Universidade do Minho

[CI-10]

Sousa, J.B., **Pais, J.C.**, Eckmann, B.

"An approach for the definition of construction and maintenance strategies for flexible pavements"

Fifth International Conference on the Bearing Capacity of Roads and Airfield, Trondheim, 1998

VOLUME III

Proceedings

Editors: Rasmus S. Nordal and Geir Refsdal

BCRA'98

Fifth International Conference on the Bearing Capacity of Roads and Airfields

TRONDHEIM, NORWAY 6 – 8 JULY 1998

BEARING CAPACITY OF ROADS AND AIRFIELDS

Fifth International Conference on the
BEARING CAPASITY OF
ROADS AND AIRFIELDS

AN APPROACH FOR THE DEFINITION OF CONSTRUCTION AND MAINTENANCE STRATEGIES FOR FLEXIBLE PAVEMENTS

JORGE B. SOUSA[1], JORGE C. PAIS[2] AND BERNARD ECKMANN[3]

[1]General Director, CONSULPAV, Taguspark, Tecnologia I, n.26, 2780 Oeiras, Portugal, Fax: +351-1-421-2296, Email: jmbsousa.consulpav@taguspark.pt
[2]Research Engineer, University of Minho, Guimarães, Portugal, Fax: +351-53-510-217, Email jpais@eng.uminho.pt
[3]Research Scientist, NYNAS, N.V., Beliweg 22, 4e Havendok, B-2030 Antwerp, Belgium, bernard@nynas.se

ABSTRACT

Design, Build, Finance and Operate contracts to develop a road network require a re-evaluation of the strategic decisions towards the design and maintenance strategies of flexible pavements.

Probabilistic analysis, based on the variability of pavement material properties and layer thickness as well as on traffic variability is required and needed as a cost effective basis for the many possible design and maintenance strategies.

The NOAH software was used to combine hundreds of possible design scenarios on a compressive basis for the decision making process towards a design criteria. The use of Rosenblueth transformations permitted the reduction of computational efforts and made possible the conclusion of this comprehensive design approach within the time frame of the tender.

The bases for the data variability parameters were actual measurements made in the existing 83 km of freeway. Data from cores and from back-calculation analysis with the FWD in the determination of stiffness layer moduli was used. Permanent deformation (structural) and flexural fatigue failure criteria used was based on SHELL´s criteria. The roughness induced costs, as proposed by the World Bank model, was also used as a part of society cost analysis.

INTRODUCTION

CONSULPAV worked with AUTOESTRADAS DO ATLANTICO (from now on called agency) to propose a strategy to design and maintain 83 Km new highway pavements and 87 Km of existing pavements for a DBFO tender by the Portuguese Highway Authority [1] during 32 years (the tender called for 30 years but is was decided to leave a remaining life of 2 years at the end of the concession to allow some time to rehabilitate the network).

The goal of the process was to provide a strategy of construction and maintenance that would minimize costs to the agency but that would take into consideration user costs. To the extent possible solutions would be found that would minimize both agency and user costs.

The main criteria for evaluation were based on the mechanistic methods proposed by Shell [2] to control fatigue cracking and structural permanent deformation. It was assumed that functional characteristics would be re-establish with a chip seal placed every seven years.

First an evaluation of the most cost effective maintenance strategy was defined based on actual data from 83 km of existing freeway. Then a deterministic analysis was made towards the definition of construction/maintenance alternatives taking into consideration only deterministic concepts. The best solution was evaluated from a probabilistic perspective using the NOAH software [3].

For the two solutions with the least agency costs evaluation of the user costs based on the effects of road roughness was made.

EVALUATION OF MOST COST EFFECTIVE REHABILITATION STRATEGY

Criteria had to be developed to evaluate the most cost effective rehabilitation criteria for all the existing segments of the network. An analysis of the traffic, deflection data, coring and soil analysis led to the determination of the conditions for the existing 83 km of the road network. For all these segments predictions of pavement deterioration had to be made based on the two criteria presented above.

Table 1 – Description of maintenance options considered and associated costs.

