Journal of Highway and Transportation Research and Development

Home page: www.sciopen.com/journal/2095-6215

Pavement damage decay performance of ordinary national and provincial trunk lines

Jianguo Rong[1**], Xiaodong Sha[2], Zongjun Pan[1], Hai Zhang[1]

1. *Roadmaint Co., Ltd., Beijing 100095, China*
2. *Highway Development Center of Jiangsu Provincial Department of Transportation, Nanjing, Jiangsu 210004, China*

Abstract: To overcome the limitations inherent in traditional road network-level models for predicting pavement damage decay on ordinary national and provincial trunk lines, this investigation draws on comprehensive detection and evaluation data from A province in eastern China, spanning from 2014 to 2020. Utilizing advanced data classification and statistical induction techniques, the study delves into the decay performance of the Pavement Condition Index (PCI). The analysis reveals that enhancing the thickness of the surface layer is a critical factor in decelerating PCI attenuation. Road sections that are 3 years old experience a pronounced decline in PCI, necessitating a focus on minor repair and maintenance with preventive maintenance as a secondary measure. For sections aged 6 to 7 years, the PCI decline rate is notably high, advocating for a strategy that prioritizes preventive maintenance and includes minor repair and maintenance. Road sections older than 8 years enter a phase of rapid PCI decline, at which point comprehensive repair and maintenance become imperative. The 'predictionworksheet' model, characterized by its low residual sum of squares (RSS) and minimal absolute and relative errors, has been identified as an effective tool for predicting PCI attenuation on ordinary national and provincial trunk lines in A province. This model exhibits strong applicability and accuracy in forecasting the damage and decay trends of road network-level trunk roads, providing a solid foundation for informed decision-making in road maintenance and management.

Keywords: Road engineering; Pavement performance decay; Prediction worksheet; National and provincial ordinary trunk lines; Scientific decision-making.

1 Introduction

Since the "14th Five-Year Plan", building a sound scientific decision-making system for road maintenance has become a common demand for maintenance management agencies at all levels of the industry.

Ministry of Transport, "The 14th Five-Year Plan Road Maintenance Management Development Outline", clearly put forward specific requirements to strengthen the maintenance of scientific decision-making: annual monitoring of the technical condition of the national highway network, strengthening the analysis of various types of testing and monitoring data for decision-making, the formation of data-driven maintenance of scientific decision-making mechanism. Strengthen the application of scientific decision-making results, build a national highway maintenance project database, and achieve dynamic management.

"The "14 the Five-Year" Highway Development Plan of A Province" also clearly stated that the existing system's basis is more mature and stereotyped, based on advanced scientific and technological innovation to build a digital-driven scientific conservation management system. Optimize the decision analysis model, build a visualized and simulable big maintenance data scientific decision-making platform for total asset management, and realize scientific reserve and dynamic management of maintenance engineering projects.

Because pavement performance directly affects the pavement maintenance countermeasures and the investment of maintenance funds, the construction of a sound scientific decision-making system for road maintenance requires the study of pavement performance decay law and evolution prediction, which is not only the basis for pavement maintenance countermeasures and economic analysis but also a necessary condition for the development of maintenance planning.

2 Pavement performance prediction methods

The earliest pavement prediction models did not have mathematical formulas. They were based mainly on the experience of managers in determining the pavement condition until the early 1960s when Carey and Irick [1] first proposed a theory related to pavement performance prediction, followed by different pavement performance prediction models in various countries.

Various pavement performance prediction models based on different theories exist at home and abroad, which can be divided into probabilistic and deterministic prediction models. The probabilistic type gives the prediction results generally for the distribution of

Received: 20 January 2024; **Revised:** 14 August 2024; **Accepted:** 25 September 2024
** *Corresponding author*: Rongjiang@roadmaint.com
DOI: 10.26599/HTRD.2025.9480049

Translated from *Journal of Highway and Transportation Research and Development* (Chinese, ISSN1002-0268), 2025, 42(2): 52−60.

RESEARCH INSTITUTE OF HIGHWAY MINISTRY OF TRANSPORT | SciOpen

road condition values, probabilistic is the prediction of different state distributions of various indicators, and the probabilistic models are the remaining life curve model, Markov model etc cetera [2]. Alessandra et al [3]. constructed a fuzzy neural prediction model by learning neural networks and fuzzy mathematics and predicting the performance of flexible pavements based on the advantages of each of them. Chen [4] wrote a data processing program using algorithms related to data processing and built an S-type pavement usage performance prediction model based on the computed data.

