COMPREHENSIVE DECISION SUPPORT SYSTEM FOR MANAGING ASPHALT PAVEMENTS

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ABSTRACT

Transportation authorities evaluate the condition of roadway pavements based on the existence of various defects and apply maintenance strategies, if needed, to secure the safety of roads. There is a lack, though, of an integrated system that would address the defect types to be detected, the attributes needed to be measured for evaluating the severity of a defect, the defect causes, the treatment of these causes to avoid future appearance of the same defects, and the available repair strategies corresponding to each combination of defects. Consequently, transportation departments manage pavements based on partial information and strategies. Presented herein is a comprehensive decision support system (DSS), contributing to the identification and connection of all elements needed for the management of roadway asphalt pavements. The system has been developed synthesizing information from 56 different transportation departments. The output consists of a decision tree and an open-access webpage, while it has been tested on a real-life urban network. The proposed system can have a significant impact on practitioners, who will have a common language for pavement evaluation and maintenance, and roadway users, whose comfort and safety will be enhanced due to improved pavement condition.

Keywords: Civil Infrastructure, Pavement Management System, Condition Evaluation, Defects, Roadway Repair Strategies, Decision Tree

INTRODUCTION

Roadways constitute the largest component of infrastructure (Fernald 1999), whilst they have a significant impact on everyday life of people (Chan et al. 2010). The overall pavement evaluation grade in the United States is close to failure (rated as 'D'), highlighting the urgency for their maintenance (ASCE 2017). A disruption, due to degradation, in a road system might cause various undesirable conditions on travelers and the society at large. Operating road pavements is a challenging task consisting of condition monitoring and decisions on the application of maintenance activities (Denysiuk et al. 2017). Pavement monitoring, is implemented either automatically (by dedicated vehicles that are expensive) or manually (that is subjective). Next, pavement condition indices are calculated based on the type, severity and extent of existing defects in a road section. These indices are comprised of different levels, which have low and high threshold values. Each level typically proposes a type of repair strategy, with the lowest level of the system recommending the replacement of the section.

There is a diversification amongst transportation departments in the length of examined sections, the inspection frequencies, and the pavement rating indices. Additionally, rating indices take into consideration different pavement defect types, classify defects severity and extent differently and finally propose diverse repair strategies. The lack of an international integrated Pavement Management System (PMS) adversely affects transportation authorities that do not consider all possible pavement defects and ignore available repair strategies that might be better in terms of pavement performance and lifetime extension. Ineffective pavement maintenance strategies and consequently poorly conditioned pavements negatively affect users' comfort and safety. Additionally, the absence of a comprehensive pavement DSS also hinders researchers, who engage in the utilization of smartphone sensors (Islam et al. 2014; Seraj et al. 2017) or vision-based techniques (Hadjidemetriou et al. 2018; Koch et al. 2012) for automated pavement monitoring, from contributing to the solution of the actual problem. They typically focus on only one type of pavement distress, without integrating their studies.

BACKGROUND

The lack of a comprehensive pavement DSS has attracted the interest of researchers, who have attempted to compare and integrate different PMSs. Zheng and Racca (1999) focused on reviewing practices of different PMSs to evaluate the pavement condition index used by Delaware Department of

Transportation (DELDOT). They concluded that this condition index is subjective because it is based on investigating the extent of only four surface forms of distress. Miller and Bellinger (2014) developed a distress identification manual for a program called Long-Term Pavement Performance, using data on pavement status, weather, and traffic collected for 20 years. Despite the absence of the connection between pavement defects and repair strategies, this study clearly labels and illustrates several defect types. Papagiannakis et al. (2009) observed that the considered distress types and the way they are summarized into indices vary significantly amongst departments in the US, while several DOTs take into consideration only the most dominant defect present. Bektas et al. (2014), developed new pavement performance indicators for Iowa pavements, based on a survey of all pavement rating systems used in the US. However, they concluded that their overall index cannot describe the real pavement condition and be applied by any DOT since it considers only some of the possible pavement defects.

Summarizing, the problem, which motivates the current study, can be briefly stated as follows: Each transportation agency maintains its own PMS, while publishing its own pavement management manual. Guidelines vary significantly in terms of defects and their classification into severity levels, condition indices, and proposed repair strategies. Given these restrictions, the objective of the current paper is the proposal of an integrated DSS for the management of asphalt pavements that can answer the following research questions: (1) Which pavement defects and which defect attributes should be considered for the evaluation of pavements? (2) What are the possible causes of the defects and how can the appearance of the same problem at the same place be avoided, after defects treatment? (3) What are the available pavement repair strategies for each defect or combination of defects?

