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Evaluation Measures of Pavement Maintenance Effectiveness.

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Evaluation Measures of Pavement Maintenance Effectiveness

استنباط معايير لتقييم كفاءة صيانة الرصف

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الملخص

الهدف الرئيسى من أعمال الصيانة الدوريه والوقائية للرصف الأسفلتى هوإطالة العمرالإنشائى وتحسين الأداء الوظيفى للرصف بطريقه فعاله وإقتصاديه. وتشمل عملية تقييم صيانة الرصف اختيار المعيار المناسب لقياس فعالية تلك الصيانة وتحديد قيمه هذا المعيارثم التعبير عن القيمه المقاسة كداله فى كفاءة البدائل الأخرى المتاحه لصيانة الرصف .
يطرح هذا البحث ثلاث معايير تشمل نماذج متغيرات يمكن صياغتها لقياس تقييم فاعلية صيانة الرصف وكذلك بدائل الصيانة الدوريه. هذه المعايير هي الحد من مستوى التدهور ، والقفز فى الأداء، و تخفيض معدل التدهور. وقد تم إستخدام نماذج وطرق حسابيه من دراسات سابقه تبين أنه يمكن تطبيقها على المعايير المستخدمه فى هذا البحث.
وقد خلصت الدراسه إلى إستنتاج صيغة رياضية لحساب كل معيارعلى حده كما أستنبطت العلاقه البينيه بين كل زوج من المعايير الثلاثة وأوضحت الدراسه أيضاً أهمية كل من نوع الصيانه ونموذج التنبؤ بالأداء والصيانه الدوريه فى حساب أى معيار. وقد تم تطبيق معايير الصيانة الثلاثة المذكوره على بدائل صيانات مختلفة لقياس الآثار المترتبة من تلك المعايير على حساب فاعلية الصيانة وبدائل الصيانة الدوريه. وقد أوضحت النتائج أنه يمكن إستخدام أي من المعايير المذكورة أعلاه لتقييم فعالية الصيانة كما وجد أن أفضل البدائل للصيانة الدوريه هو أعمال الصيانة الرئيسية حيث يكون الأداء أفضل من أعمال الصيانة البسيطة.

Abstract

The main objective of pavement maintenance preservation is to extend pavement life and improve its performance system in an efficient and cost-effective way. The evaluation process of maintenance effectiveness includes selecting a suitable effectiveness measure, determining its significant value and expressing such measured values as a function of the performance of pavement maintenance alternatives.

This paper describes three measures in which response variables for maintenance effectiveness models can be formulated to provide and assess the effectiveness of pavement maintenance and successive maintenance alternatives. These effectiveness measurements are; deterioration reduction level, performance jump, and deterioration rate reduction. The paper presents computational methods and terms identified from past studies and have an effect on the considered measures.

The paper concluded a mathematical formula for computing each measure. It also presented correlations between each pair of the three said measures. In addition, the paper indicates the significance of the type of each maintenance alternative, its performance prediction model and the successive maintenance type on any measure computation.

Finally, the application of the three measures was applied on different maintenance alternatives as a case study to define the application and implications of the measures on the computation of maintenance effectiveness and successive maintenance alternatives. The results indicate that any of the above measures can be used for maintenance effectiveness evaluation, and the best successive maintenance alternatives are found to be directed toward major maintenance with higher performance than other minor maintenance as defined hereinafter.

Keywords

Pavement maintenance, maintenance alternatives, effectiveness, condition, Pavement management

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1. Introduction

Maintenance is defined as "preservation of pavement condition, safety, and ride quality". Rehabilitation is defined as "a structural or functional enhancement that produces substantial extensions in service life, by substantially improving pavement condition and ride quality. Maintenance and rehabilitation are two different objectives and have different effects on pavement performance [2].

Millions of money is spent on pavement maintenance and rehabilitation every year in many countries. The initial and long-term effects of different maintenance and rehabilitation treatments on pavement performance still not quantified yet. The common definition of pavement performance is the serviceability history of the pavement.

Performance may be quantified by the area under the curve of serviceability versus time or traffic. For the purpose of life-cycle cost analysis (LCCA) of pavement design, maintenance, or rehabilitation alternatives, it is important to be able to estimate the performance of the different alternatives under consideration [1].

