UNIVERSITY OF COIMBRA
PORTUGAL

WORKSHOP OPTIMIZAÇÃO DE TRANSPORTES

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PAVEMENT DESIGN OPTIMIZATION MODEL

(OPTIPAV)

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MAIN TOPICS OF PRESENTATION

1. PROBLEM STATEMENT
2. AASHTO PAVEMENT DESIGN METHOD
3. PAVEMENT DESIGN OPTIMIZATION MODEL
4. HEURISTIC TO SOLVE THE MODEL
5. CASE STUDY
6. CONCLUSIONS

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PROBLEM STATEMENT

Portuguese Pavement Design/Conception Manual (MACOPAV):

Flexible pavement design period is 20 years but it is important to make a Life Cycle Cost Analysis:

- Period not inferior to 40 years (project analysis period)

- To compare different solutions in terms of global costs for the final choice of the pavement structure

- Costs: the initial cost of construction; the costs of maintenance during the analysis period; the user costs during the analysis period; and the pavement residual value at the end of the analysis period

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AASHTO PAVEMENT DESIGN EQUATION

AASHTO - American Association of State Highway and Transportation Officials

$$PSI_t = PSI_0 - (4.2-1.5)\cdot 10^{\left[\left(\log_{10}(W_{18}) - Z_R \cdot S_0 - 9.36\log_{10}(SN+1) + 0.2 - 2.32\log_{10}(M_R) + 8.07\right)\cdot\left(0.4+\frac{1094}{(SN+1)^{5.19}}\right)\right]}$$

W_{18} = number of 18-kip equivalent single axle load applications estimated for a selected design period and design lane

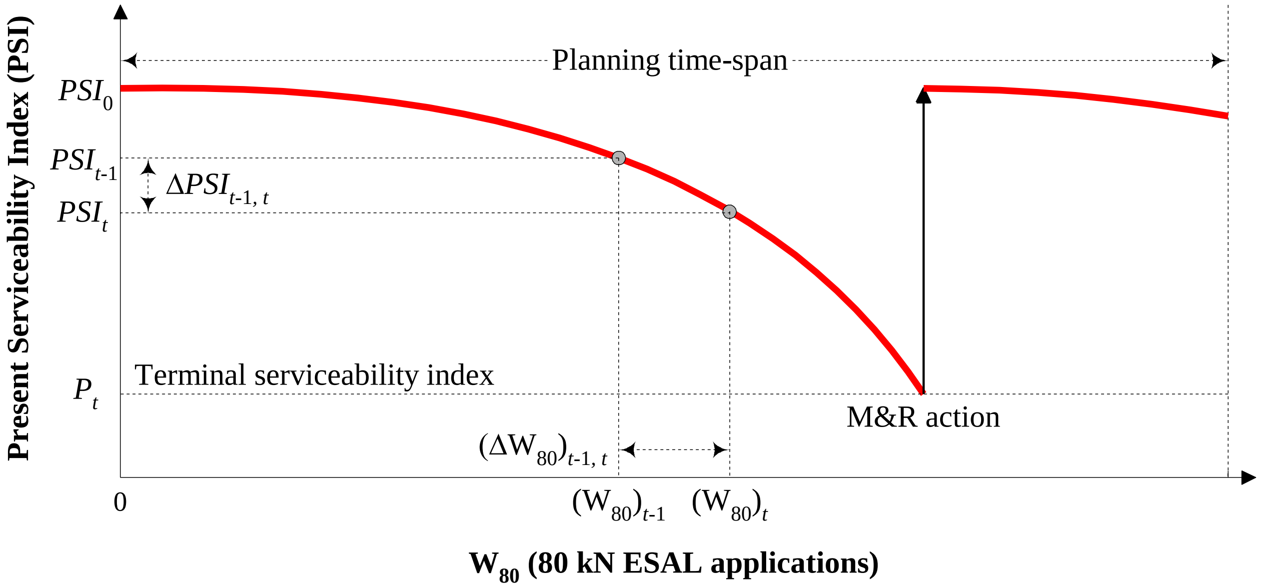
Z_R = standard normal deviate

S_0 = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the initial or present serviceability index (PSI_0) and the terminal serviceability index (PSI_t)