NAME OF ACTION	DESCRIPTION OF MAINTENANCE ACTION	COST (PTE/m2)
O5	OVERLAY 5 CM TWO LANES	1270
O10	OVERLAY 10 CM TWO LANES	2540
O15	OVERLAY 15 CM TWO LANES	3810
M5F5	MILL 5 CM + FILL 5 CM ONE LANE	935
M10F10	MILL 10 CM + FILL 10 CM ONE LANE	1870
M12F12	MILL 15 CM + FILL 15 CM ONE LANE	2770
M15F15	MILL 12 CM + FILL 12 CM ONE LANE	2230
M5O10	MILL 5 CM ONE LANE + OVERLAY 10 CM THAT LANE + OVERLAY 5 CM ADJACENT LANE	2840
M5O15	MILL 5 CM ONE LANE + OVERLAY 15 CM THAT LANE + OVERLAY 10 CM ADJACENT LANE	4040

To determined the most cost effective methods for structural rehabilitation three types of scenarios were considered; 1- allow the pavement layer moduli degrade to about 1900 MPa and then place an overlay, 2- allow the pavement deteriorate so that mill and fill would be recommended and, 3 – allow the pavement to reach a level

where mill and overlay would be needed. Based on over 7 years of pavement evaluations performed in Portugal most pavements in need of structural maintenance have bituminous layer moduli that have deteriorated from about 5000 MPa to about 1900 MPa.
It was considered that when an overlay is placed on the right lane for structural reasons an equal thickness needs to be used on the left lane (although due to the lighter traffic the overlay may not be needed). In the mill and fill option only the right lane is affected by this solution. Table 1 presents a summary of all the rehabilitation actions considered. The cost of tack coats between layers has also been considered. The costs considered are variable costs to the contractor.

For each of the pavement sections based on actual *in situ* back calculations analysis the number of ESALS reached by each of the solutions was computed using NOAH. For each solution the relationship between the cost (Portuguese Escudos-PTE) per square meter was related with the number of ESALS obtained by that action. It can be observed in Fig. 1 a typical relationship for 4 sections. For all other road segments identical plots were generated. Although the actual amount of ESALS for each type of actions depended on subgrade conditions, pavement thickness, etc the general trends were identical.

It can be observed that the most cost-effective method to reach the highest number of ESALS for a given cost in the right lane is by overlaying the pavement section. All other methods are less cost effective even taking into consideration that the cost per square meter presented is the cost only of the right lane. It is considered that the placement of the overlay on the left lane is just a "cost" without any "benefit".

Removing pavement layers should only be considered when other requirements, other then structural strength, require it (i.e., curb height, bridge clearance, etc). As such the proposed philosophy for pavement maintenance was to considered that pavements should be overlaid whenever possible and that deterioration of the pavement should only be allowed to the extend that an overlay would still be a feasible option.

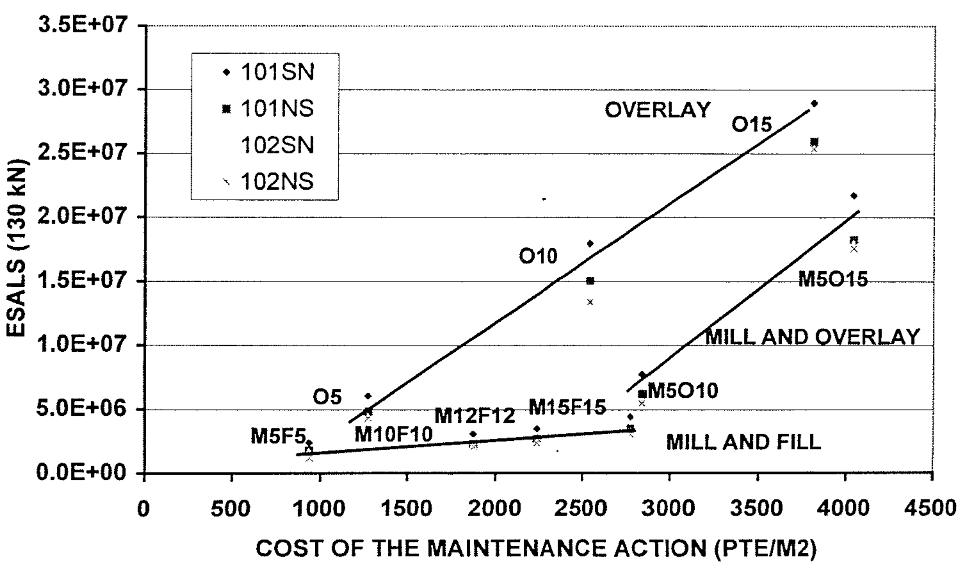


Figure 1 – Typical relationship between cost and type of rehabilitation action and number of ESALS achieved by that action.

