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Road and Rail Infrastructure III

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PAVEMENT MAINTENANCE PROGRAMMING CONSIDERING THREE OBJECTIVES: MAINTENANCE AND REHABILITATION COSTS, USER COSTS, AND THE RESIDUAL VALUE OF PAVEMENTS

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Abstract

This paper presents the development and implementation of a Multi-Objective Decision-Aid Tool (MODAT) tested with data from the Estradas de Portugal's Pavement Management System. The MODAT uses a multi-objective deterministic section-linked optimisation model with three different possible objectives: minimisation of agency costs; minimisation of user costs; and maximisation of the residual value of pavements. The MODAT also uses the deterministic pavement performance model used in the AASHTO flexible pavement design method that allows the gap between project and network management to be closed. The application of the new Decision-Aid Tool is illustrated with a case study involving part of the main road network of Portugal. The "Knee point", which represents the most interesting solution of the Pareto frontier, corresponds to an agency costs weight value of 4%, a user costs weight value of 95% and a weight value of 1% for the residual value of pavements, demonstrating that user costs, which are generally much greater than agency costs and the residual value of pavements, dominate the decision-making process.

Keywords: *multiple objective analysis, optimisation models, decision support systems, highway maintenance, pavement management*

1 Introduction

In the literature related to pavement maintenance management, only few applications have made use of multi-objective optimisation techniques [1-3]. None of these multi-objective optimisation models considers the minimisation of user costs and a pavement performance model also used for pavement design which allows closing the gap between project and network management. In addition, none of these multi-objective optimisation models considers the maximisation of the residual value of pavements at the end of the planning period which is very important for highway agencies. Greater residual value of pavements is directly related to a greater residual life of pavements which means lower maintenance and rehabilitations costs in the next planning period. This paper presents the development and implementation of a Multi-objective Decision-Aid Tool (MODAT) which considers three different objectives, the minimisation of maintenance and rehabilitation costs, the minimisation of user costs, and the maximisation of the residual value of pavements at the end of the planning period. The MODAT is tested with data from the PMS used by the main Portuguese concessionaire (Estradas de Portugal, S.A.), the institution that acted until 2007 as the Portuguese Road Administration [4, 5].

2 Multi-Objective Decision-Aid Tool

The Multi-Objective Decision-Aid Tool (MODAT) consists of the components shown in Figure 1: the objectives of the analysis; the data and the models about the road pavements; the constraints that the system must guarantee; and the results.

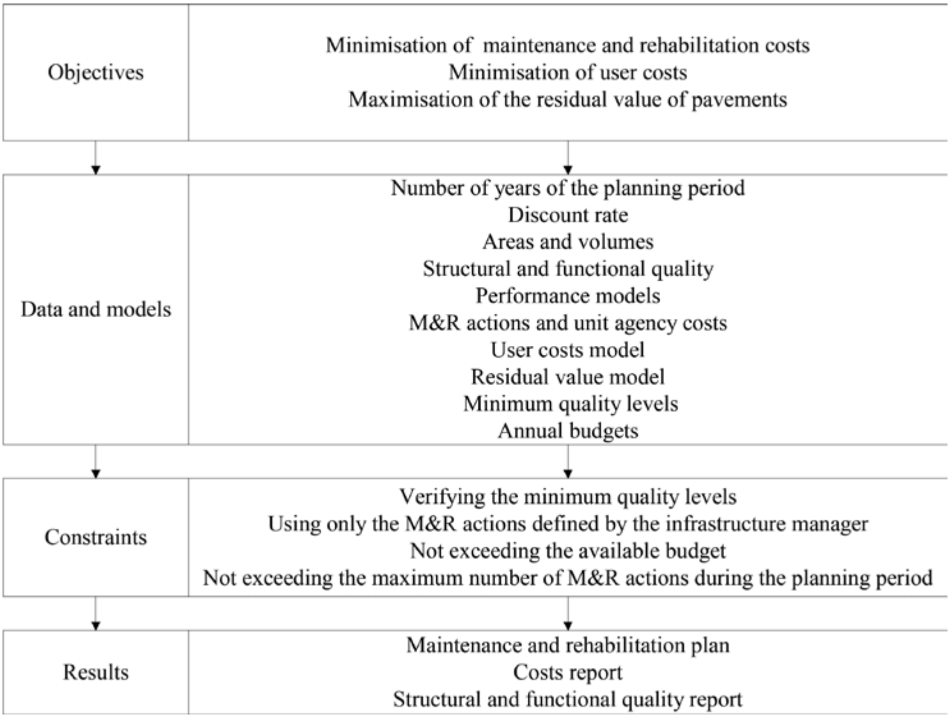

Figure 1 MODAT components.

