# Environmental Life Cycle Cost for Durable Porous Surface Layers with Synthetic Binders

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__Abstract:__ For noise reduction, the Netherlands use surface layers with a porous structure. The resulting surface layers have a shorter service life than non-porous surface layers. This causes frequent replacements and, therefore, high costs and congestion, which causes extra economical and environmental (value for time) damage. To limit these problems, this paper proposes to lengthen the service life by replacing the bitumen binder with a synthetic variant. Changing the binder to a synthetic variant is generally not considered because the binder is about 11 times more expensive than traditional. It is assumed that the resulting synthetic porous surface layer (SPSL) can have a service life that is prolonged with a decade. On the basis of indefinite life cycle cost calculations (NPV∞) on the cost effectiveness of the SPSL, it is concluded that the surface layer costs the same as traditional surface layers. The environmental life cycle cost even results in higher benefits because of less congestion nuisance (value for time). Due to a high variance in the results, it is recommended to develop SPSL for a niche market. At sharp curves and on and off ramps, a shorter service life can be cost effective and beneficial.

__Key words__: _Indefinite net present value (NPV∞); Noise reduction; Porous surface layer; Service life; Synthetic._

## Introduction

In the Netherlands many national motorways are located close to residential areas causing noise nuisance to the residents. Therefore, the Dutch government has a policy to use porous surface layers on these roads to decrease the noise nuisance [1]. This way more and higher noise barriers can be averted. Another benefit of these layers is the remaining capacity during times of rain because of the absence of splash and spray. An extra expected benefit cannot be proven; the absence of splash and spray does not generate more safety. There is no positive effect due to higher speed levels [2].

## The Problem

There are two major problems with the policy on porous surface layers. First, it is more expensive than dense asphalt because its heaviest used (slow) lane is already replaced after 10 years and the total surface after 14 years. Compare this to dense asphalt that requires replacement after 12 and 18 years, respectively [3]. Therefore, more regular replacement work is needed, adding to the direct costs.

The replacement work is also the cause of the second major problem: the user inconvenience and congestion caused by the surface layer replacement. In theory, five sections of the road

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network are under porous-surface-layer reconstruction simultaneously, as shown in the calculation below. Beside the replacements of the porous surface layers, the dense layers are replaced every 18 years. This makes the total locations under simultaneous construction even higher.

Theoretical calculation: There are 7848 kilometers of porous lane segments in the Netherlands [4]. There are three lanes in a standard two-lane motorway (two lanes plus shoulder). In total, one fourteenth of the total surface is replaced each year, resulting in 187 kilometers (equaling 7848_km_ /3 lanes /14 years) of a two-lane motorway that need to be replaced each year. (Replacements of the heaviest used (slow) lane are done overnight and are, therefore, not taken into consideration.) The two-lane motorways are replaced in 5-kilometer sections. These are 37 sections (equaling 187_km_/5_km_) of 5 kilometers each year. It takes 20 working days to replace a section when a so-called contraflow (4-0) system is used [5]. It is assumed that there are 150 working days in a year in which the conditions are good enough to replace the porous asphalt layer. Thus, in the available time window in the Netherlands, five sections (equaling 37 sections x 20 days/150 days) are under construction simultaneously in order to get all the replacement work done.

The problem is that construction locations should not be near each other because this can give a gridlock effect on the whole network. Therefore, five required reconstruction sections result in continuous juggling by the road authorities to limit the problems caused by these replacements. For example, the most intensively used parts of the road network are preferably replaced during holidays, but there are still parts of this intensively-used network replaced at normal working days.

Thus, the policy of using porous asphalt in The Netherlands causes higher direct costs and higher environmental costs (value for time) than dense service layers. Both effects are caused by the same problem: the lack of service life of the surface layer.

## Proposed Solution

Lengthening the service life, thus reducing the replacement needed

each year, results in less inconvenience for the users. Whether it is also cost effective depends on the construction method used. The service life of the structure underneath is 20 to 30 years [6]. It would, therefore, be optimal when the service layer has the same service life. The service life of porous asphalt (the traditional porous surface layer) is relatively short because of its ravelling characteristics. Ravelling is the loss of stones from the top of the surface layer as a result of a lack of cohesion of the binder and/or a lack of adhesion between the mineral aggregate and the binder [7]. Thus, the bitumen binder is an important component influencing the service life. Therefore, the emphasis of many studies is on how to modify the bitumen in order to increase the service life. However, the targeted increase in service life in these studies is not very ambitious, only several years.

