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Research Article

Appraisal of Road Pavement Evaluation Methods

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Abstract

Road pavement evaluation methods are based either on simple index of a surface characteristic, such as International Roughness Index (IRI) for roughness, Rut Depth (RD) for rutting, Sideway Force Coefficient (SFC) for skid-resistance; or, otherwise, on a complex index such as Pavement Condition Index (PCI), related with an overall consideration of the surface condition. Complex indices are commonly used in the frame of Pavement Management Systems (PMS) by road authorities worldwide, in order to assess the pavement condition and to program maintenance and rehabilitation activities along with keeping their road network up to a safe level for the users. Nowadays, these complex indices are considered to be more reliable and suitable to evaluate pavement condition and prioritize future rehabilitation actions. The first-line question is: is it really so? Meaning that, are indices like Present Serviceability Index (PSI) capable of revealing the real condition without misunderstanding or hidden issues? Can they be implemented in all cases and if so, are they enough accurate to lead road authorities to a safe conclusion and subsequently to the right and effective maintenance activities without misleads and useless costs? In the frame of the present paper, some of the most commonly used evaluation methods are enlightened, so as to dig up their advantages and their deficiencies and finally to assess their degree of efficiency.
In terms of appraising pavement evaluation methods using complex indicators, the most common methods used are hereafter examined in an attempt to determine the best one for each case. Although the Australian method seems to be the most complete and reliable one, there is no absolute answer for all the cases, meaning that the best one in terms of mitigated implementation cost is suitable for cases with serious financial constraints, whilst in case of evaluations regardless of budget, the most accurate method is the appropriate one.

Keywords: Pavement, Appraisal, Evaluation, Highway management

1. Introduction and Commonly Used Indices Overview

Road pavement evaluation is continuously being improved by using increasingly complicated methods. Nowadays, complex indicators, such as PSI, PCI, etc. stand for the main tools for assessing surface condition, considered to be multilateral and more complicated methods, compared to formerly used simple indices, such as IRI, RD, etc., that deal with one and only surface characteristic for each indicator. The upgraded point of the complex indices is considered to be a multilateral approach that takes into account more than one pavement feature, in contrast to the simple indices. Thus, it is assumed that the relevant results, depict the real surface condition in a comprehensive and reliable way.

The main disadvantage of simple indicators is their function to assess one pavement feature without considering the whole picture. So, they may lead road authorities to mistaken conclusions for maintenance programming. The primary reason for these faulty conclusions is the fact that all other pavement features are not evaluated.

On the other hand, a pavement, for example, that presents an unacceptable level of skid-resistance may at the same time present a good performance in terms of rutting. If this is the case, the question raised as regards complex indicators, is whether their output enables the authorized personnel to get a reliable decision for maintenance activities programming, inasmuch, depending on the weight each feature affects the output, the complex indicator probably presents an acceptable level although one or more features are below limit values.

Pavement evaluation is conducted by measuring pavement characteristics' indicators such as SFC, IRI, RD, in the context of a PMS. All variable methods present strong points and drawbacks at the same time, compared to each other. Usually, costly ones - in terms of financing and required time - are more precise whilst less time-consuming are proven to be implemented with less expenses, yet they are less accurate. The usual practice, especially in developing countries, stands for low-budget options and fast results.

Since 60's, subjective evaluation of pavement condition based on engineering experts' opinion was the common case, meaning that pavement was either satisfactory or unsatisfactory [1]. On that time, the firstly presented PSI as shown in Fig. 1, stands for the pavement condition indicator dealing with rating ride comfort on a scale from 0 (poor) to 5 (excellent) [2, 3]. Present Serviceability Rating (PSR) is another expression of PSI by using averaged rating for each road segment [2].

Other indicators for pavement performance evaluation are the Riding Comfort Index (RCI) [4], the IRI [5, 6] and the PCI [7]. Federal Highway Performance Monitoring System [8] has adopted IRI as the main indicator for evaluating road profile [9].

As it is easily perceptible, each method evaluating

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pavement condition is implemented by varied equipment, sometimes, completely different from the equipment of the other methods. Thus, in order to build potential of methods' comparability as well as for the standardization of pavement characteristics, correlation formulas have been established [10].

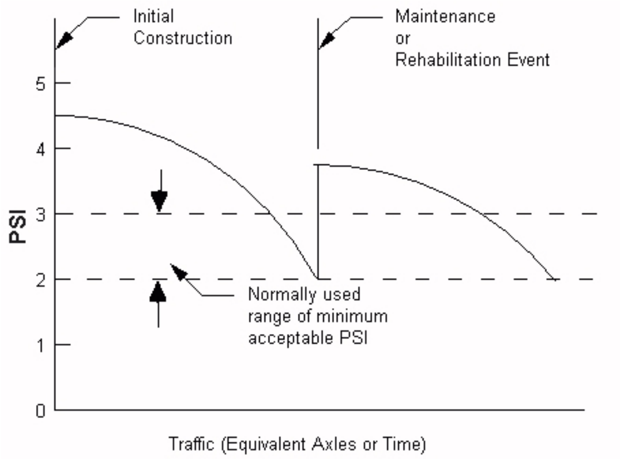

Fig. 1. Concept of pavement performance using Present Serviceability Index (PSI) [22]

As regards the PCI, it has been developed by the U.S. Army Corps of Engineers [11] and the relevant value is a rating based on the distress identification according to the type of pavement.

