalling of the 3 asphalt layers (surface, binder and base course) at year 40.

Although, initially, the same durability is considered for all the alternatives within the same case study, to evaluate the effect in the LCCA of a potential increase or decrease of the pavement durability when FRAM are used, a sensitivity analysis is done varying the service life of the alternatives, both increasing or decreasing the service life in 10% and 20% (in case study N1 where the reference is the asphalt mixture with PMB) and just increasing the service life from 10 to 40% (in case study N2, where the reference is the asphalt mixture with PEN bitumen). Just for simplicity, the increase of the service life (%) has been equally applied to the asphalt layers and the pavement structure. In tables Table 1 and Table 2, the construction, maintenance and rehabilitation schedule is shown for each alternative for case study N1 and case study N2 respectively.

Table 1. Schedule for works – Case study N1

	Case Study N1
Construction	0
Maint. 1	9
Maint. 2	13
Maint. 3	22
Rehab. 1	26
Maint. 4	35
Maint. 5	39
Maint. 6	48
Rehab. 2	52

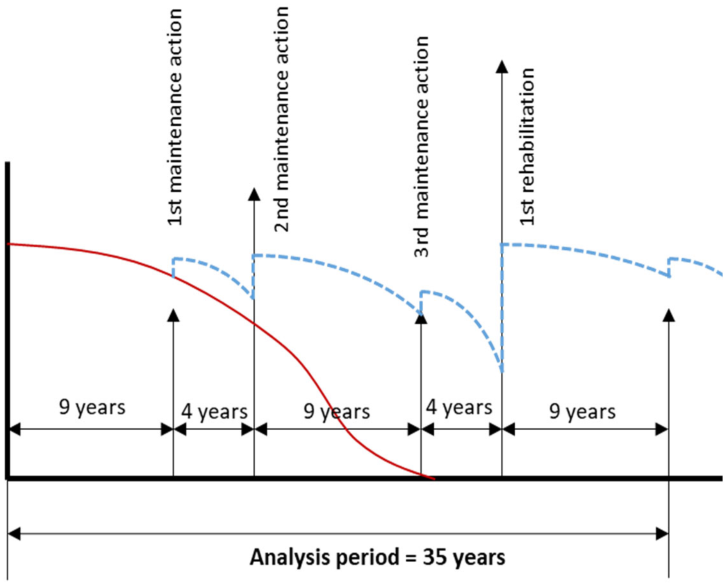
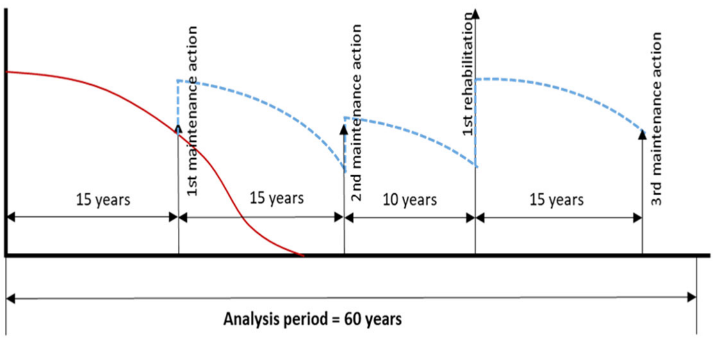


Table 2. Schedule for works – Case study N2

	Case Study N2
Construction	0
Maint. 1	15
Maint. 2	30
Rehab. 1	40
Maint. 3	55



Finally, to account for variabilities in climate, material properties and construction quality and methods, uncertainty has been incorporated to the service life of the different asphalt layers and pavement sections. Thus, the time for each actuation (maintenance and rehabiltiation works), according to tables Table 1 and Table 2, is included in the NPV calculation considering a normal distribution build with pesimistic, most-likey and optimistic values.

2.3 Analysis period

The analysis period is the timeframe over which the alternative designs are compared and over which the initial and future costs are evaluated. This length of the analysis period must be long enough to reflect significant differences in the long-term performance among the alternatives that are being compared and should be the same for all the alternatives considered in the analysis.

