Decision support model for road pavements based on whole life costing, life cycle assessment and multi-criteria analysis

Adrian J. van Leest
CROW Technology Platform, the Netherlands
vanleest@crow.nl

Steef B. van Hartskamp
Province of Noord-Brabant, the Netherlands
svhartskamp@brabant.nl

Joep P.R. Meijer
theRightenvironment, U.S.A
joepmeijer@therightenvironment.net

Abstract
In response to the growing importance of sustainable undertaking, purchasing and building, designers, consultants and pavement managers now tend to make more rational decisions than before when comparing the pros and cons of the construction, maintenance and management of various types of road pavements. Asphalt and concrete pavements offer specific advantages that need to be compared when selecting the most favourable option for long-life pavements. Financial decisions can be based on an analysis of whole life costs, but other important aspects are more difficult to quantify. Factors such as construction risks, the need for maintenance and its impact on accessibility, congestion, road user safety and energy emissions must be qualified and weighted when conducting a comprehensive comparison of pavement performance. A CROW study group has developed a decision support model that can be used to take into account economic, technical, environmental and other factors when selecting a certain type of road pavement. Besides the traditional road pavement materials that can be taken into account, also new materials like light-weight embankment materials, low temperature asphalt, steel fibre reinforced concrete and concrete with recycled aggregates are available in the materials database. The paper describes the methodology used and presents three examples of the model's application in the Netherlands.

Key words
Whole life costing / multi-criteria analysis / life cycle assessment / sustainable building / environmental impact / decision support model

1. Introduction

The Netherlands has an abundance of experience in road pavement design. When selecting a road pavement, there are often several possible solutions available that meet the technical preconditions, such as bearing capacity, durability, safety and sustainability.

In recent years – partly within the present-day context of sustainable undertaking, purchasing and building – a growing number of factors has been taken into consideration when selecting road pavements, such as costs (including maintenance), environmental impact, ecological value and landscape impact. Incorporating these factors into the decision-making process complicates the task of selecting the most favourable option.

Under the management of CROW, a Decision Support Model for Road Pavements was developed to clearly map out the factors identified above. A Microsoft Excel-orientated computer program (CROW, 2005) based on this model has been developed to assist users. This objective and transparent model can be used when selecting from a variety of road pavements: asphalt, concrete or block paving, also new materials like light-weight embankment materials and low temperature asphalt are available in the materials database. The model has been updated in 2008 with new materials like light-weight embankment materials and low temperature asphalt that are now available in the materials database.

The purpose of this paper is to introduce and publish the methodology of weighting several decision criteria, in the quest for the most favourable road pavement when it comes to cost, environmental impact and other factors. It is considered to be an objective model to decide between various road materials for several road types (from motorways to cycle tracks) in order to determine 'total costs of ownership' during the life-time.

2. Objectives of developing a decision support model for road pavements

In recent years decisions have been made by road authorities as well as contractors and consultants in order to find the 'best' pavement solution in a certain project, considering the circumstances. However there was no such thing as an uniform or universal approach or methodology for weighting several criteria, adding them up and decide what to do.
On the one hand this concerns technical and economical aspects, on the other hand also other factors, that are hard to quantify, have to be taken into account. Examples are: CO2-emissions at production and construction of pavement materials (green house effect), vibration and sound level when using the road pavement, traffic measures and congestion costs because of maintenance, mobility of people and availability of the road, global and local environmental aspects.

Reliable data on environmental impact is limited available and often provided by industry itself. This is not the most objective source of information, so to speak. Road authorities have sometimes different departments for new construction and maintenance/ rehabilitation, and also budgets for these two are separated. Some contractors prefer to supply what they want, not what the customer needs.
So all in all this makes it not easy to come to an objective and integral decision between pavements. This was the most important reason for CROW and involved market parties

to develop an uniform and transparent decision support model for pavement engineers and policy makers.

The Decision Support Model for Road Pavements is designed to enable road engineering designers, managers, consultants and decision-makers to clearly outline and take into consideration such factors as environmental impact determined using life cycle assessments (LCAs), cost effects based on life cycle costing (LCC) and the consequences of any other factors when comparing various pavement structures (design options). The model should be used at the beginning of the geometrical and structural design phase for construction or rehabilitation when pavement materials are chosen and layer thicknesses are being determined.

A comparison of road pavements can be performed in this model for all road types, including motorways, provincial highways, municipal roads, country roads and cycle tracks. For this, the user must enter the data on the composition of the pavement, subbase and sand bed for the road type in question (figure 1). The program does, however, include default road pavement structures.

