Jestr

Journal of Engineering Science and Technology Review 15 (2) (2022) 208 - 214

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Twofold Appraisal of Pavement Maintenance Technologies

Grigorios Papageorgiou*

University of Thessaly, "Geopolis" Campus, 41500, Larissa, Greece

Received 9 July 2020; Accepted 15 September 2021

Abstract

Pavement is an essential component of the road and as such, its proper maintenance is a crucial issue for road managers, constructors and users. In the context of pavement maintenance, several technologies are used in common international practice. These applications are often proven either insufficient in terms of distress treatment adequacy or difficult to be applied due to insufficient resources (financial, labor, equipment etc.). Especially in the context of modern infrastructure management, a question arises: Which is the top-notch maintenance technology? This research evaluates these techniques using criteria proposed by a recently published study and conducting a twofold appraisal in engineering and economic terms by applying the analytical hierarchy process (AHP) method. As resulted, in engineering terms, the optimal maintenance technique is the thin hot mix asphalt (HMA) overlay whilst in economic terms, microsurfacing is proven to be of the lowest cost. If the case is equally weighted engineering and economic importance, the overall optimal maintenance technique stands for the thin HMA overlay. The fruitful findings indicate that the decision for the option to be finally implemented is a complicated task depending on engineering and financial factors. The twofold appraisal proposed, serves as a tool for road authorities and constructors to decide for the best, in each case, option.

Keywords: Appraisal, Pavement management, Maintenance technologies, Infrastructure management, Decision making

1. Introduction and Literature Review

Road network is nowadays one of the most valuable assets of a country's infrastructure. This is because, in addition to travelling for tourist / social reasons, it constitutes, along with rail, air and sea transport, a pillar for freight / commercial transport. Coming out of the global financial crisis of 2008, the world has redefined the priorities of its public investment strategy, giving greater importance than ever before to its economic dimension. In addition, the expansion of road infrastructure now largely meets the demand of users, offering an extensive network of road interconnections. Wider benefits, such as sustaining local businesses, tourism and agriculture, which are connected to the access levels, are affected by the overall road quality [1].

The extreme importance of maintenance for the rehabilitation of distressed pavement is evidenced by a number of related studies linking skid-resistance and rutting to accident rates [2-13], as well as evenness to travel time costs [13-14]. In addition, the economic component is also very important according to relative studies of World Bank [15] and World Road Association (PIARC) [16].

Within this framework, one of the important issues is the effective management of this infrastructure, in the light of the best possible choice. The pavement, as a key element of the road network, is subject to maintenance, either preventive or strengthening, depending on the traffic loads. The evaluation of maintenance techniques is a cutting-edge issue, as adopting the best possible option, benefits road operators, manufacturers and road users. A road asset management system is called to predict needs and identify methods suitable to maintain and upgrade road assets by taking into consideration available financial resources [17].

In this paper, five, widely applied worldwide, preventive maintenance technologies are selected and their evaluation is adopted from a recent detailed study of Mouratidis et al. [18]. An analytical hierarchy process (AHP) method is then applied in order to obtain the optimal maintenance technology based on the above criteria.

While there are many studies evaluating maintenance technologies, they are limited to proposing an optimal choice on the basis of cost-effectiveness, remaining life period and past experience, for limited alternatives.

The Federal Highway Administration (FHWA) Report [19] on “Pavement Maintenance Effectiveness – Preventive Maintenance Treatments” presents in a comprehensive way, the most common maintenance techniques (materials, overlay thickness, equipment, field of application) as well as lessons learnt from previous experience.

The FHWA Report [20] on “Pavement Performance Measures and Forecasting and the Effects of Maintenance and Rehabilitation Strategy on Treatment Effectiveness” presents a simple distress/ possible cause / recommended operation matrix for maintenance and rehabilitation (strengthening). It also introduces the terms RFP (remaining functional period) and RSP (remaining structural period) and attempts a correlation of evolving defects with proper time for maintenance required.

In a PIARC report [16], the challenge of reduction of construction time and cost of road pavements is presented as well as an overview of actions with beneficial effects: tendering procedures, selection of technical solutions, organization methods for the works.

The “Manifesto for long-term, effective management of a safe and efficient European road network” [21], emphasizes on the importance of timely and meticulous maintenance,

*E-mail address: gpapageor@uth.gr
ISSN: 1791-2377
doi:10.25103/jestr.152.24

indicating current rates of maintenance cost (0.5%) with respect to the construction cost and respective optimum/required rates (1.5%) to extend lifetime of the existing road infrastructure.