SN = structural number indicative of the total required pavement thickness

M_R = sub-grade resilient modulus (pounds per square inch)



AASHTO PAVEMENT DESIGN EQUATION

$$PSI_t = PSI_0 - (4.2 - 1.5) \cdot 10^{\left[\left(\log_{10}(W_{18}) - Z_R \cdot S_0 - 9.36 \log_{10}(SN+1) + 0.2 - 2.32 \log_{10}(M_R) + 8.07 \right) \cdot \left(0.4 + \frac{1094}{(SN+1)^{5.19}} \right) \right]}$$

Road class	Pavement type	PSI_0	PSI_t
Highways	Flexible	4.2 – 4.5	2.5 – 3.0
National roads	Flexible	4.2 – 4.5	2.0
Municipal roads	Flexible	4.2 – 4.5	1.5
Highways	Rigid	4.5	2.5 – 3.0
National roads	Rigid	4.5	2.0
Municipal roads	Rigid	4.5	1.5

Note: PSI_0 – initial *PSI*
PSI_t – terminal *PSI*

Pavement type	Standard deviation - S_0
Flexible	0.40 – 0.50
Rigid	0.30 – 0.40

Confidence level - R (%)	Statistic value - Z_R
50	-0.000
60	-0.253
70	-0.524
75	-0.674
80	-0.841
85	-1.037
90	-1.282
91	-1.340
92	-1.405
93	-1.476
94	-1.555
95	-1.645
96	-1.751
97	-1.881
98	-2.054
99	-2.327
99.9	-3.090
99.99	-3.750

AASHTO PAVEMENT DESIGN EQUATION

$$SN = \sum_{n=1}^{N} H_n \times C_n^e \times C_n^d$$

Material	Description	C_n^e /cm
BD	Asphalt concrete for the wearing course layer	0.17323
MBD	Dense asphalt concrete for binder layer	0.17323
MB	Asphalt concrete for binder layer	0.13386
MB	Asphalt concrete for base layer	0.13386
BG	Granular base	0.05512
BTC	Base treated with hydraulic cement	0.09055
SBG	Granular sub-base	0.04331

M&R operation	Description	ΔSN
1	No action	0
2	Non structural surface rehabilitation	0.17323
3	Light structural rehabilitation	1.21261
4	Medium structural rehabilitation	2.07876
5	Major structural rehabilitation	2.55121

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PAVEMENT MAINTENANCE OPTIMIZATION MODEL

Objective function

$$\text{Min}\, Cc_{s1} + \sum_{t=1}^{T}\sum_{r=1}^{R} \frac{1}{(1+d)^{t-1}} \cdot Ca_{rst} \cdot X_{rst} + \sum_{t=1}^{T} \frac{1}{(1+d)^{t-1}} \cdot Cu_{st} - \frac{1}{(1+d)^{T}} \cdot V_{s,T+1} \quad (1)$$

Constraints

$$Z_{st} = \Phi(Z_{s0}, X_{1s1},\ldots,X_{1st},\ldots,X_{Rs1},\ldots,X_{Rst}), s=1,\ldots,S; t=1,\ldots,T \quad (2)$$

$$Z_{st}\begin{Bmatrix}\leq \\ \geq\end{Bmatrix}\overline{Z}, s=1,\ldots,S; t=1,\ldots,T \quad (3)$$

$$X_{rst} \in \Omega(Z_{st}), r=1,\ldots,R; s=1,\ldots,S; t=1,\ldots,T \quad (4)$$

$$\sum_{r=1}^{R} X_{rst} = 1,\ s=1,\ldots,S; t=1,\ldots,T \quad (5)$$

$$Cc_{s1} = \Psi c(M_{sl}, Th_{sl}), s=1,\ldots,S \quad (6)$$

$$Ca_{rst} = \Psi a(Z_{st}, X_{rst}), r=1,\ldots,R; s=1,\ldots,S; t=1,\ldots,T \quad (7)$$

$$Cu_{st} = \Psi u(Z_{st}), s=1,\ldots,S; t=1,\ldots,T \quad (8)$$

$$V_{s,T+1} = \Theta(Z_{s,T+1}), s=1,\ldots,S \quad (9)$$

$$\sum_{r=2}^{R}\sum_{t=1}^{T} X_{rst} \leq N\max_{s}, \forall s=1,\ldots,S \quad (10)$$