Highway pavement maintenance includes corrective maintenance and various levels of preventive maintenance, from ‘‘minor’’ or localized treatments such as crack sealing to ‘‘major’’ treatments such as thick overlays or reconstruction. The effectiveness of such maintenance may be evaluated for individual or with multiple treatment types and timings applied over pavement life cycle. From maintenance management and pavement management perspectives, it is useful, to assess the effectiveness of each individual maintenance treatments as possible. Such maintenance effectiveness evaluation is critical to maintenance management because it provides a basis to compare the effectiveness of maintenance across various categories of attributes such as treatment type, material used, procedure, or even work source. With regard to pavement management, an important use of short-term maintenance models is their applicability to long-term evaluation of maintenance effectiveness: pavement management operators are able to use such models to determine the expected incremental change of pavement condition as a result of a future application of any specific maintenance treatment. That way, pavement performance models can be updated to reflect maintenance application at any future point in time or cumulative usage. This study presents process for pavement maintenance effectiveness evaluation through the pavement life. There are two basic sequential issues associated with maintenance effectiveness evaluation as follow [2]:

1. How to measure the effectiveness of pavement maintenance?

2. How to correlate different variables of effectiveness measurements?

The *first step* of evaluating maintenance effectiveness is to select an appropriate measure of maintenance effectiveness such as increase of pavement condition or decrease in deterioration rate and calculating the value of the selected measure. The *second* step is to assess whether the treatment was effective, using values of the computed measure of effectiveness MOE. If maintenance effectiveness is thus confirmed, the *third step* would be developing a model to estimate such effectiveness as a function of maintenance characteristics and functional classification. In such models, the MOE values typically represent the dependent variable. This paper presents and formulates three ways of response variables for maintenance effectiveness models and suggests improvements in such formulations. The evaluation process of maintenance effectiveness models includes;

1- Selecting an appropriate measure of maintenance effectiveness and determining its value,
2- Find out whether the measured values of effectiveness are significant,

3- Expressing these measured values as a function of pavement condition for different maintenance alternatives.

2. Effectiveness of Pavement Maintenance Strategies

One important consideration in pavement maintenance is to optimize the application of different maintenance treatments. There is a need to evaluate the effectiveness of various maintenance treatments from the perspectives of both cost and benefits. A cost-effectiveness analysis (rather than cost or effectiveness information only) will help agencies to develop or update decision matrices for pavement preventive maintenance (3).

Identifying the effectiveness is an essential key to evaluate the cost effectiveness of different treatments correctly. Treatment performance models established at different traffic or environmental conditions needed for evaluating treatment effectiveness. Many models have been employed to predict treatment performance including regression, Markovian , neural network and fuzzy set models. Regression models and neural network are deterministic while Markovian models are probabilistic (4,5,6). Fuzzy set could be combined with both of them to incorporate uncertainties. Deterministic methods use models from which performance is predicted as a precise value by mathematical deterioration functions, whereas probabilistic models utilize a transition probability matrix to predict future performance. Although probabilistic models incorporate uncertainties more effectively, regression models are the most practical methods and have been widely used in existing Pavement management systems PMS (7,8).

Based on the established treatment performance model, measures of effectiveness can be accomplished by comparing the treatment performance. Several existing measures of effectiveness include the performance jump, the improved average pavement condition, the treatment service life, the extended surface layer life and the area between the performance curve and lower threshold. Among them, the area bounded by the performance curve and the lower threshold best reflects the effect of treatment since it involves both treatment service life and overall pavement condition (9).

Strategies of pavement maintenance vary widely from place to place and from time to time. Several factors usually govern these strategies such as; funds availability, historical precedent and political considerations. One or all of these items may be involved with a particular maintenance policy. A maintenance management system (MMS) is a technique or operational methodology for managing or directing and controlling maintenance resources for optimum benefits that involves the following major components (10):

1. An inventory of the physical elements of the system that can be maintained, plus operational and environmental factors.
2. Performance standards that define maintenance procedures, resources and the average accomplishment production rate.
3. Predictions of the workload generated in terms of maintenance accomplishments units by a physical element of the highway.
4. Allocation of available resources through objective budgeting mechanisms based on the specific requirements of the system and policy decisions.
5. Feedback reports to monitor and update the system.
6. Planning and scheduling procedures directed toward efficient use of resources.

3. Assessment of Pavement Deterioration

Maintenance effectiveness, or deterioration reduction, may be viewed as the increase in ‘‘positive’’ service attributes or reduction in ‘‘negative’’ attributes of an infrastructure system in response to treatment. In the context of highway pavements, such effectiveness may be in the form of an improved surface condition such as present serviceability index “PSI”, pavement quality index, and pavement condition rating “PCR” or international roughness index “IRI”, etc.

