RESEARCH NOTE

PREDICTION OF THE PAVEMENT CONDITION FOR URBAN ROADWAY A TEHRAN CASE STUDY

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Abstract This report is the result of a research project on a pavement management system that was preformed by the Transportation Division of Iran University of Science and Technology. Information used in the project was collected from 20 zones of the Tehran Municipality. Any maintenance and repair system for roads is normally compared of a number of general and coordinated activities in conjunction with programming, designing, construction, maintenance, evaluation, and research on road pavement. Prediction of pavement condition is one of the most important parts of such system. Prediction models have their application at the network level as well as project level activities. At the network level it is used in predicting the condition for budget planning. While in project level it is used in economical analysis. Many factors have been used to determine the pavement condition. These factors are the design life of the pavement, loading, climatic condition, and the type of roadway. In order to plan for future improvements, you need to predict the future condition of the pavement. In this paper, factors affecting the prediction of pavement condition are discussed. A model is developed exclusively for Tehran, based on the distress data collected of pavement condition.

Key Words Pavement, Road Maintenance, Pavement Condition, Prediction Model

چکیده گزارش حاضر حاصل یک طرح تحقیقاتی بر روی سیستم مدیریت روسازی است که توسط گروه راه و ترابری دانشگاه علم و صنعت ایران به انجام رسیده است. اطلاعات بکار رفته در این طرح از سطح مناطق ۲۰ گانه شهرداری تهران جمع آوری شده است. هر نظام تعمیر و نگهداری معابر معمولاً بر سنجش تعدادی از فعالیتهای عمومی و هم پایه در ارتباط با برنامه ریزی ، طراحی ، ساخت ، نگهداری ، ارزیابی و تحقیق بر روی روسازی مبتنی است. پیش بینی وضعیت روسازی یکی از مهمترین ارکان چنین نظامی می باشد. استفاده از مدلهای پیش بینی در رده های تصمیم گیری و همچنین عملیاتی کاربرد دارد. در رده تصمیم گیری از پیش بینی وضعیت به منظور برآورد بودجه استفاده می شود. در عین حال در رده عملیاتی استفاده از آن برای تحلیلهای اقتصادی متداول است. عوامل بسیاری در تعیین وضعیت روسازی کاربرد دارند. این عوامل عبارتند از عمر طرح روسازی ، بارگذاری ، شرا یط آب و هوایی و رده بندی معبر. برنامه ریزی برای توسعه آینده مستلزم پیش بینی وضعیت آتی روسازی می باشد. در مقاله حاضر عوامل مؤثر بر پیش بینی وضعیت روسازی مورد بررسی قرار گرفته و یک مدل بر اساس اطلاعات جمع آوری شده از وضعیت روسازی، بصورت اختصاصی برای تهران بسط داده شده است.

1. INTRODUCTION

This report is the result of a project that was undertaken as part of a research project to develop a decision support system for Pavement management in Iran and was performed by the transportation Division of Iran University of Science and Technology. Data and information used in this research was collected from all 20 district of the Tehran Municipality.

In order to manage pavements and logically make decisions about roadways, a pavement management system is required. These systems predict any pavement deterioration by the use of a prediction model. This research was undertaken to suggest a model that would best fit the urban needs and characters of the streets in Tehran. Pavement Condition Index (PCI) and two types of general models are developed in Tehran.

2. PAVEMENT CONDITION INDEX (PCI)

An important feature of a pavement management system (PMS) is the ability both to determine the current condition of a pavement network and to predict its future condition. Roadway pavement condition is among the most important parameters of a pavement maintenance management system. The pavement deterioration rate needs to be determined. Researchers are always looking to find a method which according to a specified criteria, that enable them to investigate the road pavement condition, and would allow them to plan the repair and maintenance activities in a logical manner where economics and budget constraints are accounted for. In order to report the results of pavement investigation, using numbers and figures, so that they could be used in relation to repair, research, and budgeting activities, PCI must be specified to measures destruction or deterioration intensity. Observing and determining different types of roadway deterioration can evaluate factors affecting PCI.

The PCI is a numerical index, ranging from 0 to 100, from failed to an excellent condition, which rates the condition of a pavement from a service point of view and is related to the pavement distress as is obtained by measuring pavement distress.

Table 1 shows pavement condition description in relation to PCI. In this scheme, 100 show that the road condition is excellent while zero shows an intensive destruction and chaotic and irregular condition of the roadway surface. PCI is determined by measuring different types of roadway pavement distress signs.