Structure in layers ga op de kolomtitel staan >>>>>>> voor een korte toelichting		thickness (m)		Environmental costs costs	share	Density (kg/m3)
Removal of existing pavement						
concrete cracking and seating (ready for overla		0,230		1,2E+02	0%	2425
double click to select material		0,000				0
double click to select material		0,000				0
double click to select material		0,000				0
double click to select material		0,000				0
New pavement						
Concrete C35/45, dowels + tiebars	4/22	0,260	2,0%	2,9E+05	100%	2444
double click to select material		0,000				0
double click to select material		0,000				0
double click to select material		0,000				0
double click to select material		0,000				0
double click to select material		0,000				0
double click to select material		0,000				0
Base course						
double click to select material		0,000				0
double click to select material		0,000				0
Sand subbase						
double click to select material		0,000				0
TOTAAL				**2,9E+05**		

Figure 1 Pavement structure data

3. Decision Support Model methodology

Using the data entered by the user for road type, layer thicknesses, materials and other criteria, the program calculates the standardised costs (for investments, maintenance, rehabilitation, demolition), environmental impact and other factors. This means that before comparing the scores, the data must first be converted into comparable units (standardisation). The decision support model achieves this by dividing each criterion's score by the maximum score generated for the design options entered.

Environmental impact is calculated using the TWIN^{2002} method. Developed by the Netherlands Institute for Building Biology and Ecology (NIBE, 2002), this method quantifies all environmental consequences, expressing them as a single number. In addition to quantitative data derived from environmental LCA studies, the $TWIN^{2002}$ method also takes non-quantifiable data into account, enabling a thorough assessment of structures, building products and components. The fact that the $TWIN^{2002}$ method is able to assess both quantifiable data (e.g. emissions) and qualitative aspects (e.g. nuisance for road users, people living near roads and damage to the environment) makes it the most comprehensive tool currently available to make an objective assessment of the environmental properties of building products. Examples of environmental aspects are: disturbance or nuisance due to production of noise, light or unpleasant smell, land use, exhaustion of raw materials and energy resources, emissions into the air (green house effect) during production, transport, construction and use of the pavements.

The program automatically calculates ‘environmental impact’ on the basis of both material-specific LCA data (RHED 2003) and the $TWIN^{2002}$ method.

The ‘costs’ (e.g. costs for construction, maintenance, rehabilitation and demolition) are also automatically calculated for each material. The user can enter any additional costs and adjust all unit prices. Total investment and all other costs are calculated on the basis of net present value.

The ‘other factors’ encompass a range of defined effects on construction, maintenance, nuisance and road user safety. The user of the software can, possibly in consultation with a specialist, rate these effects according to a seven-point scale. This enables the user of the program to indicate any improvements or changes for the worse with respect to the reference design option. Examples of other factors are: ability of staged construction, risks that can occur during construction and maintenance, duration of maintenance actions, possibility of diverting traffic easily (detours / disturbing traffic flow), traffic and road worker safety, road user aspects like visibility, comfort (evenness, rutting), accessibility of cables and pipes underneath the pavement, noise reduction, air quality (dust and smell).

4. Assessment method

The assessment criteria results are standardised before they are weighted. The standardisation of the scores generated as part of the qualitative assessment of the elements of the criterion ‘other factors’ is based on the assessment value of the reference situation. This qualitative assessment generates results expressed in terms of plusses and minuses which must first be converted into numeric values.
The program then calculates and presents the scores for each assessment criterion, clearly showing the interrelationships and revealing areas for improvement.

The multi-criteria analysis (MCA) method facilitates the comparison of final scores of various assessment criteria (costs, environmental impact and other factors).
A maximum of six design options can be compared for each basic data set, one of which is designated the reference option. Given the high degree of data input flexibility, it is essential for those responsible to critically assess the reliability of the end results. It is then possible to set the relative weight of the assessment criteria (costs, environmental

impact and other factors). Given the subjective nature of relative weights, they should be used judiciously.

In 1995, the Dutch Government decided that the economic assessment of national projects must take into account a 4% discount rate. For this reason, the program uses a default discount rate of 4%. The rate of inflation is set at 0%. The guidelines of other European countries stipulate using a different discount rate, e.g. Germany (3%), UK (6%), Denmark (7%) and France (8%). The European Community maintains 5% as an appropriate rate. A brief analysis of the program revealed that, given the same rate of inflation, variations in discount rate generate different results.

5. Importance of weighting

Criteria weighting evokes quite a bit of resistance. Its subjective nature is used to argue against the use of any form of weighting. Choices, however, always involve some degree of weighting. For instance, using no weighting factors in the model is actually equivalent to using a weighting factor of one. To facilitate a thorough analysis and interpretation it was decided that the program presents the user with the option of looking at both the weighted and non-weighted results.

