

Pavement Deterioration Rate and Maintenance Cost for Low-Volume Roads

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Abstract. Allocated budgets for maintenance of road networks are normally limited. Therefore, not all roads receive the required attention they deserve in a timely manner. These roads are left to deteriorate until the next maintenance round. The cost associated with delayed maintenance is significantly excessive. A Pavement Maintenance Management System (PMMS) can be a useful tool for evaluation, prioritization of Maintenance and Rehabilitation (M&R) projects, and determination of funding requirements and allocations. The pavement condition is normally indexed using a parameter called Pavement Condition Index (PCI) which represents an overall assessment of surface defects by type, severity and extent. Periodic collections of PCI over time for different sections within the roadway network provide an approach to monitor changes in pavement serviceability over time and can produce useful data to predict and evaluate required maintenance solutions and their associated cost. The researchers intend to use available data collected over the span of a year and a half on sections within the roadway network at the campus of Al-Zaytoonah University of Jordan (ZUJ) to study the relation between the maintenance cost and the pavement deterioration rate. This study may incorporate variables such as pavement age, traffic volumes, maintenance history and pavement condition assessment results. The available records of PCI will be analyzed and the findings will be clearly presented. The practical inclusion of the findings within the current PMMS used at the university will also be detailed.

Keywords: condition, deterioration, maintenance, pavements, serviceability

1 Introduction

The aim of PMMS is the achievement of better and smoother roads at a reasonable cost. According to Shahin and Walther [1] and Shahin [2], the maintenance at early stages of pavement deterioration proved to produce large saving before the start of the costly decline in pavement condition. Therefore, funding is normally allocated in the most efficient and

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economic manner to allow engineering pavement managers to employ an efficient decision-making process. Good pavement management systems require the collection of substantial amounts of road condition data over time. This can be used in the development of pavement deterioration models. The monitoring of pavement deterioration over time is the backbone of a pavement management system and is used to determine several fundamentals, including the rate of asset degradation at the project and network levels. Furthermore, it aids in the evaluation of remaining life and in the scheduling of future maintenance.

In this particular project, the pavement condition was evaluated using on a number of occasions where each section was evaluated for the surface defects including various types of flexible pavement failures such as cracking and other surface defects [3]. In addition, deterioration can lead to a reduction in ride quality as reported by some researchers [4]. Others have developed composite pavement condition indices based on pavement surface condition and ride quality [5]. In this project, the pavement condition was evaluated using the Pavement Condition Index (PCI) as developed by Shahin and Walther [1] and Shahin [2].

In the paved area of this study, traffic loading is not the leading contributor to pavement failures. Weather-related factors such as climate cycles of temperature and precipitation are the leading causes of distresses such as longitudinal and transverse cracking. Researchers have noted that pavement performance has shown that with the exception of longitudinal and wheel track cracking formation, the roughness of the road increases with additional precipitation [6]. Pavements experience thermal cracking due to compressive and tensile stress when the temperature fluctuates. Smith et al. [7] showed a dependence between temperature and pavement deterioration, where a rise in temperature leads to the development of rutting and propagation of cracking in the pavement. In some areas, thawing during the spring may result in deformation of pavement leading to fatigue and wheel path cracking [8]. In addition, some researchers suggest that snowstorms and floods can worsen road conditions by generating failure and cracking [9].

2 Literature Review

Some researchers have studied the relation between maintenance cost and pavement deterioration rate for roads.

George et al. [10] developed equations for predicting pavement deterioration. The authors employed over a 2-years period of historical information that includes structural information, traffic volume and pavement condition data. The studied areas (paved areas with asphalt surfacing) were classified into three groups including flexible pavements with no overlay, flexible pavements with one or more overlay(s), and composite pavements. In all the three equations developed for the three classifications, age of the pavement was found to be the most significant variable to predict road serviceability among other variables of traffic volume and weight, and the structural makeup of the pavement.

Shahin et al. [11] studied the economic effect of different M&R strategies. The different strategies were applied to pavement sections in a studied paved network. The results showed the economic effectiveness of asphalt overlay compared with other strategies. MicroPAVER pavement management system was used in this study to produce deterioration curves and work planning techniques for the different M&R strategies.