With regard to the number of monitoring periods used in the determination of effectiveness, there are many ways in which such effectiveness can be measured. The simplest is to use measurements taken at two points in time: one just before maintenance and the other just after maintenance. The result of such computation would be an instantaneous performance jump due to maintenance. Another way is to use two measurements: one of which is taken at a specified time say, 1 year before maintenance and the other taken just after maintenance; or one in which measurement was taken at a time just before maintenance and the other taken at a specified time after maintenance.

Yet another way is to use three measurements: one taken at a specified time say, 1 year before maintenance, the other taken at a time just before or just after maintenance, and the third measurement taken at a specified time well after maintenance. The third method enables the evaluation of maintenance effectiveness say, 1 year in terms of a reduction in the deterioration rate [2].

From the foregoing discussion, it is clear that an adjustment in pavement condition due to the application of maintenance may take one of two forms: 1) a modest improvement in current pavement condition [11; 12] measured instantaneously or after a finite time period and 2) a reduction in the rate of deterioration subsequent to maintenance. It has also been indicated that both phenomena can occur simultaneously [13].

Behavior of the pavement is the rate of change in pavement condition over time which described as the relation under certain level of use (traffic) subject to specific environmental factors and the time. The general form for pavement condition prediction, used in this paper, is as follow (14):

$$\mathbf{C = 100 - B \cdot X^{m}} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where:

C= Pavement Condition Index (PCI)

X= Pavement age in months measured from the date of last application of maintenance.

B= Slope coefficient, 0.0319 for Surface treatment, 0.0158 for thin overlay, 0.0129 for thick overlay, and 0.0104 for reconstruction/ new pavement.

m = Value that controls the degree of curvature of the performance curve (= 1.5).

Four different types, that most are known, of preservation techniques were considered in this paper. These techniques are; 1) Surface treatment, 2) Thin overlay, 3) Thick overlay, and 4) Reconstruction. According to the experiment data of maintenance application, these types of preservation techniques are applied at suitable pavement condition index ranges as follow; (85-73) for surface treatment, (73-60) for thin overlay, (60-47) for thick overlay and (<47) for reconstruction.

4. Measures of Maintenance Effectiveness

As mentioned before, three measures of effectiveness are used in this study; 1) deterioration reduction level (DRL), 2) performance Jump (PJ), and 3) deterioration rate reduction (DRR). Details of each measure are discussed hereinafter.

4.1 Deterioration Reduction Level

Deterioration Reduction Level (DRL) refers to the delayed measurement of deterioration reduction or the subsequent reduction in deterioration. Deterioration reduction level is defined as the increase in pavement condition due to maintenance application, calculated on the basis of deterioration measurements taken between two consecutive, spaced-out points in time. Fig.1 defines the performance curve of the pavement after construction and illustrates the DRL concept. Point A corresponds to the state or condition of the pavement at a specified time before maintenance, while point B is the state of the pavement just before maintenance is carried out. Point C is the state of the pavement just after maintenance, while point D is the state of the pavement at specified time after maintenance. The three ways to evaluate DRL value are as follow;

1. Difference value in deterioration between a specified time before maintenance and just after maintenance.
2. Difference value in deterioration just before maintenance and a specified time say, 1 year after maintenance.
3. Difference value in deterioration at specified time say, 1 year before maintenance, and another specified time after maintenance.

Each of the above types of the DRL measure may be expressed in one of three ways:

1. As an absolute change or a simple difference between two measurements in time relative to the first of the two measurements such as a change in PCI, ΔPCI;
2. As a relative change or ratio of the change to the initial condition, ΔPCI/initial PCI;
3. As a percentage change relative to the initial condition e.g., 100x(ΔPCI/initial PCI).

Another DRL measure, expressed as ‘‘change in roughness number,’’ was also used as a response variable in models that thought to estimate the effectiveness of general maintenance and rehabilitation [15]. Moreover, models of DRL concept were developed to estimate maintenance-induced change in IRI as a function of pavement attributes [6].

4.2 Performance Jump

Performance jump (PJ) may simply be considered as the vertical or instantaneous elevation in the performance or condition of a pavement due to maintenance. This is computed using values of deterioration taken just before and just after maintenance [11]. The concept of PJ was used to develop equations that estimate the instantaneous reduction in roughness due to overlays of varying thicknesses [17]. Performance jump expressed as the difference in pavement condition rate (PCR) just after treatment and PCR just before treatment [18].