In addition, in recent years, prediction models such as fuzzy evaluation, grey systems, genetic algorithms, artificial neural networks, Marxian distance and their combinations have emerged [5]. Granger and Bates [6] found that many scholars are researching single-indicator prediction models. The two proposed the concept of collaborative forecasting, where individual forecasting is performed first. Then the combined forecasting model is obtained by weighting the correlation coefficients of the combined forecasts.

The deterministic type gives a definite predicted value of road conditions given the corresponding conditions and can be used for pavement performance index or life cycle prediction. The common ones are mechanistic prediction models, empirical regression prediction models and mechanistic-empirical prediction models. On the foreign side, Wang [7] studied the problem of skid resistance evaluation of asphalt pavement for preventive maintenance; Dong [8] studied the problem of rutting resistance evaluation of asphalt pavement for important roads; Mensching [9] studied the prediction model of asphalt pavement overlay life; Evdorides [10] and others established the prediction model of asphalt pavement performance, pavement diseases.

Domestically, Wu et al [11]. proposed a method for predicting the service performance of asphalt pavements based on the time series analysis method; Zhang et al [12]. introduced the grey system theory to expand the pavement service performance prediction; Zhang et al. [13] proposed a performance prediction model of asphalt pavement based on LSTM-BPNN neural network; Jianguo Rong and Haoyan Wang [14] proposed a pavement damage and levelness logarithmic decay model; Cao [15] and Others also studied the problems related to pavement performance and life cycle cost. Additional scholarly works on the prediction of asphalt pavement performance are documented in Refs. [16-18].

All kinds of prediction models have advantages and disadvantages and applicability conditions. The primary data sources used in prediction models are from specific project sections, which are generally not applicable to regional road networks. Therefore, it is essential to construct a perfect scientific decision-making system for highway maintenance, build a reasonable provincial highway maintenance project database, realize dynamic management, and study the decay law of pavement performance of regional road networks.

In this paper, based on the massive inspection and assessment data (mainly asphalt pavement data, accounting for more than 99% of the road network data), combined with multidimensional basic data and annual maintenance statistics for many years, the correlation between the data was deeply dug, and the daily maintenance sections were identified, laying a solid data foundation for the subsequent study of pavement damage decay law; then, based on the multi-year research and analysis work on the general trunk highway in province A, multiple factors influencing PCI decay were preferentially selected from two dimensions: internal factors and external factors, combined with the analysis of the PCI decay values of the overlapping sections in the daily maintenance sections for many years, the decay law of PCI was studied and the main influencing factors of PCI were determined; the "prediction worksheet", prediction function trend, ARIMA model and quadratic polynomial methods to predict the PCI decay value in 2020-2021, and determine the decay model of PCI.

3 Determine the daily maintenance sections

To study the road condition decay law, we first need to determine the daily maintenance sections. The conventional method is to eliminate the rehabilitation and preventive maintenance sections from the road network. This method is time-consuming and error-prone.

This paper is innovative for determining the method of daily maintenance sections: the overlapping sections detected in two adjacent years are put together cumulatively by year to find out the two-year PCI difference of each overlapping section, combined with the annual report data and cumulative distribution map to determine the daily maintenance sections.

Specific approach: the 2014-2020 inspection and evaluation data of ordinary national and provincial trunk lines in province A were selected for study and analysis. The overlapping sections of the adjacent two years were brought together and studied in accordance with the same attributes, with a total mileage of over 100,000 km. 84.3% of the overlapping sections accounted for the road network from 2014 to 2020. As shown in Table 1.

Table 1 Length and proportion of overlapped road sections, 2014-2020.

Years	Length of overlapped road sections (km)	Total annual inspection and evaluation mileage (km) (second year))	Percentage of overlapped road sections (%)
2014-2015	11 677.32	15 733.073	74.2
2015-2016	14 297.79	17 049.665	83.9
2016-2017	15 965.26	17 796.467	89.7
2017-2018	15 357.01	17 866.26	86.0
2018-2019	14 701.92	18 701.472	78.6
2019-2020	17 699.2	19 228.799	92.0
Total	89 698.51	106 375.736	84.3

Remark: The total mileage for the 2020 review and evaluation does not include data on overtaking lanes.

According to the annual report of road maintenance statistics for 2014-2020, the overall length of rehabilitated and preventive maintenance sections in Province A accounted for 25.5% in 2014-2020 (see Table 2). The percentage of routine maintenance road sections (i.e., no rehabilitation and preventive maintenance) is 74.5%. As shown in Fig. 1 and Table 3, the cumulative percentage of PCI dif-

Table 2 Length and proportion of repair maintenance and preventive maintenance of general national and provincial trunk lines in province A, 2014-2020.