Putman et al. [22], in a report on "Ranking of Pavement Preservation Practices and Methods", presented a comprehensive distress/maintenance technique matrix, as well as, a life-cycle analysis of cost for various maintenance techniques.

Zhou et al. [23] evaluate maintenance technologies based on an "Economic-Benefit" index, and Luhr and Rydholm [24] propose an "Economic Evaluation of Pavement Management Decisions" by monitoring cost-effectiveness by location and evaluating the cost-effectiveness of individual contracts.

Zuniga-Garcia et al. [25] conducted an economic analysis of pavement preservation techniques, developing a life cycle cost assessment (LCCA) framework, comparing three primary pavement maintenance treatments used in Texas.

As Khan et al. [26] suggest, it is believed that a Multi¬Criteria Analysis (MCA) using economic, political, social and environmental factors could be utilized if economic results cannot produce a sound optimum standard. All these factors may be considered for sustainable pavement management. Jain et al. [27] considered treatment alternatives for one specific IRI, and hence no optimum standards were derived. Rather optimum strategies were chosen for a given IRI.

None of the abovementioned studies do not address the issue holistically, that is, taking into account engineering and economic criteria together, so that the result be based on a comprehensive approach to the issue. The recent research by Mouratidis et al. [18], presents for the first time such an evaluation, based on specific engineering and economic criteria, with regard to the most widespread maintenance techniques for flexible pavements, namely thin HMA overlay, slurry seal, béton bitumineux mince (BBTM), surface dressing and microsurfacing.

2. Appraisal Methodology

Evaluation of the pavement maintenance technologies is a difficult task, as the factors that influence their effectiveness are many in number, and in many cases, the best from economic point of view is not optimal from an engineering standpoint. In other words, this is a complex problem, that must be examined in all its aspects and, indeed, seen from both sides, technical and economic. In this way, it will become possible, the road operator and/or the contractor, to understand the advantages and disadvantages of each technique, so that eventually, to make the correct decision for the technique to be implemented in each case.

Another important issue is the available budget and generally the capability of the road operator to finance the project. This means that even if a maintenance technique proves to be optimal, its application is impracticable if the necessary funds are not available for its implementation. Therefore, it is understood that the optimal alternative should be determined through a detailed analysis of the technical and economic factors for each option.

In order to incorporate the above issues into the decision-making process, the appraisal methodology proposed herein, applies the AHP method with a twofold approach, as shown in Figure 1.

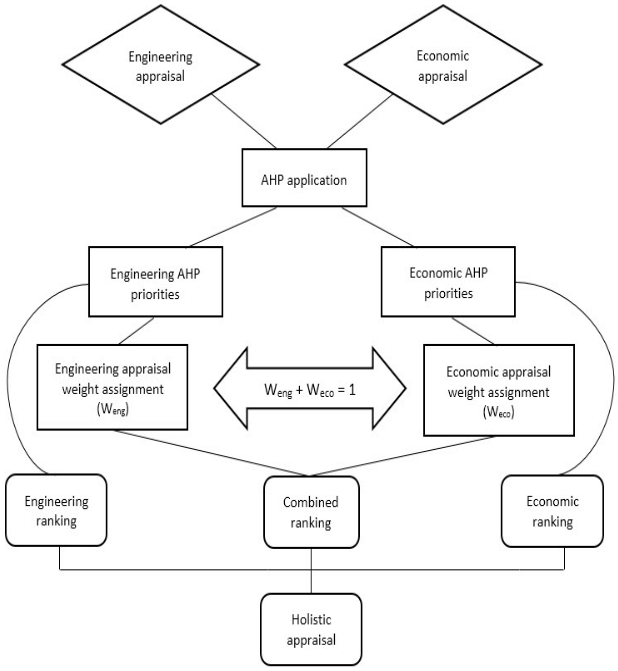

Fig. 1. Flowchart of the proposed concept

The two aspects of this twofold appraisal are as follows:

1 Engineering appraisal
2 Economic appraisal

More specifically, the concept methodology consists of the following steps:

- Both aspects of evaluation begin with the implementation of the AHP method.
- As a result, a priority register of maintenance technologies is drawn up for each of the two aspects.
- On the basis of this register, a technical and economic ranking list is drawn up.
- One weight is set for the engineering and one for the economic dimension of the appraisal, as appropriate, that is according to the financial capabilities of the road operator. Their sum is equal to 1.
- From the above, a ranking table of maintenance alternatives is set, from the most appropriate to the least appropriate.
- Finally, taking into account the three boards, namely the engineering, the financial and the combined ranking, the options available are assessed globally, considering all the necessary elements.