A real impact could be expected by increasing the service life with more than a decade. Then the kilometers that have to be replaced for the porous surface layer each year, can be decreased by half. This requires a solution other than modified bitumen. New binders should be used with more durable cohesive and adhesive properties. This can prevent or delay the ravelling phenomenon. The authors propose a synthetic (two-component polymer) binder, because such a binder generally provides good adhesion through the reaction of the two components. Aging characteristics could be better because the chemical reaction can be completed after construction. In contrast to bitumen, that can still react with the oxygen in the air [8].

In the general consensus, synthetic binders are not tested because it is assumed that the higher binder costs (over 10 times as expensive) cannot be accounted for. The aim of this study is to determine whether the much higher costs of the binder can be compensated for by the cost savings of a service life that is 10 years longer, or by a decrease in environmental consequences. To determine this, a calculation is made for a fictitious synthetic porous surface layer (SPSL). Some assumptions are made regarding the characteristics of the proposed surface layer. The main assumptions are:

1. The binder is replaced by a synthetic binder with the same percentage in the mix as standard porous asphalt.
2. All other mix characteristics are unchanged in regards to the standard porous asphalt.
3. The service life is doubled.
4. The binder is 11.4 times as expensive.
5. All other used values are based on 2005 data provided by the Dutch roads agency Rijkswaterstaat.

When this study indicates that the higher costs of the binder can be compensated for, the study can be performed with real characteristics of a surface layer developed by a supplier. Such a study can give the supplier a reference whether their product can compete with the existing porous asphalts. Therefore, this study should be seen as a first step in deciding whether other steps towards developing a real mix should be taken.

## Overview

This article will approach the possibility of using a SPSL from five points of view.

At first the technical side will be explored. In this part, a short explanation is given on whether all the functional requirements of a porous surface layer can be met with SPSL.

The second part will cover the difference in direct costs between the new porous surface layer type and traditional porous surface layer types. The costs will be calculated for each surface layer as if it were constructed and maintained indefinitely, using life cycle analysis (NPV∞).

The third part of the article gives the environmental life cycle costs for each surface layer type. Therefore, the congestion costs during times of construction are added with each surface layer in NPV∞ (value for time). All other environmental costs are considered equal for each surface layer and are therefore not added in the calculations.

The fourth part will stipulate whether a surface layer can be used as a noise reducing investment or whether insulation of households should be used. Therefore, the minimum sum of dwellings with dB(A) reduction needed for a surface layer approval are calculated for each surface layer.

In the fifth part the large variance of the results is stipulated and a possibility for implementation in a niche market is given. The article ends with conclusions and a discussion.

## The Technical Side

Next to the durability and costs, the surface layer should meet all the functional requirements of a porous surface layer like skid resistance, evenness, noise reduction, visibility, durability, and process ability [9]. It is assumed that evenness, noise reduction, and visibility can be met with SPSL. The way SPSL behaves on these characteristics should be the same as for porous asphalt, since these are based on the macro structure of the mix.

Three requirements need special attention in the design: skid resistance, durability, and process ability. The skid resistance is important for safety. Road users should be able to steer and brake in all circumstances. When a SPSL is used, all aggregates will be covered with the binder after construction, similar to porous asphalt. This will result in a reduction of the skid resistance, which is temporary for bitumen layers (bitu-planing) because it will wear off [9]. However, in the case of SPSL, the binder will not wear off and the problem could be lasting. For this problem, a solution should be found. One solution could be changing the macro texture by using special crushed aggregate. This will create small points of the aggregate at the surface. Other solutions are possible too. A study performed by Delft University of Technology (The Netherlands) with a porous surface layer with a polyurethane binder on top of a bridge deck used sand treatment as a solution [10]. The kind of solution to use is up to the designer as long as the smooth micro texture on the aggregate does not result in a lack of skid resistance.