However, because agencies typically do not carry out deterioration measurements just before and just after maintenance, it is often difficult to obtain data for PJ computation. Therefore, it is necessary to use the performance prediction models and extrapolate the performance curve from both directions to the point of maintenance, to obtain PJ values.

4.3 Deterioration Reduction Rate

The deterioration reduction rate (DRR) concept involves the ‘‘slowing down’’ of pavement deterioration with respect to time or cumulative loading, due to the application of maintenance. The effect of maintenance is to change the steep slope associated with a rapidly deteriorating pavement to a gentle slope. DRR is calculated as the difference in the slope of the deterioration curve before maintenance and after maintenance. It is worth noting that the DRR concept is more readily appreciated by considering a long-term performance curve where all kinks due to performance jumps have been smoothed out to yield a continuous curvy line on which a gentle slope suddenly following a steep slope is indicative of the application of maintenance. The effect of maintenance was to produce a significant flattening or even reversal of direction (upward trend) of the deterioration curve, a finding which is consistent with the DRR concept [19]. Fig. 1 provides a conceptual illustration of the reduction in the deterioration rate in response to a variety of pavement repair actions and pavement conditions. Pavement deterioration is assumed to be linear in case of maintenance effectiveness is being viewed over a relatively short period of time, compared to pavement life. Old pavements in poor condition suffer relatively high rates of deterioration if denied maintenance. In contrast, new pavements in good condition are assumed to deteriorate at the same rate if left without maintenance. These assumptions are consistent with the classical shape of the typical pavement performance curve that shows slow and linear deterioration at the initial phases of pavement life, but accelerated rates of deterioration as the pavement advances in age subsequent to relatively ‘‘minor’’ maintenance such as crack sealing and shallow patching. As the level of pavement maintenance increases, the deterioration curve takes on increasingly positive gradients.

Deterioration rate reduction due to a specific maintenance treatment or specific combinations thereof, is best determined at the time when the pavement received treatment. A minimum of three data points in time corresponding to two monitoring periods is needed for DRR computation.

5. Derivation of Effectiveness Measures Formulas

In this paper, schematic hypothetical condition–time pattern was used to reflect the effect of maintenance, for successive maintenance alternatives at relative timing scenarios. The slopes of the condition trend line before and after maintenance, among other considerations, enabled the derivation of expressions for each measure of maintenance effectiveness. Thereafter, formulas are derived for the computation of each of the above mentioned three measures of maintenance effectiveness as discussed hereinafter.