Years	Length of repair maintenance and preventive maintenance (km)	Total maintenance mileage (km)	Proportion (%)
2014	1 710	10 092	16.9
2015	2 176	10 423	20.9
2016	1 071	10 745	10.0
2017	1 653	11 767	14.0
2018	3 211	12 152	26.4
2019	4 780	12 251	39.0
2020	5 828	12 571	46.4
合计	20 429	80 001	25.5

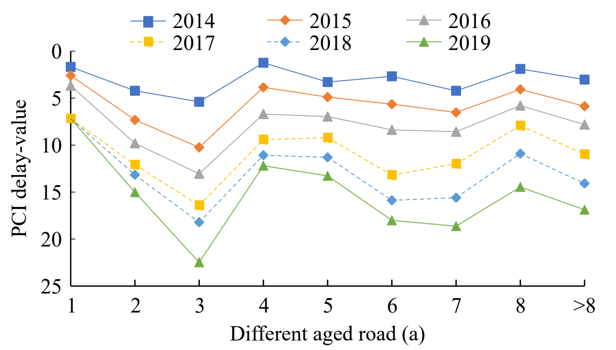

Fig. 1 PCI decline value distribution for different aged road section from 2014 to 2020 (packing diagram).

Table 3 Cumulative percentage of PCI difference in overlapping sections from 2014 to 2020.

PCI difference range	Number of road sections	Cumulative percentage (%)	PCI difference range	Number of road sections	Cumulative percentage (%)
70-80	4	100	0-1	11 217	73.88
60-70	12	100	−1-−0	11 407	61.51
50-60	16	99.98	−2-−1	10 365	48.93
40-50	64	99.96	−3-−2	8 324	37.5
30-40	196	99.89	−4-−3	6 520	28.32
20-30	652	99.68	−5-−4	4 922	21.13
19-20	151	98.96	−6-−5	3 580	15.71
18-19	171	98.79	−7-−6	2 543	11.76
17-18	194	98.6	−8-−7	1858	8.96
16-17	205	98.39	−9-−8	1 467	6.91
15-16	260	98.16	−10-−9	1 055	5.29
14-15	299	97.88	−11-−10	810	4.13
13-14	342	97.55	−12-−11	571	3.23
12-13	391	97.17	−13-−12	466	2.6
11-12	445	96.74	−14-−13	343	2.09
10-11	566	96.25	−15-−14	272	1.71
9-10	624	95.62	−16-−15	230	1.41
8-9	799	94.94	−17-−16	187	1.16
7-8	1 026	94.06	−18-−17	144	0.95
6-7	1 249	92.92	−19-−18	130	0.79
5-6	1 591	91.55	−20-−19	94	0.65
4-5	2 116	89.79	−30-−20	417	0.55
3-4	2 859	87.46	−40-−30	65	0.09
2-3	3 897	84.31	−50-−40	12	0.02
1-2	5 565	80.01	−60-−50	2	0.00

ference is 80.01 (%) when the PCI difference is 2 and below. Considering the variability of the data, the road sections with a PCI difference of 2 and below for two years were confirmed as routine maintenance road sections.

4 Pavement damage decay law analysis

4.1 Classification of influencing factors

In this paper, PCI, which has a significant influence on pavement performance, is used as the prediction index of the model. The factors affecting PCI are mainly divided into internal factors and external factors.

The internal factors mainly include pavement structure and material performance, while the external factors mainly include traffic load, environmental conditions, construction quality and maintenance level. According to the principle of "highlighting the key points and weakening the minor ones" and combining with the actual condition of the general national and provincial trunk lines in Province A, the internal factors (surface thickness and road age) and external factors (traffic volume and maintenance level) were selected for analysis. In order to compare the dimensions consistently, each factor is divided into three categories in the comparison process.

Internal factors include pavement thickness and road age. The thickness of the pavement surface of standard national trunk lines in A province is vast, ranging from 4 cm to 32 cm. According to the conventional classification principle, the thickness of the surface course is

divided into three categories: thin surface course (4 cm to 9 cm), medium surface course (10 cm to 20 cm) and thick surface course (21 cm to 32 cm). In terms of road age, the average national trunk lines in A province are calculated based on the year of construction, and their distribution range is 0-90, which is divided into less than 5 years, 5-8 years and more than 8 years according to the conventional classification of A province.