The authors believe that the durability requirement needs to be prolonged. Therefore, the raveling problem should be avoided. Raveling is the loss of stones from the top of the surface layer as a result of a lack of cohesion of the binder and/or a lack of adhesion between the mineral aggregate and the binder [7]. Thus, the binder should be good enough to resist the repetitive horizontal forces, combined with climatic effects. Next to that, the binder should be flexible enough to be able to follow the structure underneath. It is not yet certain what causes the raveling. Because of the porous
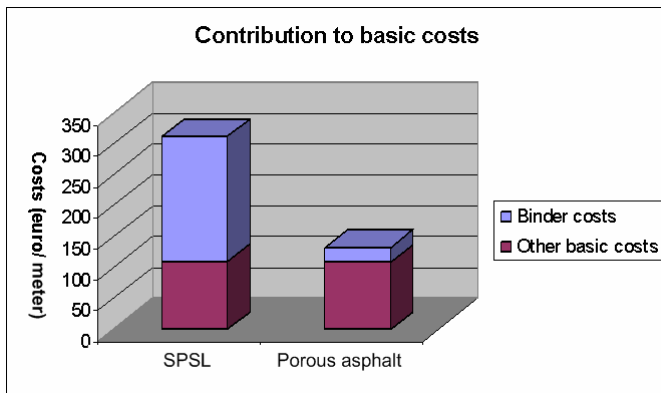
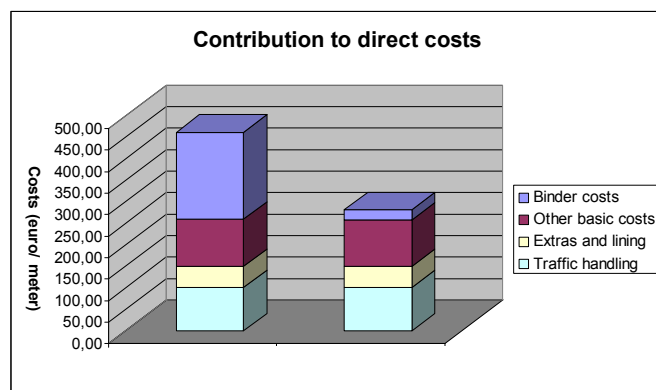**Fig. 1.** The Contribution of the Binder Costs to the Mix Costs.



**Fig. 2.** The Contribution of the Binder Costs to the Direct Costs.

structure, aging can be of influence. Aging characteristics could be better with a synthetic binder because the chemical reaction can be completed after construction. In contrast to bitumen, it can still react with the oxygen in the air [8]. It could be best to avoid polyurethane binders that use a reaction with oxygen because these binders can have the same aging problems. A longer service life also means that the surface layer should remain open for a longer time. To ensure that clogging problems do not occur, it is recommended to clean the surface layer regularly.

The process ability is a requirement that makes sure that the layer can be placed properly by machines. With a two-component binder, the hardening (reaction) time of the binder is most important. The so-called potlife should be long enough to spread and compact the layer without hardening. However, it should also be fast enough in order for the road surface to be used again by traffic directly after construction. Since the reaction time is dependent on the temperature [11], a different hardener is recommended at different temperatures. Finally, stickiness of the mixture to equipment and segregation problems should be prevented.

**The Indefinite Direct Costs Difference**

This study was performed to determine whether the high binder costs will result in high total direct costs. Therefore, the contribution of binder costs to direct costs of (re)placing a surface layer is estimated with figures from porous asphalt (re)placements used by the Dutch road agency Rijkswaterstaat. With the contribution of the binder costs to the direct costs and the cost difference between both

binders, all costs for both surface layers can be calculated. All costs for placement and maintenance of a surface layer for indefinite time are calculated using life cycle analysis.

**The Difference in Direct Costs**

For the calculations, a price of € 350 per ton bituminous binder is used. For SPSL, a synthetic binder of € 4000 per ton is used. This results in a synthetic/bitumen binder cost ratio of 11.4. Additional costs, internal road-owner costs and taxes are included in all costs by a fixed percentage. Adding these costs to the bitumen binder cost results in binder costs of € 575 per ton. The synthetic binder cost including additional costs, internal road-owner costs, and taxes is € 4918 per ton. (It is assumed that the absolute amount of additional costs and internal road-owner costs will not change with a more expensive binder. Therefore these costs are used as absolute amounts as present in the original binder costs and not as a percentage). This results in a synthetic/bitumen binder cost ratio of 8.55.

As can be seen in Fig. 1, the normal contribution of the bituminous binder to the costs of the mix is about 33%. When all other cost components remain equal, the contribution of the synthetic binder to the mix is 80%. The cost ratio between the two mixes is then 3.44.

Basic costs of placement and replacement are not only based on the product, but also based on the costs of cutting the old layer, adding a bitumen layer with stones, and the equipment and labor of adding the product. Adding those costs to both prices gives a cost ratio of 2.36 between the replacements of both layers. This can be seen in Fig. 2. Cost calculations are all based on a standard two times two-lane motorway and are stated per meter of motorway for one direction (12.5 meter width).