PAVEMENT MAINTENANCE OPTIMIZATION MODEL

Pavement condition functions

$$PSI_t = PSI_0 - (4.2 - 1.5) \times 10^{\left[\left(\log_{10}(W_{18}) - Z_R \times S_0 - 9.36 \times \log_{10}(SN+1) + 0.2 - 2.32 \times \log_{10}(M_R) + 8.07 \right) \times \left(0.4 + \frac{1094}{(SN+1)^{5.19}} \right) \right]} \tag{11}$$

$$SN_t = \sum_{n=1}^{N} H_n \times C_n^e \times C_n^d \tag{12}$$

$$W_{80_t} = 365 \times TMDA_p \times \frac{(1+tc)^{Y_t} - 1}{tc} \times \alpha \tag{13}$$

User cost function

$$VOC_t = 0.39904 - 0.03871 \times IQ_t + 0.00709 \times IQ_t^2 - 0.00042 \times IQ_t^3 \tag{14}$$

Residual value of pavements function

$$RV_{T+1} = C_{const} \times \frac{PSI_{T+1} - 1.5}{4.5 - 1.5} \tag{15}$$

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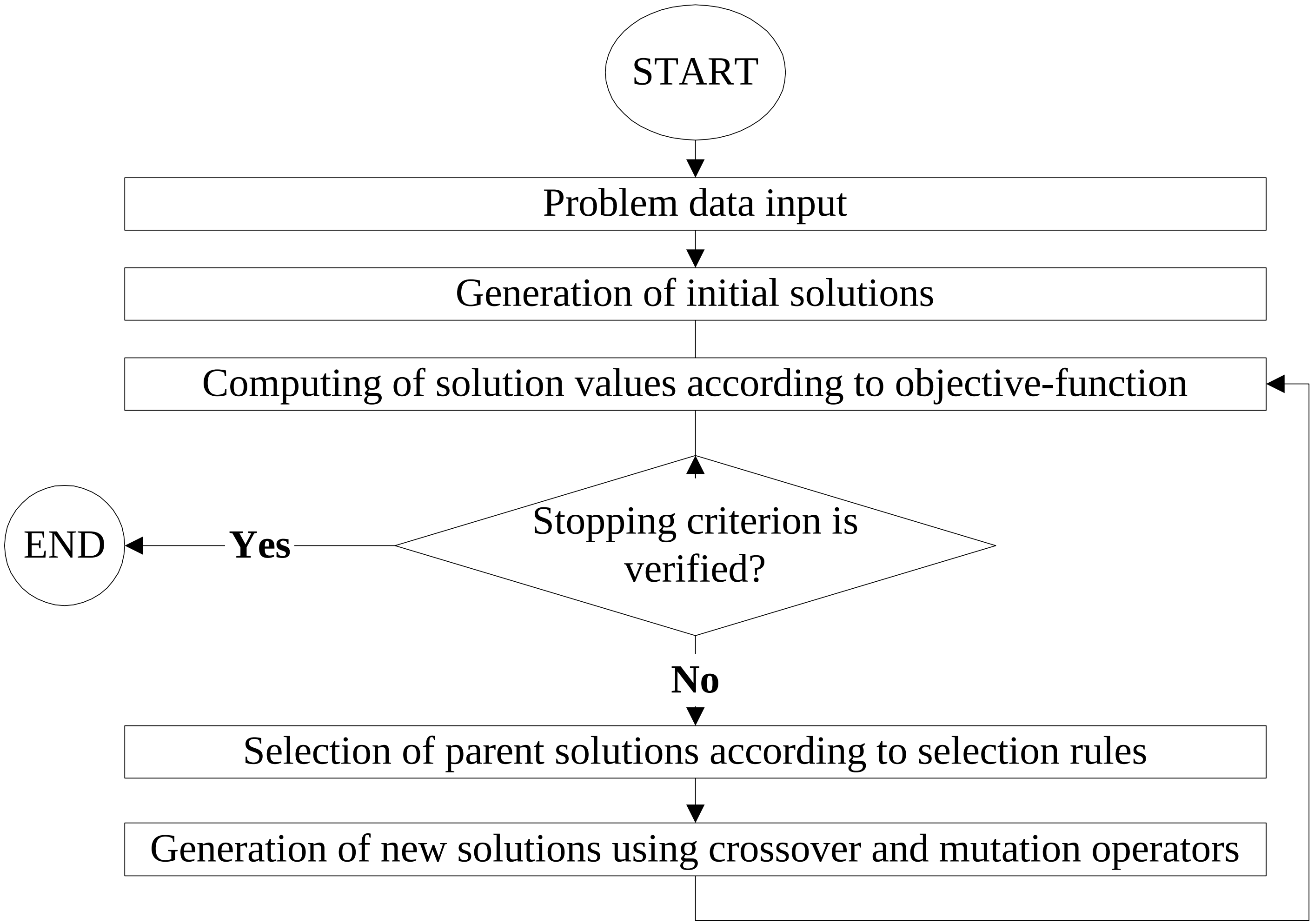
GENETIC ALGORITHM HEURISTIC TO SOLVE THE MODEL