Several objectives can be considered in the analysis, including the minimisation of maintenance and rehabilitation costs, the minimisation of user costs, the maximisation of the residual value of pavements at the end of the planning time-span, etc. The results of the application of the MODAT to a road network consist of the M&R plan, the costs report, and the structural and functional quality report. Details about the data, the models, and the constraints that the system must guarantee are described in recent published papers in international journals [6, 7].

3 Case study

The MODAT was tested with data from the Estradas de Portugal's Pavement Management System to plan the maintenance and rehabilitation of the road network considering three objectives. The MODAT was applied to the road network of the district of Castelo Branco, one of the 18 districts of Portugal. This road network has a total length of 589.9 km and the corresponding network model has 32 road sections. The discount rate considered in this study was 2.5%. The solutions of the optimisation problem were shown in a 3D representation using MATLAB. Figure 2 presents the three-dimensional (3D) Pareto optimal set of normalised solutions in the objective space by varying the weight values. The "Knee point" was obtained considering the following weight values: $(w_{AC}, w_{UC}, w_{RV}) = (0.04, 0.95, 0.01)$; and it corresponds to the following objective values (AC, UC, RV) = (€69228291.7, €1497083878.6, €37118050.1). The range of values for the three objective functions is (AC_{min}, AC_{max}) = (€44.2x10^6, €206.0x10^6), (UC_{min}, UC_{max}) = (€1424.2x10^6, €2529.3x10^6) and (RV_{min}, RV_{max}) = (€10.9x10^6, €39.2x10^6). Here, w_{AC}, w_{UC}, and w_{RV} are the weight values for each objective function; AC, UC, and RV are the individual objective function values that depend on the decision variables values; AC_{min}, UC_{min}, and RV_{min} are the minimum values obtained for each objective; AC_{max}, UC_{max}, and RV_{max} are the maximum values obtained for each objective.

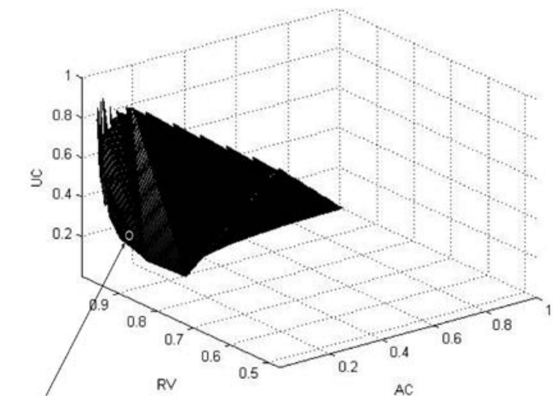

Figure 2 3D Pareto optimal set of normalised solutions.

The final best-compromise solution from the Pareto optimal set of solutions in multi-objective problems is always up to the decision maker. For that purpose, five different M&R solutions of the Pareto frontier were considered for comparison:

a Solution I: Multi-objective optimisation approach (corrective-preventive) considering the "Knee point" (w_{AC} = 0.04, w_{UC} = 0.95, w_{RV} = 0.01);
b Solution II: Multi-objective optimisation approach (corrective-preventive) considering the following weights (w_{AC} = 1.00, w_{UC} = 0.00, w_{RV} = 0.00);
c Solution III: Multi-objective optimisation approach (corrective-preventive) considering the following weights (w_{AC} = 0.00, w_{UC} = 1.00, w_{RV} = 0.00);
d Solution IV: Multi-objective optimisation approach (corrective-preventive) considering the following weights (w_{AC} = 0.00, w_{UC} = 0.00, w_{RV} = 1.00);
e Solution V: Multi-objective optimisation approach (corrective-preventive) considering the following weights (w_{AC} = 1/3, w_{UC} = 1/3, w_{RV} = 1/3).

The costs and normalised costs during the entire planning time-span for these five Pareto optimal solutions are summarised in Figures 3 and 4, respectively. Figure 3 shows that, as expected, solution I ("Knee point") is the Pareto optimal solution with the lowest total costs (M&R costs, plus user costs, minus residual value of pavements), which was the objective considered in the multi-objective optimisation model. Solution III, considering the weights (w_{AC} = 0.00, w_{UC} = 1.00, w_{RV} = 0.00), is the second best solution, which corresponds to the minimisation of user costs. It is interesting that solution II, which corresponds to the minimisation of agency costs, is the worst solution in terms of total costs. Solution V, considering equal weights for the three objectives, is an interesting solution for the road administration because it has the lowest value of M&R costs minus residual value of pavements.