Tinni [12] has argued that the estimation of pavement maintenance costs for long periods of time mostly comes with inaccurate end results. His paper has demonstrated the inaccuracy of the used methodology in Australia. The research concluded that a way to reach a reasonable accuracy is to carry out a detailed historical long term cost study for different pavements, which is rarely to be applied. The researcher also concluded that with a time period of over 20 years, the total maintenance cost of concrete pavement is at least 19 times less than for flexible pavements with the same traffic volume.

Babashamsi et al. [13] have analyzed current methods used for Life-Cycle Cost Analysis (LCCA). LCCA is an economic analysis process used to evaluate the cost-efficiency of alternatives in order to obtain optimum pavement life-cycle costs. LCCA takes into consideration the total economic worth by analyzing the initial cost and discounted future cost including maintenance, use, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment. Another study on LCCA by Wang Z. and Wang H [14] aimed at developing LCCA model to evaluate the impact of pavement preservation on agency cost (M&R work) and Vehicle Operating Cost (VOC), and estimating the optimal time of pavement preservation treatment. The study used long-term data of the International Roughness Index (IRI), a parameter for evaluating the functional condition of the pavement. It was found that the optimal timing to apply preservation treatment depends on the type of treatment, the existing condition before the treatment (or pavement age), and the effect of treatment on pavement performance deterioration. The results also showed that the cost benefits in VOC are greater than the benefit in agency cost, while the optimal timing calculated based on VOC is always earlier than the optimal timing calculated based on agency cost.

Previous studies have investigated the relation between maintenance cost and pavement condition. However, this study concentrates on the relation between maintenance cost and pavement deterioration when the paved road subjected to low-volume vehicles, and the deterioration of pavement is caused mainly by the weather.

3 Objective and Scope

The aim of this research is to develop formulas that relate maintenance cost with pavement deterioration rate for low-volume roads. This formula will depend on data collection and analysis from the road network in Al-Zaytoonah University of Jordan (ZUJ). A Pavement Maintenance Management System (PMMS) for the road network in ZUJ was previously developed and presented in research papers [15].

This research incorporated the following stages:

- Developing a database inventory for the road network at ZUJ based on a Geographic Information System (GIS) map. This inventory includes the engineering properties for each section in the road network.
- Conducting the first-round evaluation to the pavement condition following the procedures that depend on calculating PCI for each road section developed by Shahin and Walther (1990), and by using PAVER system software developed by the U.S. Army Corps of Engineering.
- Based on the results of pavement condition evaluation, priorities of the areas that need Maintenance and Rehabilitation (M&R) were decided. After this, the required work of M&R was decided and the required quantities and budget were estimated.
- Conducting the second round of evaluation to the pavement condition and using PAVER system to estimate the reduction on PCI for each road section.
- Studying the relation between the maintenance cost and the pavement deterioration rate and developing calculation equations by conducting regression analysis.

4 Process

The first step in establishing a PMMS for the paved network in the area of the study was to prepare an inventory that organizes the paved areas for M&R management using the method presented by Shahin and Walther [1] and Shahin [2]. The paved network in ZUJ was divided into four branches. Only the results for one branch named Ring Road (RINGR)

consisting of 46 sections will be used for the purpose of this paper. For practical objectives, sections were classified to identify areas with relatively consistent characteristics, such as dimensions, surface condition, traffic type and volume, and construction history. It should be noted that the pavement thickness and composition, the traffic type and volume for the different sections in the studied branch are relatively consistent.

The second step is to conduct a field inspection to evaluate the current condition of the different paved sections using Pavement Condition Index (PCI) method [1, 2]. This method uses a scale of 100 points to rate the condition of each road section that can be presented in seven pavement condition classifications as shown in Figure 1.