External factors include traffic volume and maintenance level. The traffic volume uses the "equivalent number" in the "Statistical Analysis Report of Highway Traffic Flow in Province A in 2014" - "Compilation of Traffic Volume Survey Information of General Trunk Roads in Province A in 2020". According to the principle of 3 : 4 : 3, light traffic, medium traffic and heavy traffic are determined. The maintenance level, with reference to the average annual decay value of PCI of daily maintenance sections from 2014 to 2020, and the smaller PCI decay value, the higher road condition management level is considered, and the 13 municipalities in province A are divided into three municipality clusters, each of which represents a category of maintenance management level, which are municipality cluster 1 > municipality cluster 2 > municipality cluster 3. As shown in Table 4.

A cluster of municipalities1 with a high level of conservation management, represented by municipality 12, municipality 03 and municipality 05, with typical practices such as：

(1) Municipality 12

For the restructuring of the maintenance of enterprise characteristics of the establishment of rules and regulations, the development of the introduction of the "city trunk highway maintenance management inspection and assessment and rewards and punishments" and other management measures, and strict assessment, rewarding the good and punishing the bad; minor maintenance of the implementation of two levels of quality assessment, in accordance with the "city and county management as one, bidding and consultation, dry and branch bundle" management model, the establishment of a Highway business centre, highway station two levels of road minor maintenance quality management assessment system.

(2) Municipality 03

a. Strict implementation of construction procedures. Construction, supervision and design are all tendered in accordance with the requirements. Through open bidding, the specialized service units are selected on the basis of merit, and performance assessment and credit evaluation are implemented. b. Quality control is kept to perfection. First, each process is reported and inspected on site in time, signed and accepted on site, and applied for government quality supervision in time. Secondly, the construction pursues refinement. c.

Table 4 Division table of maintenance management level of A province.

Municipality	Average annual attenuation value of PCI for daily maintenance sections							Maintenance management level division
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	Average value	
Municipality 02	1.01	2.29	1.56	1.87	1.53	1.71	1.66	Municipality cluster 1
Municipality 04	1.36	1.5	1.92	1.88	1.33	2.22	1.7	
Municipality 05	1.91	1.41	1.31	2.32	1.9	1.65	1.75	
Municipality 06	2.28	2.26	1.82	2.23	0.5	1.75	1.8	
Municipality 03	2.01	2.12	1.46	1.57	2.07	1.79	1.84	
Municipality 12	2.22	2.63	2.73	3.23	1.18	1.83	2.3	
Municipality 11	2.2	1.69	1.63	4.07	1.61	2.3	2.25	Municipality cluster 2
Municipality 01	2.22	2.32	3.04	5.63	2.58	3.3	3.18	
Municipality 10	2.95	3.17	2.81	3.02	4.24	2.92	3.18	
Municipality 09	5.02	3.92	1.83	2.84	3.76	4.29	3.61	Municipality cluster 3
Municipality 13	3.89	3.89	1.7	3.24	6.38	3.68	3.8	
Municipality 08	5.31	4.18	3.01	5.12	5.16	2.74	4.25	
Municipality 07	6.77	5.97	3.05	4.85	3.87	3.79	4.72	

Promote the application of new technology and new techniques.

(3) Municipality 05

a. Promote pavement recycling technology. For example, in the asphalt underlayer, all use plant mix hot regeneration technology, control blending 20% RAP. b. Adhere to the concept of scientific maintenance, stabilize the road condition and improve road quality.

Remark: Considering that the road condition of municipality 12 has been steadily at the top of the province in recent years, it is divided into municipality cluster 1.

4.2 Decay law analysis

The decay law of PCI for pavement damage was studied and analyzed by using the above four influencing factors, combined with the average annual decay values of PCI in different years from 2014 to 2020 for different influencing factors.

(1) With the increase of the surface course thickness, the average annual attenuation value of PCI decreases (2.99>2.93>2.35), which shows that increasing the surface course thickness can delay the attenuation of PCI to some extent, but thickening the surface course needs to increase the cost and should be considered comprehensively. As shown in Table 5.

(2) Road age, as can be seen from Table 6, the road age of 3 years of the road section PCI decline faster, need to give priority to strengthen the work of minor repairs and maintenance, with conditions appropriate to carry out preventive maintenance; road age of 6-7 years of the road section PCI decline rate is the second, it is appropriate to give priority to preventive maintenance, supplemented by minor maintenance work; road age of more than 8 years of the road section, PCI again entered a period of rapid decline, it is appropriate to implement repair maintenance.

