

A NEW METHOD FOR EVALUATING PAVEMENT SURFACE USING FUZZY SETS THEORY

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Most of the indices developed for evaluating pavement surface conditions are formulated based on an assumption that they can be uniquely evaluated from the severity of physical distresses. However, each distress takes place by assorted causes and commonly appear in diverse patterns.

Fuzzy sets theory was applied in this study to develop a new pavement surface evaluation method. It was found that no explicit critical points exist which give the criteria for repairs. Each rating on necessity for repairs varies gradually according to the change in surface condition scores calculated by the new formula developed by fuzzy quantification theory.

KeyWords: *pavement surface evaluation, fuzzy sets theory, quantification theory, airport runway pavement*

1. INTRODUCTION

Our understanding and evaluation of the pavement condition watched and touched directly by it's users, are essential in design, construction and maintenance of road and airport pavements. It is difficult to define the failure point of the pavements being compared with other civil engineering works including bridges, dams, and others, since the existence of a pavement as a structure is not related directly to its soundness. Thereby, the judgment on destruction of pavement varies depending on who, when, and how the analysis is made.

At present, the pavement condition is exclusively evaluated either by the users from their viewpoint of driving comfort and safety, or by the infrastructure administrators from their technological viewpoint of structural and functional soundness. To indicate the level of satisfaction as judged by the users or the soundness judged by the administrators, many research works have been performed on trying to link these subjective judgments with observed physical condition of pavements. Based on these results, various pavement condition indices have been proposed, such as PSI, MCI, PRI, and others¹⁾⁻¹⁵⁾. Most

of these indices try to describe surface conditions only by simple physical data: rut depth; cracking ratio; and others. These indices are formulated assuming that the pavement condition can be determined uniquely with fixed data. This is based on an assumption that all the evaluators should make identical judgments on a given pavement condition. In other words, it is expected that 100 people, for instance, will judge a new pavement as acceptable, and then all judgments may change significantly after the pavement service level is lowered with time.

Usual evaluations of pavement conditions depend on the users and administrators themselves. Since distresses are produced by diverse and complicated patterns, so that various evaluations will be likely to come out even on an identical pavement.

The purposes of this study are: to investigate the characteristic of conventional methods of pavement evaluation; to make an analysis of the synthetic results of evaluation on the pavement; and to propose a more rational method of evaluation by applying fuzzy sets theory. The evaluated data on pavement surface conditions were obtained by skilled pavement engineers including airport administrators. The evaluation

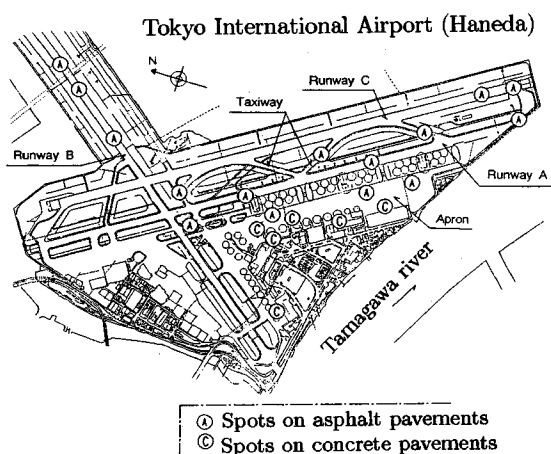


Fig. 1 Selected spots for investigation at Tokyo International Airport

methods employed are compared regarding persuasive explanations of the necessity for overall maintenance.

2. VISUAL INSPECTION ON PAVEMENT SURFACE CONDITION

The results of a visual inspection at the former Tokyo International Airport (Haneda Airport) made in 1980 by the Port and Harbour Research Institute, Ministry of Transport (Fig.1) were employed as the pavement surface evaluation data¹⁶⁾. The inspection crew was composed of twenty four pavement engineers and airport administrators. Their average working career as pavement experts was thirteen years. Distribution of the working years of investigators as experts is shown in Fig.2.

With regard to main distress patterns and the necessity for pavement maintenance, three-grade evaluations were employed for sixty four selected locations of both asphalt and concrete pavements of runways, taxiways and aprons. At the same time, measurements on objective data such as rut depth, cracking ratio, and others were also made.

Though the data retrieved from only thirty two locations for asphalt pavements in the taxiway are presented in this paper, similar analysis is possible for the runways, aprons, and each location of concrete pavements.