**The Calculation of Indefinite Time Horizons**

Given inflation, costs at different time horizons have different effects on the total costs. This can be accounted for when costs are represented into indefinite net present value (NPV∞) and calculated in accordance with Eq. (1) [12]. For this equation, a fixed time horizon was deliberately left aside because fixed time horizons can lead to an unfair comparison. The formula incorporates Eq. (2) that can be changed for each calculation to the service life of the material. Therefore, the equation uses a full replacement cycle of a product. In this case, a full replacement cycle starts after initial placement with replacing the right lane and replacing the total surface later on. After that, a new full replacement cycle starts. With Eq. (1), the replacement cycle is accounted for as many times as needed, until the effect of time makes the extra cycle insignificant.

$$NPV\infty = I + NPV°/(1-(1/(1+r)T)) \qquad (1)$$

where,
NPV∞ = Indefinite Net Present Value,
I = Initial costs year 0,
NPV° = Net Present Value of the first full cycle after initial costs,
r = Discount rate standardized at 0.04,
T = Time between time 0 and the last year of maintenance cycle,
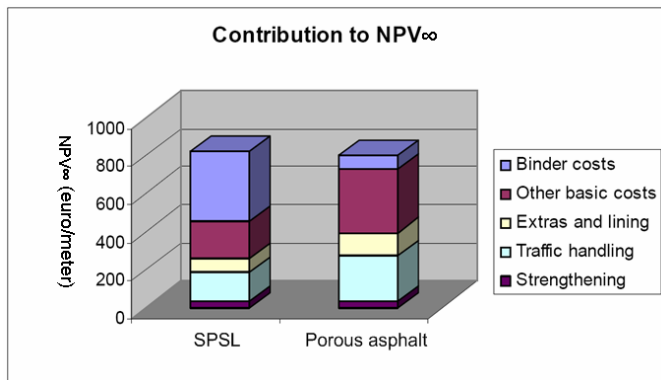
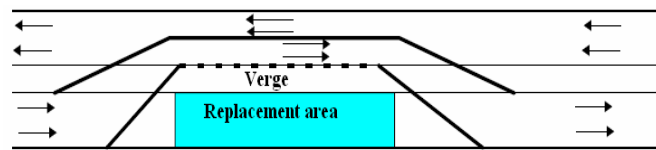**Fig. 3.** The Contribution of the Binder Costs to the NPV∞.



**Fig. 4.** Schema of a Contraflow (4-0) on a Standard Two-Lane Motorway.

**Table 1.** The Congestion Costs for (re)Placing per Traffic Category.

|  | Standardized Vehicles Per Day | Vehicle Hours Los Per Day [5] | Congestion Costs € Per Meter |
|---|---|---|---|
| Category I | x < 25000 | 0 | 0 |
| Category II | 25000 < x < 48000 | 0 | 0 |
| Category III | 48000 < x < 86000 | 1000 | 750 |
| Category IV | x > 86000 | 8000 | 6000 |

and

$$NPV° = \Sigma t \rightarrow t° \ (C*(1/(1+r)T)) \qquad (2)$$

where,

NPV° = Net Present Value of the first full cycle after initial costs,
$\Sigma t \rightarrow t°$ = Summation of t after year 0 and until the end of the cycle,
C = Costs of maintenance at time T stated in euro of time 0,
r = Discount rate standardized at 0.04, and
T = Time between time 0 and the year of maintenance.

### The Results of the Indefinite Direct Costs

In this study, the standard maintenance protocol of the Dutch road agency Rijkswaterstaat is used. The right lane of a porous asphalt surface is replaced after 10 years, and the total surface is replaced after 14 years [3]. A double service life is assumed for SPSL. Therefore, the right lane of SPSL is replaced after 20 years, and the total surface after 28 years.

Total direct costs at times of placement and replacement are based on known figures from Rijkswaterstaat for these costs. The costs are all stated in euros with a year 2005 value and an indication of the year they are spent, based on the standard maintenance protocol. A distinction is made in these figures for the origin of the costs. Costs that are the same for SPSL and porous asphalt, like traffic handling and lining, get equal values for both. The basic costs of (re)placement are different for both surface layers. Costs for

porous asphalt are known, and costs for SPSL are calculated from the costs for porous asphalt with the cost ratio 2.36 as mentioned above.

The calculations in this study include strengthening of the structure beneath the surface layer every 20 to 30 years. For the calculations, it is assumed that strengthening is done by adding an asphalt layer beneath the surface layer.

The impact of the binder costs on the total direct costs for porous asphalt and SPSL are presented in Fig. 3. It can be seen that although the binder costs are higher, the total costs are almost equal. This is because the other costs are lower since the surface layer is replaced fewer times. This results in an indefinite porous asphalt/TCGC cost ratio of 1.03.

### Environmental Costs

As explained in the introduction, porous surface layers are an environmental measure against noise nuisance and congestion at times of rain. These two effects are considered equal between both types of surface layers. Therefore, there is no use to monetize these in this comparison study. However, the economical possibilities of using a surface layer as a noise reducing measure are shifted when the noise reduction changes. Therefore, the economical measures are explained in next section and this section will focus on the environmental consequences that are different for the surface layers.