The decision support model bases its assessment of the 'environmental impact' criterion on the environmental costs incurred, determined by calculating the financial costs necessary to prevent or remediate a certain emission. Although these are not out-of-pocket costs, they can nonetheless play a role in the comparison process.

Users of the software program must enter their own weighting set for the assessment of the 'other factors' criterion.

	Structure			
	1	2	3	4
Environmental costs (k€)	Asphalt on cracked and seated concrete	Asphalt on crushed concrete granulate	Jointed concrete slabs on crushed concrete granulate	Jointed concrete slabs on cracked and seated concrete
Emissions	164	186	238	221
Use of basic materials	26	26	15	14
Land use	41	54	65	54
Hindrance	17	17	4	3
Totaal	**247**	**283**	**321**	**293**

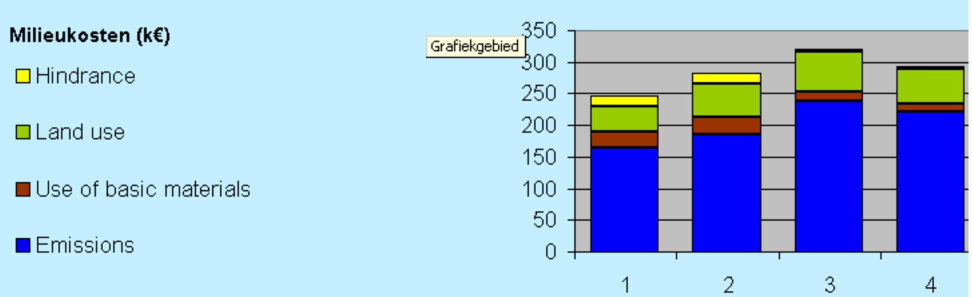


Figure 2 Results of environmental costs of 4 alternatives

The use of various weighting sets when comparing different road pavements does not always result in a clear preference for a certain design option. The final assessment depends on the weight attributed to each criterion. There is no method available to indicate what is ‘better’ or ‘worse’. The comparisons are normative. Society determines how to deal with the criteria (costs, environmental impact and other factors). A weighting set can be deemed well substantiated if it generates consensus and it can be easily explained to interested parties. That is quite different than ‘using it as you see fit’.

Today’s priorities are different from those maintained 20 years ago and those that will be maintained 20 years in the future. The comparison of various criteria can never be calculated objectively. This applies to each comparison made, both to the model’s valuation of the ‘environmental impact’ and ‘other factors’ criteria and to any MCA conducted as part of which the criteria end scores are compared to definitively assess the various types of road pavement.

Therefore, the comparisons do not generate absolute results. This means that the decision support model is not designed to make definitive decisions, but rather serves as a tool to facilitate making well-substantiated decisions based on relative differences.

Given the possibility that different comparisons can produce different results, it would seem fairly fruitless to perform such a comparison of the criteria. However, a weighting method’s strength is primarily rooted in the fact that it compels the user to make decisions and perform comparisons in as explicit, well-considered and transparent a manner as possible.

The lack of a ‘best’ option means that it is wise to assess the various criteria using several weighting sets. Comparing the various results heightens the user’s understanding of the degree to which the final result is dependent on the weighting set used. Assessments involving different weighting sets sometimes result in negligible or very limited differences. In some cases, it can be concluded that the weighting sets involved have little effect on the final result and, consequently, that the differences in positions on how to weight the different elements are not significant.

A weighting triangle is a tool to compare different weighting sets and indicates the degree to which the weighting set influences the final result (figure 3). The sides of the triangle represent the weighting factors for the ‘costs’, ‘environmental impact’, and ‘other factors’ criteria, ranging from 0 to 100%. This enables the criteria to be compared. The road pavements scoring well with this weighting set used are presented in the triangle. The location at which the weighting factor scores intersect, reveals whether the weighting set selected falls squarely in the domain of a single road pavement or near the interface of several road pavement options. While the former can be read as a clear preference for one type of road pavement (i.e. a slightly adjusted weighting set will not produce a different result), the latter signifies that different road pavements generate comparable scores and there is no clear preference. This has always to be considered in conjunction with the results of the MCA itself.