2.1 Implementation of Twofold Appraisal

The criteria used to implement the proposed twofold appraisal concept, as well as their evaluation, are adopted from the study cited above by Mouratidis et al. [18], as shown in Figures 2 and 3. The criteria set to evaluate techniques by engineering judgement and in terms of economic evaluation, are presented in Table 1.

With regard to "construction cost", figures in parentheses (Figures 2, 3) refer to the cost of materials and laying [19, 22, 28]. The values included in Figures 2, 3 refer to estimated current prices in Europe according to the data collected by Mouratidis et al. [18].

TYPE OF ASPHALT OVERLAY / TECHNIQUE	EASE AND RATE OF APPLICATION	VERSATILITY	EFFECTIVENESS	DURABILITY	ENVIRONMENT
Thin HMA Overlay d=2-3 cm	**Good** (Modified binder, dense mix, simple equipment)	**Very good** (Aging, evenness, structural support)	**Very good**	**Excellent** (7-10 years)	**Fair** (High energy and material consumption)
Slurry seal (cold – single layer) d=0.5-1.5 cm	**Fair** (Emulsion, opening to traffic after 2-12 hours, special equipment)	**Fair** (Small cracks, raveling)	**Good**	**Fair** (3-5 years)	**Excellent** (Normal noise level, low energy consumption)
BBTM (hot) d=2-3 cm	**Very good** (Modified binder, simple equipment)	**Very good** (Slipperiness, small cracks, moderate rutting, bleeding)	**Very good**	**Very good** (6-8 years)	**Good** (Material consumption, reduced noise level)
Surface dressing (single) d=0.5-1.5 cm	**Good** (Emulsion, hard aggregates, opening to traffic after 2 hours)	**Fair** (Slipperiness, small cracks)	**Good** (Moderate vehicle speed)	**Fair** (3-5 years)	**Good** (Increased noise level, pollutants according to binder type)
Microsurfacing (cold) d=1-1.5 cm	**Fair** (Modified emulsion, special equipment)	**Good** (Evenness, rutting, small cracks, bleeding, raveling)	**Very good**	**Good** (5-7 years)	**Very good** (Reduced noise level)
Local Repair (fog seal, crack sealing)	**Good** (Generally, easily applicable, simple equipment)	**Fair** (Small cracks, raveling)	**Fair**	**Fair** (2-6 years)	**Very good** (Very light application, normal noise level)

Fig. 2. Engineering evaluation of preventive maintenance techniques [18]

TYPE OF ASPHALT OVERLAY / TECHNIQUE	CONSTRUCTION COST	MAINTENANCE MANAGEMENT COST	COST AT OPERATIONAL STAGE	INCREASED TOLL FEE PRICE / OFF-ROAD REVENUES	SOCIETAL BENEFITS
Thin HMA Overlay	**Very high** (1.8-2.2 €/m^2)	**Low**	**Very low**	**High**	**High**
Slurry seal (cold – single layer)	**Fair** (0.7-1.1 €/m^2)	**Fair**	**Fair**	**Fair**	**Fair**
BBTM (hot)	**High** (1.2-2.0 €/m^2)	**Low**	**Low**	**High**	**High**
Surface dressing (single)	**Fair** (0.8-1.2 €/m^2)	**Low**	**High**	**Fair**	**Fair**
Microsurfacing (cold)	**High** (1.1-1.6 €/m^2)	**Very low**	**Low**	**High**	**High**
Local Repair (fog seal, crack sealing)	**Very low** (0.3-0.5 €/m^2)	**Fair**	**Fair**	**Low**	**Low**

Fig. 3. Economic evaluation of preventive maintenance techniques [18]

Table 1. Description of engineering and economic evaluation criteria

Engineering criteria	**Description**
Ease and rate of application	Availability of equipment and materials, of range of laying temperatures, of familiarity with the technique and of possible or current rates of application
Versatility	Field of its application, the range of distress targeted (e.g. rutting, slipperiness, disintegration)
Effectiveness	Expected engineering result of the implemented technique, the pavement performance after operations
Durability	Resilience over time, illustrated by time required until the next operation
Environment	Impacts, positive and negative on the environment, including material and energy consumption, emissions during operations, but also increase in speed and decrease in pollution after operations
Economic criteria	
Construction cost	Necessary expenses for materials and implementation (equipment, labor)
Maintenance management cost	Operations cost during engineering activities
Cost at operational stage	Corrective maintenance costs and benefits from reduced routine maintenance
Increased toll fee price / off road revenues	Income from toll fees and off-road facilities
Societal benefits	Decrease in accident rates, reduced travel time, spare parts required, decrease in fuel consumption, reduced insurance costs