Generally, the analysis period incorporates at least one rehabilitation activity. The Asphalt pavement alliance recommends a minimum period of 40 years including at least one rehabilitation activity for each pavement option [3]. This complies with the FHWA-recommendation of a minimum analysis period of 35 years [7]. In the case of concrete pavements, ACPA recommends an analysis period of 45-50+ years so that at least one major rehabilitation effort is captured for each alternate [4].

In order to include the rehabilitation works in all the alternatives, an analysis period of 35 years and 60 years is assumed for Case Study N1 and N2 respectively.

2.4 Discount rate

As shown above, the discount rate is one of the variables that are necessary to calculate the NPV. This index is used to account for the time value of money, so the future costs can be discounted back to the present. Here, the *real* discount rate is used since it reflects the true value of the money considering both nominal interest rate and the rate of inflation. Therefore, for NPV calculations, non-inflated costs can be used as proxies for future costs.

Discount rates can significantly influence the analysis result. However, a realistic selection of the discount rate is not evident to make because it is (1) related to economic trends in the future and (2) related to a long-term horizon. In this sense, historical trends in the US have indicated that real discount rate ranged between 3 to 5% from 1985 to 2000. However, the Office of Management & Budget (OMB) annually updates the 30-year discount rate and has revealed drops to 2.0% in 2012 and even to negative values (-0.3%) in 2021 [8]. On the other hand, the EUPAVE guideline on LCCA (2018) [2] proposes the use of a real discount rate ranging from 1% to 3% for average EU circumstances.

Considering the high uncertainty and high influence of this parameter, in this study, the variability of the real discount rate is accounted by considering a probability distribution of this input into the analysis. Thus, a normal distribution was selected with an average real discount rate of 2% ranging from 1% (pesimistic) to 3% (optimistic).

2.5 Agency cost

Agency costs are those costs incurred directly by the Road Owner over the analysis period and include the initial construction costs, maintenance costs, and rehabilitation or reconstruction costs. Other costs such as administrative and engineering costs are excluded since they are comparable for all the alternatives within the same case study.

The agency costs corresponding to design alternatives in the Netherlands have been provided by BAM. In the case of Norway, inputs from VEIDEKKE and personnel from the Norwegian Public Roads Administration have been obtained. In Table 3, construction quantities and unit prices of the different materials considered in this study are presented.

Table 3. Construction quantities and unit costs – Case study N1 and N2

Case Study N1			
Top layer of 2LPA_PMB (€/ton)	69	Pavement markin(€/m)	1.51
Top layer of 2LPA_PEN (€/ton)	83.5	Tack coat (€/m^2)	0.15
Top layer of 2L_FRPA (€/ton)	82	Milling (€/ton)	10
Bottom layer of 2LPA (€/ton)	60	Transportation (€/km-ton)	0.1
60% RAP AC (binder course)	35		
60% RAP AC (base course)	35		
Case Study N2			
AC_PEN (wearing course) (€/ton)	100	Pavement marking (€/m)	1.51
FRAC (wearing course) (€/ton)	112	Tack coat (€/m2)	0.24
AC_PMB (€/ton)	120	Milling (€/m2)	3.1
AC (binder course) (€/ton)	100	Transportation (€/ton)	15
AC (base course) (€/ton)	95		

In the first case study, the initial construction costs include all the costs involved in the implementation of the three asphalt layers (2LPA, AC for the binder and AC for the base course) for the two lanes in one direction. As explained before, three maintenance actions are considered that consist of: 1) in year 9, the milling and overlay of the top layer of the 2LPA of the right lane, 2) in year13, the milling and overlay of the 2LPA of both the left and right lanes and 3) in year 22, the milling and overlay of the top layer of the 2LPA of the right lane. Finally, reconstruction costs involve the milling and overlay of the three asphalt layers in both lanes, the 2LPA, the binder and the base layer.

In the second case study, initial construction costs include the costs involved in the implementation of the three asphalt layers (wearing, binder and base course) for the two lanes (two directions). Two maintenance actions are done during the asphalt layers service life, consisting in the milling and overlay of the AC surface layer (both lanes) at year 15 and year 30. Reconstruction costs involve the milling and overlay of the three asphalt layers (both lanes).