The major difference between porous asphalt and SPSL is the service life and, thus, the amount of maintenance. Replacing the surface layers less frequently will result in less congestion due to replacements. This is accounted for with value of time for road users. Secondly, the congestion can result in extra emissions. Besides that, there will also be a difference in emissions in the construction process and in the life span of the material. However, emission details are not accounted for as they go beyond the scope of this study.

It is presumed that replacements of the right lanes are done with lane closure systems at night. This is assumed to give no real congestion, thus this will be kept out of the congestion costs calculations. The replacement of the total surface is done with a contraflow (4-0) system because of safety, quality, and efficiency reasons [5]. Fig. 4 gives a schema of a contraflow (4-0) on a standard two-lane motorway. Replacing 5 kilometers of surface layer costs 20 working days. The capacity of two lanes is reduced to 3500 vehicles per hour per direction [5]. Dependent on the traffic category of a road, this could cause problems, as can be seen in Table 1. With traffic categories 1 and 2 (lowest traffic volumes and up to 48,000 vehicles per day), the replacement will not cause problems. With traffic category 3 (up to 86,000 vehicles per day) and 4 (above 86,000 vehicles per day), congestion problems will occur. A loss of an hour for a vehicle in the Netherlands is represented by 15 euros [13]. Therefore, replacing the surface layer can cost up to 6,000 euros extra per meter in vehicle losses. With the standard maintenance protocol and these figures, the NPV∞ for replacement congestion cost is calculated for each surface layer. The NPV∞ at per traffic category per meter of motorway are presented in Fig. 5. This results in an indefinite environmental porous asphalt/TCGC cost ratio of 0.80 at high traffic volumes.
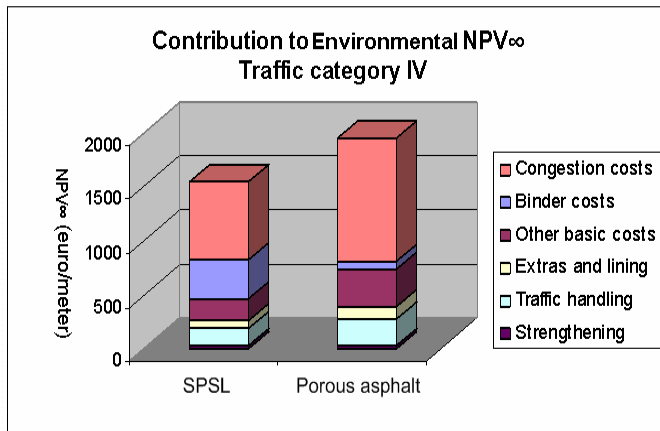
**Fig. 5.** The Contribution of the Binder Costs to the Environmental NPV∞ at High Traffic Volumes.

## The Noise-Reducing Investment

Porous asphalt is used because of its noise reduction capabilities. The same will hold for SPSL. The one layer systems give an initial 4 dB(A) noise reduction [14]. The extra costs of the surface layer above the costs of dense asphalt can be considered as a noise-reducing investment. Not all investments are considered economical; therefore, the Netherlands uses an investment criterion to determine if an investment should be made. The investment criterion in the Netherlands states that when a noise-reducing measure costs less than € 5,700 per dwelling per dB(A) reduction, the investment can be taken [15]. Otherwise the surface layer is not approved and the dwellings should be insulated. This criterion only accounts for noise reduction that takes the dwellings back within a prescribed norm value. More reduction is a bonus but not accounted for.

Depending on the amount of dwellings next to the motorway and the amount of dB(A) that these dwellings should be reduced with, the surface layer can or cannot be used as a noise reduction measure. It is interesting to find out when the investment for noise reduction can be taken with a surface layer (the minimum requirement). The minimums can be calculated with a reversed calculation of the investment criterion. The minimum for porous asphalt is 26 houses per kilometer and for SPSL it is 28. Beneath the minimum the dwellings will be insulated. The ratio stays similar to the ratio at the direct costs.

## The Variance of the Results

The results as presented in previous sections are based on a mix with these assumptions:
1. The binder is replaced by a synthetic binder with the same percentage in the mix as standard porous asphalt.
2. All other mix characteristics are unchanged in regards to the standard porous asphalt.
3. The service life is doubled.
4. The binder is 11.4 times as expensive.
5. All other used values are based on 2005 data provide by the Dutch roads agency Rijkswaterstaat.