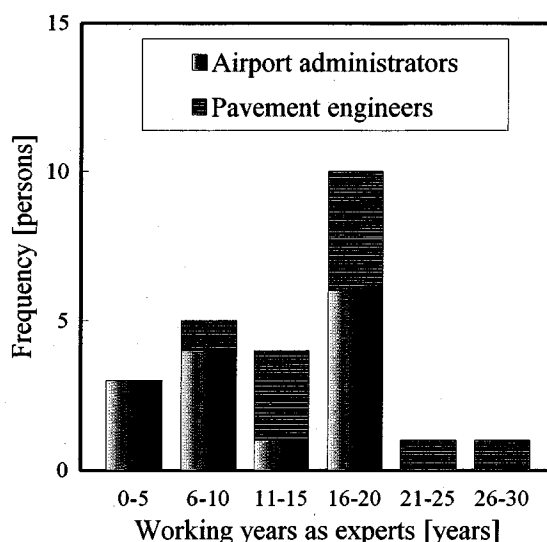


Fig. 2 Distribution of working years of investigators as experts

3. ANALYSIS ON RESULTS OF VISUAL INSPECTION

(1) Results of inspection

Distresses surveyed in the visual inspection for each distress included:

- Rutting;
- Evenness;
- Opening of construction joints;
- Linear cracking;
- Planar cracking;
- Pothole;
- Texture;
- Bleeding.

Three-grade evaluations were employed for the severity of each distress. Similar evaluations were performed for:

- Synthetic evaluation on distresses;
- Needs for repairs.

Typical results from the evaluations performed on three out of thirty two locations selected in taxiways are illustrated in Fig.3. It can be seen that the evaluations performed by twenty four experts are not identical for each of the surveyed items. As an example, some experts judged that a pavement might require urgent repair, while the others determined the same location did not.

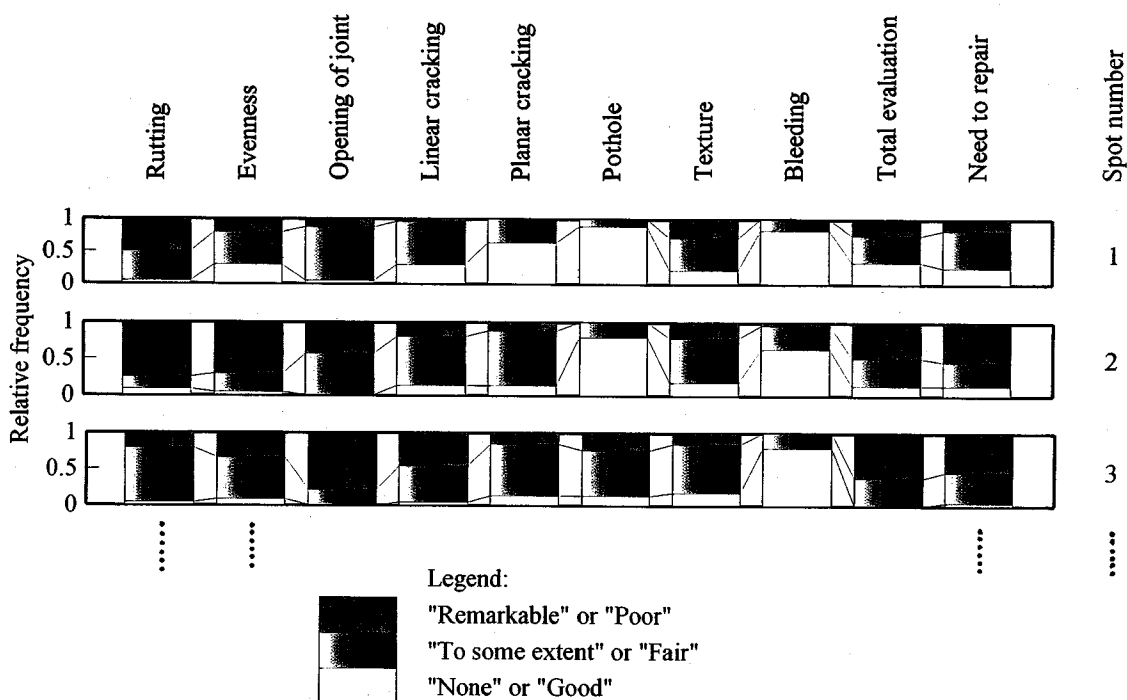


Fig. 3 Typical results of visual inspections by 24 experts

(2) Analysis based on linear discriminant function

Following the same analysis concept as proposed in the AASHO road test by employing PSI, an analysis was made with regard to extent of repair as can be explained by three physical measurements: — rut depth; cracking; and evenness.