(3) As can be seen from Table 7, the effect of traffic volume on the attenuation of PCI is not significant. From Table 8, it can be seen that 20.84% of the heavy traffic sections are concentrated in municipality cluster 1 (higher level of maintenance management), while 18.21% of the light traffic sections are concentrated in municipality cluster 3 (relatively low level of maintenance management). Municipalities with a higher level of maintenance management have guaranteed pavement quality and more timely pavement maintenance interventions, further delaying the trend of PCI decay. The analysis of the attenuation value of PCI under the influence of different levels of maintenance and management is shown in Table 9.

(4) The cluster of municipalities with a higher level of maintenance management has relatively timely daily maintenance and a

Table 5 Analysis of PCI attenuation value, influenced by the surface course.

Surface course type	Average annual attenuation value of PCI for daily maintenance sections						Average value	Standard deviation	Variable coefficient
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020			
Thin surface course	3.49	3.05	2.35	3.22	3.03	2.80	2.99	0.388	0.13
Medium surface course	2.62	3.03	2.28	3.60	3.16	2.87	2.93	0.455	0.16
Thick surface course	2.50	2.12	2.06	2.73	2.43	2.29	2.35	0.249	0.11

Table 6 Analysis of PCI attenuation value influenced by road age.

Road age	Average annual attenuation value of PCI for daily maintenance sections						Average value	Standard deviation	Variable coefficient
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020			
1-4Total	3.97	3.17	2.70	2.86	1.68	2.21	2.73	0.787	0.28
1 year	1.67	0.92	1.08	3.51	–	–	1.79	1.189	0.66
2 year	4.21	3.10	2.49	2.28	1.08	1.85	2.50	1.077	0.43
3 year	4.39	3.85	2.81	3.36	1.80	4.27	2.76	1.342	0.36
4 year	1.24	2.61	2.84	2.72	1.67	1.12	2.03	0.783	0.39
5-8**Total**	3.29	2.39	2.02	3.13	2.77	2.69	2.71	0.466	0.17
5 year	3.29	1.60	2.07	2.26	2.08	1.98	2.21	0.569	0.26
6 year	2.67	2.96	2.74	4.81	2.69	2.14	3.00	0.927	0.31
7 year	4.22	2.30	2.05	3.42	3.60	3.03	3.10	0.817	0.26
8 year	1.89	2.18	1.72	2.14	2.98	3.55	2.41	0.707	0.29
>8 years	3.02	2.83	1.96	3.15	3.12	2.79	2.81	0.444	0.16

Table 7 Analysis of PCI attenuation under the influence of traffic volume.

Traffic volume	Average annual attenuation value of PCI for daily maintenance sections						Average value	Standard deviation	Variable coefficient
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020			
Light traffic	3.68	3.38	2.12	4.11	4.45	3.78	3.59	0.805	0.22
Medium traffic	2.44	2.38	2.25	2.50	2.68	2.43	2.45	0.143	0.06
Heavy traffic	2.09	2.26	1.94	2.77	2.24	2.38	2.28	0.286	0.13

Table 8 Distribution of different traffic volumes in different municipalities.

Traffic volume Municipality cluster	Light traffic	Medium traffic	Heavy traffic	Total
Municipality cluster 1	7.85%	18.55%	20.84%	47.24%
Municipality cluster 2	5.86%	5.93%	6.59%	18.38%
Municipality cluster 3	18.21%	8.18%	7.99%	34.38%
Total	31.92%	32.66%	35.42%	100%

Table 9 Analysis of PCI attenuation under different maintenance management levels.

Maintenance management level	Average annual attenuation value of PCI for daily maintenance sections						Average value	Standard deviation	Variable coefficient
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020			
Municipality cluster 1	1.88	2.04	1.74	2.18	1.64	1.95	1.91	0.198	0.10
Municipality cluster 2	2.36	2.31	2.57	4.13	3.07	2.87	2.89	0.677	0.23
Municipality cluster 3	5.16	4.23	2.26	3.71	4.50	3.82	3.95	0.978	0.25

higher level of maintenance quality, and a relatively lower mean annual PCI decay value compared to the cluster of municipalities with a lower level of maintenance management. Therefore, improving the maintenance management level of local municipalities plays an essential role in slowing down the trend of PCI decay.

4.3 Identify the main influencing factors

For road condition prediction, the multi-factor prediction may fit the reality, but the calculation could be more convenient and conducive to practical operation. It is recommended to select 1-2 factors as the main influencing factors for PCI forecasting.