3. IMPORTANT FACTORS THAT AFFECT PCI

There are many different factors that can have an effect on pavement condition. Such factors are; age

TABLE 1. Pavement Condition Index, PCI [9].

PCI	Condition Rating	Pavement Condition Description
100-85	1	Excellent
85-70	2	Very Good
70-55	3	Good
55-40	4	Acceptable
40-25	5	Deteriorated
25-10	6	Not acceptable
10-0	7	Failed

TABLE 2. Classification of Flexible Pavement According to Age.

Asphalt Pavement	
Time (years)	Classification
Less Than 5	Newly constructed
5-10	Fairly New
10-15	Intermediate
15-20	Old
More Than 20	Very Old

of the pavement, roadway hierarchy, traffic loading (equivalent to single axle load), weather conditions (environment), initial design and construction, design life and maintenance programs (based on past maintenance procedures). Each of these factors is examined as follows:

3.1. Pavement Age

Pavement condition directly depends on the age of pavement, thus, as age of pavement increases, the PCI for that pavement is reduced. Table 2 shows classification of flexible pavements according to the age of the pavement.

The results in this study, however, indicated a rapid drop in pavement condition immediately during the first year of its operation for both overlay and new reconstructed pavement. Tehran Municipality is studying this problem. In place the Municipality using special recycling equipment to minimize human errors is using recycling recently. Pavements in Tehran reach an unacceptable

TABLE 3. The Effect of the Class of the Roadway on Predicted PCI.

Road Type	Coefficient (X1)
Freeway	1.0
Expressway	1.0
Arterial I	0.8
Arterial II	0.75
Collector	0.6
Local	0.5

TABLE 4. Determination of ESAL for Use in the Model.

ADT	Heavy Vehicles Percentage	ESAL
More Than 5,000 Max. 7,000	0 5 10	51 (71) 1679 (2351) 3207 (4954)
1,500-5,000 Max. 4,500	0 5 10	15 (46) 503 (1511) 992 (2977)
500-1,500 Max. 1,000	0 5 10	5(10) 168(336) 330 (661)
Less Than 500 Max. 400	0 5 10	(4) (134) (264)

TABLE 5. Relationship Between PLE and ESALs.

PLE	ESAL
1	Less Than 4
0.999	4-10
0.998	10-50
0.989	50-160
0.964	160-500
0.89	500-15,00
0.708	1,500-3,000
0.5	More Than 3,000

condition at their intermediate age, as classified utilizing the results of libratory testing on the pavement age and common linear methods in Table 2, even with normal routine maintenance. Areas enhancement of pavement life was designed, construction methods, and maintenance practices. For developing a model, pavement age was sought to be the most important factor since weather conditions and traffic loads would show their affect on the pavement over time.

3.2. Road Hierarchy Class Depending on the existing and projected traffic volumes and loads carried by different types of roadways, the pavement design including the thickness of different layers varies. Therefore it is clear that PCI will differ according to the roadway classification due to the different traffic volume and mix on each class. Tehran's urban network is divided into the following classification groups: Freeway (Azad Rah), Expressway (Bozorg Rah), and Arterial I (Shariani Asli), Arterial II (Shariani Faree), Collector (Jam Konnandeh), Local (Mahalli). The coefficient X1 is a number less than 1 and is determined based on the traffic load and speed from the proper graphs. Table 3 shows the effect of class of road on the predicted PCI in the form of coefficient X1.

3.3. Loading Factor As the traffic loading on a pavement increases, so will the level of pavement deterioration translate into lower PCI. Loading is handled using the equivalent single axle loads (ESAL).

In order to determine the ESAL, hourly traffic volumes of a given lane and percentage of heavy vehicles must be specified. Table 4 shows an example on obtaining ESAL values suitable to be used in the proposed prediction model. These were calculated based on Tehran's typical conditions using instruction in the Reference 7. The amounts in the parenthesis in this table indicate the maximum possible value for that specific range of ADT and percent of heavy vehicles.

A Pavement Loading Equivalent (PLE) is developed based on the ESAL. This PLE will manifest the effect of ESALs on PCI in form of a coefficient. The relation between the PLE and ESAL are suggested as shown in the following equation, which was used in the deterioration model as described later in this paper.

$$PLE = e^{-2.3\times10^{-4}} (ESAL) \quad (1)$$

The PLE values are grouped in Table 5 according to the ESAL's. For roads with less traffic volume and loading PLE=1, and for roads with an average traffic volume and loading PLE = 0.7 while for roads with heavy traffic volume and loading PLE= 0.5.