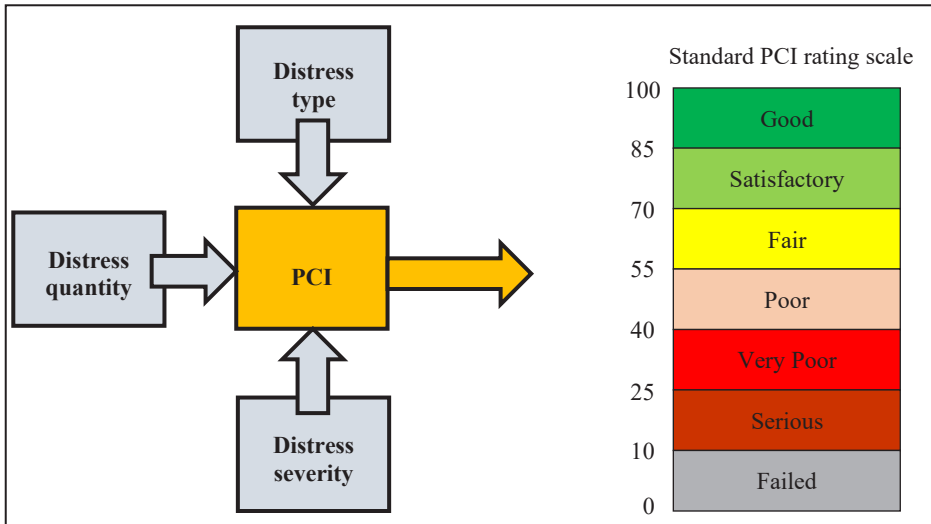


Fig. 1. Rating scale used for Pavement Condition Index (PCI) method (Source: Shahin (2005))

In this study, two cycles of field inspections were conducted with a time period of 1 year. Between the first cycle and the second, M&R project was implemented on some of the poor, very poor, serious and failed sections in ZUJ road network. The areas that need M&R were decided regarding the pavement condition evaluation, the location importance and the available budget. Hence, the number of PCI high rated sections has increased in 2018 compared with what was in 2017, while the number of low rated sections has decreased, as shown in Figure 2.

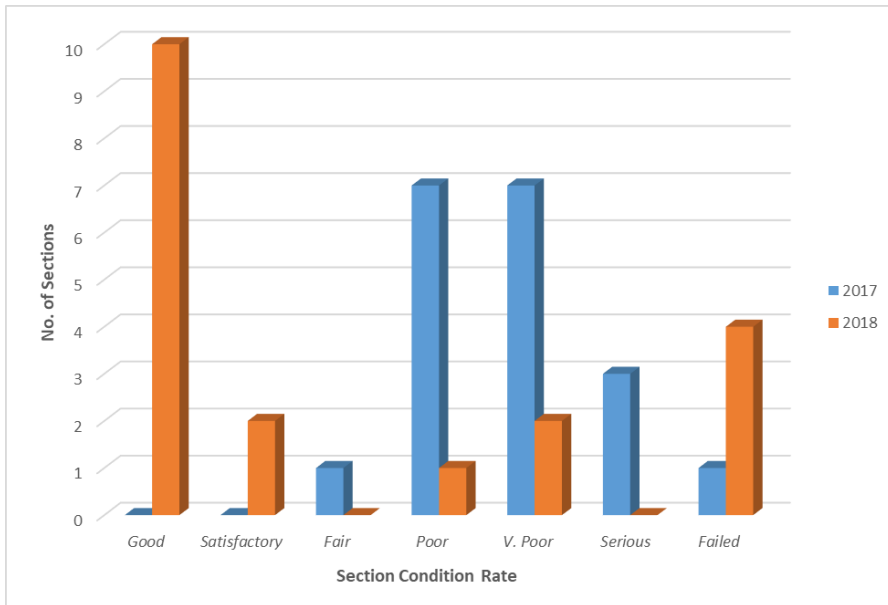


Fig. 2. Comparison of Pavement Condition between 2017 and 2018

The results of the field inspections and the calculations of PCI values for the two cycles of the years 2017 and 2018 were conducted by using Paver 7 software. Figure 3 shows the PCI results for the road section where no M&R works have executed, while Figure 4 shows the results for the maintained sections. The 100 points scale and the seven colour-coded layers for the pavement conditions were used in the two figures.