RESEARCH METHODOLOGY

The current research work is exploratory in nature. It is focused on asphalt pavements, approaching the problem from a long-term infrastructure perspective, and on the application of the appropriate repair strategies based on the current condition of pavement (defect type and severity). The following rules were set for the development of a comprehensive system: the description of the framework elements was extracted and integrated using manuals that define them clearly and specifically; same elements, which are termed differently by different studies, were merged and only one term was selected; elements, that were described by only one DOT, were not included in the proposed framework; and finally, for defect severity classification, quantitative explanations with definite dimensions (e.g. width), if existed, were preferred over qualitative descriptions (e.g. minor).

The current study reviews and compares guidelines for 56 transportation agencies, covering a range of climate zones, while adding elements extracted from related research studies. The reviewed agencies are located in the United States (50 states and the District of Columbia), the UK, Canada (British Columbia), Ireland, Germany, Australia, and New Zealand. The studies of Papagiannakis et al. (2009) and Bektas et al. (2014), which collected information about all U.S. DOTs, consist the basis for identifying the general guidelines of the proposed DSS. Additionally, the peer reviewed documents were used to define and connect the elements of the proposed framework that are divided into four categories: defects, causes of defects, treatment of causes and repair strategies. Finally, the proposed DSS was tested on a real-life urban network. The following subsections present the activities conducted for the development of the proposed DSS, along with the results.

General guidelines for pavement management

Each DOT follows its own strategy regarding the length of evaluation section, survey frequency and rating index. The evaluation length of the examined 56 agencies varies significantly from 10 m to 4828 m. The most frequently used length is 161 m (0.1 miles), with 10 DOTs using it, followed by the the group of 50-64 m, with 5 DOTs using it. Comparing the most widespread options, the current research proposes the separation of networks into 50 m-length sections since this length is small enough to assist an objective determination of the section status. Regarding survey time intervals, 27 out of 56 DOTs inspect their network annually; 12 of them assess it on a biennial basis; and 3 departments survey their network using different frequencies based on the type of road. The current study proposes a maximum time interval of 1 year for the inspection of the entire network. Additionally, the current study has identified 28 different pavement distress indices used by the 56 DOTs, which are unable to be compared since they are computed using different scales, descriptions, defect types and attributes.

Types of pavement deterioration

Pavement management manuals define several defect types, while classifying their condition in severity levels. The current study compared the defects used by the 56 examined DOTs to define those needed for an objective pavement evaluation. The studies of Adlinge and Gupta (2013) and ASTM International (2018) formed the basis for classifying these defects into four main "diseases".

Cracking "disease" refers to fissures occurring due to complete or incomplete fractures of the surface and fundamental pavement layers. This class consists of transverse, longitudinal, edge, block and alligator cracks. Disintegration "disease" describes the progressive division of pavement into loose pieces, while it can be divided into potholes and patches. Surface deformation "disease" is a change of pavement structure, which leads to transformation of roadway surface. It is composed of shoving that is localized pavement bulging with the form of ripples; rutting that produces channels in the wheel-tracks; and distortion that is a restricted surface area, with its level being slightly lower than the surrounding surface area. Surface defects "disease" refer to the loss of surface microtexture or macrotexture. This class is divided into raveling that is separation of pavement surface materials, and bleeding that is the presence of excess binder on pavement surface, causing a sticky surface.

The aforementioned defects are classified by the current study into severity levels (Table 1), selecting clear and quantitative definitions from the literature and mainly from the studies of Johnson (2000), Northwest Pavement Management Association (1999) and ASTM International (2018) that consider almost every defect type, while they evidently and similarly classify defect types.

Causes of defects and treatment of defect causes

The present study identifies the possible causes of distressed pavement (Table 2), connects every defect with its possible causes (Table 3), and proposes the treatment of each cause (Table 4), if available. The treatment of a cause might prevent or delay future appearance of the same defect at the same place. The identification of defect causes and available treatment strategies were based on the studies conducted by the Asphalt Institute (2009) and the British Columbia Ministry of Transportation and Infrastructure (2016), adding information extracted from the 56 manuals.

Repair strategies of defects

After identifying and fixing the causes of defects, the defects of the examined pavement section need to be repaired. The work of Johnson (2000) as well as Richardson and Lusher (2015) form the basis for the identification of available repair strategies. The present study is not interested in temporary repair strategies since it explores pavement management from a long-term infrastructure perspective. A specific defect or a combination of defects might be treated by a range of techniques. Table 5 presents the repair strategies used in the proposed DSS, their classification into categories and their expected lifetime in years. They are classified into: crack sealing, crack filing, patching, sealing and overlay. Table 6 correlates each severity level of every defect with the applicable repair strategies.