3.4. Sweater Condition Environnementales conditions affect pavement condition. Moisture in particular adversely affects pavement performance and causes the pavement to deteriorate faster. Moisture not only affects pavement ingredients but can also Effect by causing physical damage.

In colder climates freezing may possibly lead to deterioration through cracks. Freeze-thaw cycle damages pavement integrity. An increase in the moisture content in pavement materials may lead to faster pavement deterioration. The prediction model, therefore, has to consider and account for adverse weather conditions. Since climatic diversity within Tehran is non-existent therefore this factor was considered a constant and not modeled.

3.5. Design Standards The material and workmanship used in building a roadway will affect it useful life. In addition, if the assumptions made during design are not correct then they may lead to an under designed pavement. For instance if traffic growth used in the initial design calculations are less than the traffic volume which actually uses the road, then the pavement will deteriorate at a faster pace.

3.6. Maintenance Programs Under equal conditions, the PCI will be higher for those pavements that are maintained properly.

3.7. Techniques for Developing Prediction Models The following are some of the most popular pavement condition prediction models reported in the literature.

a. Regression Models:

$$y = \alpha + \beta X_i \text{ or } (y = \beta_0 + \beta_{1x_1} + ... + \beta_{nx_n}) \quad (2)$$

b. Multi Equation:

$$y = a + \sum_i \beta_i X^i \quad (3)$$

c. Inverse Regression:

$$y = 1/(\alpha + \beta x) \quad (4)$$

c. Marcov Distribution (used to calculate a probability matrix):

$$y = 100 - \alpha e^{\beta x} \quad (5)$$

3.8. Transition of Condition PCI is divided into ten ranges and each range is assigned a Simple Condition Rating (SCR) which is a number from 1 to 10 as shown in Table 6.

Pavement deteriorates in time and its condition changes. Table 7 shows a schematic presentation of how condition can vary over time for two different deterioration schemes. The aim is to predict the most probable condition that will occur in the year directing following any given year according to the prevailing conditions of the given year.

There are two reasons for using SCR:

1) They represent boundary conditions and do not overemphasize the PCI that may give the decision maker a false sense of accuracy due to PCI's wide range. SCR therefore groups together close values and the decision maker has to contemplate the values before making any decisions.

2) A SCR prediction table gives the decision maker, who is not normally an engineer and is reluctant to use mathematical tools, a comfortable, "user friendly" look. The decision maker easily understands the transition from year to year which may happen in pavement condition.

4.THE FORECASTING MODELS USED FOR TEHRAN

A unique top-down approach was used to develop two models for pavement condition in Tehran.

1- Observed pavement condition index is used to calculate Simple condition Ratings.

2- Age of pavement is plotted against SCR.

3- A basic model is defined that according to the engineers may be the basis for the final model.

4- Trial and error loop and much iteration are used to change the model parameters and constant values in order to reach a final solution that agreed may produce results that

TABLE 6. Condition Ranges for PCI.

PCI	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
SCR	1	2	3	4	5	6	7	8	9	10

TABLE 7. A schematic Presentation of Changing Condition of Pavement (Two Deterioration Schemes).

Year	SCR Change From Condition to Condition, From Year To Year									
1	1	2	3	4	5	6	7	8	9	10
2	1	2	3	4	5	6	7	8	9	10
3	1	2	3	4	5	6	7	8	9	10
4	1	2	3	4	5	6	7	8	9	10
5	1	2	3	4	5	6	7	8	9	10
6	1	2	3	4	5	6	7	8	9	10
7	1	2	3	4	5	6	7	8	9	10
8	1	2	3	4	5	6	7	8	9	10
9	1	2	3	4	5	6	7	8	9	10
10	1	2	3	4	5	6	7	8	9	10
11	1	2	3	4	5	6	7	8	9	10
12	1	2	3	4	5	6	7	8	9	10
13	1	2	3	4	5	6	7	8	9	10
14	1	2	3	4	5	6	7	8	9	10
15	1	2	3	4	5	6	7	8	9	10

TABLE 8. Observed Values for Arterial I Type Streets Reported By District Number.