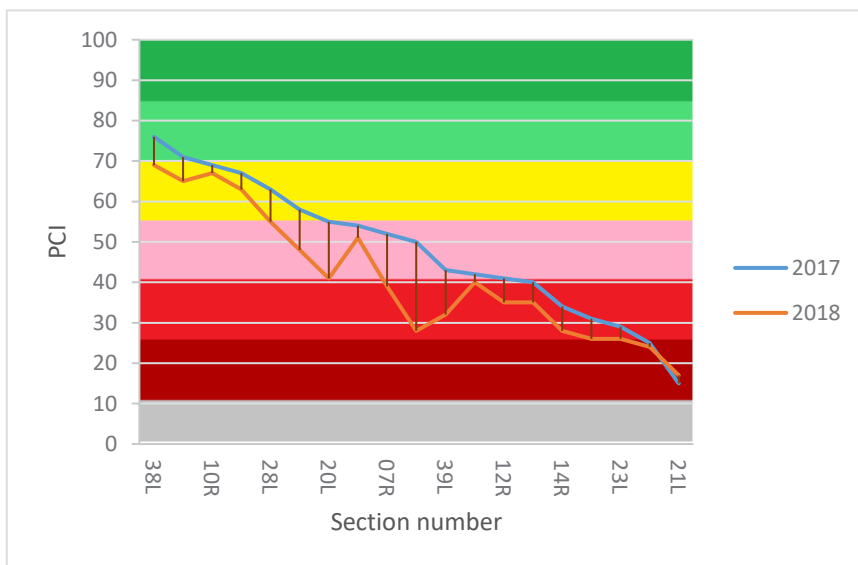


Fig. 3. PCI Results for Road Sections with no M&R Works

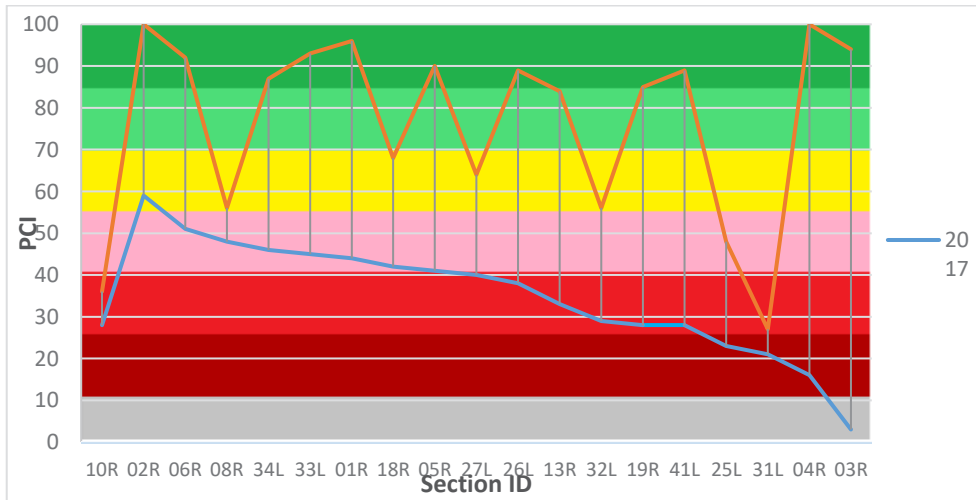


Fig. 4. PCI Results for Road Sections with M&R Works

5 Results

The aim of this study is to develop a relation between the maintenance cost and deterioration rate. To fulfil this aim, the paved areas subjected to maintenance and repair were classified into three groups regarding their condition evaluation prior to the M&R implementation. The three groups include Poor, very poor, and failed and serious pavement condition ratings to reflect the quantity, severity and type of distresses in the road sections prior to the M&R project implementation. The type of repairs used for the defected areas depended on the type and severity of each defect. Figure 4 represents examples of repair types may be used for certain conditions of pavement.