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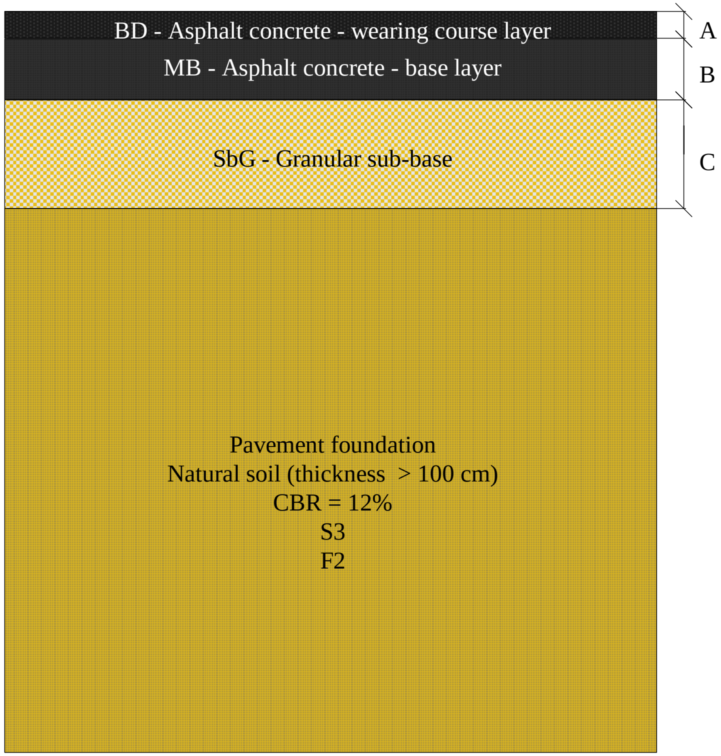
CASE STUDY

Structures of the Portuguese Pavement Design/Conception Manual



Attribute	Value
Road length (m)	10000
Road width (m)	10
Annual_average_daily_traffic (section)	5800
Annual_average_daily_heavy_traffic (one way)	450
Annual_growth_average_tax	4%
Truck_factor	4.00

Alternative pavement	A (cm)	B (cm)	C (cm)
1	4	12	20
2	4	18	20
3	5	20	20
4	5	23	20
5	6	24	20
6	6	26	20

Alternative pavement	Construction cost
1	24.53 €/m^2
2	29.70 €/m^2
3	32.77 €/m^2
4	35.36 €/m^2
5	37.56 €/m^2
6	39.29 €/m^2