Karan et al. [12] propose the pavement quality index (PQI), by rating 40 segments for riding comfort, structural adequacy and surface distress. FHWA presented an index that incorporates various measurements of pavement status [13].

Juang and Amirkhanian [14] used the concept of fuzzy sets to propose the unified pavement distress index. Zhang et al. [15] developed a detailed pavement rating index based on fuzzy set theory, namely overall acceptance index, considering roughness, surface discomfort, structural strength and skid-resistance. Shoukry et al. [16] introduced Fuzzy Distress Index (FDI) and dependent on this, a maintenance ranking was set. On the basis of PSI and PCI, Thube et al. [17] proposed pavement distress evolution models for low-volume roads of India. Meanwhile, Gharaibeh et al. [18], found that phenomenally similar pavements may present differentiated condition indices, despite their similarities.

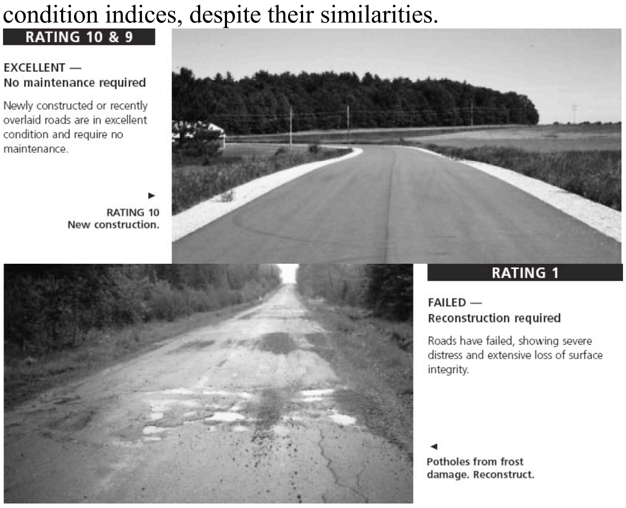

Fig. 2 Photographs from Asphalt PASER [19]

Pavement Surface Evaluation and Rating Manual (PASER) [19] was introduced by the University of Wisconsin-Madison. It is a rather simple manual, using a ten-grade ranking system according to the best match of inspected pavement with one of the photographs the manual provides as shown in Fig. 2.

Another evaluation method, VIZIR [20], lies on a scheme of three damage levels, where each pavement inspected can be attributed at one of them. Flexible pavements stand for the main subject of the method. The type, the severity and the extent of the damage are recorded accordingly. The survey can be conducted either manually or using the LCPC's DESYROUTE equipment. Fig. 3 depicts a catalogue of distress and accordingly a method of graphical presentation as guidance for the inspector. Severity values as shown in Fig. 3, are average values suitable for many roads.

Severity / Damage	1	2	3
Deformation rutting	Perceptible to user but small f < 2 cm	Severe deformations, localised subsidence or rutting 2 ≤ f ≤ 4 cm	Deformation severely affecting safety or travel time f ≥ 4 cm
Cracking	Hair line cracks in wheel tracks or centerline	Open and / or branching cracks	Markedly branched and/or wide open cracks: edges sometimes damaged
Crazing	Fine crazing with no loss of materials large mesh (> 50 cm)	Tighter crazing (< 50 cm) sometimes accompanied by loss of materials, stripping, and incipient potholes	Very open crazing forming blocks (< 20 cm), sometimes accompanied by loss of materials
Patching and Repair	☐ Either rebuilding of part or all of pavement	Surface work related to type A defects	
	☐ Or surface work related to type B defects	☐ Repair has stood up well	☐ Visible damage to repair itself

Table 1: Level of severity of type A damage

Severity / Damage	1	2	3
Longitudinal joint crack	Hair line isolated	• Wide (1 cm or more) without stripping or • Hair line & branching	• Wide with spalling of edges or • Wide and branching
Pothole	• Number < 5 • Dia, not more than 30 cm	5 to 10 < 5 or Dia. 30 cm Dia. 100 cm	> 10 5 to 10 or Dia. 30 cm Dia. 100 cm
	Per 100 m of pavement		
Movement of material Ravelling, fretting, bleeding, etc.	Localised. Roadbase not visible	Continuous or localised but roadbase visible	Continuous and roadbase visible
	Localised.	Continuous in one wheel track	Continuous and "marked" in one wheel track

Table 2: Level of severity of type B damage

Fig. 3. Types of damage in terms of VIZIR

Australian authority "Austroads" provide the Australian Pavement Evaluation manual in parallel with Part 5 of Austroads Guide to Pavement Technology: Pavement Evaluation and Treatment Design (AGTPT Part 5) [21]. The inspector must refer to the visual assessment sections in both manuals. Pavement evaluation process is illustrated on Fig. 4.