EVALUATION OF MOST COST EFFECTIVE CONSTRUCTION/REHABILITATION STRATEGY – DETERMINISTIC EVALUATION

With the understanding that overlays would be the most cost-effective method to maintain the network it was necessary to determined how thick to build the new pavements and consequently how often to overlay during the life of the concession.

Three scenarios were considered:

1- Minimum initial construction costs with as much deferred maintenance as possible. It was considered that the minimum reasonable asphalt concrete layer thickness for construction and rehabilitation was 5 cm. The rational for this solution would be that the agency would minimize the use of its own money and have the maintenance paid by the toll revenue. This strategy was called **Strategy 1.**
2- Initial construction of such an extent that no structural rehabilitation/maintenance actions would be needed over the project life. The rational for evaluating this option was to consider the possibility of borrowing as much money as needed, to minimize user delays and cost, and possible agency costs. This strategy was called **Strategy 3.**
3- An intermediate solution where the pavement would be built with only structural capabilities to resist half of the project was considered. An overlay would then be placed that would last the remainder of the project. This would correspond to the traditional design life considerations where pavements in Portugal are design for 15 or 20 years design life. This strategy was called **Strategy 2.**

In this evaluation the two criteria proposed by the SHELL method for pavement design where used; the limiting tensile strain criteria on the bottom of the asphalt concrete layers and, the maximum compressive strain criteria on the top of the subgrade. It was considered also that at the end of each design life the pavement asphalt layer moduli was half of its initial value. This is a conservative criterion because in most pavements it would be reduced to about 1900 MPa. However because FWD annual evaluation are executed on an annual basis it will be possible to insure that pavement moduli will not degrade below the require value. It was also further assumed that the fatigue failure criteria should not apply for asphalt concrete layers with a moduli degraded to below 2000 MPa. It was also assumed that asphalt concrete layer moduli would not degrade below 500 MPa.

The assumed evolution of the layer moduli function of the life of the pavement can be observed in Table 2. It can be observed that the Strategy 1 a thin pavement was built only with 5 cm thicker bituminous layer. After reaching its design life of 3.4E4 ESALS (failure by fatigue of the asphalt concrete layer) an overlay is placed. However from now on the failure criteria for the overlay is not clearly define. As such two hypotheses were considered; A - one based on subgrade failure and B-another based on fatigue crack propagation. Because after each overlay there is anther interface the life computed based on the tensile strains of each interface was computed. It was considered the failure criteria for hypothesis B based on the fatigue life on the bottom of the layer with at least 2000 MPa.

Table 2 presents for each of the Strategies and hypotheses the estimated moduli and lives based on the above assumptions.

Table 2 – Estimated Moduli at the time of each overlay associated with estimated life after each maintenance action

Strategy 1A and 1B.

INITIAL CONST.	1st OVERLAY	2nd OVERLAY	3rd OVERLAY	4th OVERLAY	5th OVERLAY
					5 cm 40/50 6000 MPa *N=9.9E12*
				5 cm 40/50 6000 MPa >>>> *N=1.7E13*	3000 MPa *N=1.9E32*
			5 cm 40/50 6000 MPa >>>> *N=2.0E13*	3000 MPa >>>> *N=2.2E7*	**2000 MPa** ***N=2.8E6***
		5 cm 40/50 6000 MPa >>>> *N=5.8E11*	3000 MPa >>>> *N=1.4E7*	**2000 MPa>>>>** ***N=1.9E6***	1000 MPa *N=1.1E6*
	5 cm 40/50 6000 MPa >>>> *N=2.5E8*	3000 MPa >>>> *N=3.4E8*	**2000 MPa>>>>** ***N=1.0E6***	1000 MPa >>>> *N=5.9E5*	500 MPa *N=1.4E6*
5 cm 40/50 **6000MPa >>>>** ***N=3.9E4***	**3000 MPa >>>>** ***N=2.0E5***	**2000 MPa >>>>** ***N=1.3E5***	1000 MPa >>>> *N=2.1E5*	500 MPa >>>> *N=4.0E5*	500 MPa
30 cm ABC 200 MPa	200 MPa	200 MPa	200 MPa	200 MPa	200 MPa
Subgrade 100 MPa *N=1.4E5*	100 MPa *N=5.3E5*	100 MPa *N=1.6E6*	100 MPa *N=3.5E6*	100 MPa *N=6.3E6*	100 MPa *N=10.7E6*