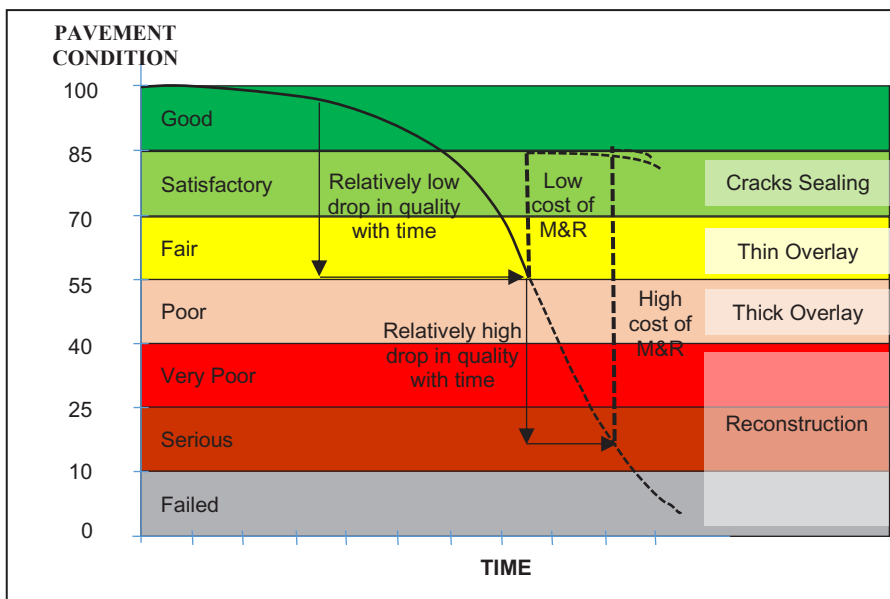


Fig. 5. Examples of repair types may be used with PCI evaluation

The sections subjected to M&R applications were used to study the relation between improvement or change in the pavement condition (Δ PCI) and maintenance cost. The relations were studied for the whole ratings as well as for the classified groups of pavement, as shown in Figure 6.

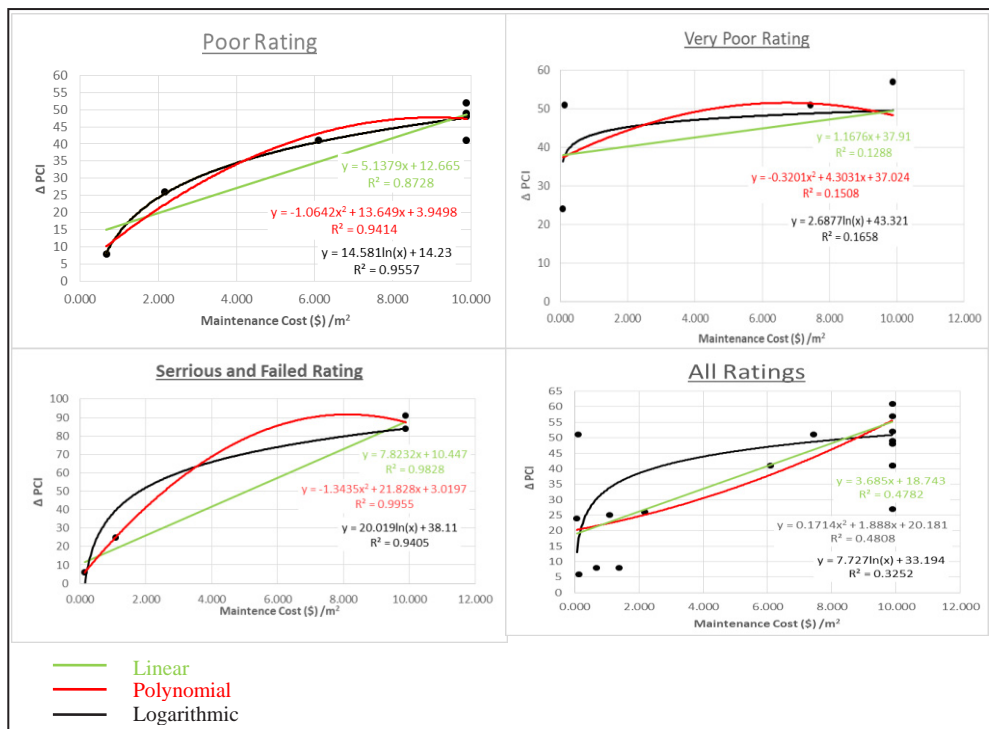


Fig. 6. Relation of Δ PCI and maintenance cost

As shown in Figure 6, regression analysis was conducted by using three types of relations including linear, polynomial and logarithmic equations. The analysis was conducted and presented for the results of the whole maintained sections as well as for the separated groups of poorly rated sections, very poor rated sections, and serious and failed sections. The results were summarized in Table 1. Also, the detailed calculations for Δ PCI and maintenance cost per meter square are shown in Tables 2 and 3.