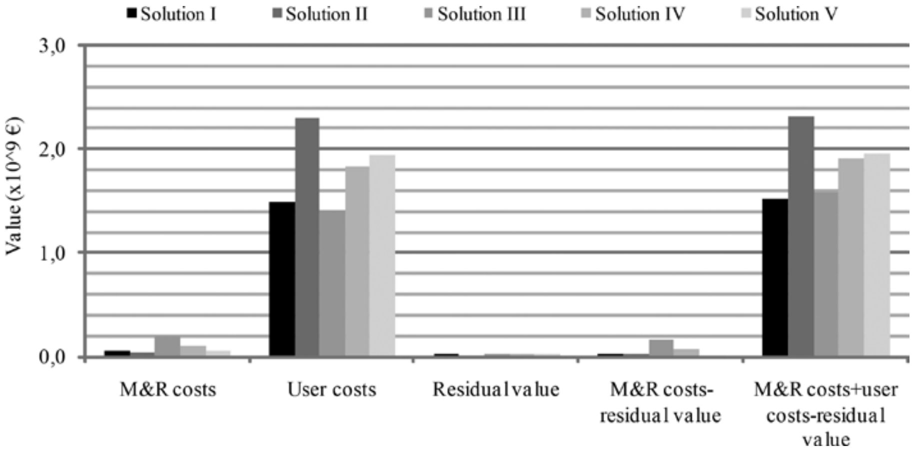

Figure 3 Costs throughout the planning time-span of 20 years.

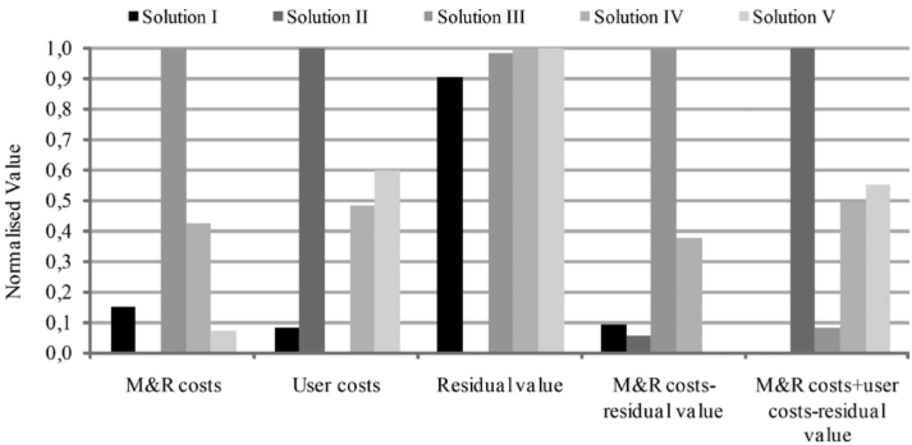

Figure 4 Normalised costs throughout the planning time-span of 20 years.

Figure 5 presents the predicted PSI average value over the years of the planning time-span for all the road network pavements and for each solution. One can conclude that solution III, i.e. the solution of the multi-objective optimisation approach considering the weights ($w_{AC} = 0.00$, $w_{UC} = 1.00$, $w_{RV} = 0.00$), corresponds to the highest average PSI values, as expected, because this solution corresponds to the minimisation of the user costs. Solution I ("Knee point") is the second best solution in terms of average PSI values, also as expected, because this solution corresponds to a high weight value for user costs and small weight values for the other two objectives ($w_{AC} = 0.04$, $w_{UC} = 0.95$, $w_{RV} = 0.01$). As expected, solution II, which corresponds to the minimisation of agency costs, is the worst solution in terms of average PSI values.

The results presented above were defined at network-level. At project-level, the MODAT provides extensive information about the M&R strategy to be implemented for each road section. To analyse these road section-linked results, four road sections were chosen with different attributes in the present year. Table 1 shows the attributes of these four road sections including their present PSI value. Table 2 presents the M&R operations to be applied in the four road sections, considering the five M&R solutions of the Pareto frontier.