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**AVG**
1	*	98	86	93	*	98	*	*	*	*	*	*	*	*	*	*	*	90	93	*	93
2	88	*	*	*	*	*	85	84	85	85	*	*	83	*	87	*	*	*	*	*	85
3	82	78	*	84	*	82	*	*	*	*	84	84	*	*	*	*	82	77	78	85	82
4	*	*	*	*	79	79	77	77	68	88	*	87	82	*	*	*	80	*	*	84	80
5	75	74	76	78	74	77	75	74	74	*	*	*	73	72	74	*	76	75	71	70	74
6	89	72	72	76	74	76	76	73	69	75	73	76	77	70	69	*	77	*	*	*	75
7	68	67	68	70	70	44	67	68	68	69	69	78	68	69	67	*	*	*	*	*	67
8	65	67	*	68	64	78	69	67	66	66	68	67	63	79	*	63	*	60	71	*	68
9	65	65	*	65	*	*	65	62	61	42	56	63	64	59	*	43	61	63	64	*	60
10	60	*	52	*	*	*	*	60	60	56	*	*	61	61	62	*	*	62	66	58	60
11	59	*	55	*	*	*	*	*	*	57	*	*	54	54	55	*	53	*	52	53	55
12	*	49	*	49	48	46	52	*	49	*	*	*	*	*	*	47	*	*	51	*	49
13	20	46	48	50	51	47	32	*	*	*	*	46	49	46	*	47	*	*	*	*	44
14	*	*	41	43	44	*	*	39	*	41	*	*	41	42	43	41	*	*	42	40	42
15	41	*	53	40	39	*	50	*	*	*	*	*	40	38	39	42	*	38	*	39	42

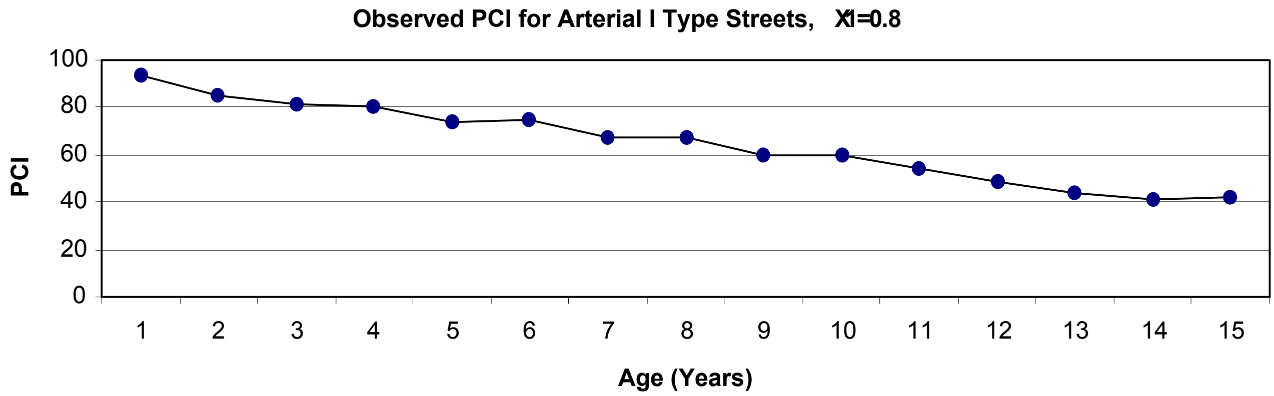

Figure 1. Average values of observed PCIs versus age of pavement.

are close to what happens in reality. All changes are done manually through careful thinking.

5- SCRs Obtained by as a result of using the model is compared to those calculated through data collection.

6- Slight adjustments are made and the results are compared again.

Average PCI values are used. Anytime there was an uncertainty with the data collected, that data point was eliminated. Most common uncertainties were associated with the pavement age and past maintenance practices. Municipality of Tehran Districts each has a district mayor and operates independently.

This has caused different pavement practices and contractors to emerge in each district. Two models are developed in this manner; one is based on type of road and the other one is based on loading features. The PCI data for Arterial I type streets are shown on Table 8 for each district. No data was available for urban freeways and expressways, which are, build and maintained by the Municipality of Tehran and not the districts.

Figure 1 shows the plot of the average values of observed PCI versus age of the pavement, which is based on values on Table 8.