2.6 User cost

User costs are costs incurred by the highway user over the life of the project. In this work, only those associated with work zone operations will be taken into account and they will consist of the aggregation of vehicle operating costs and user delay costs. User costs linked to the normal operations category are neglected since they are expected to be the same for all the design alternatives. On the other hand, the work zone operations category reflects highway user costs associated with increase vehicle idling, stops and user delays due to construction, maintenance and rehabilitation activities.

User costs is only included in Case Study Nº1 analysis. In Case Study N2, the affection of maintenance activities in the low traffic volume of this road is expected to be small. Concerning Case Study Nº1, due to the high degree of uncertainty in the user costs estimation because of their dependency on the workzone management, the demand distribution, the good estimations of delays costs or the number of lanes and traffic volume, among others, the results of the analysis with and without these costs is provided.

To calculate the user costs, the Kentucky Highway User Costs Program v1.0 is used. In Table 4, the assumptions made for the main parameters used in the calculation are presented. In strategy Nº1 two lanes (out of two) are kept open, in the 2nd strategy, only one lane (out of two) is kept open and the works take place 24 hours a day and finally, in the 3rd strategy, one lane (out of two) is closure but only for 8 hours per day (from 6 to 14). Finally, the total user costs obtained for the FRPA alternative including idling, time value and added cost per 1000 stops are shown in Table 5 considering a traffic growth rate of 1% and for the three different workzone management strategies. To include these costs in the calculation of the NPV, these costs need to be converted into their present value according to eq. 1.

Table 4. Assumptions made for the estimation of user costs

	Strategy 1	Strategy 2	Strategy 3
Initial ADT (per direction)	15000	15000	15000
% Trucks	20	20	20
Initial Speed (km/h)	120	120	120
Workzone speed (Km/h)	60	60	60
Number of lanes - normal	2	2	2
Number of lanes during works	2	1	1

Table 5. User costs for the three strategies considered – Case study N1

User costs	Strategy 1	Strategy 2	Strategy 3
Initial construction (€)	19584	35624	25704
Maintenance 1 (€)	2680	16085	4746
Maintenance 2 (€)	11160	99496	30768
Maintenance 3 (€)	3054	63826	26781
Rehabilitation (€)	25432	945928	514008
Maintenance 1	3468	312507	174240

2.7 Salvage value

The salvage value is comprised of two major components: the residual value and the remaining service life (RSL). The residual value is the net value in the market of the pavement when recycled. The RSL accounts for differences in the service life between the alternatives at the end of the analysis period. The residual value would be very similar for all the alternatives and will not be included in the analysis. Concerning the RSL, the FHWA [7] recommends to estimate it as the portion of the cost of the last rehabilitation corresponding to its remaining life. In this analysis, in addition to the last rehabilitation, a percentage of previous actuations with some remaining life at the end of the analysis period is also considered.

3 Results and discussion

3.1 Case study Nº1: Porous asphalt

The resulted NPV for the three alternatives tested in the pilot section in the Netherlands is shown in Figure 1, assuming the same service life for the three of them. The results are presented in a Cumulative Probability Plot. In this chart, each generated data obtained by the Monte Carlo simulation is plotted against the fraction of all the generated values for that output that are less or equal to that value. According to the results, and considering the same service life for the three alternatives, a similar NPV is obtained for the three pavement sections, with differences lower than 2%.