2. Pavement Evaluation Framework

When appraising various evaluation methods, the most important factors considered are reliability and effectiveness, because whether the method does not work properly and adequately, then there is no meaning in implementing. Also, different methods treat for different hazards, and it is helpful to know what each method will be treating for. The next important factors stand for simplicity, scope, integration in PMS, and apply cost. Thus, the appraisal of the most common evaluation methods concludes to fruitful and comprehensive ascertainments, laid on widely accepted factors, avoiding at the same time, costly solutions. In this context, applicability, algorithm, recording process and results of each method, need to be thoroughly assessed. Additionally, the pavement type along with the road category are potentially prohibitive factors, that subsequently exclude pavement evaluation methods that are not suitable for such cases, as shown in Tab. 1. The flow diagram of Fig. 5 presents the evaluation framework proposed.

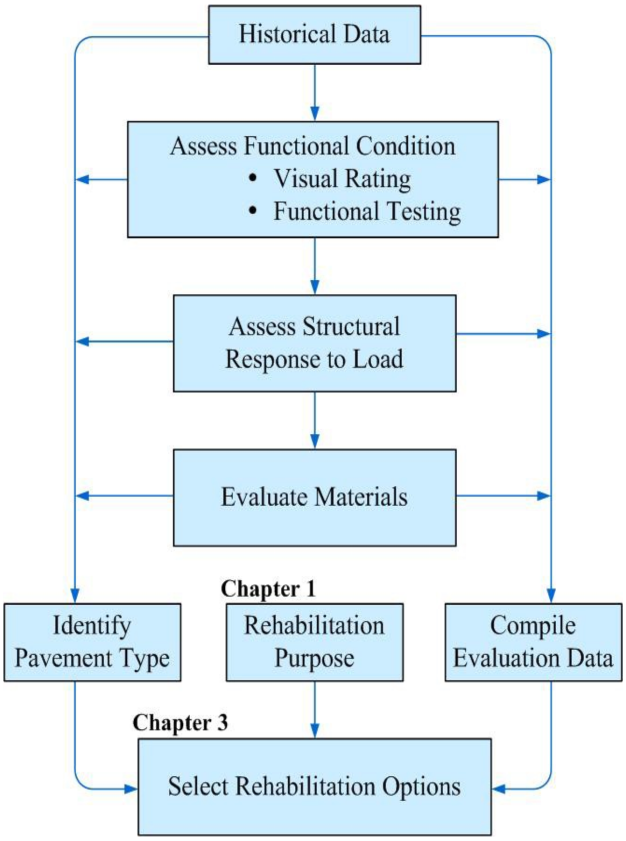

Fig. 4. Australian pavement evaluation process

Table 1. Suitable method(s) according to pavement type and road category

Pavement type	**Pavement evaluation methods**				
	PSI	**PCI**	**PASER**	**VIZIR**	**AUSTRALIAN**
Flexible	√	√	√	√	√
Rigid	√	√	√	√	√
Composite	√	√	√	√	-
Gravel	-	√	-	-	-
Road category	All	Freeway, arterial, collector, local	County, rural, urban	All	All

3. Appraisal of Evaluation Methods

Appraising evaluation methods by comparative analysis is undoubtedly a difficult task. Though, there are certain distinct differences that enlighten advances and drawbacks for each one as compared with the others. Such a differentiation lies on the pavement type each method is suitable for evaluating, meaning that whilst all methods are competent for flexible pavements, gravel pavements cannot be evaluated by any method except PCI. Apart from the above, the road category to be examined is undoubtedly a decisive criterion as well, as shown in Tab. 1.

Considering necessary equipment and staff training requirements, PASER is the less demanding method, for as much as visually surface rating stands for the cornerstone of the evaluation procedure. On the other hand, the Australian method requires the most complex equipment to complete the survey, including ground penetrating radar (GPR), NAASRA roughness meter and other special machinery, which may not be the common case for a road authority. At the same time, the Australian method demands highly trained and specialized personnel in order to be implemented. VIZIR stands for the second in raw, with basic equipment requirements and elemental staff training. The next one is PSI, requiring a more advanced, but not sophisticated training level. As for PCI, the main drawback is installing the expensive device to measure IRI.