One or more of these assumptions could be different, which in turn would result in different outcomes. The results especially depend on the price of the binder and the service life. The actual variance of the results is somewhere between minus 20% and plus 30% of the mean results as presented in this article. Therefore, there are some risks to producing an SPSL. Small changes in service life and binder costs can result in more expensive surface layers. Therefore, the mix can only be used when these values can be described accurately. This will make the development procedure long, because the service life can only be proven in a real situation. A service life of 20 years for the right lane and 28 years for the other lanes is needed. This gives a development procedure of 30 years.

## Other Possible Surface Layers

There is, however, a more favourable possibility. Porous asphalt is a one-layered system. Next to porous asphalt, two-layered porous asphalt is used with an extra 2 dB(A) of noise reduction [14]. However, this surface layer is even more expensive and has a shorter service life. SPSL can also be made in a two-layered system (two-layer SPSL) with the same extra noise reducing capacity but with potentially a longer service life. There is also the possibility of combining the two systems. This results in a top layer with a synthetic binder and a bottom layer of traditional porous asphalt. The two-layer combination is used in the comparison to limit the extra direct costs of a SPSL surface layer.

For this alternative, it is assumed that the raveling phenomenon can be stopped by embedding just the top stones with a stronger binder. It is presumed that the horizontal forces in the lower centimeters can be resisted by the bituminous binder. However, the lower layer has a bituminous binder that is still under influence of the environment. Therefore, the aging of this binder could cause a shorter service life. It is not clear why two-layer porous asphalt has a shorter service life than porous asphalt. Therefore, two service life cycles are considered for the two-layer surface layers.

When the lower service life is caused by a fatigue type of failure, for instance because of the use of smaller aggregates, this can manifest itself in two-layer SPSL and two-layer combination. Then the service life is estimated to be twice the one of two-layer porous asphalt (7 and 11 years [3]), being 14 and 22 years. When the lower service life is caused by the production of a thinner layer with bitumen (cooling characteristics), then it can be expected that two-layer SPSL is not hindered by this problem, and the same service life that is relevant for standard SPSL (20 and 28 years) is relevant here. A "22" is added to the names of the calculated costs for two-layer systems with a service life of 14 and 22 year. The cost calculations for two-layer systems with the same service life as SPSL will be referred to as two-layer SPSL 28 and two-layer combination 28.

The indefinite direct costs results are given in Fig. 6. (These are the costs at category 1 and 2). Most of the two-layered systems are less expensive than two-layered porous asphalt. Also, most are more expensive than porous asphalt. At the highest traffic volumes, they are all less expensive than two-layered porous asphalt and most are less expensive than porous asphalt. As given in Fig. 7, most surface layers can compete with porous asphalt as a noise reducing investment. This result originates in the extra noise reduction of a
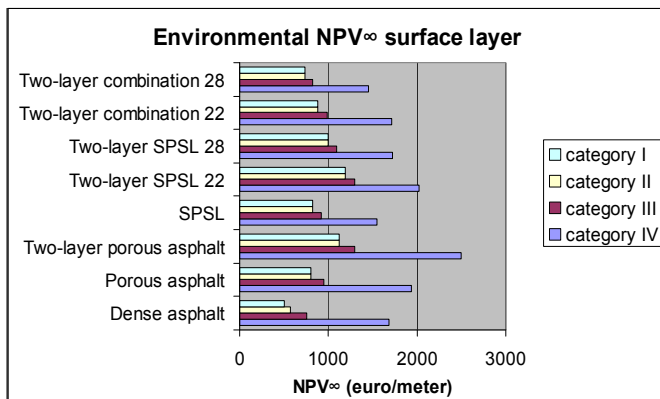
**Fig. 6.** The Environmental NPV∞ of All Surface Layers at All Traffic Categories.
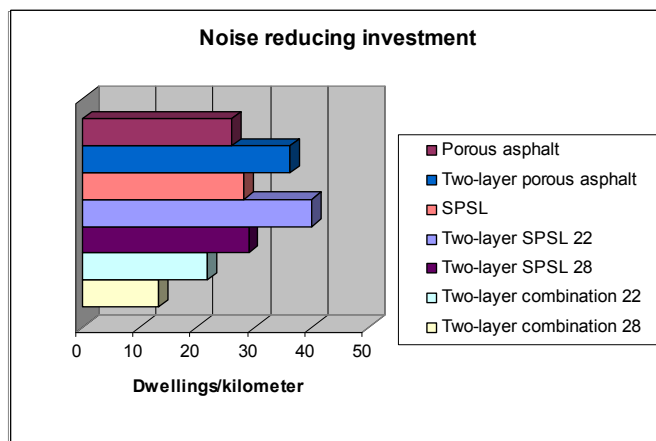


**Fig. 7.** The Minimum Dwellings Per Surface Layer at Maximum Noise Reduction.

two-layered system. This figure is without congestion costs, so combined with Fig. 6, the surface layers can be impressive.