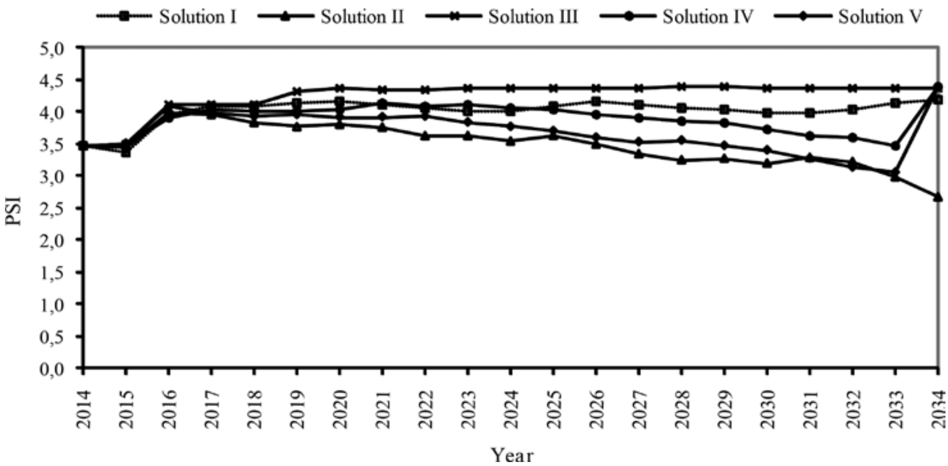

Figure 5 PSI average value for all the road network pavements.

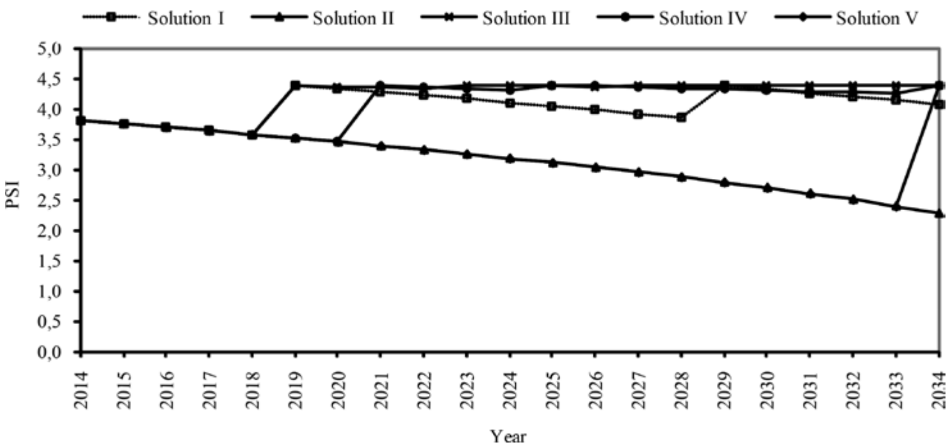

Figure 6 Evolution of PSI for pavement 05001 of a national road.

Figure 6 shows the predicted evolution of the PSI value over the years for pavement section 05001 of a national road as a consequence of the execution of the M&R plan. For this pavement section, which is in good condition (PSI value of 3.81), if solution I ("Knee Point") of MODAT is adopted, only two M&R operations 2 (non-structural maintenance) will be applied to the pavement section, one in year 2018 and another in year 2028. If solution II of MODAT is adopted, no M&R operation will be needed during all the planning time-span. If solution III of MODAT is adopted the recommended M&R operations are very different. The MODAT recommends the application of M&R operation 5 (major rehabilitation) in years 2018, 2022, 2026 and 2030. For solution IV, the MODAT recommends one M&R operation 4 (Medium rehabilitation) in year 2020 and the application of two M&R operation 3 (minor rehabilitation) in years 2024 and 2033. If solution V of MODAT is adopted only one M&R operation will be needed during all the planning time-span, i.e. M&R operation 2 in year 2033. An identical analysis could be made for any other pavement section.

Table 1 Attributes of road sections.

Attributes	**Road sections**			
Section_ID	05012	05004	05001	05003
Road_class	EN	IC	IP	IC
Pavement_type	Flexible	Flexible	Flexible	Flexible
District	Castelo Branco	Castelo Branco	Castelo Branco	Castelo Branco
Length (m)	21,455	19,439	1931	14,635
Width (m)	5.9	8.8	9.4	8.6
Sub-grade_CBR (%)	5	10	6	4
Structural_number	2.47	3.51	5.20	4.80
Age_of_pavements (years)	16	14	8	3
Annual_average_daily_traffic	744	6,212	4316	5,828
Annual_average_daily_heavy_traffic	100	1000	300	1000
Annual_growth_average_tax	3.0	4.0	3.0	4.0
Truck_factor	2.0	4.0	3.0	4.0
PSI_0	1.79	2.75	3.81	3.90

Table 2 M&R operations to be applied in road sections.