Strategy 2A

Initial Construction	1st Overlay
	5 cm 40/50 6000 MPa *N=7.1E9*
5 cm 40/50 6000 MPa >>>> *N=4.4E8*	5 cm 40/50 3000 MPa *N=3.9E13*
13 cm 20/30 10000MPa >>>> *N=7.6E6*	13 cm 20/30 5000 MPa *N=2.6E6*
30 cm ABC 200 MPa	30 cm ABC 200 MPa
Subgrade **100 MPa** ***N=7.1E6***	**Subgrade** **100 MPa** ***N=7.6E6***

Strategy 2B

Initial Construction	1st Overlay
	6 cm 40/50 6000 MPa *N=1.1E11*
5 cm 40/50 6000 MPa >>>> *N=4.4E8*	5 cm 40/50 3000 MPa *N=1.1E12*
13 cm 20/30 10000MPa >>>> *N=7.6E6*	**13 cm 20/30** **5000 MPa** ***N=6.5E6***
30 cm ABC 200 MPa	30 cm ABC 200 MPa
Subgrade **100 MPa** ***N=7.11E6***	Subgrade 100 MPa *N=1.5E7*

Strategy 3

Initial Construction
5 cm 40/50 6000 Mpa *N=8.3E8*
15 cm 20/30 10000MPa *N=20.5E6*
30 cm ABC 200 MPa
Solo Fundação 100 MPa ***N=16.1E6***

ABC – Aggregate Base Course, >>>> - indicates "evolution of the layer moduli towards value in the next cell"
Values in *italic* (*N=*) are estimated number of ESALS (130kN) associated with the distress at each of the corresponding layers. Values in **bold** are adopted (as most likely to occur) limiting conditions after each overlay.

The evolution of the remaining life of the pavement for all these cases is displayed on Fig. 2. It can be noted that for all combinations there is a remaining life at the end of the design period of 32 years.

The determination of the net present value of all these strategies was made considering that every 7 years a chip seal was placed to restore surface conditions. It can be observed in Fig. 3 that for discount rates below 7% the most cost effective solution based on in the agency cost was Strategy 3. For higher discount rates Strategies 2 would be more favorable. Clearly the strategy of deferring maintenance with the least initial cost presents the highest net present value at all discount rates. These analysis deals only with the agency costs. Delay costs for maintenance work and user costs associated with higher IRI values presented in the Strategies 1 and 2 were not considered. Taking them into consideration (as costs to society) would likely point towards the selection of Strategy 3 regardless of the discount rate (within the range considered).