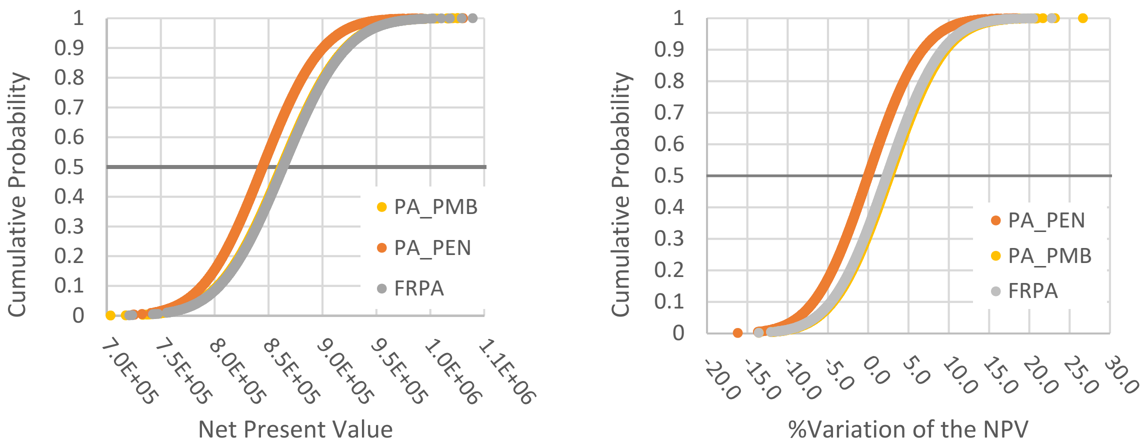


Figure 1. NPV for the three alternative pavements in Case Study N1: PA_pmb, PA_pen and FRPA. a) NPV; b) NPV differences (in %) between alterantives with PA_Pen as the baseline

According to the laboratory results of the FIBRA project [9, 10], the fibre reinforcement improves the mechanical performance of the porous asphalt when it is compared with a conventional PA with PEN bitumen. However, its behaviour, although comparable, is expected not to outperform the PMB. In particular, the FRPA mixture presented a slightly lower mechanical performance in terms of particle loss, resistance to water damage and fatigue comparing to the PMB mixture. However, the long-term performance of these mixtures will also greatly depend on their resistance to aging. In this moment, the aging performance of the FRPA comparing to the PA wtih PMB is unknown. The evolution of the asphalt mixtures implemented in the pilot sections, both in Norway and the Netherlands will provide some light in this regard. Due to the current lack of information about this, a sensitivity analysis is done to evaluate the impact in the LCCA of increasing or reducing the service life of the FRPA comparing to the PA_PMB. The results to these analyses are shown in Figure 2. A decrease in the service life in a 10% or 20% increases the life cycle cost of the road section in around 9% and 22% on average, respectively. However, increasing 20% the service life of the road pavement reduce the NPV in around 12%. In Figure 3, the cost distribution among the different phases of road pavement life cycle is shown for the different alternatives and service life assumptions.

Considering current difficulties in the recyclability of PMB due to the need of high temperatures that can age the bitumen during the mixture manufacturing, if similar durabilities are achieved by FRAM, this would already be an improvement regarding the use of PMB since, according to the laboratory resutls in [9], the recyclability of these mixtures does not seem to be harmed by the use of fibres. Thus, the value of the RAP would be higher in the case of FRAM mixes.

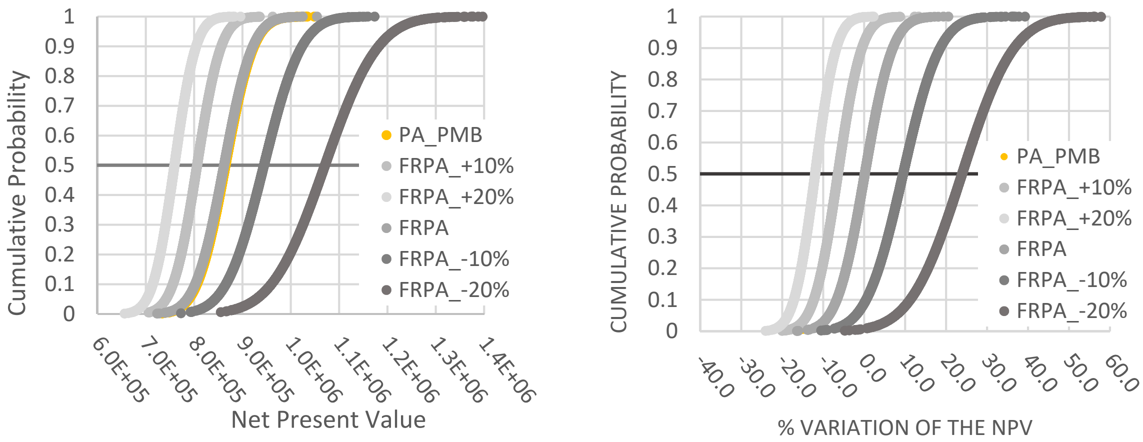


Figure 2. Sensitivity analysis of varying FRPA service life. a) NPV; b) NPV differences (in %) between FRPA and PA_PMB with the latter as the baseline