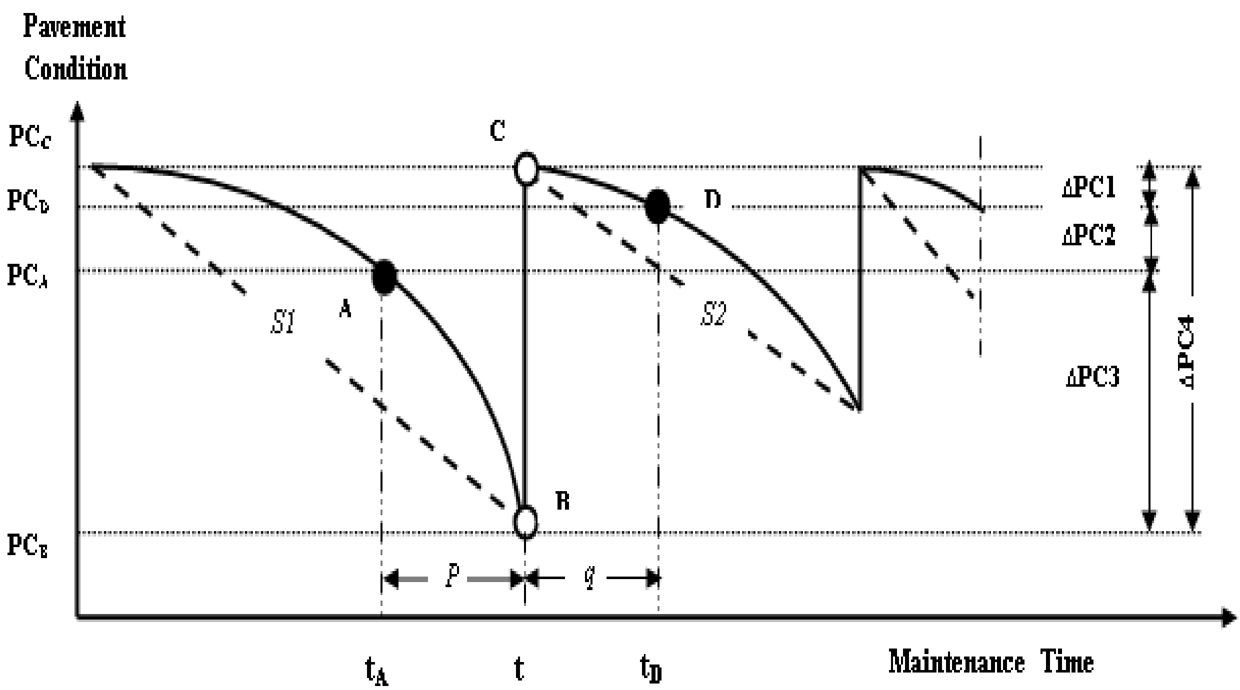

Figure1: effect of maintenance application on the pavement deterioration with time

Where;
A: Point of deterioration curve at a period p before Maintenance
B: Point of deterioration curve just before the execution of maintenance
C: A virtual point representing pavement condition just after maintenance
D: Point of deterioration curve at a period q after Maintenance
PC_C, PC_D, PC_A, PC_B ***are the levels of deterioration that correspond to the above points***
S_1 **:** ***Slope of the deterioration curve before maintenance.***
S_2 **:** ***Slope of the deterioration curve after maintenance.***
k : Ratio of slope before maintenance to slope after maintenance = s_2/s_1
$\Delta PC1$: = ***Deterioration reduction level***
$= (PC_C – PC_D)$
$\Delta PC2$: = ***Deterioration reduction level***
$= (PC_D – PC_A)$
$\Delta PC3$: = ***Deterioration reduction level***
$= (PC_A – PC_B)$
$\Delta PC4$: = ***Performance jump***
$= (PC_C – PC_B)$

5.1 Performance Jump (PJ)

PJ due to maintenance at time "t";

$$PJ = \Delta PC4 = PC_C - PC_B$$

But,

$$PC_C = PC_D + S2*q = PC_D + (k*S1)*q$$

So,

$$PJ = [PC_D + (k*S1)*q] - PC_B = PC_D + [k*\{(PC_A - PC_B)/p\}*q] - PC_B = PC_D + (k*q/p)[PC_A - PC_B] - PC_B \quad (2)$$

5.2 Deterioration Reduction Level (DRL)

Deterioration reduction level represented by the subsequent change in deterioration due to maintenance at year "t" which can be represented as follow;

DRL is defined as the difference in deterioration at specified time say, 1 year before maintenance A, and another specified time after maintenance D, as represented by ΔPC4 in Figure (1)

$$DRL = PC_D - PC_A \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

5.3 Deterioration Reduction Rate (DRR)

Deterioration reduction rate due to maintenance at year "t" represented by the reduced reduction rate value after maintenance than it before maintenance as follow;

$$DRR = [(PC_A – PC_B)/(t-t_A)] – [(PC_C-PC_D)/(t_D-t)] = [(PC_A – PC_B)/p]-[(PC_C-PC_D)/q] \quad (4)$$

Where, *P & q* = 1 in case of using deterioration measurement at 1 year before maintenance and another one year after maintenance. In this case, the percentage of DRR is given by;

$$DRR = [(PC_A – PC_B) - (PC_C-PC_D)] / (PC_A – PC_B) \quad (5)$$

5.4 Relationships between the three Maintenance Effectiveness Measures

From the above Equations 1&2, we can get the relation between PJ and DRR as follow;

$$PJ=DRL+PC_A+(k^* q/p)[PC_A - PC_B] - PC_B$$
$$= DRL+(PC_A- PC_B)[1+(k^* q/p)] \quad (6)$$

The relation between PJ and DRR from Equations 3&1 is as follow;

From Eq. 3;

$$(PC_A – PC_B)/ p = DRR + (PC_C-PC_D)/q$$

By using Eq.1;

$$PJ= PC_D + (k.q/p)[PC_A - PC_B] - PC_B$$
$$= PC_D+(k.q)[DRR+(PC_C-PC_D)/q - PC_B$$
$$= PC_D+(k.q.DRR)+ k^*(PC_C-PC_D) - PC_B$$
$$= k.q (DRR)+PC_D-PC_B+k^*(PC_C-PC_D) \quad (7)$$