Development and testing of related decision tree and webpage

The results of the aforementioned data analysis are summarized in a decision tree (Fig. 1), to the nodes of which codes have been assigned (Table 2, Table 4, Table 5). Despite of having the information on the connection between every severity level of each defect with the available repair strategies (Table 6), this information is not shown in Fig. 1 since the high number of connections makes the visualization impossible. If more than one defect type exists in a road section, the proposed system proposes the application of common repair strategies which are able to fix all appeared distress forms simultaneously. If there is no common repair strategy, then total reconstruction of the section is proposed.

The assembled knowledge and the proposed DSS on the management of asphalt pavements have been transfused into a developed webpage (https://www.roadpavementmanagement.com). The developed tool/website is adjustable to geographical location and users' requirements since they can add or delete elements. It was tested on an urban road network of a total length of 10 km in Nicosia, Cyprus, that was divided into 50 m-length sections. Videos were acquired from a camera positioned at the rear of a moving vehicle. For each section, firstly, distressed areas were automatically detected using a developed algorithm by the authors (Hadjidemetriou and Christodoulou 2019) and secondly, the distressed areas were manually classified into defect types and severity levels. After that, the developed tool was used to provide information regarding the defect cause, treatment of the cause and the appropriate repair strategy for the section. The newly developed tool showed the potential to save time for inspectors in taking the appropriate decisions.

CONCLUSIONS

The results of the review of 56 transportation agencies guidlines and related research studies have indicated that there is a wide diversification amongst DOTs, with the knowledge being dispersed in the literature. Nonetheless, there is no integrated pavement management system that firstly identifies all elements and secondly connects them. This gap of knowledge has motivated the development of the proposed framework. The following characteristics summarize the novelty and contribution of the current paper: (1) the four steps process for managing pavements, including not only pavement defects and repair strategies, but also causes of defects and treatment of the causes; (2) the provision of a common language for DOTs; and (3) the open-access webpage/tool.

The utilization of the proposed DSS can have a significant impact on practitioners who will be able to have an objective picture of pavement condition and be informed about the existence of repair strategies that they might not be familiar with. In addition, DOTs will have the opportunity of having a common language for pavement management procedures, allowing comparisons and collaborations. The proposed DSS will also contribute to the improvement of pavement monitoring and maintenance, and consequently to the enhancement of the general pavement condition as well as users' comfort and safety. Future work comprises the use of this system as an example for developing DSSs for the management of other types of infrastructure; and the development of a pavement condition index based on the information extracted from the proposed DSS, which will consider defects extent and be combined with other elements (e.g. forecasting performance, life-cycle costs, traffic, safety) for identifying the optimal timing to apply maintenance strategies in a system level.

Data Availability Statement: Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request. The available data consists of tables and figures, which present information about the PMSs of the examined 56 DOTs and they were created and used by the authors for the development of the described methodology.

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List of Tables

Table 1. Severity classification of pavement defects

Defect	Severity		
	Low	Medium	High
Transverse cracks	Mean width (MW) < 6 mm	6 mm ≤ MW ≤ 19 mm	MW > 19 mm
Longitudinal cracks	MW < 6 mm	6 mm ≤ MW ≤ 19 mm	MW > 19 mm
Edge cracks	Cracks without loss of material	Cracks with loss of material ≤ 10% of the evaluation section length	Cracks with loss of material > 10% of the evaluation section length
Block cracks	MW < 6 mm	6 mm ≤ MW ≤ 19 mm	MW > 19 mm
Alligator cracking	Branched discontinuous cracks, MW < 6 mm	Interconnected cracks, 6 mm ≤ MW ≤ 19 mm	Interconnected cracks with individual loosened pieces, MW > 19 mm
Potholes	Max depth < 25 mm	25 mm ≤ Max depth ≤ 51 mm	Max depth > 51 mm