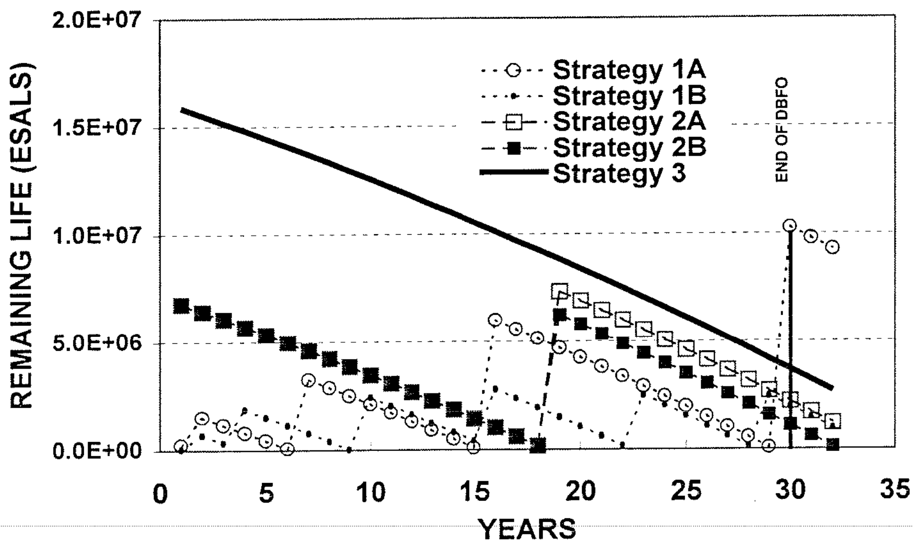


Figure 2– Evolution of remaining life for each of the deterministic strategies considered.

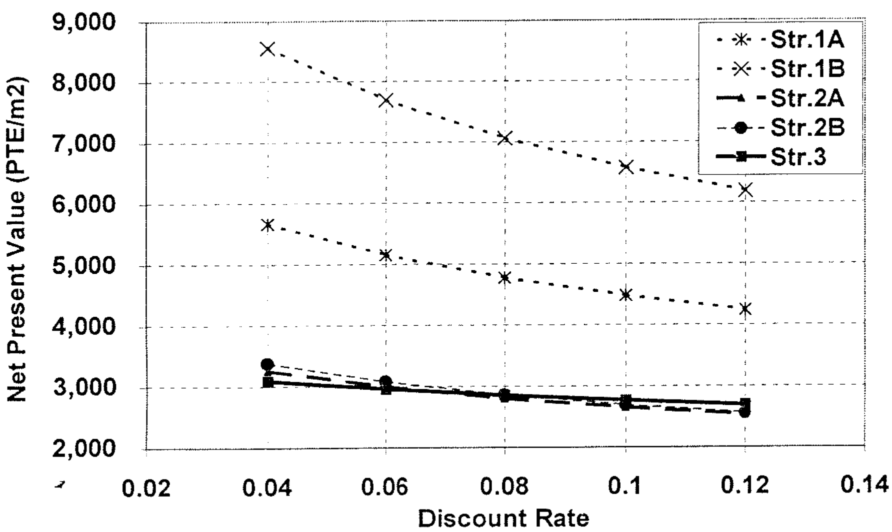
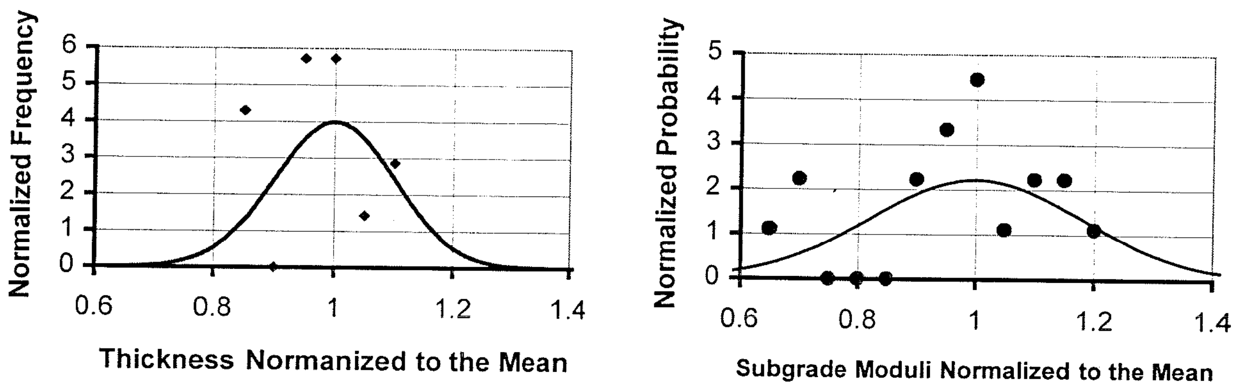


Figure 3 – Net Present Value for each of the deterministic strategies considered.