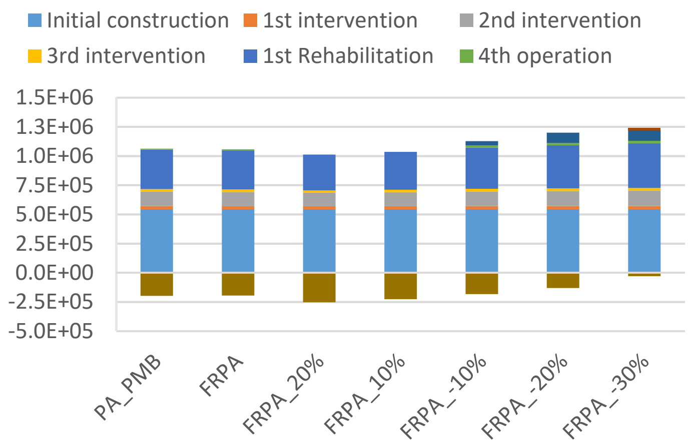


Figure 3. Cost distribution among the road pavement life cycle phases

Impact of User Costs

Figure 4 shows the results of the LCCA when the user costs are included in the assessment. As explained before, three different strategies for the workzone management have been considered. In the case of the strategy nº1, the user costs represents less than 5% of the total life cycle costs. A similar increase in the life cycle costs is observed than in the previous analysis in which the user costs were not included. However, when strategy 2 is applied, the user costs suffer a drastic increase, reaching in some cases the 40% of the total life cycle costs. The impact in the LCC of reducing the service life also increases due to the higher number of actuations during the analysis period and the large user costs associated to them. Thus, when the service life is reduced by 20% the NPV increases up to 40%.