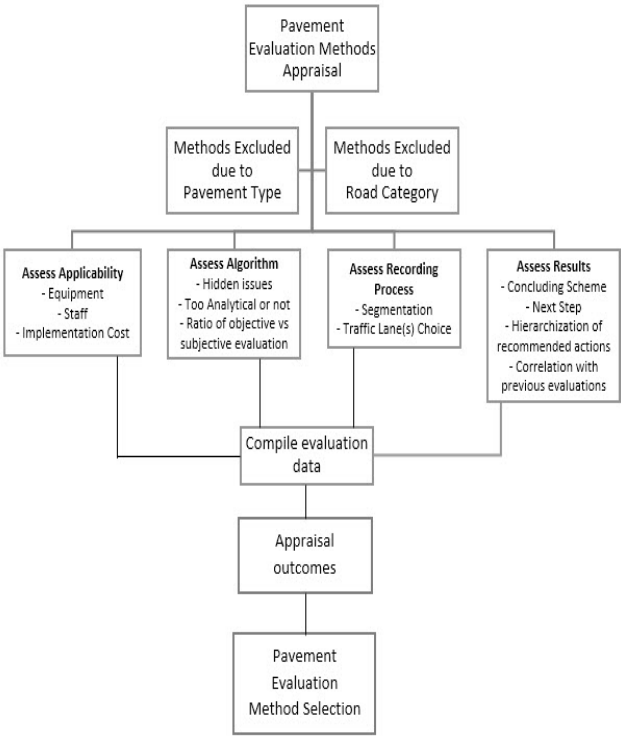

Fig. 5. Flow diagram for pavement evaluation methods appraisal

As regards the characteristics of the algorithm each method is based on, the Australian one appears to be the most complete as it performs a holistic approach by using a data map of several measured and obsvered pavement features and materials.

Given the above, Tab. 2 contains succinct remarks for main features appraised for each pavement evaluation method and Tab. 3 shows appraisal outcomes for several crucial criteria, namely applicability, algorithm, impact level, recording, results and measurements repetition.

Fig. 6 provides a representation of the types of evaluation methods available to the agencies and the related simplicity and resources required to collect the necessary information according to evaluation outcomes from Tab. 2 and Tab. 3.

Table 2. General appraisal of pavement evaluation methods

Features	**Pavement evaluation methods**				
	PSI	**PCI**	**PASER**	**VIZIR**	**AUSTRALIAN**
Advantages	No panel required	Accuracy	Easy implementation, costless	Easy implementation	Accuracy, predicted future conditions evaluated
Deficiencies	Limited distress types	Panel developed, subjective	Subjective	Limited distress types	Special equipment needed
Completeness	Moderate	High	Moderate	Moderate	Highest
Reliability	Statistical estimate of the mean of the PSR	According to panel experts	Low due to visual objective rating	Moderate due to evaluation of limited distress types	Fairly with certain flaws due to demanding resources
Simplicity	Fairly	Fairly	Highest	Yes	No
Scope (application field)	Pavement performance evolution	Maintenance priorities	Maintenance objectives	Maintenance objectives	PMS asset
Integration in PMS	√	√	√	√	√
Cost	Moderate	High	Extremely low	Moderate	Highest

Table 3. Appraisal of pavement evaluation methods in terms of certain characteristics

Criteria	**Pavement evaluation methods**				
	PSI	**PCI**	**PASER**	**VIZIR**	**AUSTRALIAN**
Applicability					
Pavement type	Flexible, rigid, composite	Flexible, rigid, composite, gravel	Flexible, rigid, composite	Flexible, rigid, composite	Flexible, rigid
Road category	All	Freeway, arterial, collector, local	County, rural, urban	All	All
Equipment complexity	Low	Moderate	Minimum	Minimum	Maximum
Staff training requirements	Moderate	Moderate	Minimum	Minimum	Highest
Algorithm					
Degree of completeness	Limited distress types	Surface conditions only	Surface conditions only	Surface conditions, traffic	Data map (holistic approach)
Blind areas	Underlying problems	Underlying problems	Underlying problems	√	Fairly no
Too explicit	No	No	No	No	Yes
Objective measurements (O) vs subjective personal assessments (S)	Minor/major	Mainly subjective	Mainly subjective	Mainly subjective	Mainly objective
Impact level	Worldwide	USA	Wisconsin, Michigan	Worldwide	Australia mainly
Recording					
Segmentation	Non available	√	√	√	√
Representative segments	Unclear	5,000 square feet	½ mile – 1 mile for rural, 1-4 blocks for urban	500 m for damage index in PMS	Determined by condition data (e.g. by using deflection results), 100 m for rutting
Results					
Concluding scheme	Pavement surface condition rating	PCI decision matrix	Pavement surface condition rating	Pavement quality rating	Selection of alternative rehabilitation options
Next step	No suggestions	Maintenance activity	Safety, future traffic	General maintenance	Explicit maintenance

		suggestion	projections, original construction, pavement strength should be considered to dictate maintenance suggestion	suggestions	suggestions
Hierarchization or recommended actions	Not strictly defined	Yes	Not strictly defined	Not strictly defined	Not strictly defined
Correlation with the previous measurement	No	Yes (annual database)	No	No	Yes (historical data)
Measurements repetition	Not strictly defined	Annually	Not strictly defined	Not strictly defined	Annually