EVALUATION OF THE MOST COST EFFECTIVE CONSTRUCTION/REHABILITATION STRATEGY USING A PROBABILISTIC EVALUATION

Highway materials have inherent variability. Moduli, pavement layer thickness's and subgrade moduli considered are usually "MEAN" values. It was considered necessary to evaluate to which extent the effect of material variability combined in a probabilistic approach, would affect the conclusions determined above in a deterministic fashion.

From actual values determined from the existing pavement sections, back-calculated stiffness layer moduli, pavement thickness and subgrade moduli were determined from uniform sections. The variability of the data is presented in Fig. 4. For bituminous layers the standard deviation of the stiffness moduli and the thickness was about 10%. The standard deviation for subgrade moduli was about 18%. In Fig. 4 it can also be observed how well a normal distribution with those standard deviation values fits the actual observed data.



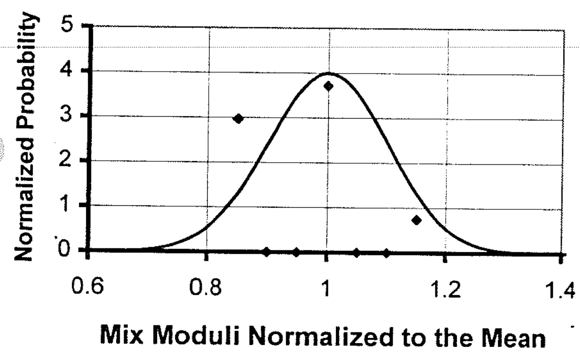


Figure 4 – Normal distribution curves superimposed over actual normalized frequency plots function of the normalized mean of subgrade moduli, bituminous layer thickness moduli and moduli.

It was assumed that the same variability would be present in the new pavements that will have to be constructed. As such the values considered in the deterministic analysis could be considered as corresponding to the mean values expected for those materials. Taking into consideration the actual variability, then there is a probability that the expected life would not be reached, at least in some segments of the pavement, because the layer moduli and layer thickness would be less then expected. This variability would have a stronger effect on thinner pavements given the logarithmic nature of the failure criteria selected. As such two strategies were investigated:

Strategy P1 – For the pavement structure selected from the deterministic analysis (Strategy 3) identify which actions would have to be performed to insure that the pavement would have no structural failure with 90% reliability.

Strategy P2 – Identify which pavement structure would have to be initially built to insure, with 90% reliability, that no structural rehabilitation/maintenance actions would have to be conducted during 32 years.

The NOAH software was used a basic tool to combine hundreds of possible design scenarios on a compressive basis. The use of Rosenblueth transformations permitted the reducion of computational efforts and made possible the conclusion of this compreenshive design approach within the time frame of the tender. The values adopted for each Strategy are presented in Table 3.

Table 3 - Estimated Moduli at the time of each overlay associated with estimated life after each maintenance action taking into account a design relaibility of 90%.

Strategy P1A

Initial Construction	1st Overlay
	6 cm 40/50 6000 MPa
5 cm 40/50 6000 MPa >>>>	5 cm 40/50 3000 MPa
H=15 cm 20/30 STD=1.5 cm E=10000MPa >> STD=1000 MPa *N(90%)=9.2E6*	H=15 cm 20/30 STD=1.5 cm E=5000 MPa STD=500MPa *N(90%)=6.0E6*
30 cm ABC 200 MPa	30 cm ABC 200 MPa
Subgrade **E=100 MPa** **STD=18 MPa** ***N(90%)=5.6E6***	**Subgrade** **E=100 MPa** **STD=18 MPa** ***N(90%)=11.0E6***

Strategy P1B

Initial Construction	1st Overlay
	7 cm 40/50 6000 MPa
5 cm 40/50 6000 MPa >>>>	5 cm 40/50 3000 MPa
H=15 cm 20/30 STD=1.5 cm E=10000MPa >> STD=1000MPa *N(90%)=9.2E6*	**H=15 cm 20/30** **STD=1.5cm** **E=5000 MPa** **STD=500 MPa** ***N(90%)=7.9E6***
30 cm ABC 200 MPa	30 cm ABC 200 MPa
Subgrade **E=100 MPa** **STD=18MPa** ***N(90%)=5.6E6***	Subgrade E=100 MPa STD=18 MPa *N(90%)=13E6*

