

Exs-PRM: A Cutting-Edge Knowledge-Based Expert System for Advanced Pavement Repair and Maintenance

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1 ABSTRACT

This research introduces the creation of the Pavement Repair and Maintenance Expert System (Exs-PRM) a knowledge based tool intended to assist engineers and newcomers, in concrete pavement building assignments effectively. The Exs-PRM provides an approach to handling pavement variations such as rigid and flexible pavements as well as continuously reinforced concrete pavements along with composite and brick pavements, under different subgrade/subbase conditions. The system thoroughly analyses and offers suggestions, on how to deal with pavement issues by providing explanations of problems and their causes well as steps to prevent them and assess their severity accurately; it also includes testing protocols and repair instructions in addition to informative videos, for guidance purposes. By helping users make informed decisions and offering content while storing valuable expertise for later use; Exs-PRM strives to improve the overall efficiency and effectiveness of pavement maintenance and management practices.

Keywords: pavement, repair, maintenance, engineering, planning.

2 INTRODUCTION

Artificial intelligence-based expert systems resemble human thinking to solve complicated issues when specialized knowledge is limited [1]. These technologies offer effective, economical solutions for traffic control and infrastructure planning in civil engineering [2]. Fuzzy logic and hybrid computational techniques are especially useful in Pavement Management Systems (PMS) for solving confusion in data and optimizing maintenance plans [3], [4]. These technologies have been effectively used in recent applications for surface index prediction [7], concrete pavement inspection [6], and historic bridge assessment [5]. Additionally, advanced algorithms currently support machine learning-based structural health monitoring and road risk assessment [8], [9]. Even with these developments in analysis, specific tools are still required to impart this knowledge to users. As a result, this study presents Exs-PRM, a knowledge-based educational system intended to instruct civil engineers in the identification, avoidance, and economical repair of concrete pavement issues [10]. It offers best practices and cost-effective maintenance methods tailored to the severity of defects. The system aims to address challenges, identify defects, serve as an educational resource, and preserve expert knowledge for future generations, enhancing the overall quality and efficiency of pavement construction and maintenance projects.

3 SYSTEM DEVELOPMENT AND MAINTENANCE

Exs-PRM is a Windows program for managing rigid, flexible, composite, reinforced, subgrade, and subbase pavements. It was created in C# and Visual Studio using an Access database. It is made to be quickly improved with new maintenance methods and makes use of six different forms and tables for defect evaluation.

In order to maximize resources, 40 engineers, separated by experience (5–9 and >10 years), were questioned before the system was developed to confirm its requirement. Responses to seven 5-point Likert scale items Table 1 verified the usefulness and educational value of the method (Table 2).

Score Interval	Rules	Evaluation Criteria
1	Very low level	1-1.79
2	Low level	1.8-2.59
3	Medium level	2.6-3.39
4	High level	3.4-4.19
5	Very high level	4.20-5

Table 1: Evaluated Criteria for Likert Scale.

No.	Question	Gr. 1		Gr. 2	
		Mean	SD	Mean	SD
Q1	The recommended system will be essential.	4.07	0.573	4.00	0.577
Q2	The recommended system will help novice engineers fix a variety of flaws and problems.	4.20	0.600	4.33	0.699
Q3	An engineer can benefit from the suggest system when learning about field issues.	4.13	0.618	4.37	0.706
Q4	The realm issues would be archived by the proposed system.	4.37	0.605	4.43	0.667
Q5	Engineers working in the research area can share knowledge by using the proposed system.	4.13	0.718	4.33	0.699
Q6	To manage the volume of projects, there aren't enough domain experts.	4.33	0.471	4.43	0.616

Table 2: Evaluation of the questionnaire regarding the suggested system's necessity.

Exs-PRM is a Windows-based program that needs the proper 32-bit or 64-bit AccessDatabaseEngine for operation. The setup file is used for installation, which creates a desktop shortcut for quick access. In order to catalog pavement defects, the software was created by converting logic flowcharts into C# code and connecting six diagnostic forms with a Microsoft Access database. Users may easily access and find specialized maintenance data according to the user-friendly primary interface (Figure 1), which has separate buttons for the Concrete, Block, Composite, Asphalt, and Subgrade/Subbase categories.

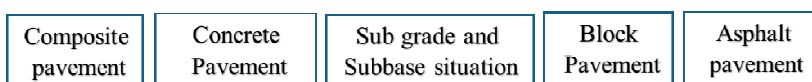


Fig. 1: Main form graphical user interface of Exs-PRM

The “Flexible Pavement” interface, which lets users switch between descriptions and problems, is shown in Figure 2. A cross-sectional diagram of the structure shows how the pavement is defined as layers of asphalt and gravel that flex to distribute traffic loads.