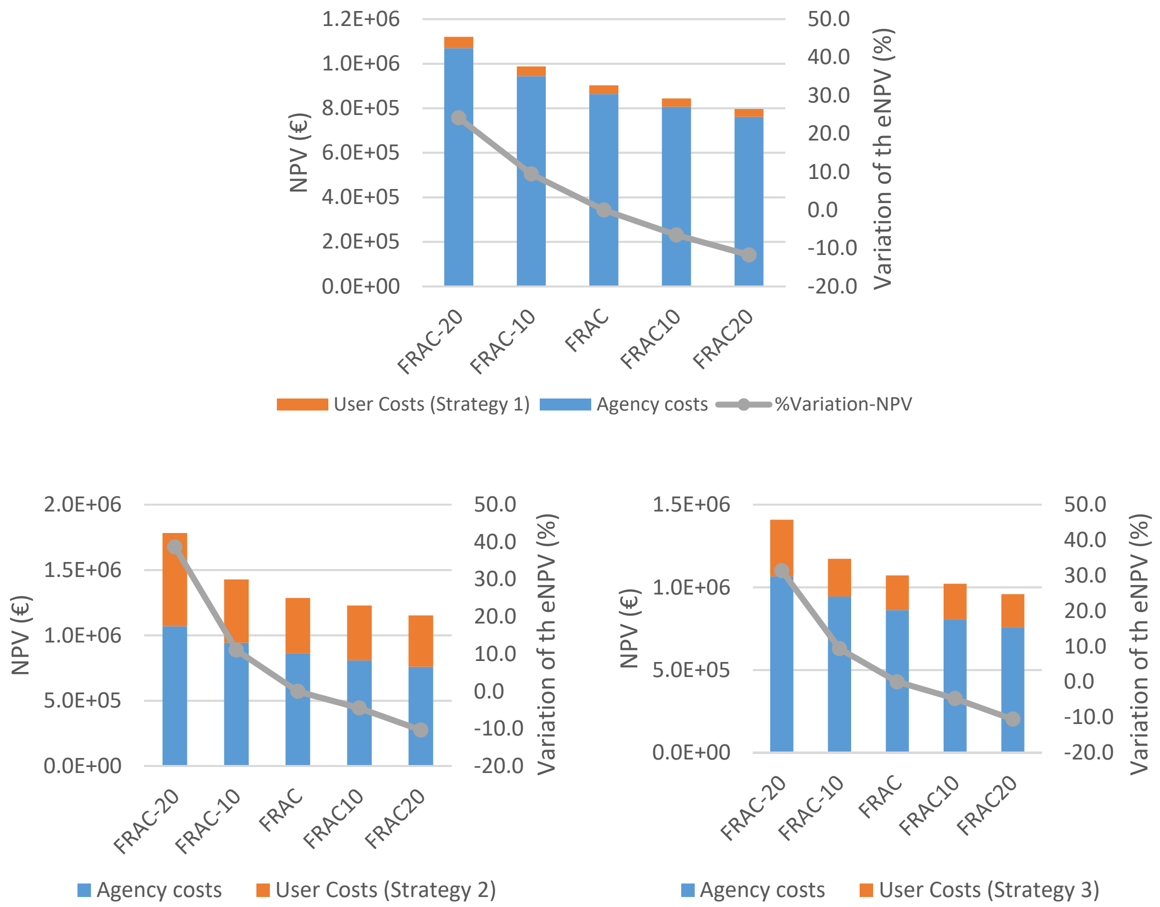


Figure 4. Influence of user cost in LCCA results for three different workzone management strategies

3.2 Case study Nº2: Asphalt concrete

The life cycle costs corresponding to the three alternatives tested in Norway are shown in Figure 5. The use of FRAM and PMB in the wearing course increases the NPV by 4.4% and 7.4% respectively. According to the laboratory tests carried out in the FIBRA project [9,10], the FRAC mixes designed for the wearing course presented better moisture and rutting resistance and a similar fatigue performance. Therefore, it is expected than the service life of the pavement will be enhanced when FRAC mixes are used instead of conventional AC mixtures with PEN. To evaluate the impact of the increase in durability of the pavement, a sensitivity analysis has been done increasing the pavement service life from 10 to 40% (. With a 10% increase in the durability, the NPV is reduced by almost 5% compared to the reference. Reductions of 10 to 20% in the NPV can be achieved with an increase in the pavement durability of 20 to 40% respectively. In Figure 7, the cost distribution among the different phases of road pavement life cycle is shown for the different alternatives and service life assumptions.

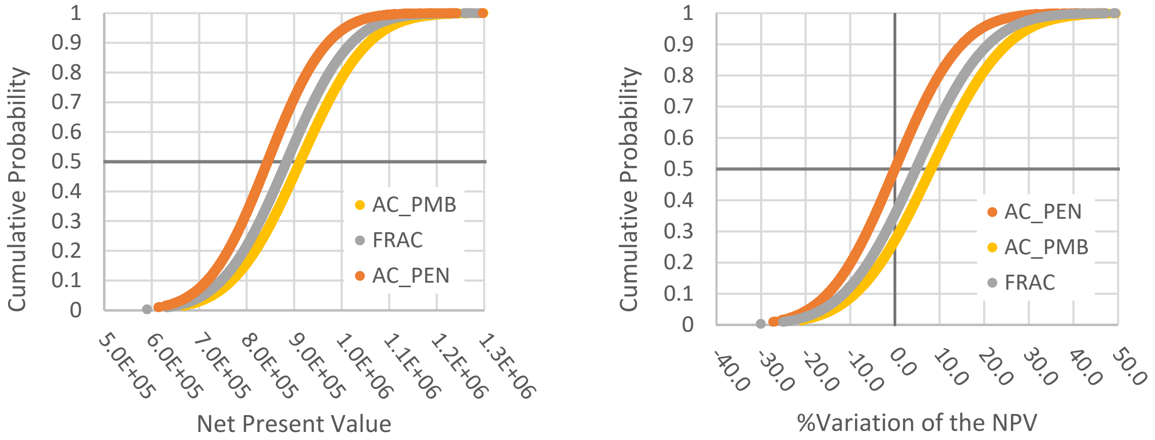


Figure 5. NPV for the three alternative pavements in Case Study N2: AC_pmb, AC_pen and FRAC. a) NPV; b) NPV differences (in %) between alterantives with AC_Pen as the baseline