M&R ACTIONS AND OPERATIONS

M&R action	Description	Cost
1	Do nothing	€0.00/m^2
2	Tack coat	€0.41/m^2
3	Surface levelling (1 cm)	€1.23/m^2
4	Surface levelling (2 cm)	€2.45/m^2
5	Membrane anti-reflection of cracks	€1.88/m^2
6	Base layer (10 cm)	€8.63/m^2
7	Binder layer (5 cm)	€6.13/m^2
8	Non structural wearing course layer	€3.13/m^2
9	Wearing course layer (5 cm)	€6.69/m^2

M&R operation	Description	M&R actions involved	Cost
1	No action	1	€0.00/m^2
2	Non structural surface rehabilitation	2+3+2+8	€5.18/m^2
3	Light structural rehabilitation	2+4+2+5+2+9	€12.25/m^2
4	Medium structural rehabilitation	2+4+2+5+2+7+2+9	€18.79/m^2
5	Major structural rehabilitation	2+4+2+5+2+6+2+9	€21.29/m^2

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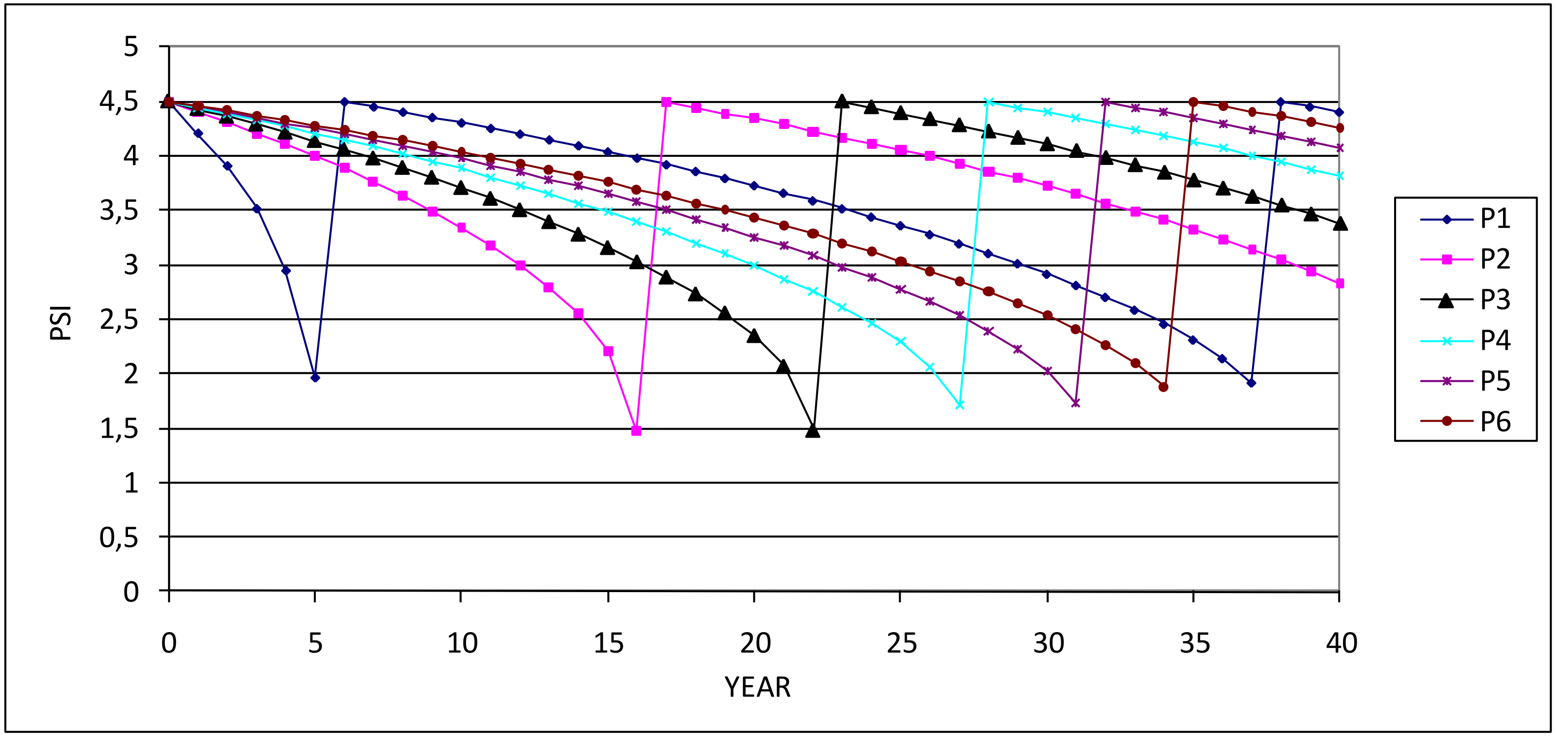
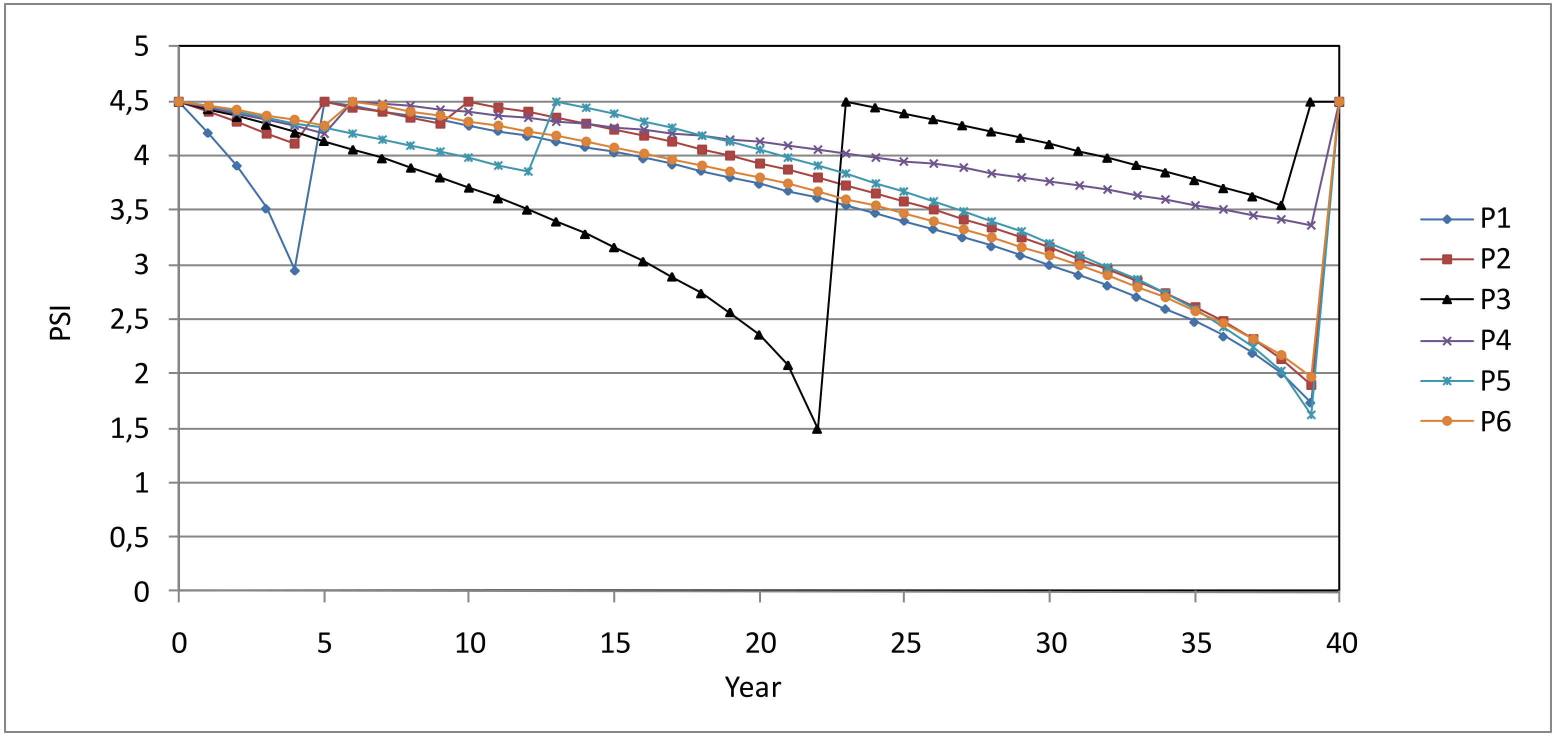
RESULTS (CORRECTIVE M&R INTERVENTIONS)