## Implementation

The use of SPSL-type surface layers can be cost effective. However, this is dependent on a long service life, and, therefore, a long development procedure is needed. This problem can be solved. There are places on the motorways where horizontal forces are so high that using porous asphalt will result in early raveling. These places are on/off ramps and sharp curves. At these niche markets, a shorter service life can be cost effective. When noise reduction is needed at these places, because there are dwellings that should get noise reduction, other measures should be taken. The only possible noise measures left are insulation and noise barriers. Both these measures can involve high costs. SPSL-type surface layers probably will have good resistance to early raveling.

When that is the case and when a two-layer SPSL surface layer is used on an on/off ramp, a service life of 7 years will give indefinite direct costs equal to the indefinite direct costs of a 1-meter high noise barrier. This 1-meter noise barrier can give a reduction of about 2 dB(A) [16]. A surface layer with two-layer SPSL gives a reduction of 6 dB(A). Thus, the reduction with this kind of surface layer is larger while it costs the same to maintain them indefinitely.

Hence, the same noise reduction would be more cost effective with a SPSL-type surface layer. This means that with a development program of only 8 years, a SPSL surface layer can be developed and validated that is useful in a niche market and is cheaper than the current alternatives.

The Dutch motorways have 2,278 on and off ramps (unpublished data from information telephone line Rijkswaterstaat). Placing a 6.25-meter width of two-layer SPSL for a length of 500 meters; replacing that every 7 years will need a one-time investment of 350,000 euros per ramp. Placing a 4-meter high noise barrier gives the same noise reduction [17]. The costs of placing and replacing that barrier every 30 years over a length of 500 meters are 1.4 million euros (assuming noise barrier costs 492 euros per square meter [18]). Hence, the possible cost savings for the Netherlands is somewhere between 0 and 2.3 billion euros, depending on the required reduction and noise barrier decrease at the specific locations. A service life that exceeds 7 years and possible use in other places, like sharp curves, could result in even higher benefits.

## Conclusions and Discussion

The two surface layers are almost equal in indefinite direct costs when a SPSL surface layer is made with these assumptions:
1. The binder is replaced by a synthetic binder with the same percentage in the mix as standard porous asphalt.
2. All other mix characteristics are unchanged in regards to the standard porous asphalt.
3. The service life is doubled.
4. The binder is 11.4 times as expensive.
5. All other used values are based on 2005 data provide by the Dutch roads agency Rijkswaterstaat.

There is, however, a difference in the costs they cause for congestion at traffic categories 3 and 4. SPSL causes 30 to 400 euros NPV∞ congestion costs, less than porous asphalt per meter motorway. Two-layer combination (bottom layer porous asphalt and on top a layer of SPSL) is 9% less expensive to 10% more expensive in indefinite direct costs than porous asphalt. The congestion costs difference can be the same as with SPSL.

However, the real direct costs of the mixtures are highly dependent on the real mix characteristics and real service lives. Therefore, there is a high risk to developing a mixture for use on the entire motorway. Development can give high cost savings but could also result in high extra costs. At a niche market, where the horizontal forces on the motorway are too high for porous asphalt, more cost savings can be expected. This is because those cost savings should be compared to other noise-reducing measures like noise barriers. Thus, the development and validation for the niche market, where porous asphalt is not an option, could generate a cost savings for the Dutch government. Since a SPSL surface layer is cost effective when it stays in tact for 7 years in the niche market, a test setting could prove its cost effectiveness within 8 years.

Further development of the mixtures and proven service life in the niche market can give results that indicate a possible use for the entire motorway. When the mixtures are good enough to be used for the entire motorway, they will probably have a service life of well over 20 years. In that case, problems due to frequent replacements will become history. Because of this, development of these kinds of

mixtures should be stimulated. Once these mixes are developed the calculations can be done again. The results will present the real benefits of SPSL. The government and society as a whole will benefit from less inconvenience, less congestion, and budget savings.