In this paper, the F-test two-sample ANOVA was chosen to determine the main influencing factors. The F-test two-sample ANOVA is used to compare the overall variance of the two samples to determine whether there is a significant difference between the two samples and, thus, to determine the main influencing factors of PCI.

The four factors of surface course, road age, traffic volume and maintenance management level were combined in two-by-two combinations and analyzed with the data results in 3.2, and the results are shown in Table 10.

As can be seen from Table 10, only two groups have *P*-values less than 0.01, which are surface course/maintenance management level (P=0.000 4) and road age/maintenance management level (P=0.004), indicating that there is a significant difference between these two groups of data, which has a more significant influence on the decay of PCI, and the common factor in these two groups of data is the maintenance management level. Therefore, the maintenance management level was selected as the main influencing factor of PCI decay.

Table 10 Summary of F test results under different influencing factors groups.

Different influencing factors		Surface course	Road age	Traffic volume	Management level
Average value (annual PCI decay value)		2.71	2.76	2.77	2.91
Variance (annual PCIS decay value)		0.19	0.31	0.58	1.16
F (statistic value)	Surface course	−	0.82	0.34	0.16
	Road age	−	−	0.53	0.26
	Traffic volume	−	−	−	0.50
	Management level	−	−	−	−
P (*F* ≤ *f*) single tail (less than or equal to the probability of calculated *F* value or greater than or equal to calculated *F* value)	Surface course	−	0.35	0.02	0.000 4
	Road age	−	−	0.10	0.004
	Traffic volume	−	−	−	0.08
	Management level	−	−	−	−
F single tail criticality	Surface course	−	0.43	0.43	0.43
	Road age	−	−	0.44	0.44
	Traffic volume	−	−	−	0.44
	Management level	−	−	−	−

5 Prediction of pavement damage performance

According to the “1 Pavement Performance Forecasting Method” and the actual situation in Province A, the “Time Series Analysis Method” was selected as the forecasting method. The time series analysis method is based on a set of historical data related to past demand and can be used to forecast future demand. Historical data may contain factors such as trends, seasons, cycles, et cetera. Common time series analysis methods include simple moving average, weighted moving average, exponential smoothing, regression analysis, Baucus-Jenkins method, Siskin time series, ARIMA model, et cetera.

This paper intends to use prediction worksheet, prediction function trend, ARIMA model and quadratic polynomial as prediction methods.

(1) Forecasting worksheet. Forecasting worksheet for EXCEL comes with a function based on historical time data to predict the data in any future time period, the basic principle of moving average and the exponential smoothing method.

(2) Forecasting function trend, using a linear regression equation for forecasting, that is, $y = a + bx$ formula, where Y is the forecast value, a is the intercept of the regression line, b is the slope, x is the variable, in short, is based on the trend of increase or decrease of existing data to predict the size of the subsequent data.

(3) ARIMA model. The full name of the ARIMA model (Autoregressive Integrated Demographic Average Model) is the most common statistical model used for time series prediction. The full name of the ARIMA model (Autoregressive Integrated Demographic Average Model) is the most common statistical model used for time series prediction. The ARIMA model treats the data series of predictors over time as a random series, and the dependence of this set of random variables reflects the continuity of the original data in time, which is both influenced by external factors and has its own variation pattern.

ARIMA model contains 3 parts, namely, autoregressive (AR), the difference (I) and moving average (MA). Their meanings are: AR indicates autoregressive (Auto Regression), I indicates single integer order (Integration), and the time series must be smooth to build the econometric model. The unit root test for the time series, if it is a non-stationary series, then it needs to be transformed into a stationary series by differencing, and after several times of differencing into a stationary series, it is called several orders of single integer; MA denotes moving average model (Moving Average).

(4) Quadratic polynomial. The quadratic polynomial is a polynomial whose highest degree is quadratic. The general form is : $y = ax^2 + bx + c$, where a, b and c are constants, and $a \neq 0$, y is the predicted value, x is the variable. Quadratic polynomial prediction of road conditions is to predict road conditions by constructing a quadratic polynomial model.

The PCI values are proposed to be categorized by PCI level based on the different PCI level miles from 2014-2020 to determine the PCI decay values at different stages. As shown in Table 11.

The PCI attenuation values were predicted separately for the categories with different maintenance management levels according to the three categories of PCI levels: excellent, good and medium to poor, and the predicted results are shown in Tables 12-14.

Tables 12-14 show the prediction results for different PCI levels, different maintenance management level categories, and different prediction methods.