Based on these, an implementation example of the proposed twofold appraisal is presented hereafter. Local Repair is excluded from the twofold appraisal, since it refers to localized operations, thus not comparable to the others. Moreover, to conclude to the best pavement evaluation method, the analytical hierarchy process (AHP) technique [29] is followed hereafter. The AHP hierarchy for this decision is shown in Figures 4 and 5, for engineering and economic appraisal, accordingly. The priorities are derived from a series of pairwise comparisons involving all the nodes, meaning each box in the hierarchy diagram. The nodes at each level will be compared, two by two, with respect to their contribution to the nodes above them. The results of these comparisons will be entered into a matrix which is processed mathematically to derive the priorities for all the nodes on the level, according to the methodology of the AHP technique [30].

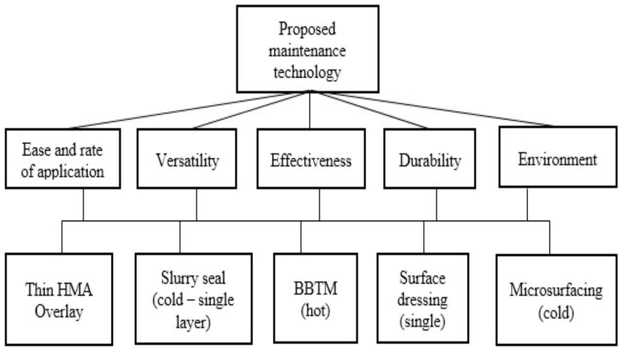

Fig. 4. AHP scheme for pavement evaluation methods in terms of engineering appraisal

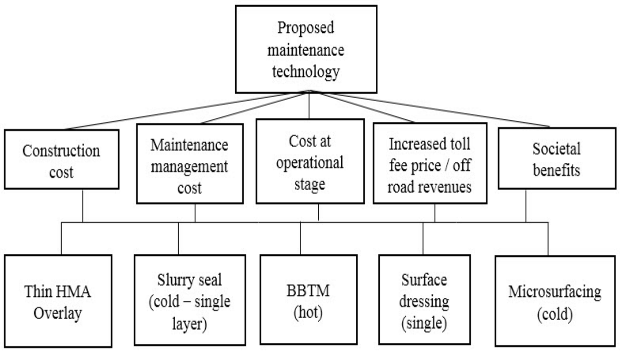

Fig. 5. AHP scheme for pavement evaluation methods in terms of economic appraisal

The AHP fundamental scale for pairwise comparisons (scale of relative importance) is adopted by Saaty [29, 30].

2.2 AHP Application for Engineering Criteria

The application of the AHP method from an engineering point of view is given in Table 2 and begins by comparing the alternative maintenance technologies with respect to their strengths in meeting each of the appraisal criteria. The consistency ratios for ease and rate of application, versatility, effectiveness, durability and environment pairwise comparisons, are 1.2%, 1.2%, 0%, 3% and 2.8%, accordingly. In sequence, pairwise comparison of the criteria with respect to their importance to reaching the goal, meaning the best alternative, takes place as shown in Table 3, with a consistency ratio of 0%. Finally, overall priorities/weights for the maintenance technologies, applying the AHP method, are shown in Table 4.

Table 2. Pairwise comparison matrix for engineering criteria

Ease and rate of application	**Thin HMA Overlay**	**Slurry seal (cold – single layer)**	**BBTM (hot)**	**Surface dressing (single)**	**Microsurfacing (cold)**	**Priority**
Thin HMA Overlay	1	3	1/3	1	3	0.194
Slurry seal (cold – single layer)	1/3	1	1/5	1/3	1	0.073
BBTM (hot)	3	5	1	3	5	0.466
Surface dressing (single)	1	3	1/3	1	3	0.194
Microsurfacing (cold)	1/3	1	1/5	1/3	1	0.073
Versatility						
Thin HMA Overlay	1	5	1	5	3	0.359
Slurry seal (cold – single layer)	1/5	1	1/5	1	1/3	0.064
BBTM (hot)	1	5	1	5	3	0.359
Surface dressing (single)	1/5	1	1/5	1	1/3	0.064
Microsurfacing (cold)	1/3	3	1/3	3	1	0.153
Effectiveness						
Thin HMA Overlay	1	3	1	3	1	0.273
Slurry seal (cold – single layer)	1/3	1	1/3	1	1/3	0.091
BBTM (hot)	1	3	1	3	1	0.273
Surface dressing (single)	1/3	1	1/3	1	1/3	0.091
Microsurfacing (cold)	1	3	1	3	1	0.273
Durability						
Thin HMA Overlay	1	7	3	7	5	0.514
Slurry seal (cold – single layer)	1/7	1	1/5	1	1/3	0.053
BBTM (hot)	1/3	5	1	5	3	0.258
Surface dressing (single)	1/7	1	1/5	1	1/3	0.053
Microsurfacing (cold)	1/5	3	1/3	3	1	0.122
Environment						
Thin HMA Overlay	1	1/7	1/3	1/3	1/5	0.046
Slurry seal (cold – single layer)	7	1	5	5	3	0.504
BBTM (hot)	3	1/5	1	1	1/3	0.102
Surface dressing (single)	3	1/5	1	1	1/3	0.102
Microsurfacing (cold)	5	1/3	3	3	1	0.245