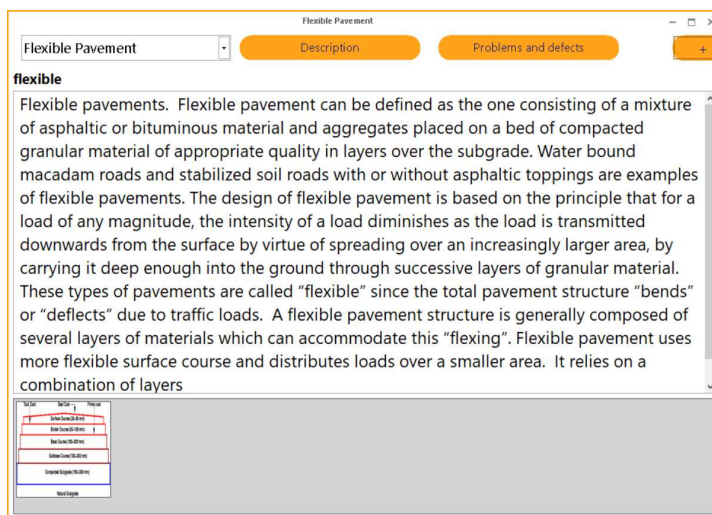


Fig. 2: Flexible pavement of Exs-PRM software system.

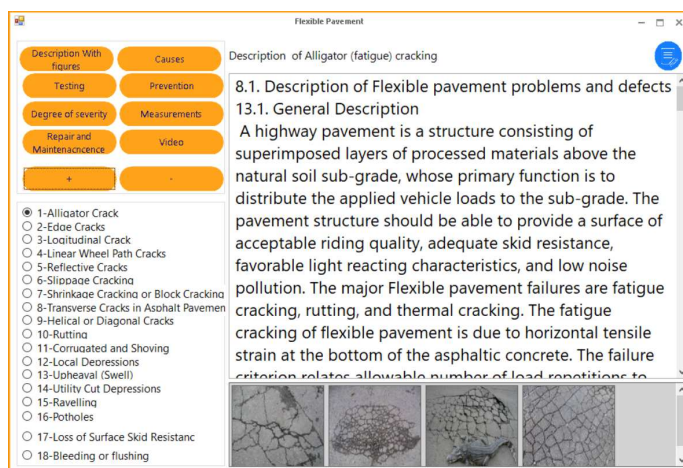


Fig. 3: Rigid pavement Exs-PRM software system.

The “Flexible Pavement” interface with a focus on alligator cracking is shown in Figure 3. Via side buttons, users can choose particular flaws and view full details such as causes, extent, repair methods, and videos. In order help with efficient maintenance management, the section uses graphical images to describe pavement physics and failure modes, such as stress and rutting.

The process from installation to testing is shown in Figure 4. In order to access resources relevant to defects, such as descriptions, causes, degree assessments, measurements, testing, prevention measures, repair guides, and instructional videos, users must first select a pavement type on the main page.



Fig. 4: Flow chart of the Exs-PRM software system operating.

Through a multi-phase process of unstructured and organized interviews, the expert system was developed by combining expert knowledge with literature. Pavement flaws were found, classified according to physical features, and then confirmed multiple times by experts. Five main categories make up the resultant classification, as shown in Table 3: jointed rigid, continuously reinforced, asphalt, subgrade/base, and composite/brick pavement problems.

To achieve objective and correct maintenance decisions, Exs-PRM uses specified, measurable limits for problem severity rather than relying simply on qualitative descriptions. The system uses common measurements such as Pavement Condition Index (PCI) ranges, crack width dimensions, percentage of damaged area, rut depth limits (measured in millimeters), and International Roughness Index (IRI) values. For example, while analyzing flexible pavements, a rut depth of less than 6 mm may result in a minor maintenance or monitoring advice, whereas depths greater than 12 mm will lead the system to recommend a major structural repair or milling intervention. By including these measurable parameters into the 'Degree of severity' module, the program eliminates subjective evaluations and directs the user to the specific maintenance activity required.

Pavements often show several parallel problems in field situations, such as immediate rutting and alligator cracking. The Exs-PRM inference engine uses a hierarchical decision-making logic that ranks distresses according to their structural impact in order to address this. When a user enters many defects, the system uses a predetermined prioritization matrix to assess the overall impact. Functional or surface-level flaws (such as bleeding or moderate ravelling) are subordinated to distresses that indicate deep structural failure (such as substantial fatigue cracking or deep subgrade settlement). As a result, the method generates a cohesive rehabilitation plan that tackles the most important underlying cause first, guaranteeing that treatments for small surface imperfections are not suggested if a complete structural overlay is truly necessary.