In the analysis, linear discriminant function was employed instead of multiple regression analysis, since the external criteria were not numerical data. In other words, the degree of necessity for pavement maintenance was not rated by indices, but was evaluated by qualitative statements: "maintenance is necessary immediately;" "maintenance is necessary in the near future;" and "maintenance is not necessary for some time."

The result of the analysis is shown in Fig.4. As Fig.4 illustrates, a horizontal axis indicates an index having a similar meaning to PSI as calculated from the pavement surface condition data. The index increases as the surface distresses progress. The word "standardized" in this paper refers to a minimum value set to zero (0) and the maximum value set to ten (10).

Provided that the necessity for pavement main-

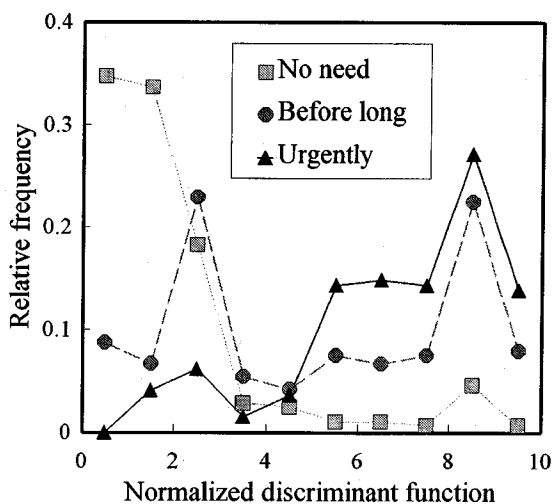


Fig. 4 Results of discriminant analysis on necessity of pavement repairs

tenance is categorized into the three groups mentioned above by the value of the discriminant function, it should also be divided into three

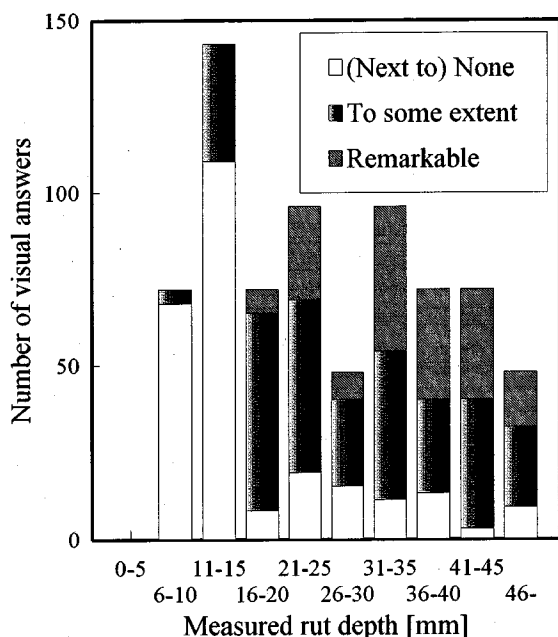


Fig. 5 Distribution of actual rut depth related to each scored group

peaks in order from the left: "maintenance is not necessary for some time," "maintenance is necessary in the near future," "maintenance is necessary immediately" without overlapping each other. The decision whether the pavement should be repaired or not can be made easily by using only these physical data. However, Fig.4 illustrates the three curves are overlapping especially for higher values of the discriminant function. So it may be concluded that pavement evaluation is more diversified as the necessity for maintenance increases. With this kind of model, the pavement with no needs of maintenance, in the near future, can be identified almost automatically, although it is impossible to make distinctions between "maintenance is necessary in the near future" or "maintenance is required immediately."

To investigate further, an investigation was made on the rutting. The distribution of rut depth as determined by a subjective evaluation made by the engineers is shown in Fig.5. It was found that the visual evaluations made by the engineers on the extent of rutting are increasingly diverse as rut depth increases. In summery, it appears that the engineers evaluate the rutting with other factors, besides physically measured depth. A similar tendency is seen in the evaluation of cracking and evenness.