Among the prediction results, the results of the prediction worksheet are relatively intermediate or low, and the results of the quadratic polynomial are relatively high. The accuracy or otherwise of the prediction results of each forecasting method needs to be verified by the actual values in 2020-2021.

Table 11 Mileage, share and classification of different PCI levels, 2014-2020.

PCI grade (last year of two-year overlapping sections)	Mileage of different PCI grades from 2014 to 2020 (km)	Share of different PCI grades from 2014 to 2020 (%)	Quasi-classification
Excellent	74 864.654	68.99	Excellent
Good	26 458.206	24.38	Good
Medium	4 883.964	4.50	
Secondary	1 417.712	1.31	Medium to poor
Poor	891.681	0.82	
Total	108 516.217	100	/

Table 12 Prediction results of different prediction methods when PCI is excellent.

Different maintenance and management levels	Average annual attenuation value of PCI in daily maintenance sections with excellent PCI							Prediction results			
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	Average value	Prediction worksheet	Prediction function trend	ARIMA model	Quadratic polynomial
Municipality cluster 1	1.770	1.895	1.769	2.158	1.637	1.894	1.854	1.513	1.877	1.400	1.709
Municipality cluster 2	2.181	2.273	2.617	4.375	2.924	2.841	2.868	2.393	3.569	2.870	2.208
Municipality cluster 3	4.624	3.749	2.468	3.334	4.186	3.372	3.622	3.482	3.214	3.480	4.690

Table 13 Prediction results of different prediction methods when PCI is good.

Different maintenance and management levels	Average annual attenuation value of PCI in daily maintenance sections with good PCI							Prediction results			
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	Average value	Prediction worksheet	Prediction function trend	ARIMA model	Quadratic polynomial
Municipality cluster 1	2.583	3.236	1.421	2.329	1.559	2.422	2.258	1.526	1.766	2.260	2.622
Municipality cluster 2	3.523	2.600	2.298	3.254	3.211	2.931	2.970	2.375	2.952	2.930	3.664
Municipality cluster 3	6.026	4.228	1.575	3.987	4.701	3.856	4.062	3.936	3.361	4.060	6.390

Table 14 Prediction results of different prediction methods when PCI is medium difference.

Different maintenance and management levels	Average annual attenuation value of PCI in daily maintenance sections with medium to poor PCI							Prediction results			
	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	Average value	Prediction worksheet	Prediction function trend	ARIMA model	Quadratic polynomial
Municipality cluster 1	4.712	4.648	3.194	3.089	5.332	4.694	4.278	4.797	4.464	4.280	6.464
Municipality cluster 2	5.410	4.415	1.338	3.687	5.526	3.033	3.902	3.868	3.282	3.900	5.323
Municipality cluster 3	7.361	7.418	3.041	5.938	6.617	6.102	6.079	6.288	5.499	6.100	8.374

6 Validation of prediction results

The prediction accuracy is evaluated by comparing the difference between the predicted and actual values, and a slight difference results in a high prediction accuracy. In this paper, the residual sum of squares (RSS), absolute error from the true value and relative error are used for prediction accuracy evaluation.

Residual sum of squares (RSS): According to the year, each project road condition has an actual value, and a predicted value can also be obtained through the model, and the difference between the actual value and its corresponding position (predicted value) on the regression line is statistically called the residual (the point to the direct connection in the figure below), we add up each residual square and call it the residual sum of squares (Residual Sum of Squares, RSS), which is the square of the difference between the actual value and the predicted value The sum represents the size of the random error. Obviously, the smaller the residual sum of squares of a set of data, the better the fit.

The following is a comparison between the prediction results and the actual values with different prediction methods.

The comparison results in Table 15 show that the residual sum of squares (RSS) of the "prediction worksheet" is smaller, and the absolute and relative errors are also more minor, so the "prediction worksheet" is selected as the pavement damage PCI attenuation prediction method for A common national and provincial trunk routes.

Table 15 Comparison of calculation results of different prediction methods (Provincial results).

Different prediction methods	Prediction worksheet	ARIMAmodel	Prediction function trend	Quadratic polynomial	Remark
Residual sum of squares (RSS)	175 389	176 478	180 845	201 363	The actual PCI value of pavement damage on daily maintenance sections in 2021 is 89.24
Predicted value	89.03	88.94	88.85	88.20	
Absolute error	0.21	0.30	0.39	1.04	
Relative error (%)	0.24	0.34	0.44	1.17	

7 Conclusion

Based on the inspection and evaluation data of the general national and provincial trunk lines in Province A from 2014 to 2020, the PCI decay performance of the general national and provincial trunk lines in Province A was studied and analyzed, and the conclusions are as follows:

(1) Increasing the thickness of the surface course can, to a certain extent, slow down the tendency of PCI decay.