Patches	Patch has at most low-severity distress of any type.	Patch has moderate-severity distress of any type.	Patch has high-severity distress of any type.
Shoving	6 mm ≤ Average Depth (AD) ≤ 13 mm	13 mm < AD ≤ 19 mm	AD > 19 mm
Rutting	6 mm ≤ Average Depth (AD) ≤ 13 mm	13 mm < AD ≤ 19 mm	AD > 19 mm
Distortion	3 mm ≤ Maximum vertical deviation (MVD) from a 3 m straightedge located on the pavement parallel to the road centre line ≤ 51 mm	51 mm < MVD ≤ 102 mm	MVD > 102 mm
Raveling	The aggregate and binder has started wearing away. The pavement appears slightly aged and rough.	The texture is moderately rough and pitted. Fine aggregate is partly missing from the surface.	The surface texture is deeply pitted and very rough. Pitting has the depth of half of the coarse aggregate size.
Bleeding	Minor quantities of aggregate are covered by excess asphalt	Significant amounts of aggregate are covered with excessive asphalt	Most of aggregate is covered by excessive asphalt. The surface is wet, while it is sticky in hot weather

Table 2. Possible causes of pavement defects

Cause category	Cause
Weather	1. Frost heave
	2. Hot weather
Design - Mix	3. Weak asphalt mixes
	4. Lack of asphalt
	5. Mix too high in asphalt
	6. Base failure due to poor quality materials, lack of strength or insufficient granular
	7. High fine aggregate content
	8. Low air voids
	9. Heavy prime or tack coat
	10. Fine aggregate mix with low penetration asphalt and absorptive aggregates
	11. Inadequate design of layers thickness
	12. Improper or inferior materials
Construction	13. Insufficient base structure
	14. Improper compaction
	15. Rounded or smooth aggregate
	16. Inadequately applied seal coat
Traffic	17. Load induced by heavy traffic
	18. Low traffic volume
	19. Heavy loaded vehicles speeding up or slowing down

Moisture	20. Poor drainage - excess moisture 21. Excessive moisture on the basis
Secondary	22. Continued deterioration of another defect type

Table 3. Correlation between defects and causes

Defect	Cause (Indices from Table 2)
Transverse cracks	1, 17
Longitudinal cracks	1, 17
Edge cracks	1, 3, 6, 13, 20
Block cracks	10, 14, 18
Alligator cracking	6, 13, 14, 20
Potholes	3, 20, 22
Patches	6, 12
Shoving	5, 7, 15, 19, 21
Rutting	3, 11, 14
Distortion	1, 12
Raveling	4, 14, 17, 20
Bleeding	2, 5, 8, 9, 16

Table 4. Correlation between defect causes and treatment of causes

Cause (Indices from Table 2)	Treatment strategy
1, 2	I. No available treatment
3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	II. The same mistakes must be avoided, when the pavements section is maintained or reconstructed.
17	III. Lanes designed with different mixes and used only by heavy vehicles.
17, 18	IV. Improved traffic allocation, designed by DOTs.
19	V. Measures for reducing speed change of vehicles (e.g. traffic signs, speed humps)
20, 21	VI. Ditches, surface water drain. Road slope and culverts must be checked and repaired, if needed.
22	VII. The surrounding defects must also be repaired.

Table 5. Pavement repair strategies

Repair strategy	Repair strategy category	Expected lifetime (years)
a. Rout and seal	Crack sealing	3
b. Clean and seal		3
c. Asphalt emulsion	Crack filling	1

d. Rubberized fillers		2-3
e. Microsurfacing material		2-3
f. Full-depth crack repair		5
g. Cold-mix asphalt	Patching	1
h. Hot-mix asphalt		1
i. Spray injection		5
j. Slurry or micro-surfacing		3-5
k. Slurry seal	Sealing	3-5
l. Seal coat		3-6
m. Double chip seal		7-10
n. Microsurfacing		5-8
o. Thin hot-mix overlay	Overlay	5-8
p. Hot in-place recycling, thin overlay		6-10
q. Cold in-place recycling, thin overlay		6-15
r. Fog seal	Other	1-2

Table 6. Correlation between repair strategies and severity level of each defect

Defect	Repair strategy (Indices from Table 5)		
	Low severity	Medium severity	High severity
Transverse cracks	a, b, l, m, q	a, b, c, l, m. p, q	c, d, e, f, g, h, i, j, l, m, p, q,
Longitudinal cracks	a, b, c, d, e, m, p, q	a, b, c, d, e, f, m, p, q	c, d, e, f, g, h, i, j, m, q
Edge cracks	c, d, e, k, l, m, o, n, p, q	l, m, o, p, q	m, o, q
Block cracks	a, b, l, m, p, q	l, m, o, p, q	c, d, e, g, h, i, j, m, o, q
Alligator cracking	l, p, q, m	g, h, i, j, p, q	g, h, i, j, q
Potholes	g, h, i, j	g, h, i, j	g, h, i, j
Patches	p	g, h, i, j, p, q	g, h, i, j, q
Shoving	p, q	g, h, i, j, p, q	g, h, i, j, q
Rutting	g, h, i, j, k, n, p, q	g, h, i, j, k, o, n, p, q	g, h, i, j, o, n, p, q
Distortion	m, o, p	o, p, q	q
Raveling	r	r, l,	g, h, i, j, k, l, m, o, n
Bleeding	k, l, m, n	k, l, m, n	k, l, m, n, o