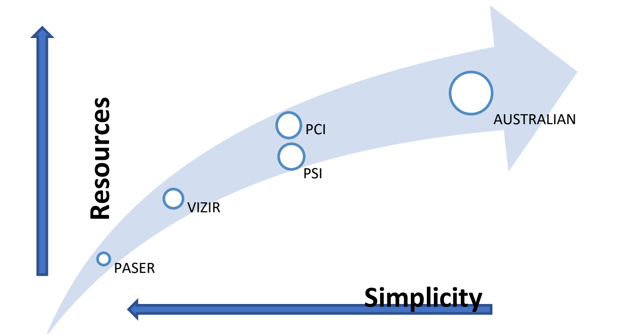

Fig. 6. Required resources and simplicity of pavement evaluation methods

Moreover, to conclude to the best pavement evaluation method, the analytical hierarchy process (AHP) technique [23] is followed hereafter. The evaluation criteria used are: a) cost, b) completeness, c) reliability and d) simplicity. The AHP hierarchy for this decision is shown in Fig. 7. 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 [24]. The AHP fundamental scale in assigning the weights is shown in Tab. 4. The appraisal is conducted considering evaluation outcomes from Tab. 2 and Tab. 3, and begins by comparing the alternative evaluation methods with respect to their strengths in meeting each of the appraisal criteria, namely cost, completeness, reliability and simplicity, as shown in Tab. 5. In sequence, comparison of the criteria with respect to their importance to reaching the goal, meaning the best alternative, takes place as shown in Tab. 6. The calculations for the alternative pavement evaluation methods with respect to the criteria set, concluding to attributed weights to each criterion, are shown in Tab. 7.

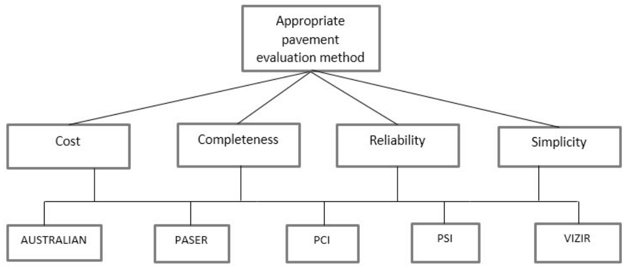

Fig. 7. AHP scheme for pavement evaluation methods

Table 4. Fundamental scale for pairwise comparisons (scale of relative importance)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

*Intermediate values to reflect compromises: 2, 4, 6, 8
** Values for inverse comparison: 1/3, 1/5, 1/7, 1/9

Table 5. Pairwise comparison matrix for appraisal criteria

Cost	AUSTRALIAN	PASER	PCI	PSI	VIZIR	Priority
AUSTRALIAN	1	1/9	1/3	1/5	1/7	0.033
PASER	9	1	7	5	3	0.513
PCI	3	1/7	1	1/3	1/5	0.063
PSI	5	1/5	3	1	1/3	0.129
VIZIR	7	1/3	5	3	1	0.262
Completeness	**AUSTRALIAN**	**PASER**	**PCI**	**PSI**	**VIZIR**	**Priority**
AUSTRALIAN	1	5	3	5	5	0.501

PASER	1/5	1	1/3	1	1	0.088
PCI	1/3	3	1	3	3	0.236
PSI	1/5	1	1/3	1	1	0.088
VIZIR	1/5	1	1/3	1	1	0.088
Reliability	**AUSTRALIAN**	**PASER**	**PCI**	**PSI**	**VIZIR**	**Priority**
AUSTRALIAN	1	9	5	7	5	0.575
PASER	1/9	1	1/5	1/3	1/5	0.036
PCI	1/5	5	1	3	1	0.159
PSI	1/3	3	1/3	1	1/3	0.071
VIZIR	1/5	5	1	3	1	0.159
Simplicity	**AUSTRALIAN**	**PASER**	**PCI**	**PSI**	**VIZIR**	**Priority**
AUSTRALIAN	1	1/9	1/5	1/5	1/7	0.032
PASER	9	1	5	5	3	0.504
PCI	5	1/5	1	1	1/3	0.108
PSI	5	1/5	1	1	1/3	0.108
VIZIR	7	1/3	3	3	1	0.248

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

Criteria	Cost	Completeness	Reliability	Simplicity	Priority
Cost	1	1/5	1/9	1/3	0.046
Completeness	5	1	1/5	3	0.203
Reliability	9	5	1	7	0.657
Simplicity	3	1/3	1/7	1	0.094

Table 7. Weights of criteria according to pavement evaluation method used

Criterion	Pavement evaluation method	A	B	C
Cost	AUSTRALIAN	0.033	0.046	0,001518
	PASER	0.513		0,023598
	PCI	0.063		0,002898
	PSI	0.129		0,005934
	VIZIR	0.262		0,012052
Completeness	AUSTRALIAN	0.501	0.203	0,101703
	PASER	0.088		0,017864
	PCI	0.236		0,047908
	PSI	0.088		0,017864
	VIZIR	0.088		0,017864
Reliability	AUSTRALIAN	0.575	0.657	0,377775
	PASER	0.036		0,023652
	PCI	0.159		0,104463
	PSI	0.071		0,046647
	VIZIR	0.159		0,104463
Simplicity	AUSTRALIAN	0.032	0.094	0,003008
	PASER	0.504		0,047376
	PCI	0.108		0,010152
	PSI	0.108		0,010152
	VIZIR	0.248		0,023312

* Column A shows the priority of this alternative with respect to each criterion. Column B shows the priority of each criterion with respect to the goal. Column C shows the product of the two, which is the global priority of each alternative with respect to the goal.