Table 3. Pairwise comparison matrix of engineering criteria with respect to reaching the goal

Engineering criteria	**Ease and rate of application**	**Versatility**	**Effectiveness**	**Durability**	**Environment**	**Priority**
Ease and rate of application	1	1/3	3	5	7	0.111
Versatility	3	1	5	7	9	0.333
Effectiveness	1/3	1/5	1	3	5	0.111
Durability	1/5	1/7	1/3	1	3	0.333
Environment	1/7	1/9	1/5	1/3	1	0.111

Table 4. Overall weights of pavement maintenance technologies from engineering scope

Maintenance technology	**Priority with respect to**					
	Ease and rate of application	**Versatility**	**Effectiveness**	**Durability**	**Environment**	**Goal**
Thin HMA Overlay	0.0215	0.1195	0.0303	0.1712	0.0051	0.3476
Slurry seal (cold – single layer)	0.0081	0.0213	0.0101	0.0176	0.0559	0.1130
BBTM (hot)	0.0517	0.1195	0.0303	0.0859	0.0113	0.2987
Surface dressing (single)	0.0215	0.0213	0.0101	0.0176	0.0113	0.0818
Microsurfacing (cold)	0.0081	0.0509	0,0303	0.0406	0.0272	0.1571

2.3 AHP Application for Economic Criteria

The application of the AHP method from an economic point of view is given in Table 5 and begins by comparing the alternative maintenance technologies with respect to their strengths in meeting each of the appraisal criteria. The consistency ratios for construction cost, maintenance management cost, cost at operational stage, increased toll fee price / off road benefits and societal benefits pairwise comparisons, are 1.2%, 0.9%, 2.8%, 0% and 0%, accordingly. In sequence, pairwise comparison of the criteria with respect to their importance to reaching the goal, meaning the best alternative, takes place as shown in Table 6, with a consistency ratio of 0.9%. Finally, overall priorities/weights for the maintenance technologies, applying the AHP method, are shown in Table 7.

Table 5. Pairwise comparison matrix for economic criteria

Construction cost	**Thin HMA Overlay**	**Slurry seal (cold – single layer)**	**BBTM (hot)**	**Surface dressing (single)**	**Microsurfacing (cold)**	**Priority**
Thin HMA Overlay	1	1/5	1/3	1/5	1/3	0.055
Slurry seal (cold – single layer)	5	1	3	1	3	0.343

BBTM (hot)	3	1/3	1	1/3	1	0.129
Surface dressing (single)	5	1	3	1	3	0.343
Microsurfacing (cold)	3	1/3	1	1/3	1	0.129
Maintenance management cost						
Thin HMA Overlay	1	3	1	1	1/3	0.165
Slurry seal (cold – single layer)	1/3	1	1/3	1/3	1/5	0.063
BBTM (hot)	1	3	1	1	1/3	0.165
Surface dressing (single)	1	3	1	1	1/3	0.165
Microsurfacing (cold)	3	5	3	3	1	0.444
Cost at operational stage						
Thin HMA Overlay	1	5	3	7	3	0.469
Slurry seal (cold – single layer)	1/5	1	1/3	3	1/3	0.086
BBTM (hot)	1/3	3	1	5	1	0.201
Surface dressing (single)	1/7	1/3	1/5	1	1/5	0.043
Microsurfacing (cold)	1/3	3	1	5	1	0.201
Increased toll fee price / off road revenues						
Thin HMA Overlay	1	3	1	3	1	0.273
Slurry seal (cold – single layer)	1/3	1	1/3	1	1/3	0.091
BBTM (hot)	1	3	1	3	1	0.273
Surface dressing (single)	1/3	1	1/3	1	1/3	0.091
Microsurfacing (cold)	1	3	1	3	1	0.273
Societal benefits						
Thin HMA Overlay	1	3	1	3	1	0.273
Slurry seal (cold – single layer)	1/3	1	1/3	1	1/3	0.091
BBTM (hot)	1	3	1	3	1	0.273
Surface dressing (single)	1/3	1	1/3	1	1/3	0.091
Microsurfacing (cold)	1	3	1	3	1	0.273