Strategy P2

Initial Construction
5 cm 40/50 6000 MPa
E=19 cm 20/30 STD=1.8cm E=10000MPa STD=1000MPa *N(90%)=28.5E6*
30 cm ABC 200 MPa
Subgrade E=100 MPa STD=18 MPa ***N(90%)=14.0E6***

ABC – Aggregate Base Course
STD – Standard Deviation
>>>> - indicates "evolution of the layer moduli towards value in the next cell"
Values in *italic* are estimated number of ESALS (130kN) associated with the distress at each of the corresponding layers.
Values in **bold** are adopted (as most likely to occur) limiting conditions after each overlay or initial construction.

With 90 % reliability it could be inferred that strategy P1 would require an overlay at the end of 14 years. Then either a 6 or 7 cm overlay would have to be placed to insure with 90% reliability that the design life would be sufficient to insure another 18 years of structural life. Strategy P2 would require a 19 cm thick bituminous layer to insure that with 90% reliability the structural design life of 32 years would be achieved.

Figure 5 presents the variation of the remaining life with time for the two strategies.

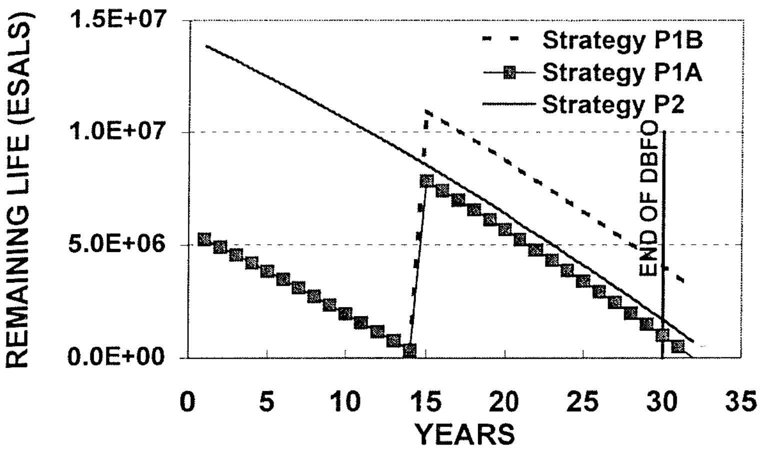


Figure 5 – Variation of remaining life with time for the two probabilities strategies considered to achieve design life with 90% reliability.

The Net Present value of these strategies is presented in Fig. 6. It can be observe that for discount rates below 7% strategy P3 is more cost effective from an agency costing perspective. However no considerations where made for user cost and delay costs. A chip seal treatment was also considered every 7 years to re-establish surface functional requirements.

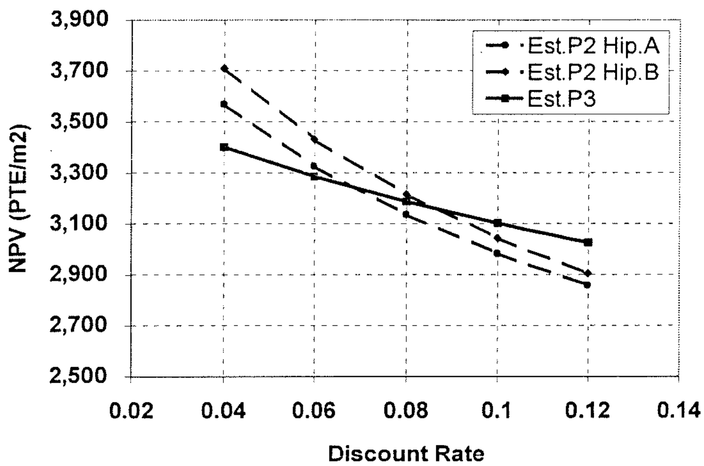


Figure 6 – Variation of Net Present Value for the Probabilistic Strategies over a range of discount rates

INVESTIGATION OF THE COSTS TO SOCIETY OF THE MAINTENANCE STARTEGIES

The evaluations made have only considered the direct costs to the agency. However in the award process the Government should take into consideration the costs to society of the different alternatives. This is a very complex issue. However, a simplified assumption was made considering the costs to the user caused by roughness. The cost model proposed by the World Bank [5] function of the IRI was used assuming the traffic was only composed of VW 1200. This is a truly conservative criterion given that the traffic composition is based on far more expensive vehicles. The evolution of the IRI function of traffic was assumed to be identical to the model proposed by the World Bank between 1.5 and 4. It was assumed that at the end of the design life the pavement would have an IRI value between 4 and 5. The variation of the IRI value between the initial construction until the overlay or end of design life would be an exponential function as presented in Fig. 7.