Section	PSI_0	Year																			
		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Solution I - Knee point (w_{AC} = 0.04, w_{UC} = 0.95, w_{RV} = 0.01)																					
05012	1.79	**5**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**2**
05004	2.75	**4**	1	1	1	1	1	1	1	**2**	1	1	1	1	1	1	**2**	1	1	1	1
05001	3.81	1	1	1	1	**2**	1	1	1	1	1	1	1	1	1	**2**	1	1	1	1	1
05003	3.90	1	1	**3**	1	1	1	1	**2**	1	1	1	**2**	1	1	1	1	**2**	1	1	1
Solution II (w_{AC} = 1.00, w_{UC} = 0.00, w_{RV} = 0.00)																					
05012	1.79	**5**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
05004	2.75	**3**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
05001	3.81	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
05003	3.90	1	1	1	1	1	**2**	1	1	1	1	**3**	1	1	1	1	1	1	1	1	1
Solution III (w_{AC} = 0.00, w_{UC} = 1.00, w_{RV} = 0.00)																					
05012	1.79	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	1	1	1	1
05004	2.75	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	1	1	1	1
05001	3.81	1	1	1	1	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1
05003	3.90	1	1	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	**5**	1	1	1	1	1
Solution IV (w_{AC} = 0.00, w_{UC} = 0.00, w_{RV} = 1.00)																					
05012	1.79	**5**	1	1	1	**3**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**2**
05004	2.75	**5**	1	1	1	**3**	1	1	1	1	**4**	1	1	1	1	1	1	1	1	1	**3**
05001	3.81	1	1	1	1	1	1	**4**	1	1	1	**3**	1	1	1	1	1	1	1	1	**3**
05003	3.90	1	1	1	1	1	1	**5**	1	1	1	1	1	1	**5**	1	1	1	1	1	**3**
Solution V (w_{AC} = 1/3, w_{UC} = 1/3, w_{RV} = 1/3)																					
05012	1.79	**5**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**2**
05004	2.75	**3**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**2**
05001	3.81	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**2**
05003	3.90	1	1	1	1	**4**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**2**

KEY (M&R operations):
1 – Do nothing; 2 – Non-structural maintenance; 3 – Minors rehabilitation; 4 – Medium rehabilitation; 5 – Major rehabilitation.

4 Conclusions

The Multi-objective Decision-Aid Tool (MODAT) is a useful new tool to help the road engineers in their task of maintenance and rehabilitation of pavements. In this MODAT application, the Knee point, which represents the most interesting solution of the Pareto frontier, corresponds to an agency costs weight value of 4%, a user costs weight value of 95% and a weight value of 1% for the residual value of pavements, demonstrating that user costs, which are generally much greater than agency costs and the residual value of pavements, dominate the decision-making process. While the case study of this paper focuses on a national road network, the approach proposed is applicable to any transportation infrastructure network, e.g., municipal road network, bridge network, where the decision-making process often involves multiple objective considerations.

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References

[1] Fwa, T., Chan, W., and Hoque, K.: Multiobjective optimization for pavement maintenance programming. Journal of Transportation Engineering, 126 (5), 367-374, 2000.

[2] Wang, F., Zhang, Z., and Machemehl, R.: Decision making problem for managing pavement maintenance and rehabilitation projects. Transportation Research Record, 1853, 21-28, Washington DC, USA, 2003.

[3] Wu, Z., Flintsch, G.: Pavement preservation optimization considering multiple objectives and budget variability. Journal of Transportation Engineering, 135 (5), 305-315, 2009.

[4] Picado-Santos, L., and Ferreira, A.: Contributions to the development of the Portuguese road administration's pavement management system. Proceedings of the Third European Pavement and Asset Management Conference, CD Ed., paper 1138.pdf, 1-10, Coimbra, Portugal, 2008.

[5] Ferreira, A., Picado-Santos, L., Wu, Z. and Flintsch, G.: Selection of pavement performance models for use in the Portuguese PMS. International Journal of Pavement Engineering, 12 (1), 87-97, 2011.

[6] Meneses, S., Ferreira, A. and Collop, A.: Multi-objective decision-aid tool for pavement management, Proceedings of the Institution of Civil Engineers-Transport, 166 (2), 79-94, 2013.

[7] Meneses, S. and Ferreira, A.: Pavement maintenance programming considering two objectives: maintenance costs and user costs, International Journal of Pavement Engineering (ISI Journal), 14 (2), 206-221, 2013.