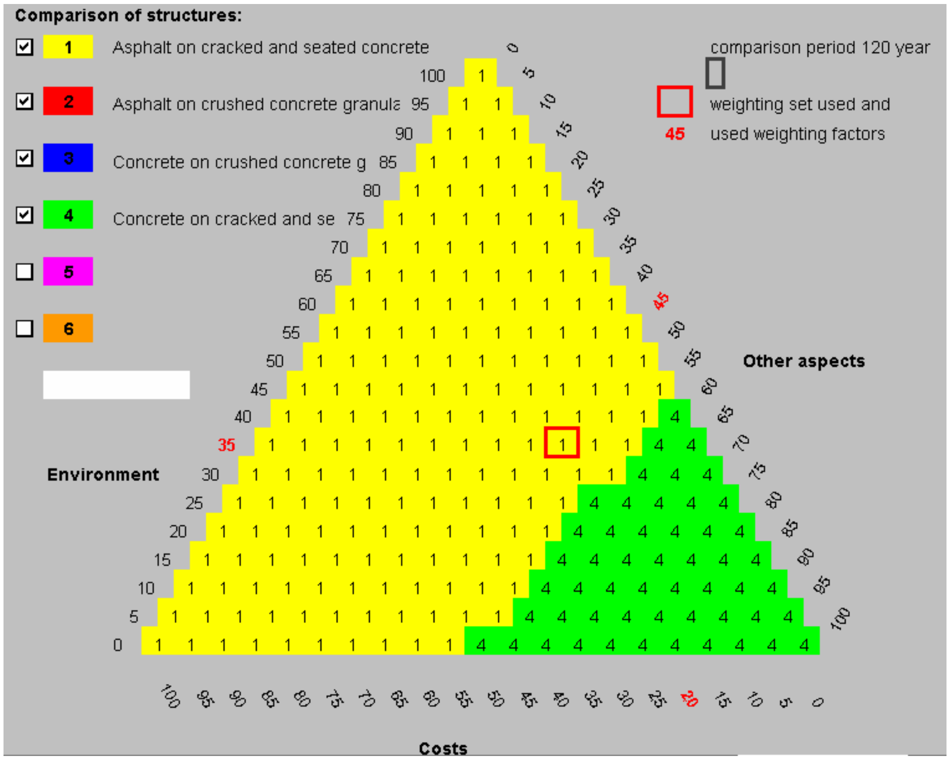


Figure 3 MCA results presented by weighting triangle tool;
the position of the red box represents the current weighting set

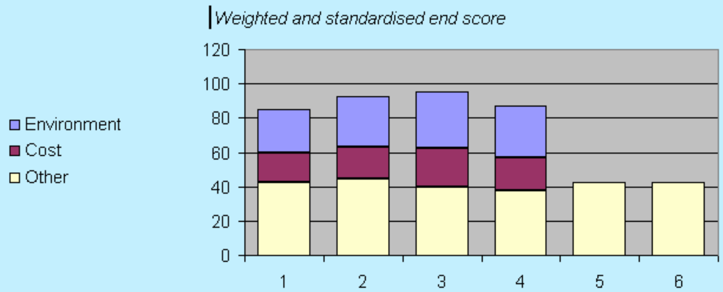
6. Multi-criteria analysis

MCA is a tool to compare the final scores of the various assessment criteria.

Before comparing the scores, the data must first be converted into comparable units (standardisation). The decision support model achieves this by dividing each criterion's score by the maximum score generated for the design options entered.

The decision support model's MCA is based on the weighted sum method and standardisation using the maximum score generated.

Aspect		Calculated weighting set	Structure 1: Asphalt on cracked and seated concrete	2: Asphalt on crushed concrete granulate	3: Jointed concrete slabs on crushed concrete	4: Jointed concrete slabs on cracked and seated	5	6	Motive for inputted weighting factors
Environme	3	33%	77	88	100	91	0	0	Mobility (availability) and reduction of traffic noise are very important issues, followed by environment and costs
Cost	2	22%	77	84	100	86	0	0	
Other	4	44%	95	100	90	85			
Weighted and standardised			85	93	96	87			



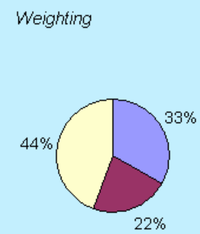


Figure 4 MCA results for 4 pavement options after weighting

The final scores of the three assessment criteria are weighted, standardised and added together, and all the data is presented in a table and in a histogram (figure 4). The weighting set used is also presented. The pavement structure with the lowest score is considered the preferred or most favourable choice using this weighting set. Whether this result is significant can be determined using the weighting triangle tool.