There is a correlation between DRL & DRR from Eq's 5&6 as follow;

$$DRL+(PC_A- PC_B)[1+(k^* q/p)] = k q (DRR) + PC_D - PC_B + k^*(PC_C-PC_D)$$
$$DRL =k q (DRR)+PC_D-PC_B+k^*(PC_C-PC_D)- (k q/p)[PC_A - PC_B] \quad (8)$$

This was done for four maintenance alternatives; surface treatment (***ST***), thin overlay (***TO***), thick overlay (***TkO***) and reconstruction (***REC***):

Table 1: Prediction of pavement condition for different maintenance alternatives

Year	Reconstruction (RC)	Surface Treatment (ST)	Thin Overlay (TO)	Thick Overlay (TKO)
1	99.6	98.7	99.3	99.5
2	98.8	96.2	98.1	98.5
3	97.8	93.1	96.6	97.2
4	96.5	89.4	94.7	95.7
5	95.2	85.2	92.7	94.0
6	93.6	80.5	90.3	92.1
7	92.0	75.4	87.8	90.1
8	90.2	70.0	85.1	87.9
9	88.3	64.2	82.3	85.5
10	86.3	58.1	79.2	83.0
11	84.2	51.6	76.0	80.4
12	82.0	44.9	72.7	77.7
13	79.7	37.8	69.2	74.9
14	77.4	30.5	65.6	71.9
15	74.9	23.0	61.8	68.8

Table (2) effectiveness measures values for consecutive of maintenance alternatives

Maintenance Alternatives	Year	PC_A	PC_B	PC_C	PC_D	PJ	DRL	DRR
Construction /ST.	13	82	79.7	100	98.7	20.3	16.7	0.43
Construction /Th. Ov.	17	72.3	69.7	100	99.3	30.3	27	0.73
Construction /Tk. Ov.	21	62.0	59.4	100	99.5	40.6	37.5	0.81
Tk.Ov/ST	11	83.0	80.4	100	98.7	19.6	15.7	0.50
Tk. Ov./Th. Ov.	16	68.7	65.8	100	99.3	34.2	30.6	0.76
Tk. Ov./Reconstruction	22	50.0	46.7	100	99.6	53.3	49.6	0.88
Tk. Ov./Tk. Ov.	19	59.3	56.2	100	99.5	43.8	40.2	0.84
Th. Ov./Th. Ov.	14	69.2	65.6	100	99.3	34.4	30.1	0.81

Table (3) effectiveness measures values for different maintenance alternatives

Maintenance Alternatives	PC_A	PC_B	PC_C	PC_D	PJ	DRL	DRR
Surface	77.5	65.4	100	98.7	34.6	21.2	0.893
Thin Overlay	65.4	51.7	100	99.3	48.3	33.9	0.949
Thick Overlay	51.7	36.5	100	99.5	63.5	47.8	0.967
Reconstruction	36.5	22.3	100	95.7	77.7	59.2	0.697