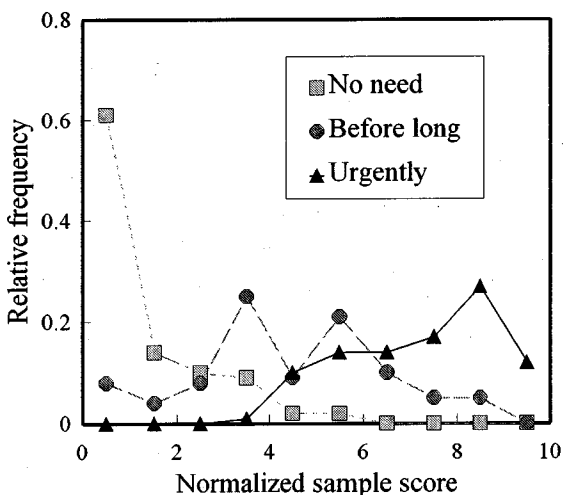


Fig. 6 Results of quantification analysis on necessity of pavement repairs

(3) Analysis based on quantification theory (Type II)

According to the results of above investigation, to know the necessity for maintenance as judged by engineers, the judgment by the same engineers on the degree of each distress seems to be more persuasive than the physical data. As a result, an analysis was made based on quantification theory (type II) in which the explanatory variables are the qualitative data¹⁷⁾. In summery, the subjective scales on each distress judged by the engineers are employed as explanatory variables instead of the physical data as rut depth. As shown in Fig.6, the distress explanation is more persuasive than the above mentioned discriminant analysis. This is most evident in the area where sample scores are higher, a curve judged that the immediate maintenance is necessary holds higher value. This method of pavement analysis is considered to be more accurate and useful. The curve that indicates required maintenance in the near future holds certainly a higher place at the center, though the three curves are laid across the whole chart and three skirts are not divided sharply into three peaks. The necessity for the maintenance can still not always be judged in one meaning.

Sample scores on the horizontal axis in the figure are indices similar to the discriminant function in Fig.4, calculated from the result of evaluation for the scale of each damage by the engineers.

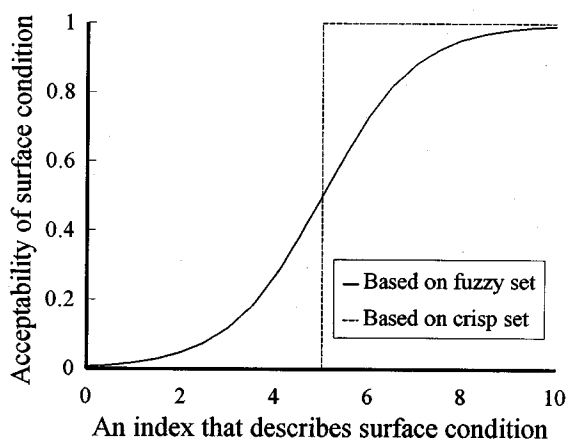


Fig. 7 Concept of pavement surface evaluation based on fuzzy and crisp theories

(4) Analysis based on fuzzy quantification theory (Type II)

The necessity for pavement maintenance can not always be explained by the above presented analysis. The shortcoming of these analyses is not attributable to incorrect or poor quality data. Thus, pavement surface condition analysis was made incorporating the fuzziness¹⁸⁾ into the quantification theory (type II). Even for the same conditioned pavement, results of evaluation seem to be dependent on the subjectiveness of the evaluators. One engineer may have difficulty in judging whether maintenance is necessary immediately, or in the near future. In addition, there seems to be some cases where the evaluator wants to mark more than one category on the check list. This means that various evaluations are possible even for the same sample score incorporating fuzzy sets theory.

The concept of pavement surface evaluation based on fuzzy set theory is shown in Fig.7. According to traditional crisp sets, acceptability of the pavement surface transits abruptly at five in this schematic, as shown by the dotted line. Fuzzy sets allow gradual transition from membership to non membership, as shown by the solid line. The curve is called a membership function, showing gradual transition. The fuzzy logic allows for the analysis of pavement surface condition that is both partly satisfactory and partly unsatisfactory, although the summation of the condition degrees is always kept at one.

Conventional pavement assessment theory assumes that only one category is marked of each item. PSI, PRI, MCI and other indeces used cur-

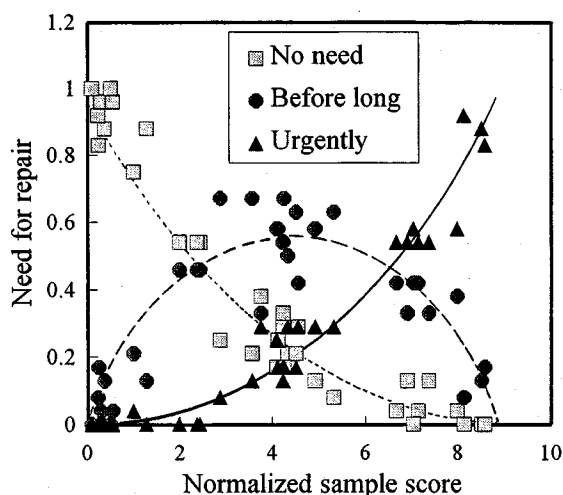


Fig. 8 Results of fuzzy quantification analysis on necessity of pavement repairs

rently in actual administration in our country are all obtained based on this kind of concept. In the fuzzy quantification theory¹⁹⁾ employed here, however, the evaluated results by the twenty four engineers are regarded as membership functions and an analysis is made with the extended theory to be able to make them direct input data. The difference of input data between conventional and fuzzy quantification theories is shown in Table 1. In fuzzy quantification theory, all categories of an item can have values for condition that the summation in the item is always kept at just one.