7. User-friendly and transparent tool

The transparent structure and clear presentation of the data entered by the user and generated by the program make the Decision Support Model for Road Pavements highly user friendly. This new program makes comparing various, technically equivalent design options quite simple. To reduce the amount of data input required, it is possible at start-up to select the default structure for a number of common road types, such as motorways, provincial and municipal roads, country roads and cycle tracks. The user can also enter and save personalised sets of data for use at a later date. The program includes a great deal of information explaining how the program works and the methods involved.

Road pavement decisions taken without the involvement of a decision support model that includes a long-term MCA are neither transparent nor well substantiated.

Factors with the greatest impact on the comparison results are the structural design life of equivalent road pavements and the associated maintenance regimes, assigned life time periods, unit prices for construction and maintenance, and the weighting of the assessment criteria (costs, environmental impact and other factors).

It should be noted in this context that, as far as total investment costs in infrastructure (new construction) are concerned, road pavement accounts for only 15% of the total project costs for motorways. The defaults and underlying database represent the Dutch situation. The tool has not been tested or adapted for regional differences that may occur in other countries.

8. Case histories

In the past, little attention was paid to choosing between various types of road pavements during the process of construction or rehabilitation of a road. The majority of road agencies preferred asphalt pavements or, if cables and pipes were present beneath the pavement, block paving. Concrete pavements were used infrequently. Despite this fact, several road managers have been comparing road pavements for years and have come to the conclusion that concrete pavements are preferable in certain circumstances.

The CROW Decision Support Model for Road Pavements makes it possible to substantiate this in a transparent manner. The user can only enter and change his own data for the ‘other factors’ criterion. This is in fact the only way in which the user can influence the final score, apart from unit prices and design life periods assigned to pavement options. On the whole, the user’s ability to skew the scores is fairly limited. This benefits the objectivity of the results.

The previous part of this paper discussed the underlying principles of the decision support model. The following part presents three examples of the model’s application: one involves a provincial road, another a motorway and the third one a comparison between several concrete pavement options.

8.1. Provincial road: basic principles

To begin with, the basic principles and policy assumptions must be clear. Are the noise level requirements of the pavement to be chosen consistent with the performance of dense asphalt concrete (DAC), which will serve as the reference road pavement in this example, or are pavement types with lower noise emission required? What is the current traffic intensity (particularly the amount of heavy goods vehicles, HGV) and what will it be at the end of the design period? Will the road profile be designed according to typical Dutch Sustainable Safety concept principles? What is the road’s expected life? These basic principles and assumptions are taken into consideration when calculating the alternative design options. This example assumes the following: noise emission equal to or less than DAC, 15,000 vehicles a day (of which 10% HGV) and road design in accordance with Sustainable Safety principles. For the sake of simplicity, the example hereafter will only include two alternative designs (full depth asphalt and exposed aggregate concrete EAC), designed for a certain structural design life using the BISAR and VENCON 2.0 programs, respectively. Table 1 presents the results.

Table 1 Provincial road pavement alternatives considered

Reference option: full depth asphalt pavement (20 years design life)	Alternative: jointed concrete slab EAC pavement (30 years design life)
40 mm DAC 0/16 mm (wearing course)	
40 mm asphalt concrete with crushed stone aggregate 0/16 mm	265 mm jointed concrete slab EAC pavement 4/8 mm C35/45 quality
120 mm asphalt concrete with crushed stone aggregate 0/22 mm	
250 mm mix of crushed masonry and concrete	250 mm mix of crushed masonry and concrete

8.1.1. User-specified criteria in the decision support model

The decision support model compares the criteria 'costs', 'environmental impact' and 'other factors'. User-specified assessment factors can be added for the road section in question. For the current example, it is essential to indicate that, for continuity's sake, concrete pavement is already present on both sides of this road section. Design in accordance with Sustainable Safety principles is also a key issue in selecting the road pavement because the relatively narrow lanes and limited traffic wander require a pavement which resists rutting.

The results of the comparison are then weighted as part of an MCA, for which the user determines the relative weight of the assessment criteria. These are usually based on the policy principles of the competent authority. Finally, the weighting triangle tool can be used to determine the degree to which changes to the weighting set involved will generate a different result.

8.1.2. Result of the comparison

In the current example, the relative weight of the construction risks and of the safety and nuisance levels during operation is twice that of the other factors. The concrete alternative scores better in terms of Sustainable Safety design and maintenance risks, but worse in terms of construction time and ability for staged construction. The user can only influence the result of the 'other factors' criterion, which, in the current example, works to the advantage of cement concrete.