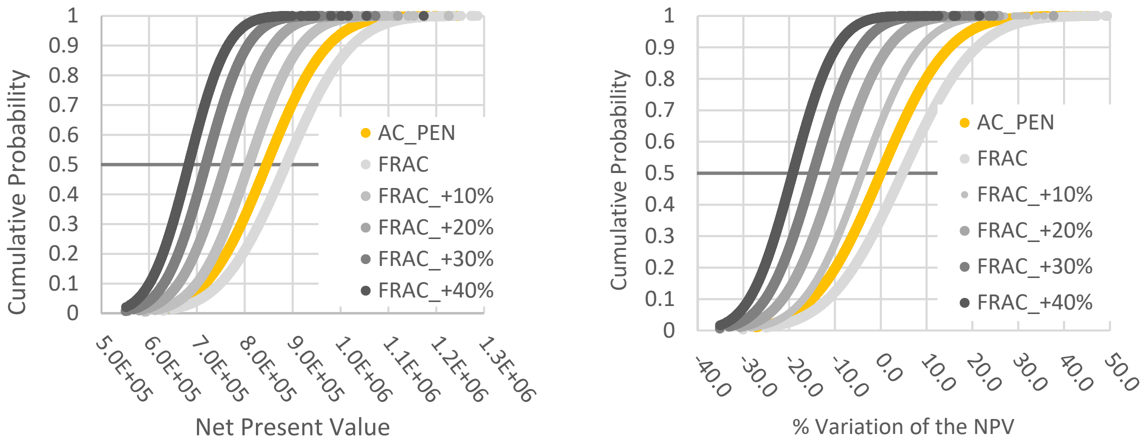


Figure 6. Sensitivity analysis of varying FRPA service life. a) NPV; b) NPV differences (in %) between FRAC and AC_Pen with the latter as the baseline

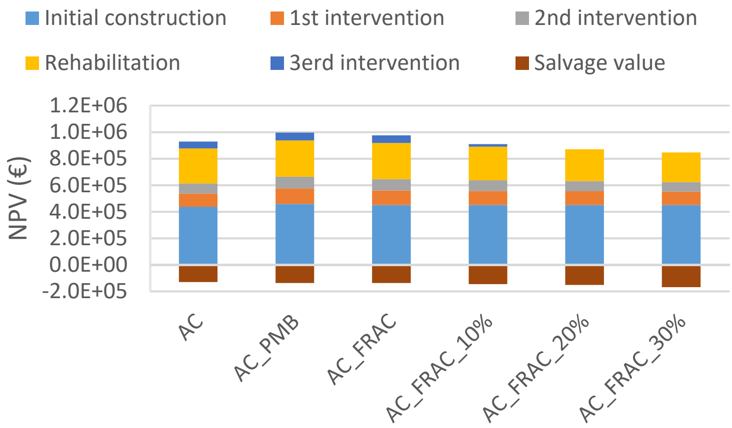


Figure 7. Cost distribution among the road pavement life cycle phases

4 Effect of pavement durability

In task 4.4 of the FIBRA project, a numerical simulation has been carried out to evaluate the long-term performance of different pavement sections where FRAM mixes in one or more layers have been implemented. The long-term behaviour of these sections have been compared to conventional layers with conventional PEN grade bitumen without fibres or high performance asphalt mixtures with PMB. The pavement responses to traffic and the fatigue damage and rutting evolution with time have been predicted by numerical analysis with FlexPAVETM.