The result of the analysis applying fuzzy quantification theory is shown in Fig.8. By connecting every evaluation on necessity for maintenance, the membership functions can be obtained for every sample score. In this analysis, different judgments on the necessity for maintenance can be allowed even if the sample scores are identical. This fact is accepted as fuzziness instead of being refused as data error. As a result, more natural and rational interpretation can be performed on the necessity for maintenance intensifies gradually as the value of the sample score becomes higher due to increasing of each pavement distress.

In the fuzzy quantification analysis conducted in this study, the normalized sample score was obtained. Although it seems to be similar to pavement surface evaluating indeces, it is not an absolute index that describes the need for repair directly. Rather, it simply shows that the need for repair changes gradually according to the deterioration of pavement surface condition. And at the same time, it implies that conventional main-

Table 1 Difference of input data between conventional and fuzzy quantification analyses

a. Conventional quantification analysis

Data Number	Items									External criterion		
	Rutting			Evenness			Linear Cracking			Needs for Repair		
	(Next to) None	To some extent	Remarkable	Good	Fair	Poor	(Next to) None	To some extent	Remarkable	No need	Before long	Urgently
1	0	1	0	0	0	1	0	0	1	0	1	0
2	1	0	0	0	1	0	0	1	0	1	0	0
3	0	0	1	0	0	1	0	1	0	0	0	1
4	...	...	...	...	...	...	...	...	...	...	...	...

b. Fuzzy quantification analysis

Data Number	Items									External criterion		
	Rutting			Evenness			Linear Cracking			Needs for Repair		
	(Next to) None	To some extent	Remarkable	Good	Fair	Poor	(Next to) None	To some extent	Remarkable	No need	Before long	Urgently
1	0.75	0.28	0.02	0.90	0.05	0.05	0.90	0.10	0.00	0.70	0.30	0.00
2	0.55	0.45	0.00	0.10	0.85	0.05	0.40	0.50	0.12	0.67	0.33	0.00
3	0.00	0.50	0.50	0.00	0.10	0.90	0.10	0.60	0.30	0.90	0.10	0.00
4	...	...	...	...	...	...	...	...	...	...	...	...

tenance and rehabilitation standards employing crisp judgment can be upgraded incorporating the results of this new analysis carefully.

4. CONCLUSION

Fuzzy sets theory was employed to perform a more rational evaluation of pavement surface condition. Fuzzy quantification theory was developed and applied to pavement surface condition data collected subjectively by twenty four pavement engineers and airport administrators at the Tokyo International Airport (Haneda Airport). Pavement evaluation was made by visual survey employing a three-grade pavement damage scale and indicating the necessity for maintenance of the runways, taxiways and aprons. Measurement of rut depth, surface cracking, and other distresses were analyzed. The research generated the following results.

- Conventional pavement surface evaluation methods that describe the necessity for pavement repairs only from the physical data (i.e. rut depth, surface cracking, and others), appear to have limitation in its ability.
- The analyzed results can be improved slightly by incorporating subjective evaluation made by engineers into explanatory variables.
- By introducing fuzzy sets theory in the quantification analysis process, it is possible to avoid discontinuous interpretations resulting from evaluation changes given growths in pavement damage over time.

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ファジィ集合理論を用いた舗装表面の新しい評価方法に関する研究

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本研究では、空港の滑走路、誘導路およびエプロンについて、路面の主要な破損形態の発生程度、およびその舗装の維持修繕の必要性についてのデータに対して、ファジィ集合理論を応用した新しい評価モデルを作成し、路面性状を合理的に説明する手法を開発した。

その結果、伝統的なわだち掘れ深さ、ひびわれ率、平坦性といった路面性状の物理量だけではなく、ファジィネスを積極的に取りこんだ評価モデルを開発することにより、今まで健全であると評価されていた舗装が僅かな破損の進展により突然に維持修繕を必要とすると判断されるようになるというような不連続的な解釈を回避することが可能となった。