Table 6. Pairwise comparison matrix of economic criteria with respect to reaching the goal

Economic criteria	Construction cost	Maintenance management cost	Cost at operational stage	Increased toll fee price / off road revenues	Societal benefits	Priority
Construction cost	1	3	3	3	1/3	0.236
Maintenance management cost	1/3	1	1	1	1/5	0.088
Cost at operational stage	1/3	1	1	1	1/5	0.088
Increased toll fee price / off road revenues	1/3	1	1	1	1/5	0.088
Societal benefits	3	5	5	5	1	0.501

Table 7. Overall weights of pavement maintenance technologies from economic scope

Maintenance technology	Priority with respect to					
	Construction cost	Maintenance management cost	Cost at operational stage	Increased toll fee price / off road revenues	Societal benefits	Goal
Thin HMA Overlay	0.0130	0.0145	0.0413	0.0240	0.1368	0.2296
Slurry seal (cold – single layer)	0.0809	0.0055	0.0076	0.0080	0.0456	0.1476
BBTM (hot)	0.0304	0.0145	0.0177	0.0240	0.1368	0.2234
Surface dressing (single)	0.0809	0.0145	0.0038	0.0080	0.0456	0.1528
Microsurfacing (cold)	0.0304	0.0391	0.0177	0.0240	0.1368	0.2480

3 Appraisal Results and Discussion

Utilizing the above findings from the application of the AHP method, the next step based on the flow chart of the proposed concept (Figure 1), is the drawing up of a table, ranking the pavement maintenance technologies, according to the priority given in the appraisal by engineering and economic point of view. Subsequently, the importance of engineering and economic appraisal is given by specialized engineers. The weight assignment depends on the priorities the road manager has at the time of the evaluation. If, for example, the budget available is small and the financial component is very important for the implementation of the project, then the weight given to the economic appraisal should be greater than the engineering one. On the other hand, if there are no financial commitments, the greatest importance is given to engineering evaluation. In the application performed in the present study, the weight assignment is conducted with a balanced approach, that is 0.5 for each dimension.

Finally, combined appraisal is the sum of the engineering and economic evaluation results multiplied by the corresponding weighting coefficient. In this way, the results of applying the proposed method consist of three hierarchical classifications, namely engineering, economic and combined hierarchy, as shown in Table 8.

Table 8. Engineering, economic (with equal weights) and combined priorities and ranking of pavement maintenance technologies

Maintenance technology	Engineering ranking (EnA)	Weight for engineering appraisal (EnW)	Economic ranking (EcA)	Weight for economic appraisal (EcW)	Combined ranking (EnA*EnW+ EcA*EcW)
Thin HMA Overlay	1 (0.3476)	0.5	2 (0.2296)	0.5	1 (0.2886)
Slurry seal (cold – single layer)	4 (0.1130)		5 (0.1476)		4 (0.1303)
BBTM (hot)	2 (0.2987)		3 (0.2234)		2 (0.2611)
Surface dressing (single)	5 (0.0818)		4 (0.1528)		5 (0.1173)
Microsurfacing (cold)	3 (0.1571)		1 (0.2480)		3 (0.2026)

Evaluating the findings of Table 8, it appears that the Thin HMA overlay technique is first in the engineering hierarchy while in the financial hierarchy it comes second among five and in the combined it is also first.

From the better supervision provided in Figure 6, it also appears that from the economic point of view, Microsurfacing (cold) technique stands for the most advantageous, yet it appears less effective in terms of engineering integrity. In addition, the BBTM (hot) technique holds high engineering and economic levels and a very good combined rating.