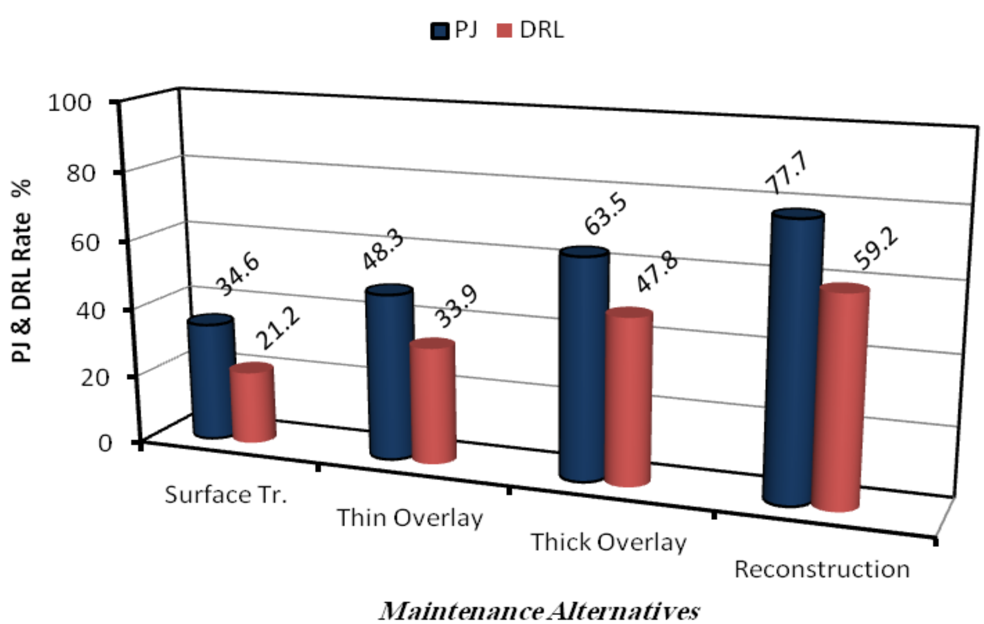

Figure 1: PJ & DRL for different maintenance alternatives

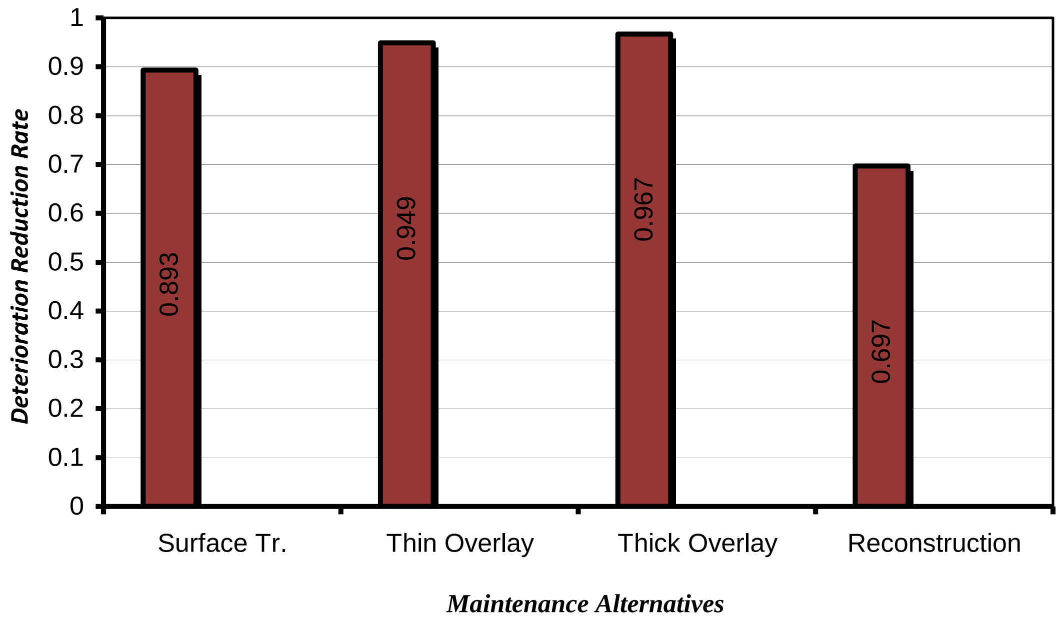

Figure 2: DRR for different maintenance alternatives

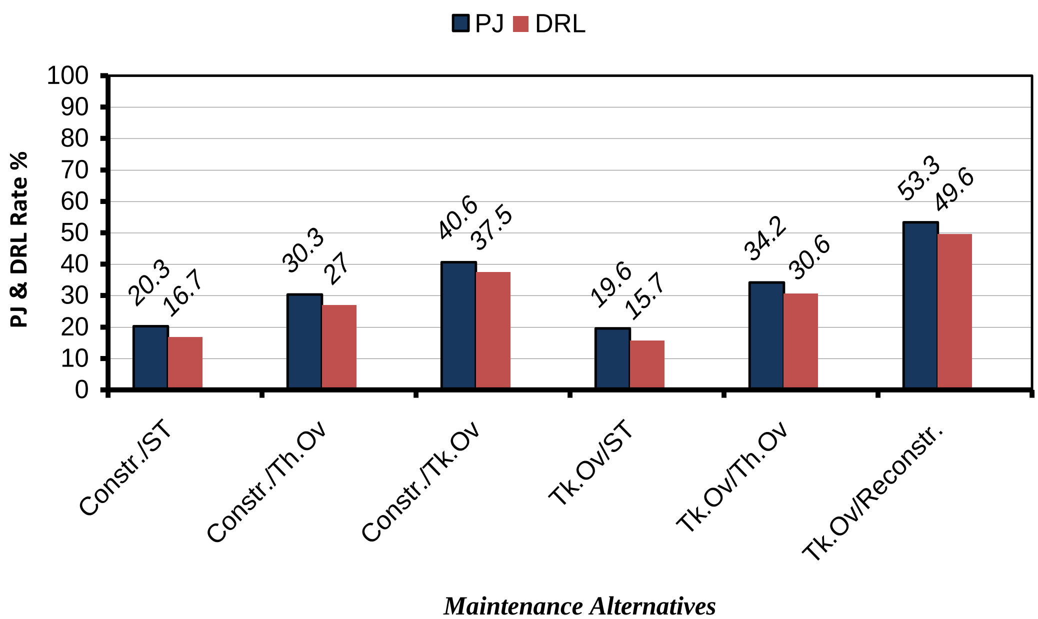

Figure 3: PJ &DRL for consecutive of different maintenance alternatives

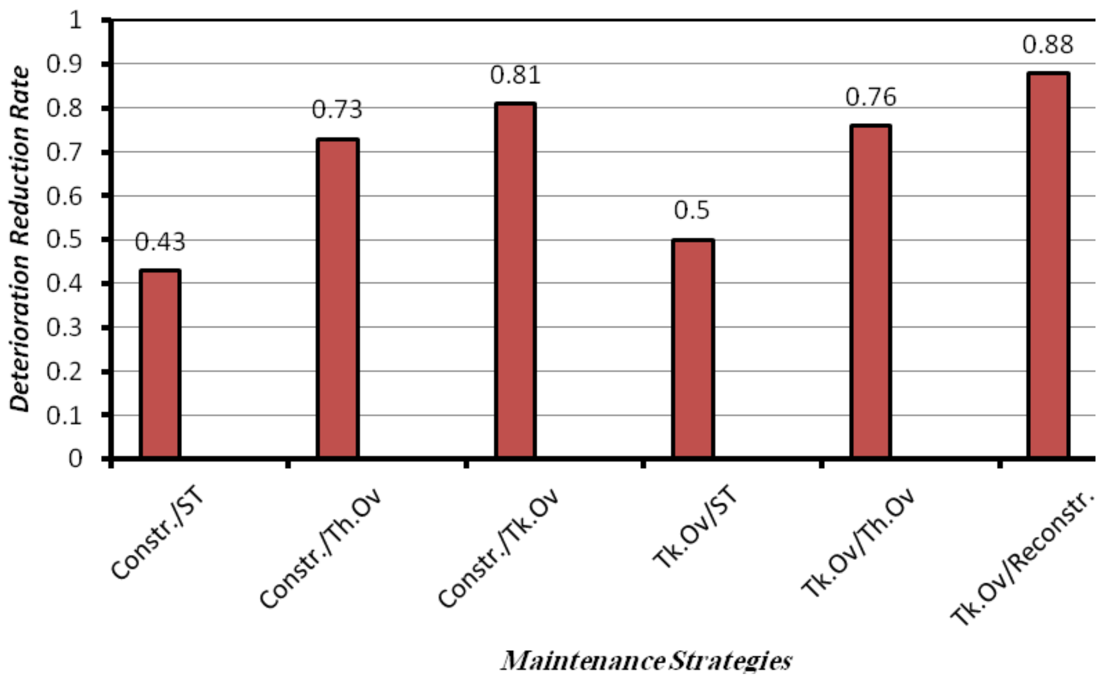

Figure 4: DRR for consecutive of different maintenance alternatives

6. Summary and Conclusions

This paper concerned with the measures that can be used to evaluate the effectiveness of pavement maintenance techniques. Three measures were used; deterioration reduction level (DRL), performance jump (PJ), and deterioration reduction rate (DRR). The method of computation and equivalent terms identification were discussed for each measure. Based on the relations between the concerned variables, mathematical formulas have derived that can be used to compute each measure of effectiveness to define the effects of each measure for different maintenance techniques. With these measures, values of the response variable can be computed and modeled as a function of maintenance treatment. Also, relationships between each pair of the three measures have been derived. Finally, representative data was used as an application case for different maintenance alternatives to define the effect of each measure.

It noticed from Figure (1) that reconstruction have higher PJ & DRL than other maintenance alternatives while it has the lowest DRR as defined from Figure (2). Also, surface treatments have the lowest PJ & DRL from Figure (1), while thick overlay have the highest DRR as per Figure (2). It concluded from Figures (3&4) that the best successive maintenance alternatives, based on the above three effectiveness measurements, are ranked as; thick overlay/Rec., const./thick overlay, thick overlay/thin overlay, constr./thin overlay, thick overlay/surface treatment and construction/surface treatment respectively.

The paper concluded that any of the above three evaluation measures could be used in maintenance effectiveness evaluation. The paper provides three basics for an appropriate evaluation measure of maintenance effectiveness as a main stage of pavement maintenance management.

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