No.	pavement problems and their scope
1	Rigid Pavement with Joint: Includes issues like map cracking, plastic shrinkage, scaling, surface wear, popouts, delamination, material-related cracks, various types of cracking (transverse, longitudinal, corner), faulting, joint/crack spalling, joint curling and warping, blowup.
2	Continuously Reinforced Rigid Pavement (CRCP): Focuses on longitudinal cracking, irregular transverse cracking, punchouts, and transverse cracking specific to CRCP.
3	Asphalt Pavement Defects: Encompasses a wide range of issues such as alligator cracking, edge cracks, longitudinal cracks, reflective cracks, rutting, surface distortions, potholes, loss of skid resistance, and many others.
4	Subgrades and Base Situation Defects: Addresses problems like settlements, cracking due to backfill settlement, corner break and settlement, frost heave, settlement under traffic, loss of support, and consolidation of soil.
5	Composite Asphalt Defects: Involves corner cracking, transverse and longitudinal cracking, reflective cracking, joint issues, and compression failure at transverse joints.
6	Brick Pavement Problems: Covers various issues such as loss of sand in joints, inconsistent joint widths, chipping, spalling, depressions, pumping, rutting, creeping, settlement, potholes, among others.

Table 3: Evaluation of the questionnaire regarding the suggested system's necessity.

Exs-PRM is an expert system based on rules that uses predictive inference to identify pavement flaws. It was created in Visual Studio. It has a complete user interface with separate versions for developers (documented source) and highway engineers (secured executable), and it is based on an extensive amount of literature and expert skills. During its development, the system received extensive verification and validation, including unit, integration, performance, security, and usability testing, to guarantee consistency. The accuracy and operational readiness of the system were verified by these quality assurance procedures in conjunction with user input.

Confirming that surface treatments can be supported by the underlying structure is a crucial part of efficient pavement maintenance. Exs-PRM incorporates structural evaluation prerequisites into its logic because surface repairs will unavoidably fail if the structural capacity is insufficient. The system specifically asks the user to perform structural assessments, such as Falling Weight Deflectometer (FWD) testing, core sampling, or dynamic cone penetrometer (DCP) tests, before verifying a surface repair for high-severity faults or problems strongly associated with base/subgrade failure. This guarantees that pavements that truly need base reinforcement or full-depth restoration won't have maintenance treatments administered incorrectly.

4 TESTING UNIT, INTEGRATION, AND USER ACCEPTANCE

Verification and validation are essential but difficult aspects of system development. We employed continuous integration and unit testing for Exs-PRM to make sure every component worked as intended. Every core logic and variable was carefully checked by engineers. The few problems found were promptly resolved before the release.

Integration testing followed component testing to guarantee overall system consistency. Users with no technical expertise can easily enter the region, problem description, location, and layer using Exs-PRM's user-friendly interface. Knowledge engineers confirmed all inputs and system recommendations. Lastly, ten computer engineers and ten construction professionals performed User Acceptance Testing (UAT), rating the system's operation and user satisfaction based on Table 4.

No.	Question	G. 1		G. 2	
		Mean	SD	Mean	SD
Q1	The outcomes are fully and understandably presented.	4.20	0.872	4.10	0.831
Q2	Repair and treatment can be provided by an Exs-PRM.	3.90	0.700	4.10	0.700
Q3	Exs-PRM are helpful in identifying the underlying causes of problems.	4.00	0.775	4.00	0.775
Q4	Using an Exs-PRM can help you take preventative action.	4.30	0.781	4.20	0.748
Q5	Exs-PRM can be helpful in assessing the effects of problems.	4.00	0.775	4.10	0.831
Q6	Exs-PRM are simple to use.	4.10	0.943	3.90	0.943
Q7	Exs-PRM work quickly.	4.50	0.806	4.70	0.458
Q8	Utilizing the user interface is simple.	3.90	0.700	4.11	0.875
Q9	It is easy to obtain an interpretation from the Exs-PRM	4.00	0.775	3.91	0.900
Q10	The description are helpful.	3.90	0.700	3.90	0.700
Q11	The phrases are obvious	3.8	0.872	3.80	0.872

Table 4: Results of Exs-PRM evaluation.

The survey findings demonstrated excellent satisfaction with Exs-PRM's speed and user-friendly interface, with average ratings above 3/5. T-tests provided additional evidence of how well the system represented

expert knowledge. Overall, thorough unit, integration, and user acceptability testing demonstrated that Exs-PRM satisfies all stakeholder demands and expectations.