Finally, overall priorities/weights for the pavement evaluation methods are shown in Tab. 8.

Table 8. Overall weights of pavement evaluation methods (no budget constraints)

	Priority with respect to				
Evaluation method	**Cost**	**Completeness**	**Reliability**	**Simplicity**	**Goal**
AUSTRALIAN	0,001518	0,101703	0,377775	0,003008	0,484004
PASER	0,023598	0,017864	0,023652	0,047376	0,11249
PCI	0,002898	0,047908	0,104463	0,010152	0,165421
PSI	0,005934	0,017864	0,046647	0,010152	0,080597
VIZIR	0,012052	0,017864	0,104463	0,023312	0,157691
Totals:	0,046	0,203	0,657	0,094	1

Based on the choice of decision criteria, on assigned experts' judgments about the relative importance of each, and on their judgments about each pavement evaluation method with respect to each of the criteria, Australian method, with a priority of 0.484, is the most suitable. PCI and VIZIR, with a priority of 0.165 and 0.158 accordingly, are a step below, and PASER, PCI complete the appraisal list.

It is strongly noted that the relative importance of each criterion, as well as the judgment about each pavement evaluation method with respect to each of the criteria, should be set by specialized engineering personnel considering each case's special features along with available budget and other potential constraints. In case there is need for specific findings to be extracted from the implementation of pavement evaluation, the methods that either satisfy or not satisfy the required results, must be assigned to proper relative importance weights.

A sensitivity analysis of cost's influence - in comparison to the previous AHP results - on the final decision is shown in Table 9. This AHP technique application considers very strict budget constraints, where cost mitigation is a crucial issue for the decision. Consequently, with respect to cost, weights of 9, 7, 5 and 3 are assigned to PASER compared to Australian, PCI, PSI and VIZIR, accordingly. In this case, PASER, with a priority of 0.327, is the most suitable. Despite the fact of being the most cost demanding, Australian method lies on the second place of the appraisal with a priority of 0.242, indicating strong features reflected to the evaluation criteria, and the other ones follow in sequence.

Table 9 Overall weights of pavement evaluation methods (very strict budget constraints)

	Priority with respect to				
Evaluation method	**Cost**	**Completeness**	**Reliability**	**Simplicity**	**Goal**
AUSTRALIAN	0,018414	0,047595	0,174225	0,001376	0,24161
PASER	0,286254	0,00836	0,010908	0,021672	0,327194
PCI	0,035154	0,02242	0,048177	0,004644	0,110395
PSI	0,071982	0,00836	0,021513	0,004644	0,106499
VIZIR	0,146196	0,00836	0,048177	0,010664	0,213397
Totals:	0,558	0,095	0,303	0,043	1

4. Conclusions

As it easily perceptible from the previous analysis, considering no budget limitations, the most preferable method is the Australian, due to its strong reliability and completeness. On the other hand, whether resources constraints show up, the most suitable is the PASER method.

The usual practice followed by road authorities, that stands for implementing the same pavement evaluation method over the years, ignoring any flaws or lack of resources, may very likely lead to false output due to insufficient implementation issues as regards the evaluation procedure. For example, the Australian evaluation method can not deliver concise and safe results whether the staff has not been trained adequately, due to lack of relative resources.

The aim of this appraisal stands for pointing out the holistic frame that available methods should be evaluated into and is meant to be a comprehensive tool for road experts, to complete the task of pavement assessment whilst, in parallel, take into account the available resources.

To sum up, all methods show up advantages and handicaps, depended on required results and budget limitations. In order to select safely the most suitable method for pavement evaluation, the authorized staff has to carefully weigh the aforementioned parameters that take place in each case examined.

References

1. Haas, R., Hudson, W.R., and Zaniewski, J., 1994. Modern Pavement Management, Krieger Publishing Company, Malabar, Florida.
2. Carey, W.N., and Irick, P.E., 1960. The Pavement Serviceability Performance Concept, Highway Research Bulletin 250, Highway Research Board, Washington, D.C., pp. 40-58.
3. Highway Research Board, 1962. The AASHO Road Test, Report 3: Traffic Operations and Pavement Maintenance, Special Reports No. 61C, National Academy of Sciences, National Research Council, Washington, D.C.
4. Carriage of Goods by Road Act., 1965. United Kingdom Legislation.
5. Gillespie, T.D., Sayers, M.W., and Segel, L., 1980. Calibration of response-type road roughness measuring system, National Cooperative Highway Research Program, Report 228, Transportation Research Board, Washington, D.C.
6. Sayers, M.W., Gillespie, T.D., and Queiroz, C.A.V., 1986. The International Road Riding Quality Experiment: establishing correlation and a calibration standard for measurements, Technical Paper 45, World Bank, Washington, D.C.
7. Shahin, M.Y., and Kohn, S.D., 1979. Development of a pavement condition rating procedure for roads, streets and parking lots, Department of the Army, Construction Engineering Research Laboratory, Champaign, Illinois.
8. Federal Highway Administration, 1987. Highway Performance Monitoring System: field manual for the continuing analytical and statistical database, Appendix J, Order M5600.1A, OMB No. 2125-0028, FHWA.
9. Huang, Y.H., 1993. Pavement analysis and design, Prentice Hall, Englewood Cliffs, New Jersey.
10. Bennett Christopher R., Chamorro Alondra, Chen Chen, Hernan de Solminihac, and Flintsch Gerardo W., 2007. Data Collection Technologies for Road Management, East Asia Pacific Transport Unit, The World Bank, Washington, D.C.
11. U.S. Army, 1982. Pavement Maintenance Management, Technical Manual TM 5-623.
12. Karan, M.A., Chiristison, T.J., Cheetlam, A., and Burdahi, G., 1983. Development and implementation of Alberta's pavement in formation and and needs system. Transportation Research Board, TRR 938, Washington DC, 11-20.
13. FHWA, 1990. An advanced course in pavement management systems, Course notes, Federal Highway Administration, Washington, D.C.