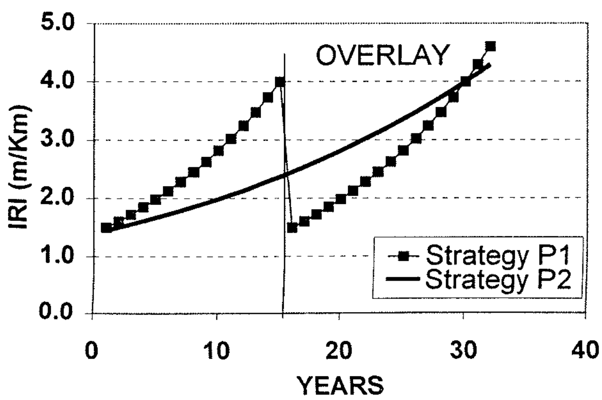


Figure 7 – Assumed variation of IRI between initial construction and overlay or end of design life for the two probabilistic strategies

The net present value of the costs to society was computed as the sum of the agency costs and user costs. These values are presented in Fig. 8 over a range of discount rates. It can be observed that the strategy with the least costs to Society is the 32 years design with 90% reliability.

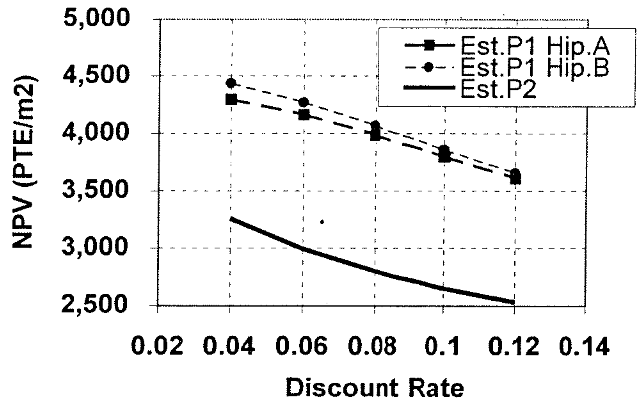


Figure 8 – Net Present Value of Society costs for the probabilistic strategies considered.

CONCLUSIONS

Based on the above criteria and conditions the following conclusions could be reached:

- Overlaying a two-lane highway (if possible) is more cost effective then milling and filling just the right lane damaged by the heavy traffic.
- A design strategy based on the initial construction of thicker pavements lasting 32 years with only surface maintenance is more cost effective than overlay strategies with 5, 15 or 20 years design lives for discount rates below 7% (from an agency view point).
- Designing for 90% reliability over the 32 years design life is more cost effective then designing for 32 years with 50% reliability for discount rates below 7%.
- If user costs are taking into consideration the design strategy based on a 32-year design with 90% reliability is more beneficial to society then any other strategy considered over a wide range of discount rates. It should be considered that the Government should favor solutions that have the lowest overall costs to society even if that implies paying higher costs to the agency.

ACKNOWLEDGEMENTS

The authors acknowledge and are thankful to the insight and support of Eng. Vasco Leite of Autostradas do Atlântico, SA.

REFERENCES

1- Sousa, J.B., "Estudo dos Pavimentos para a AutoEstradas do Atlântico", May 1997, CONSULPAV

2- Eckmann, B., " New Tools for Rational Pavement Design " Proceedings 8th International Conference, August 10-14, 1997. Seattle, Washington, pg 25-42.

3- SHELL Design Manual

4- Shell Design Manual, Shell, Amsterdam.

5- Archondo, R, Faiz, A " Estimating Vehicle Operating Cost" World Bank Technica Paper n. 234