The user can hardly influence the comparison of the 'environmental impact' and 'costs' criteria. The decision support model uses databases containing information about the costs of environmental impact and the costs of construction and maintenance, the latter being adjustable by the user. In terms of environmental impact, the score for the EAC jointed concrete alternative is comparable to the asphalt option's score. In contrast, the concrete option is by far the cheapest (calculated over the road pavement's entire life cycle).

These results are included in an MCA, in which the 'environmental impact', 'costs' and 'other factors' criteria are weighted in a 2:3:3 proportion. This means that the 'costs' and ‘other factors’ criteria weigh a bit more heavily in the comparison than the ‘environmental impact’ criterion.

What is clear is that, in this example, the EAC jointed concrete alternative generates the best score. This is based on the result of the MCA itself, see Table 2 and those of the weighting triangle, see figure 5.

Table 2 Weights and scores for the provincial road MCA
The lower the score, the better the result.

Criterion	Relative weight	Score	
		Reference option 1: asphalt with DAC	Alternative option 4: concrete with EAC
Environmental impact	2	98	100
Costs	3	100	81
Other factors	3	100	89
Weighted and standardised		99	89

The weighting triangle generated by the decision support model indicates that changes to the weighting set used will not lead to a different conclusion (figure 5). The red box representing the chosen weighting set is clearly located in the ‘green’ area of the triangle, the exposed aggregate concrete. This road pavement would remain the preferred option even if substantial changes were made to the individual assessment criteria. Consequently, the preference in this example is deemed significant. It should be noted that the choice for a specific option has to be considered in conjunction with the results of the MCA itself.

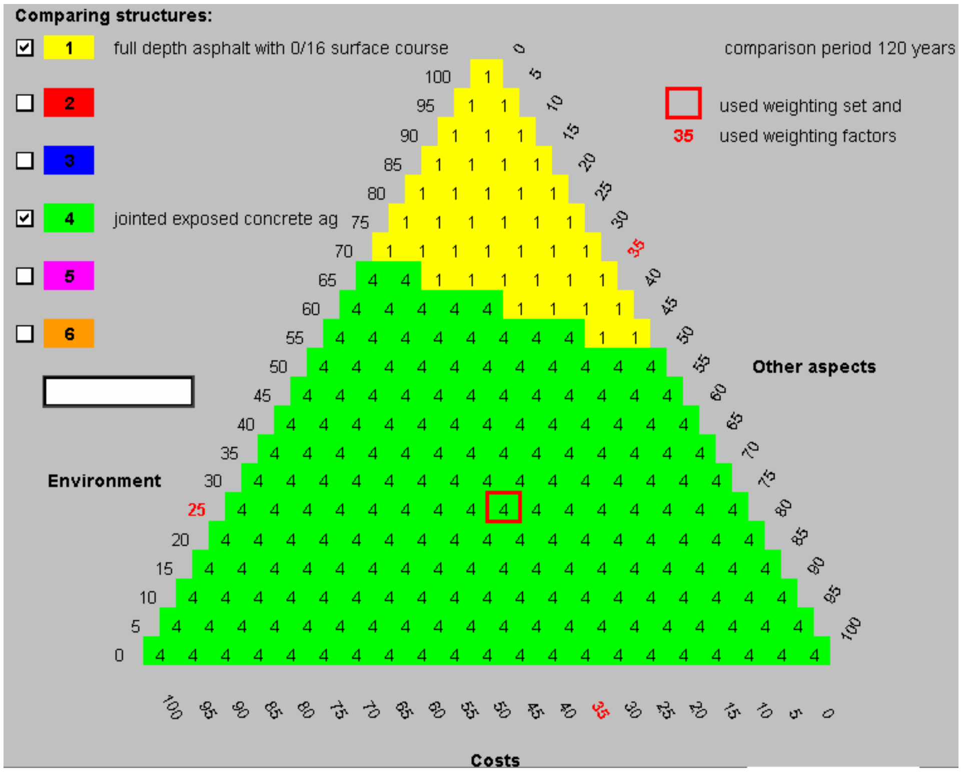


Figure 5 Weighting triangle tool for the comparison of two provincial road design options

8.2. High-volume motorway: basic principles

This example involves a comparison for a new dual two-lane carriage way on a motorway. In 2020, an estimated 112,000 vehicles, of which 44% is HGV, will drive along this road section each working day.

Given the high traffic intensity, the risk of rut formation is considered a real disadvantage of flexible pavements because this will require additional maintenance. Although rut formation is not an issue with continuously reinforced concrete pavement (CRCP), the initial costs of this road pavement are higher. The choice between pavement structures (one involving asphalt and the other CRCP) is supported using the CROW decision support model.