14. Juang, C.H. and Amirkhanian, S.N., 1992. Unified pavement distress index for managing flexible pavements, Journal of Transportation Engineering, ASCE, 118 (5), 686-699.
15. Zhang, Z., Singh, N. and Hudson, W.R., 1993b. Comprehensive ranking index for flexible pavement using fuzzy sets model. Transportation Research Board, TRR 1397, 96-102.
16. Shoukry, S.N., Martinelli, D.R. and Reigle, J.A., 1997. Universal pavement distress evaluator based on fuzzy sets. Transportation Research Board, TRR 1592, 180-186.
17. Thube, D.T., Jain, S.S. and Parida, M., 2007. Development of PCI based composite pavement deterioration curves for low volume roads in India, Highway Research Bulletin, Indian Roads Congress, 76, 55-69.
18. Gharaibeh, N.A., Zou. Y. and Saliminejad, S., 2010. Assessing the agreement among pavement condition indexes. Journal of Transportation Engineering, ASCE, 136 (8), 765-772.
19. Walker, D., 2013. Pavement Surface Evaluation and Rating Manual (PASER). Wisconsin Transportation Information Center, 432 North Lake Street, Madison, WI 53706.
20. BCEOM, 1998. Pavement Management System. Draft Final Report. Appendix II/2/1 to Part II. Road Dictionary and Data Acquisition. VIZIR Method for Quality Evaluation of Paved Roads.
21. Austroads, 2009b. Guide to Pavement Technology Part 5: Pavement Evaluation and Treatment Design (Austroads Publication No. AGTP05/09), Austroads, Sydney.
22. Hveem, F.N. and Carmany, R.M., 1948. The Factors Underlying a Rational Design of Pavements. Proceedings. Highway Research Board.
23. Saaty, Thomas L., 2006. Fundamentals of Decision Making and Priority Theory. Pittsburgh, Pennsylvania: RWS Publications. ISBN 0-9620317-6-3.
24. Saaty, Thomas 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.