(2) Road age of 3 years of the road section PCI decline faster, need to give priority to strengthen the work of minor repairs and maintenance, with conditions appropriate for preventive maintenance; road age of 6-7 years of the road section PCI decline rate is the second, it is appropriate to give priority to preventive maintenance, supplemented by minor maintenance work; road age of more than 8 years of the road section, PCI again into a period of rapid decline, it is appropriate to implement repair maintenance.

(3) The "prediction worksheet" has a smaller residual sum of squares (RSS) and more minor absolute and relative errors, so the

"Prediction Worksheet" is chosen as the method for predicting the PCI attenuation of general national and provincial trunk lines in Province A.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

Data Availability Statement

Some or all Data, models, or code that support the findings of available from the corresponding author upon reasonable request.

References

[1] Carey WN, Irick PE. The Pavement Serviceability-Performance Concept. Highway Research Board Bulletin, 1960, 250: 40–58.

[2] Xu XJ, Wang JZ, Pan ZJ, et al. Typical Pavement structure deterioration rule and maintenance technology for common trunk road in guangdong province. Journal of Highway and Transportation Research and Denelopment, 2017, 34(8): 16–22

[3] Kangas M, Heikinheimo M, Hippi M. RoadSurf: a modelling system for predicting roadweather and roadsurface conditions. Meteorological Applications, 2015, 22(3): 544−553. DOI:10.1002/met.1486.

[4] Setianingsih AI, Sangaji S, Setyawan A. Road maintenance and rehabilitation program using functional and structural assessment. Iop Conference, 2017, 176: 012030. DOI:10.1088/1757-899X/176/1/012030.

[5] CHENG PF, ZHENG W. Research on the prediction of pavement performance based on the improved residual grey model. Journal of China & Foreign Highway, 2015, 34(3): 60–63.

[6] Balasubramanian M, Anandh KS, Kumar TP. Study and assessment of rural road network in agriculture productivity. International Journal of Technology, 2015, 5(2): 125−130.

[7] Wang H, Wang Z. Evaluation of pavement surface friction subject to various pavement preservation treatments. Construction & Building Materials, 2013, 48: 194−202.

[8] Dong ZJ, Gong XB, Xiao GQ, et al. Rutting resistance evaluation of structural combinations of asphalt pavement subjected to heavy duty. Advanced Engineering Forum, 2012, 5: 316−321.

[9] Mensching DJ, McCarthy LM, Mehta Y, et al. Modelling flexible pavement overlay Performance for use with quality-related specifications. Construction and Building Materials, 2013, 48: 1072−1080.

[10] Evdorides H, Burrow M, Sulaiman S. A methodology to model the variability in pavement performance. Proceedings of the Institution of Civil Engineers Transport. Institution of Civil Engineers, 2013, 166(4): 233−240.

[11] Wu JM, Liu DB, Li FC, et al. Performance prediction of asphalt pavement maintenance based on time series analysis. Journal of Chang'an University (Natural Science Edition), 2015, 35(3): 1–7.

[12] Zhang HW, Lian P, Yang D. Prediction of pavement performance index based on grey model[J]. Highway, 2015(12): 34–38.

[13] Zhang PP, Quan L, Li SL, et al. Model for Asphalt Pavement Performance Prediction Based on LSTM-BPNN Neural Network. Journal of Highway and Transportation Research and Development, 2023, 40(Sup2):54−60.

[14] Rong JG ,Wang HY. The calibration of asphalt pavement performance decay model of road network. Journal of Transport Science and Engineering, 2019, 35(4): 22−27.

[15] Cao ZY, Zhang QS. Pavement performance and life cycle cost analysis. Journal of China & foreign highway, 2006, 26: 29–34.

[16] Wang HY, Yang GF, Pan YL. Prediction of wear condition of asphalt pavement based on the structural depth of pavement. Highway, 2019(1): 59–65.

[17] Wang J. The study on the evaluation and prediction, and decision of expressway asphalt pavement performance for Gansu Province. Lanzhou: Lanzhou Jiaotong University, 2018.

[18] He ZM, Sun XL,Yang WY, et al. Performance prediction model and accuracy analysis of asphalt pavement of sixth ring freeway in Beijing. Municipal Engineering Technology, 2020, 38(6): 34−36.