5 COMPARATIVE ASSESSMENT OF PREVIOUS EXPERT SYSTEMS

Another validation strategy involves presenting the system's inputs and outputs to an independent panel of subject matter experts. Their evaluation of the system's diagnostic capabilities, reasoning, findings, and recommendations serves as a benchmark for comparison. The experts reviewed and validated Exs-PRM's deliverables related to the identification of underlying issues, preventive measures, and potential outcomes. While Exs-PRM shares similarities with existing expert systems in the field of pavement, it also introduces several distinct enhancements. Previous systems often lacked functionalities such as testing recommendations, severity assessments, measurement instructions, and integrated video/visual analysis. A significant advantage of Exs-PRM is its broad coverage of various pavement types. Table 5 illustrates that prior expert systems predominantly focused on either flexible or rigid pavements. In contrast, Exs-PRM offers a comprehensive solution that addresses a wide range of pavement types, including flexible pavements, rigid pavements, continuously reinforced concrete pavements, composite pavements, brick/block pavements, and subgrade/subbase conditions. Exs-PRM delivers in-depth analysis for each pavement type, encompassing problem descriptions, causal factors, preventive guidance, severity evaluations, proposed testing and measurements, supporting video illustrations, and repair or treatment options.

Expert system	Title of Expert	Expert Program scope applications embrace (description, issue causation, mitigation, severity level, testing, measurement, video and problem maintenance and remedies)					
		Asphalt pavements	Concrete pavement	Cautiously Reinforced Rigid Pavement	Composite Pavement	Block Pavement	Subgrade and Subbase
An expert system for assessing concrete roads (PAVEMENT EXPERT)	PAVEMENT EXPERT		✓				
Expert Surface Status System for Pavement Restoration and Maintenance	EXPEAR	✓					
Road Infrastructure maintenance supported by a multi-expert system is represented by this French abbreviation.	SCEPTRE	✓					
Expert System Approach for Rehabilitating Asphalt roads	ERASMEF	✓					
Expert system for Flixible Road designing	PARE	✓					
Expert System for discerning pavement defects		✓	✓				
Pavement repair appeal and priority can be determined using PAVER and MicroPAVER expert systems.	PDS	✓	✓				
Pavement repair appeal and priority can be determined using PAVER and MicroPAVER expert system		✓					
Predictive Pavement Efficiency with Fuzzy Logic	PMDSS	✓	✓				
Categorization of building issues in concrete roadway pavements	F3PS		✓				
a knowledge base system to manage issues with rigid highway paving.	CCPRHP		✓				
Governance issues with construction in flexible asphalt with an expert system.	BSCPRHP	✓					
Expert system to control construction problems in flexible pavements		✓					
An educational structure based on knowledge that addresses in concrete roads construction issues for students studying civil engineering.	ESCCPPF		✓				
A revise of web-based expert systems for adaptable pavement upkeep	EKBSCESC	✓					
A web-based expert system initial prototypes for adaptable pavement upkeep	WBEXFPM	✓					
Expert system for Pavement repair and maintenance.	(Exs-PRM)	✓	✓	✓	✓	✓	✓

Table 5: Exs-PRM Versus earlier expert systems comparison.

Exs-PRM exceeds the scope of previous, more constrained expert systems by addressing all construction types and subsurface components, advancing pavement management. Owners, engineers, and contractors may use it as a lifecycle resource, and independent assessments verify that it performs better than its

specialized counterparts. Superior utility and efficacy in network maintenance are provided by its integrated, multi-domain analysis.

6 CONCLUSION

The exploring of Exs-PRM marks a significant advancement in pavement infrastructure management by providing a comprehensive and user-friendly solution to address a broad range of pavement faults and maintenance challenges. Leveraging expert knowledge and advanced computational capabilities, Exs-PRM has demonstrated exceptional efficacy, accuracy, and user satisfaction through thorough verification, validation, and quality assurance processes. Unlike previous expert systems, Exs-PRM offers extensive coverage across various pavement types and components, facilitating the efficient management of the entire pavement network lifecycle. Objective assessments by domain experts confirm that Exs-PRM not only meets but exceeds the quality standards of existing specialized systems. Its adaptability to new knowledge and intuitive interface enhance its utility for both seasoned professionals and novice engineers, while its role as an educational resource bridges the gap between theoretical understanding and practical application. As Exs-PRM continues to evolve, it holds promise as an advanced, universal tool for addressing the complexities of pavement construction and maintenance, thereby contributing to the development of more efficient, durable, and environmentally sustainable transportation infrastructure.

Exs-PRM is intended to provide economical maintenance techniques, as was previously mentioned. By recommending extremely accurate, technically sound repair techniques, the system in its current version naturally achieves this financial effectiveness by avoiding the expensive misapplication of improper treatments and increasing pavement lifetime. The authors do recognize, yet, that advanced quantitative economic analysis, such as Life-Cycle Cost Analysis (LCCA) and explicit budget constraint modeling is also essential for thorough management. Currently undergoing maintenance, the specialized Exs-PRM budget and economic evaluation module will be deployed in a future version. This feature will enable users to immediately evaluate the long-term costs of various repair options and account for particular project budget limits once it is enabled.

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