8.2.1. Alternatives considered

Table 3 presents an overview of the pavement structures considered. Each of the pavement structures has a wearing course comprising two layers of porous asphalt friction course (PAFC) to reduce noise emission. Enrobé à module elevé (EME) is a high modulus asphalt mixture developed in France, with increased stiffness and resistance to rut formation. The reference option is a standard construction using asphalt with crushed stone aggregate (STAB).

Table 3 Motorway road pavement alternatives considered

Reference option (asphalt): STAB (20 years design life)	Alternative option (asphalt): EME (20 years design life)	Alternative option (concrete): CRCP (40 years design life)
70 mm dual-layer PAFC	70 mm dual-layer PAFC	70 mm dual-layer PAFC
300 mm STAB 0/22 mm	240 mm EME	250 mm CRCP C35/45
		60 mm asphalt
250 mm mix of crushed masonry and concrete	250 mm mix of crushed masonry and concrete	250 mm mix of crushed masonry and concrete
1 m sand base	1 m sand base	1 m sand base

8.2.2. Comparing is choosing

Unfortunately, the decision support model does not generate an indisputable final result with the simple flick of a switch. The implicit choices made as part of the comparison process can greatly influence the end result. The advantage of the decision support model is that the choices are made in a structural, transparent and traceable manner, providing insight into the validity of the conclusions.

Implicit choices to be made concern:

- Details in the calculation of pavement thickness. The structural design and layer thicknesses of asphalt road pavements are usually determined using the ASCON/CARE (linear elastic multi layer programs) applications, while the same information for concrete road pavements is calculated using VENCON2.0. Because construction costs depend on road pavement structural design and layer thicknesses entered by the user, the settings of the design calculations do affect the outcome of the comparison. Temperature gradients for the CRCP design were selected to include the beneficial effect of the porous asphalt friction course, derived form measurements on similar pavements.
- The probability that an asphalt road pavement will have to be reinforced by application of an overlay at the end of the structural design life, must be based on practical experience with comparable road pavements. Extensive experience with reference asphalt pavements indicates that 50% of the pavements require strengthening and/or profiling at the end of their structural design life, and that 50% will last for at least 10 years more. Aging due to climate effects is negligible because of the presence of the porous asphalt friction course, which needs replacement every 10 years.
- The decreased risk of rut formation through the application of EME instead of the standard STAB mix must also be based on practical experience with comparable road pavements. A vast body of experience with high modulus asphalt pavements exists in France, proving that cracking is not an issue. Raveling is restricted to the porous asphalt friction course.

8.2.3. Comparison results

Table 4 presents the final scores of the comparison. The environmental impact was analysed using the TWIN^{2002} approach in the decision support model, expressing emission, exhaustion of raw materials, land use and nuisance as environmental costs. The 'Other factors' category includes construction risks (17%), nuisance due to construction and maintenance (33%), road user safety (17%) and traffic delays during maintenance (33%). The conclusion is that the alternatives are better than the reference option (viz. STAB) and the costs are much lower. EME's 'environmental impact' score is the best because of the reduced asphalt thickness, while CRCP's 'other factors' score (related to maintenance) is the best. When looking at the cumulative score of all the criteria, EME and CRCP ultimately prove quite similar.

Table 4 Weights and scores for the motorway MCA
The lower the score, the better the result.

Criterion	Relative weight	Score		
		Reference: STAB	Alternative (asphalt): EME	Alternative (concrete): CRCP
Environmental impact	1	78	76	100
Costs	3	100	87	89
Other factors	2	100	67	58
Weighted and standardised		96	78	81

A sensitivity analysis reveals (not presented here) that the final scores are greatly influenced by the settings for the road pavement thickness design, the valuation of other factors (estimated risk of rut formation), and the scores and relative weights for comparison of other factors and the MCA. Given the expected growth in HGV proportion in the Netherlands, similar comparisons in which rut formation plays an greater role will become more common. For a valid comparison, the implicit choices to be made in the process must rely on experimental data rather than wishful thinking.

8.3. Choice between JPCP, SFRCP and CRCP: basic principles

From another CROW-study (Braam et al, 2008) it was supposed that SFRC pavements should be regarded as being an alternative for jointed plain concrete rather than for continuously reinforced concrete pavements. The reason for this is that the amount of reinforcement required in continuously reinforced pavements (app. 61 kg/m^3) can hardly be replaced by an equivalent amount of steel fibres. Compared with plain concrete pavements with dowels and tie-bars (app. 8 kg/m^3), the improved flexural tensile strength and the post-cracking strength capacity of SFRC (steel fibres app. 40 kg/m^3) enables a reduction of the number of transverse shrinkage joints. As a result, the amount of saw cutting and of steel required for dowels and tie-bars can be considerably reduced.