A consensus among the engineering team was sought as a substitute for mathematical curve fitting. This decision was based on the intuition that (1) Manual data collection was not able to rate all the pavement sections in a uniform manner since several data collection teams were used, (2) members of data collection teams tended to rate pavement differently later in the project compared to their early ratings, (3) data collection teams tended to impose their opinions on the numbers they assigned to certain type of conditions that would be different from team to team 4). Tehran's street network has developed so rapidly in the past 12 years that has caused considerable traffic generation and considerable shift in traffic stream movements. Therefore, the utilization of streets by traffic streams has been changing and has not followed a steady pattern 5). The four above mentioned reasons cause variation in the data points that a mathematical curve-fitting scheme may not be able to account for without considerable use of theories and statistical techniques, many of which require considerable historical data that was missing here. Whenever a consensus among the project team, to agree on a curve that would resemble

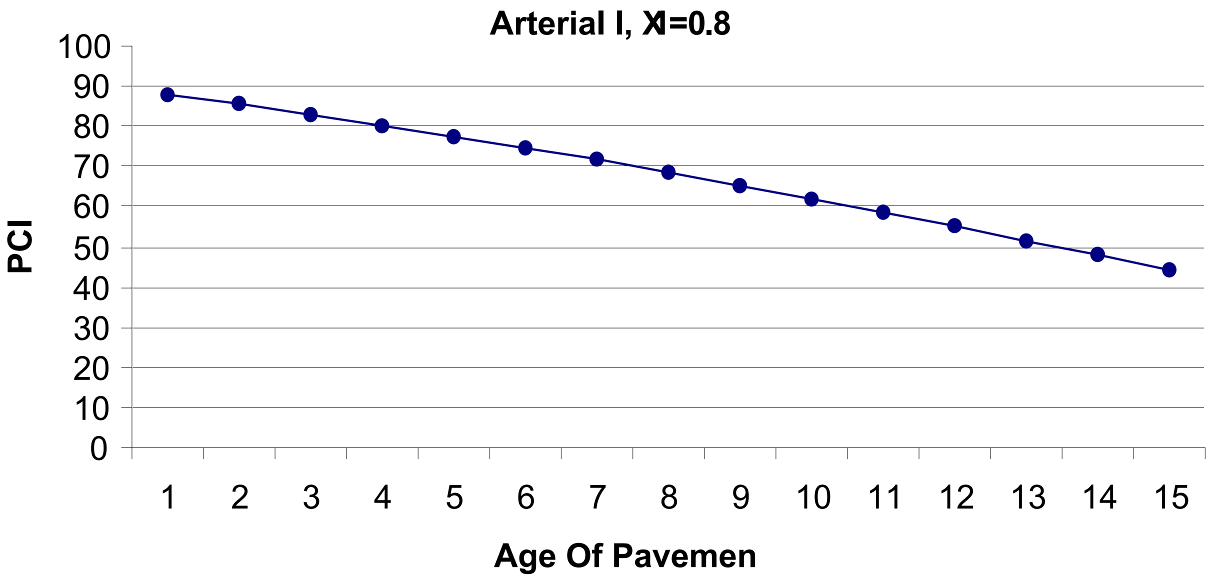

Figure 2. Deterioration prediction for Type I arterial streets using the first model.

TABLE 9. Predicted SCR Based on the First Model for Type I Arterial Streets X1 = 0.8.

PCI		87	85	82	80	77	74	71	68	65	62	58	55	51	47	44
Age	X2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SCR		8	8	8	8	7	7	7	6	6	6	5	5	5	4	4

theoretical deterioration curves was sought as an alternative.

4.1. Road Hierarchy Model

$$PCI = 100\beta_1[2 - 0.08X_1X_2 - e^{-0.05X_1X_2}] \quad (6)$$

where

PCI= Pavement Condition Index
β_1 = Past maintenance coefficient
X_1 = Type of road coefficient
X_2 = Road age coefficient
Note: β_1 = 1 for new pavement and β_1 = 0.9 for older pavement

For type I arterial streets the model would result in a deterioration prediction curve by equating X_1 = 1 as shown in Figure 2. The values obtained from this model are used to obtain SCR, which are shown in Table 9. The SCR values obtained here give the decision maker a picture of what may take place in the future from a pavement point of view.

4.2. Load Factor Model This model was developed to use when loading conditions can be predicted. Owing to the rapid growth of Tehran traffic and aggressive road construction activities, where even within the existing street network several expressways are under construction and access points are provided at places where such access did not exist, traffic loads can not be predicted with any degree of certainty at this point. Many attempts have been made to model traffic predictions but due to instability of laws and regulations this has not been successful.

Therefore it is not suggested to use the second model until such time that the future traffic volume and mix can reasonably be predicted.

$$PCI = 100\beta_1[2 - 0.04(\frac{X_2}{PLE}) - e^{0.025(X_2 / PLE)}] \quad (7)$$

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