## Acknowledgements

## References

1. Swart, J.H., Fafié, J.J., Dohmen, L.J.M., van Dommelen, A.E., Doorduijn, J., van Gogh, F., Eikelboom, J., and Henny, R.J., (1998). Economische Afweging van Alternatieve Verhardingsconstructies, *Handleiding Wegenbouw, Ontwerp Verhardingen*, pp. 1-6, 4th Rijkswaterstaat - Dienst Weg en Waterbouwkunde, the Netherlands.
2. Besseling, P., Groot, W., and Verrips, A., (2004). Bijlage 2: Kosten en baten van ZOAB, *Economische Toets op de Nota Mobiliteit*, pp. 83, CPB, Den Haag, the Netherlands.
3. Hofman, R., Fafié, J.J., Sule, M.S., Hooghwerff, J., Kegel, J.C., Langebach, W.J., and Hermens, P., (2005). Bijlage 2: Berekening Kosteneffectiviteit, *IPG - advies Toepassing 2L ZOAB op Het HWN Hoofdwegennet - Deel 2: Toelichting Bij Het Advies*, pp. 29, Dienst Weg en Waterbouwkunde, the Netherlands.
4. Verra, N., van den Bol, M., and Gaarkeuken, B., (2003). Inleiding, *De levensduur van ZOAB*, pp. 4, Dienst Weg en Waterbouwkunde, the Netherlands.
5. Dienst Weg en Waterbouwkunde, (2000). Thema's, *Rapportage contraflow. Uitvoering Groot Onderhoud op Autosnelwegen Met Twee Rijbanen en Twee Rijstroken*, pp. 13-18, Dienst Weg en Waterbouwkunde, Delft, the Netherlands.
6. Hooghwerff, J., (2004). Basisgegevens Kosten van Wegdekken, *Kosteneffectiviteit 2-Laags ZOAB IPG - Advies 2005*, pp. 4, Dienst Weg en Waterbouwkunde, the Netherlands.
7. C.R.O.W., (1996). Hoofdtekst, *Zoab Rest Levensduur*, pp. 25, C.R.O.W., Ede, the Netherlands.
8. Hendriks, C., (2004). Construction Materials, *Materials for Road an Hydrolic Constructions*, pp. 181-182, Aeneas - Technical publishers, Boxtel, the Netherlands.
9. VBW Asfalt, (2000). Hoofdtekst, *Asfalt in Wegen en Waterbouw*, pp. 11-21, VBW Asfalt, the Netherlands.
10. Ven, M.F.C. van de, Medani, T.O., and Molenaar, A.A.A., (2004). Open Synthetic Wearing Course, *TRB 2004 Annual Meeting*, pp. 3, Washington, DC, USA.
11. Pasetto, M. and Spinoglio, S., (1997). The Use of a Synthetic Aggregate in No-Skid and Noise Abatement Microsurfacings for Road Maintenance, Performance Improvements and Environmental Impact, *Proceedings 4th ISSA (International Slurry Surfacing Association) World Congress*, pp.5, Paris, France.
12. Swart, J.H., Fafié, J.J., Dohmen, L.J.M., van Dommelen, A.E., Doorduijn, J., van Gogh, F., Eikelboom, J., and Henny R.J., (1998). Economische Afweging van Alternatieve Verhardingsconstructies, *Handleiding Wegenbouw, Ontwerp Verhardingen*, pp. B3.1-2-B3.1-4, 4th Rijkswaterstaat - Dienst Weg en Waterbouwkunde, the Netherlands.
13. Korse, M.J., Schermers, G., Radewalt, N.M.D., de Hoog, A., and Alkim, T., (2003). Overwegingen, *Op koers!?: Resultaten van de Proef Met Het Lane Departure Warning Assistant systeem*, pp. 44, Adviesdienst Verkeer en Vervoer, the Netherlands.
14. Hofman, R., Fafié, J.J., Sule, M.S., Hooghwerff, J., Kegel, J.C., Langebach, W.J., and Hermens, P., (2005). Toelichting Advies, *IPG - Advies Toepassing 2l ZOAB op Het HWN Hoofdwegennet - Deel 1: Advies*, pp. 3, Dienst Weg en Waterbouwkunde, the Netherlands.
15. Hooghwerff, J., (2004). 7 Aandachtspunten, *Kosteneffectiviteit 2 - Laags ZOAB IPG - Advies 2005*, pp. 21, Dienst Weg en Waterbouwkunde, the Netherlands.
16. Hooghwerff, J., (2004). Praktijkvoorbeelden, *Kosteneffectiviteit 2 - Laags ZOAB IPG - Advies 2005*, pp. 15-18, Dienst Weg en Waterbouwkunde, the Netherlands.
17. Acoustics Group of the University of Sheffield, (2006). Calculation Formula, Sound Reduction Behind an Environmental Noise Barrier, www.acoustics.group.shef.ac.uk/barriers.php.
18. Hooghwerff, J., (2004). IPG kostenbenaderingen, *Kosteneffectiviteit 2 - Laags ZOAB IPG - Advies 2005*, pp. 7, Dienst Weg en Waterbouwkunde, the Netherlands.