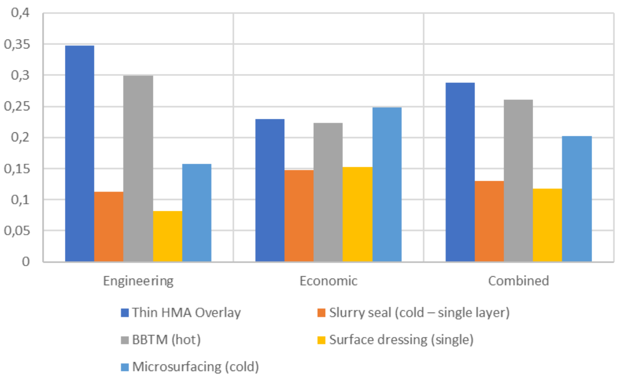

Fig. 6. Holistic view of pavement maintenance technologies with respect to engineering, economic (with equal weights) and combined appraisal

The main originality of the current research lies on the holistic appraisal of the most known maintenance technologies, in the context of engineering completeness combined with economic effectiveness. None of the aforementioned relative studies do not address the issue in such an approach, meaning that the evaluation is based either on economic or on engineering criteria individually, according to each study. As an exception to the rule, the recent research by Mouratidis et al. [18], presents an appraisal, evaluating both engineering and economic criteria with qualitative assessment of each one. The proposed method, for the first time evolves the appraisal to quantitative scores of maintenance techniques, aiming at ranking applied maintenance technologies in engineering, economic and combined frame.

4 Conclusions

One of the main objectives of this study is the creation of a tool for road operators and constructors, so they will be able to reach to the optimal choice for pavement maintenance, depending on the economic situation and the priorities of each case. In this way, they avoid options that prove cost-intensive or technically incomplete compared to the others. By applying the proposed method, a specific and overall picture of the options available is created. Thus, it is relatively easy to evaluate all alternatives for decision-making.

From the engineering scope, the optimal maintenance technique is the thin HMA overlay, whilst in economic terms, the most advantageous technique is microsurfacing. Overall, if the case is equally weighted engineering and economic criteria, the optimal maintenance technology stands for the thin HMA overlay, with BBTM as second in the ranking. To be noted, that appraisal of engineering and economic criteria with attributed weights, is responsibility of specialized personnel in each case, while the proposed twofold methodology stands for a tool for conducting such an appraisal.

Notable are the wide variations in pavement maintenance technologies and the conclusion that choosing the best one is not a one-dimensional decision, but depends on many factors, such as funding opportunities and timing. In sum, the proposed twofold appraisal results in a holistic analysis of pavement maintenance technologies and helps decision makers to conclude to the optimal choice according to their priorities and potentials.

References

1. World Road Association (PIARC), 2014. The importance of road maintenance, La Défense, France.
2. Rizenbergs, R.L., Burchett, J.L. and Napier, C.T., 1972. Skid Resistance of Pavements, Report No. KYHPR-64-24, Part II, Kentucky Department of Highways, Lexington, Kentucky.
3. Gothie, M., 1996. Relationship between Surface Characteristics and Accidents, Proc. 3rd International Symposium on Pavement Surface Characteristics, Christchurch, New Zealand, 3-4 September 1996, pp. 271-282.
4. Wallman, C.G., and Aström, H., 2001. Friction Measurement Methods and the Correlation between Road Friction and Traffic Safety – Literature Review, Project Code 80435, Swedish National Road and Transport Research Institute, Linköping, Sweden.
5. Viner, H., Sinhal, R., and Parry T., 2004. Review of UK Skid Resistance Policy, Paper prepared for 5th International Symposium on Pavement Surface Characteristics---Road and Airports, Toronto, Ontario, Canada.