One of the conclusions of this study recommends the use of FRAM in the wearing course and the use of PMB in the base asphalt layer [10]. This optimum pavement section (OPT) would reduce the %damage (in terms of fatigue) in 35% and the rutting depth by 21% comparing to a reference section built with conventional mixtures with PEN grade bitumen (AC_FLEX). The NPV of the two pavements are compared in Figure 8 including a sensitivity analysis in which the impact of assuming a higher service life (from 10 to 30%) is evaluated. When the service life of both pavements is assumed the same, the NPV of the optimum pavement, with a FRAM and an AC with PMB, is around 10% higher than that of the reference pavement. If the OPT pavement achieves a 30% increase in the service life, the NPV can be reduced by around 10%.

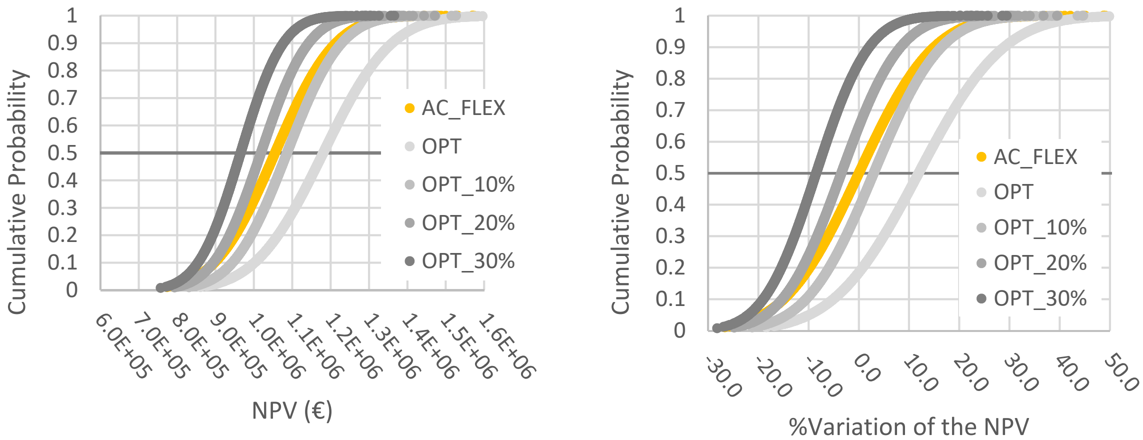


Figure 8. NPV comparison of two alternative pavements: OPT and AC_Flex. a) NPV; b) NPV differences (in %) between alterantives with AC_Flex as the baseline

5 Conclusions

In this study, the economic impact of using fibres to reinforce asphalt mixtures have been evaluated and compared to conventional mixtures with PEN or PMB bitumen. The analysis has been done on the pilot sections implemented in the FIBRA project including the specific conditions of each country and road.

By performing the LCCA on the two case studies within the FIBRA project, all the costs that are caused by the construction, maintenance and rehabilitation could be made visible. Comparing the three different cross sections, the study helps to identify the benefits and threats of the use of fibres to reinforce asphalt mixtures. From the results obtained, the following conclusions can be drawn:

- Very slight differences have been found in the life cycle costs of pavements sections that incorporate FRAM, asphalt mixtures with PMB or asphalt mixtures with PEN, when the same service life is assumed.
- For the FRAM to be economically feasible, a similar or a better performance comparing to the PMB should be obtained in Case Study N1. The long-term performance of the FRAM comparing to the PMB need to be assessed in the pilot sections in order to confirm the durability of both alternatives.
- In case study 2, the use of FRAM will be economically feasible if the pavement section with FRAM outperforms the asphalt mixture with PEN by at least 10%.
- The user costs can have a huge impact of the LCCA of a road pavement, being this impact largely dependent on the workzone strategy followed by the contractor. The higher the impact of user costs relative to the total costs, the increase in the durability of the pavement becomes more important in terms of the life cycle costs. Thus, in roads with high traffic volume and high-expected user costs, the use of materials with higher durability are highly recommended.
- The optimum pavement proposed in deliverable 4.2 [10] would result economically feasible only if the increase in the service life is higher than 15 or 20% compared to the reference, likely probable considering the results obtained by the numerical simulation in terms of the fatigue and rutting performance of the two pavements.

6 References

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