Structure	PSI	Construction_cost	Maintenance_cost	User_cost	Residual_value	Total	Difference	Difference (%)
1	4,5	2453000,0	4258000	699687292,8	2375321,7	704022971,1	4594427,0	0,66%
2	4,5	2970000,0	2129000	696576264,9	1321650,0	700353614,9	925070,8	0,13%
3	4,5	3277000,0	2129000	696077223,2	2054679,0	699428544,2	0,0	0,00%
4	4,5	3536000,0	2129000	696669469,6	2728613,3	699605856,3	177312,1	0,03%
5	4,5	3756000,0	2129000	698083587,5	3218892,0	700749695,5	1321151,4	0,19%
6	4,5	3929000,0	2129000	698906341,9	3617299,3	701347042,6	1918498,4	0,27%



RESULTS (PREVENTIVE M&R INTERVENTIONS)

Structure	PSI	Construction_cost	Maintenance_cost	User_cost	Residual_value	Total	Difference	Difference (%)
1	4,5	2453000,0	4258000,0	701534060,6	2453000,0	705792060,6	9808256,5	1,4%
2	4,5	2970000,0	3872000,0	699554532,4	2970000,0	703426532,4	7442728,3	1,1%
3	4,5	3277000,0	3872000,0	695649185,0	3277000,0	699521185,0	3537380,9	0,5%
4	4,5	3536000,0	3104000,0	692879804,1	3536000,0	695983804,1	0,0	0,0%
5	4,5	3756000,0	2647000,0	700014199,3	3756000,0	702661199,3	6677395,2	1,0%
6	4,5	3929000,0	2647000,0	699990942,9	3929000,0	702637942,9	6654138,9	1,0%



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RESULTS (PREVENTIVE M&R INTERVENTIONS)

Structure	PSI	Construction_cost	Maintenance_cost	User_cost	Residual_value	Total	Difference	Difference (%)
1	4,5	2453000,0	4258000,0	701534060,6	2453000,0	705792060,6	9808256,5	1,4%
2	4,5	2970000,0	3872000,0	699554532,4	2970000,0	703426532,4	7442728,3	1,1%
3	4,5	3277000,0	3872000,0	695649185,0	3277000,0	699521185,0	3537380,9	0,5%
4	4,5	3536000,0	3104000,0	692879804,1	3536000,0	695983804,1	0,0	0,0%
5	4,5	3756000,0	2647000,0	700014199,3	3756000,0	702661199,3	6677395,2	1,0%
6	4,5	3929000,0	2647000,0	699990942,9	3929000,0	702637942,9	6654138,9	1,0%

Structure	PSI	Construction_cost	Maintenance_cost	User_cost	Residual_value	Total	Difference	Difference (%)
1	4,5	2453000,0	4258000,0	0,0	2453000,0	4258000,0	1611000,0	60,9%
2	4,5	2970000,0	3872000,0	0,0	2970000,0	3872000,0	1225000,0	46,3%
3	4,5	3277000,0	3872000,0	0,0	3277000,0	3872000,0	1225000,0	46,3%
4	4,5	3536000,0	3104000,0	0,0	3536000,0	3104000,0	457000,0	17,3%
5	4,5	3756000,0	2647000,0	0,0	3756000,0	2647000,0	0,0	0,0%
6	4,5	3929000,0	2647000,0	0,0	3929000,0	2647000,0	0,0	0,0%

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CONCLUSIONS AND FUTURE RESEARCH

This new approach allows optimizing the design of pavement structures, in function of the zone (different construction costs, different maintenance costs, etc.)

Genetic Algorithms can solve this kind of optimization model

In the near future, our research will follow two main directions:

- Application to all combinations between pavement structure, traffic and pavement foundation from MACOPAV
- Application considering other pavement design methods (Shell, University of Nottingham, etc.)

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PAVEMENT DESIGN OPTIMIZATION MODEL

(OPTIPAV)

END

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