6. Davis, R.B., Cenek P.D., and Henderson, R.J., 2005. The effect of skid resistance and texture on crash risk, Proceedings of the International Surface Friction Conference, Christchurch, New Zealand, 1-4 May 2005.
7. Highways Agency (HA), 2007. Guidance for HA Service Providers on Implementing the Skid Resistance Policy (HD28/04), Interim Advice Note 98/07, September 2007, UK.
8. Chan, Y.C., Huang, B., Yan, X., and Richards, S., 2008. Effects of Asphalt Pavement Conditions on Traffic Accidents in Tennessee Utilizing Pavement Management System (PMS), Southeastern Transportation Center. University of Tennessee, Knoxville, USA.
9. Mayora, J.M., and Pina, R.J., 2009. An assessment of the skid resistance effect on traffic safety under wet-pavement conditions, Accident Analysis and Prevention, Elsevier, 41, pp. 881-886.
10. Chan, Y.C., Huang, B., Yan, X., and Richards, S., 2010. Investigating effects of asphalt pavement conditions on traffic accidents in Tennessee based on the pavement management system (PMS), Journal of Advanced Transportation, 44, pp. 150-161.
11. Liu, W., and Tinkler, B., 2010. Variable Slip Skid Resistance Testing for Road Safety Investigation and Pavement Management, ASCE Conf. Proc., doi: http://dx.doi.org/10.1061/41104(377)56, Paving Materials and Pavement Analysis (GSP 203), Proceedings of the 2010 GeoShanghai International Conference.
12. Fwa, T.F., Pasindu, H.R., and Ong, G.P., 2012. Critical Rut Depth for Pavement Maintenance Based on Vehicle Skidding and Hydroplaning Consideration, Journal of Transportation Engineering, 138 (4), pp. 423-429.
13. Papageorgiou, G., and Mouratidis, A., 2015. Defining Threshold Values for Pavement Surface Characteristics, Proceedings of the Institution of Civil Engineers – Transport, ICE Publishing, Thomas Telford, London, United Kingdom, 168 (3), pp. 223 –230.
14. Ihs, A., and Leif, S., 2003. An Overview of HDM-4 and the Swedish Pavement Management System (PMS), VTI (Swedish National Road and Transport Research Institute).
15. World Bank, 2012. “It’s unwise to pay too much, but it’s foolish to spend too little”: Sustainable road sector development through asset management in the Kyrgyz Republic, World Bank, Washington, USA.
16. World Road Association (PIARC), 2012. Reduction of construction time and cost of road pavements, La Défense, France.
17. Ibraheem, A.T., and Gani, S.M., 2011. Evaluation of Common Maintenance Methods for Flexible Pavements, Am. J. Eng. Applied Sci., 4, pp. 413-424.
18. Mouratidis, A., Daniilidou, C.G., and Papageorgiou, G.P., 2019. Evaluation of pavement maintenance and strengthening techniques, Proc. 7th International Conference “Bituminous Mixtures and Pavements”, 12-14 June 2019, Thessaloniki, Greece.
19. Federal Highway Administration (FHWA), 1996. Pavement Maintenance Effectiveness – Preventive Maintenance Treatments, Publication No. FHWA-SA-96-028, Prepared by Center for Advanced Transportation Systems Research. Arizona State University, VA, USA.
20. Federal Highway Administration (FHWA), 2017. Pavement Performance Measures and Forecasting and the Effects of Maintenance and Rehabilitation Strategy on Treatment Effectiveness (Revised), Publication No. FHWA-HRT-17-095, VA, USA.
21. European Road Federation (ERF), 2013. A Manifesto on Road Asset Management (RAM) ‘Keeping Europe Moving – A Manifesto for long-term, effective management of a safe and efficient European road network’, Brussels.
22. Putman, B.J., Ogle, J.H., Huang, Y., and Reed, L., 2006. Ranking of Pavement Preservation Practices and Methods, Report No. FHWA-SC-16-05, Clemson University, South Carolina, USA.
23. Zhou, B., Zhang, C., Tsai, J., Guo, X., and Zhou, X., 2013. Asphalt Pavement Maintenance Technologies Evaluation Model based on “Economic-Benefit” index, Procedia – Social and Behavioral Sciences, 96, pp. 2115-2122.
24. Luhr, D.R., and Rydholm, T.C., 2015. Economic Evaluation of Pavement Management Decisions, 9th International Conference on Managing Pavement Assets, Alexandria, VA, USA.
25. Zuniga-Garcia, N., Martinez-Alonso, W., Smit, A., Hong, F., and Prozzi, J.A., 2018. Economic Analysis of Pavement Preservation Techniques, Transportation Research Record, DOI: 10.1177/0361198118768515.
26. Khan, M.U., Mesbah, M., Ferreira, L., and Williams, D.J., 2017. Development of optimum pavement maintenance strategies for a road network, Australian Journal of Civil Engineering, DOI: 10.1080/14488353.2017.1362823.
27. Jain, K., Jain, S.S., and Chauhan, M.S., 2013. Selection of Optimum Maintenance and Rehabilitation Strategy for Multilane Highways, International Journal for Traffic and Transportation Engineering, Belgrade, Serbia 3 (3): pp. 269-278.
28. Cerea, P., 2010. Preventive Maintenance Treatments on Road Pavements: Multi-Approach Life-Cycle Assessment, Graduation Thesis, Politecnico di Milano, Italy.
29. Saaty, T.L., 2006. Fundamentals of Decision Making and Priority Theory, Pittsburgh, Pennsylvania: RWS Publications. ISBN 0-9620317-6-3.
30. Saaty, T.L., 2008. Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. Pittsburgh, Pennsylvania: RWS Publications. ISBN 0-9620317-8-X.