Table 1. Formulas developed to relate maintenance cost and deterioration rate of paved areas

Rating	# of sec.	Linear		Polynomial		Logarithmic	
		Equation	R ²	Equation	R ²	Equation	R ²
Poor	7	Δ PCI = 5.1379	0.8728	Δ PCI = -1.0642(Mc) ²	0.9414	Δ PCI = 14.581	0.9557
Very Poor	7	Δ PCI = 1.1676	0.1288	Δ PCI = -0.3201(Mc) ²	0.1508	Δ PCI = 2.6877	0.1658

Rating	# of sec.	Linear		Polynomial		Logarithmic	
		Equation	R ²	Equation	R ²	Equation	R ²
Failed &	4	$\Delta\text{PCI} = 7.8232$	0.9828	$\Delta\text{PCI} = -1.3435(\text{Mc})^2$	0.9955	$\Delta\text{PCI} = 20.019$	0.9405
All Ratings	18	$\Delta\text{PCI} = 3.685 \text{ Mc} + 18.743$	0.4782	$\Delta\text{PCI} = 0.1714(\text{Mc})^2 + 1.888$	0.4808	$\Delta\text{PCI} = 7.727 \ln(\text{Mc})$	0.3252

Mc = Maintenance cost per square meter in U.S Dollar (\$).

Table 2. Detailed Calculations for Sections after Maintenance

Section ID	Area (m ²)	PCI Before	PCI After	ΔPCI	Maintenance Cost (\$)	Maintenance Cost (\$)/ m ²
10R	180	28	36	8	175	1.373
02R	300	59	100	41	2100	9.887
06R	994.2	51	92	41	6959	9.887
08R	370.3	48	56	8	175	0.667
34L	570.2	46	87	41	2458	6.090
33L	197	45	93	48	1379	9.887
01R	465.3	44	96	52	3257	9.887
18R	919.5	42	68	26	1414	2.172
05R	174.8	41	90	49	1224	9.887
27L	2701	40	64	24	140	0.073
26L	1183.4	38	89	51	98	0.117
13R	829.6	33	84	51	4368	7.437
32L	818	29	56	27	5726	9.887
19R	301	28	85	57	2107	9.887
41L	301	28	89	61	2107	9.887
25L	495	23	48	25	378	1.079
31L	359	21	27	6	35	0.138
04R	174.8	16	100	84	1224	9.887
03R	95.7	3	94	91	670	9.887

Table 3. Detailed Calculations for Sections without Maintenance

Section ID	Area(m ²)	PCI Before	PCI After	ΔPCI	Maintenance Cost (\$)	Maintenance Cost (\$)/ m ²
38L	506	76	69	-7	0	0
09R	1411.6	71	65	-6	0	0
10R	711.9	69	67	-2	0	0
16R	1387.3	67	63	-4	0	0
28L	279	63	55	-8	0	0
17R	191.8	58	48	-10	0	0
20L	583.4	55	41	-14	0	0
35L	292.5	54	51	-3	0	0
07R	1750	52	39	-13	0	0
15R	184.6	50	28	-22	0	0
39L	286.3	43	32	-11	0	0
40L	588.5	42	40	-2	0	0
12R	234	41	35	-6	0	0
11R	174.2	40	35	-5	0	0
14R	184.6	34	28	-6	0	0
24L	162	31	26	-5	0	0
23L	304.25	29	26	-3	0	0
29L	300	25	24	-1	0	0
21L	147.2	15	17	2	0	0

The results indicated the reliance of maintenance cost on the condition evaluation of pavement prior to the M&R projects execution. Linear regression proved to appropriately represent the relation between the cost of maintenance and the rate of deterioration. The results of R² calculations indicated a high level of reliability and validity of the equations. The equations can be used as a prediction model for estimating the cost of required maintenance for paved areas with low traffic volume. In future studies, it is recommended to conduct comparative studies to study the effect of the traffic volume and the structure of pavement for broader areas of pavement. This requires conducting more tests and collecting more data during a longer period of the road network life-cycle.

6 Conclusion

The developed equations can be used as a prediction model to estimate the required cost for maintaining paved areas depending on information about pavement condition, rate of deterioration and the area for each evaluated section. Values of R² refers that the equations are representing the results in a good manner, and so the equations can be used for cost prediction.

Conduction more iterations of PCI evaluation during the coming years and after M&R projects will help to improve the prediction equations. In the future development of this study, it is recommended to use modern tools and methods for more effective evaluation of the conditions of paved areas, such as using image processing, remote sensing and ground-penetrating radar techniques. Improvement of pavement condition valuation and setting for M&R work will aim at making the required procedures become more robust.

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