List of Figures

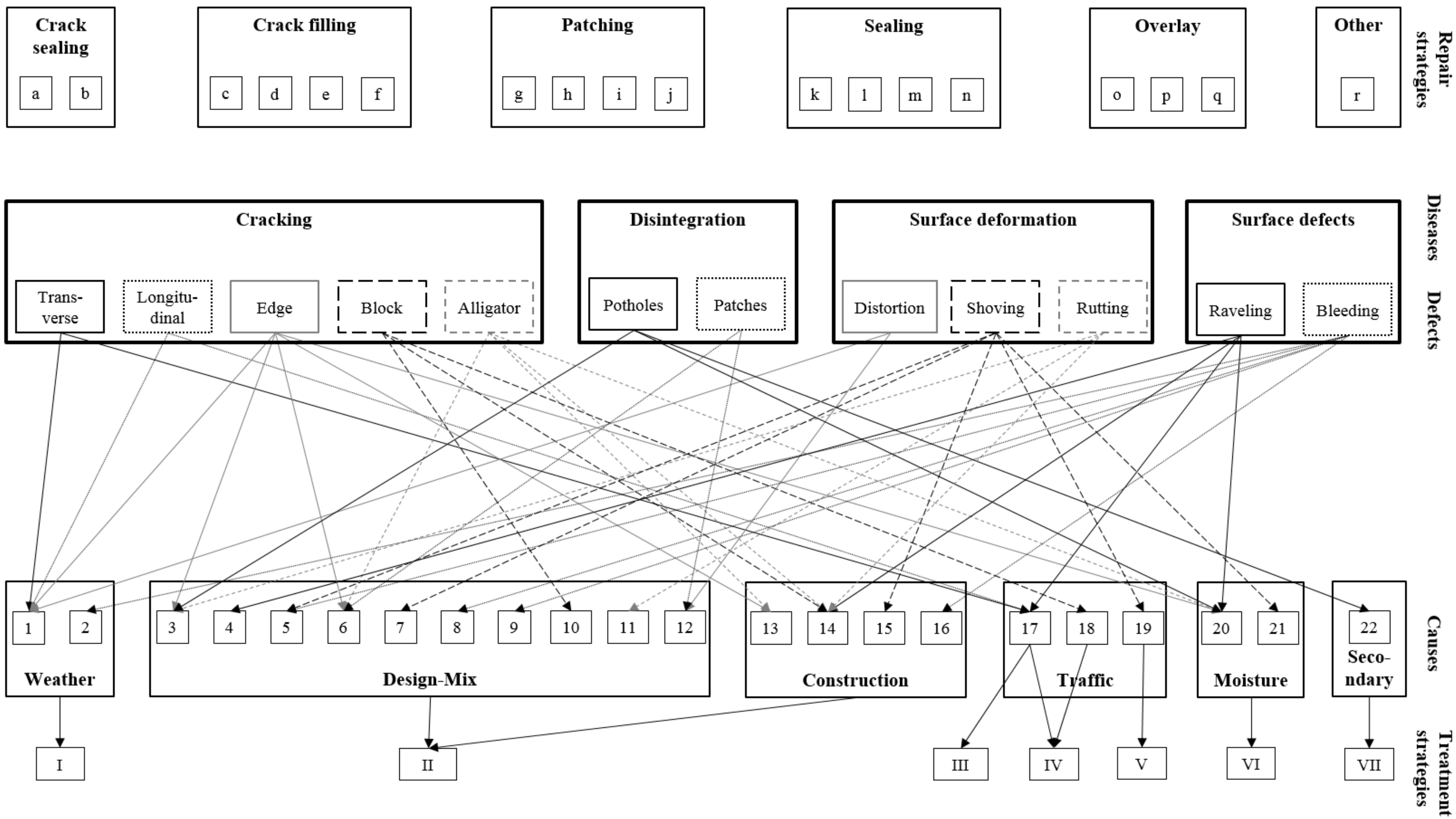

Fig. 1. Framework of the proposed integrated PMS