The question is of course whether the assumption that SFRCP and JCPC are equal from the economical and environmental viewpoint can be supported by calculations from the decision support model. Therefore unit prices must be known, in the Netherlands the following prices per m^2 at 250 mm thickness of concrete pavement are considered realistic: 115% for CRCP, 130% for SFRC pavements related to the investment for JPCP that is 100%. By using the Dutch design software VENCON2.0 (CROW, 2004), equivalent structures for CRCP and JPCP can be calculated. The design of SFRCP is mainly based on experiences from recent projects. This results in a thickness for CRCP of 238 mm (on top of 50 mm bituminous interlayer), for JPCP of 266 mm and for SFRCP of 225 mm. All these input data in the decision support model lead to the results as shown in table 5.

Table 5 Weights and scores for JPCP, SFRCP and CRCP
The lower the score, the better the result.

Criterion	Relative weight	Score		
		Reference: JPCP	Alternative: CRCP	Alternative: SFRCP
Environmental impact	1	76	100	81
Costs	1	94	100	94
Other factors	1	100	100	100
Weighted and standardised		90	100	92

Table 5 presents an overview of the concrete pavement structures considered. From these results it can be concluded that with the weighting criteria all being 1 and the presented thicknesses, there is no significant difference between JPCP and SFRCP and they can be considered equal from an economical and environmental point of view. But which is not necessarily the case for structural equality.

9. Conclusions

Road pavement decisions taken without the involvement of a decision support model that includes a long-term MCA are neither transparent nor well substantiated.

In the past, little attention was paid to choosing between various types of road pavements during the process of construction or rehabilitation of a road. Road managers have been comparing road pavements for years and have come to the conclusion that concrete pavements are preferable in certain circumstances. The CROW Decision Support Model for Road Pavements makes it possible to substantiate this in a transparent manner.

The Decision Support Model for Road Pavements is developed to enable road engineering designers, pavement managers, consultants and decision-makers to clearly outline and take into consideration such factors as environmental impact determined using life cycle assessments (LCAs), cost effects based on life cycle costing (LCC) and the consequences of any other factors when comparing various pavement structures (design options). Using the model enables road pavement engineers and decision-makers to come to the right choice of pavement type in a transparent way. This tool will convince road authorities that not only investment of construction is important, but especially the ‘total costs of ownership’ during the life-time of the road pavement.

Factors with the greatest impact on the comparison results are the structural design life of equivalent road pavements and the associated maintenance regimes, assigned life time periods, unit prices for construction and maintenance, and the weighting of the assessment criteria (costs, environmental impact and other factors).

The Decision Support Model for Road Pavements is available in Dutch language and can be ordered through CROW (www.crow.nl).

References

Braam, C.R., Van Leest, A.J., Van Hartskamp, S.B., Jurriaans, G., Van der Steen, C.A. & Stet, M.J.A. (2008); "*Fibre concrete mixes in road pavements; in between plain and reinforced concrete?*". 9th International Conference on Concrete Pavements, San Francisco, USA.

CROW (2005); *VENCON 2.0* "*Design software for concrete roads*" (in Dutch). CD-ROM D925. CROW, Ede, the Netherlands.

CROW (2008); *Afwegingsmodel Wegen (AMW) [Decision Support Model for Road Pavements] version 1.1*, (CD-rom D926), CROW Technology Platform, Ede, the Netherlands.

NIBE (2002); *Basiswerk Duurzaam & Gezond Bouwen: Milieuclassificatie Bouw, Monetarisering (verborgen milieukosten) [Reference sustainable & healthy construction: Building and construction environmental classification system, monetisation (hidden environmental costs)]*, NIBE Research bv, Bussum, the Netherlands.

NIBE (2002); *Basiswerk Duurzaam & Gezond Bouwen: Milieuclassificatie Bouw, TWIN-model 2002 [Reference sustainable & healthy construction: Building and construction environmental classification system, TWIN2002 method]*, NIBE Research bv, Bussum, the Netherlands.

RHED; *DWW-wijzer 85: Werking van de Levenscyclusanalyse [RHED guide 85: Life cycle assessment methodology]*, Directorate-General for Public Works and Water Management, Road and Hydraulic Engineering Division, Delft, the Netherlands.

RHED (2003); *Keuzemodel Kust- en Oeverwerken (KKO) [Decision-making model for coastal defence structures and river embankments] version 2.0*, Directorate-General for Public Works and Water Management, Road and Hydraulic Engineering Division, Delft, the Netherlands.