Appendix

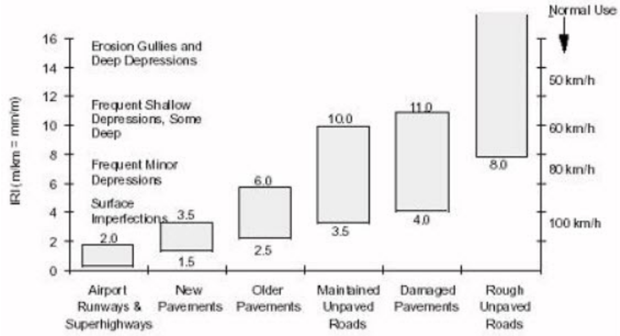

Fig. A. IRI roughness scale for evaluation

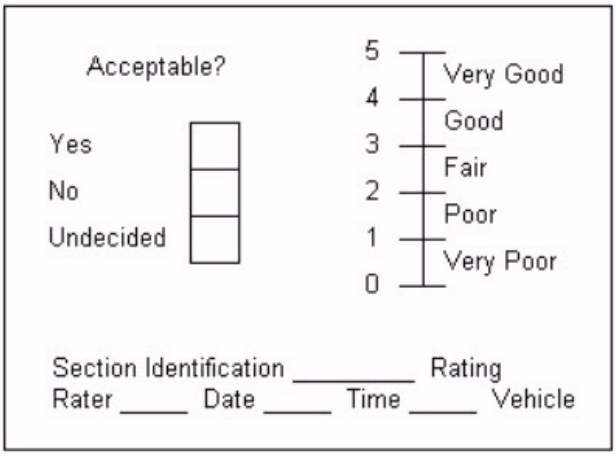

Fig. B. Individual PSR evaluation form

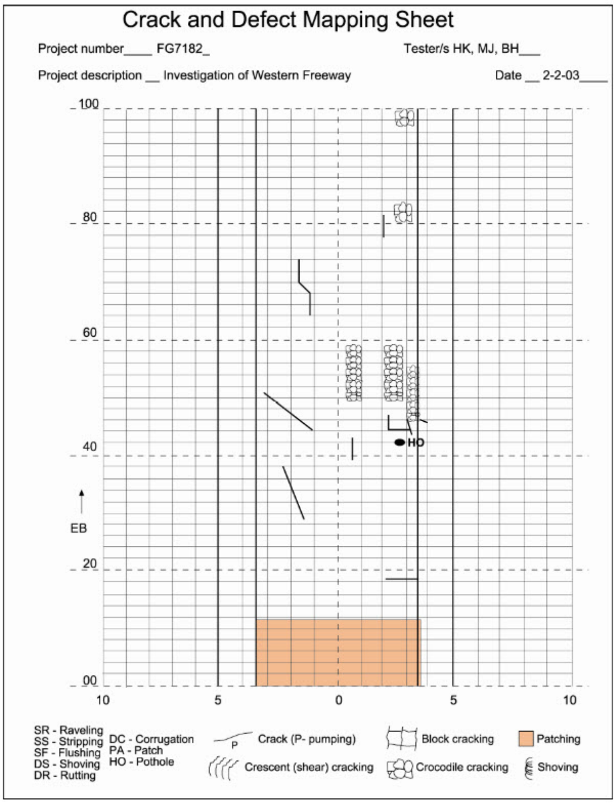

Fig. C. Example of a defect mapping sheet for a flexible pavement, from Austroads Guide to Pavement Technology: Pavement Evaluation and Treatment Design (AGTPT Part 5)

Surface rating	Visible distress*	General condition/ treatment measures
10 Excellent	None.	New construction.
9 Excellent	None.	Recent overlay. Like new.
8 Very Good	No longitudinal cracks except reflection of paving joints. Occasional transverse cracks, widely spaced (40' or greater). All cracks sealed or tight (open less than ¼").	Recent sealcoat or new cold mix. Little or no maintenance required.
7 Good	Very slight or no raveling, surface shows some traffic wear. Longitudinal cracks (open ¼") due to reflection or paving joints. Transverse cracks (open ¼") spaced 10' or more apart, little or slight crack raveling. No patching or very few patches in excellent condition.	First signs of aging. Maintain with routine crack filling.
6 Good	Slight raveling (loss of fines) and traffic wear. Longitudinal cracks (open ¼"–½"). Transverse cracks (open ¼"–½"), some spaced less than 10'. First sign of block cracking. Sight to moderate flushing or polishing. Occasional patching in good condition.	Shows signs of aging. Sound structural condition. Could extend life with sealcoat.
5 Fair	Moderate to severe raveling (loss of fine and coarse aggregate). Longitudinal and transverse cracks (open ½" or more) show first signs of slight raveling and secondary cracks. First signs of longitudinal cracks near pavement edge. Block cracking up to 50% of surface. Extensive to severe flushing or polishing. Some patching or edge wedging in good condition.	Surface aging. Sound structural condition. Needs sealcoat or thin non-structural overlay (less than 2")
4 Fair	Severe surface raveling. Multiple longitudinal and transverse cracking with slight raveling. Longitudinal cracking in wheel path. Block cracking (over 50% of surface). Patching in fair condition. Slight rutting or distortions (½" deep or less).	Significant aging and first signs of need for strengthening. Would benefit from a structural overlay (2" or more).
3 Poor	Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion. Severe block cracking. Some alligator cracking (less than 25% of surface). Patches in fair to poor condition. Moderate rutting or distortion (greater than ½" but less than 2" deep). Occasional potholes.	Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of overlay.
2 Very Poor	Alligator cracking (over 25% of surface). Severe rutting or distortions (2" or more deep). Extensive patching in poor condition. Potholes.	Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective.
1 Failed	Severe distress with extensive loss of surface integrity.	Failed. Needs total reconstruction.

** Individual pavements will not have all of the types of distress listed for any particular rating. They may have only one or two types.*

Fig. D. PASER rating system for evaluation

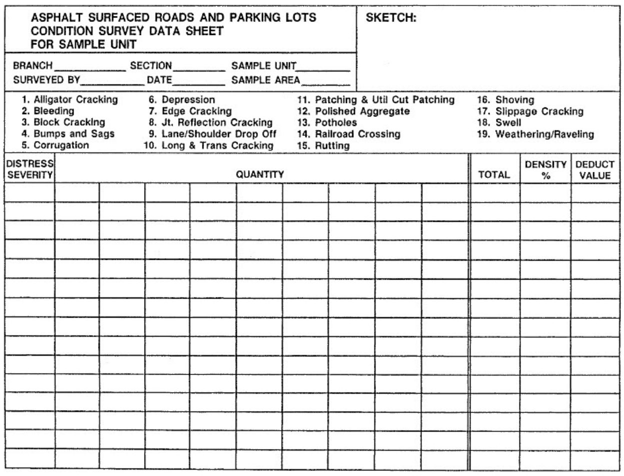

Fig. E. PCI flexible pavement condition survey data sheet