Research Article

Research on Relationships among Different Disease Types of Cement Concrete Pavement Based on Structural Equation Model

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In order to determine the key content of preventive maintenance of the cement concrete pavement in military airports in the seasonal frozen area, the relationship among pavement diseases is analyzed in this paper, and the degree of impact of each disease on pavement damage is quantified. Based on the survey data of 36 sample airports in 12 provinces, such as Hebei, Shandong, and Liaoning, a questionnaire covering many disease variables affecting pavement damage was designed. The exploratory factor analysis method and structural equation model (SEM) were used to analyze the interaction among joint disease, surface disease, vertical disease, repair disease, and fracture disease. And the influence degree of each disease on pavement damage was quantified as well. The research results show that the questionnaire has good reliability and validity and is suitable for confirmatory factor analysis. The SEM fits well with the observed data and meets the adaptation standard. Joint disease, surface disease, and vertical disease all have significant positive direct impact on pavement damage. Moreover, joint disease and surface disease can also indirectly affect pavement damage. The effects of surface disease (0.327), vertical disease (0.283), and joint disease (0.219) on pavement damage decrease in turn. Surface diseases have the greatest impact on pavement damage, which are the critical diseases to accelerate the pavement damage. By strengthening the prevention and control of surface diseases and delaying the conversion process of other diseases to surface diseases, the service life of the pavement can be greatly improved, and the maintenance cost can be reduced.

1. Introduction

Airport pavement is the most basic and important facility for aircraft flight. Whether it is a runway, taxiway, or apron, it assumes important tasks such as aircraft take-off, taxiing, and parking and is the basic platform for aircraft transportation and combat functions to be fully utilized. As a common type of the military airport pavement, cement concrete pavement will have a variety of diseases in the use process. Its disease is aggravated by the combined effects of wheel loads and environmental influences, resulting in gradual degradation of pavement performance, accelerated aircraft damage, and increased flight safety risks [1]. Pavement preventive maintenance refers to the reasonable and planned maintenance measures taken for the existing pavement system in good condition, so as to delay the

attenuation of pavement performance and reduce maintenance cost [2, 3]. At present, it has been widely used in the highway asphalt pavement and has achieved good practical results. However, the maintenance work of the airport pavement of our army is still in the stage of “repairing after the failure,” and the time of overhaul or reconstruction usually comes early, so the benefit-cost ratio cannot be maximized. Therefore, it is of great practical significance to carry out research on preventive maintenance of the cement concrete pavement in military airports and promote the application of the concept of preventive maintenance in the pavement maintenance of our military airport. However, it is the basis of preventive maintenance research to accurately understand the relationship among the diseases of the cement concrete pavement and analyze the types of the diseases and the interaction mechanism among the diseases.

At present, scholars in China and abroad have applied different methods to study the relationship among cement pavement diseases, mainly in the field of highway [4–9]. Combining with the status quo of a national highway cement concrete pavement, Xiao-xiao and Li-mei analyzed the transformation mechanism of several common diseases [10]. Long et al. analyzed the causes and mechanisms of typical diseases of the cement concrete pavement and established a comprehensive relationship of diseases of the cement concrete pavement [11]. Khabiri et al. aimed at the cracks that occurred during the use of the pavement and the impact of the size and geometry of the cracks on the secondary diseases, and the degree of damage to the pavement was evaluated [12]. According to the environmental characteristics of the seasonal frozen soil area, Zhao et al. analyzed the formation mechanism of pavement diseases [13]. Cafiso et al. studied various diseases that may appear during the use of pavement and analyzed the potential relationship among different diseases [14].

However, there are few research studies on the relationship of airport cement concrete pavement diseases. Sun and Ling analyzed the common diseases of the airport concrete pavement and summarized the five major diseases such as cracks, fractures, joints, vertical displacements, and surface layers according to the different types of pavement damage [15]. Chen et al. studied the internal and external causes of the formation of crack-type diseases on the airport concrete pavement and analyzed the evolution mechanism of crack-type diseases [16]. Sahagun et al. collected airport pavement disease data under different climatic conditions and studied the relationship among diseases [17]. Arabali et al. studied the typical diseases on the pavement of general aviation airport and formulated the corresponding preventive maintenance strategies [3].

The objectives of this study are as follows: (1) determine the main factors that affect the pavement damage of military airports in seasonal frozen areas, and classify the factors. (2) Design a questionnaire and analyze its reliability and validity. (3) Establish a SEM to describe the relationship between pavement damage and influencing factors. (4) Remove the potential variables with poor measurement ability and rebuild the model. (5) Evaluate the effect of each influencing factor and determine the critical diseases that accelerate the damage of the pavement.

The main methods of the traditional research on the comprehensive disease relationship include empirical analysis, field investigation, and data statistics. These analysis methods are mainly based on the current pavement conditions, and the analysis process is simple and direct. However, the obtained disease relationship is relatively simple and shallow, with fewer disease factors involved. It is difficult to identify the internal relationship among different diseases, and it is impossible to systematically and comprehensively understand the relationship of diseases. In order to overcome this limitation, some researchers tried to learn from the methods of other disciplines to study the comprehensive disease relationship of the pavement. SEM is a method to establish, estimate, and test the causal relationship model. The model contains both measurable

observed variables and potential variables that cannot be directly observed. SEM can not only quantitatively analyze the interaction among variables but also analyze the direct and indirect effects among variables, so as to understand the interaction among variables in complex models [18, 19]. SEM is a statistical data analysis tool. Compared with traditional multivariate statistical methods, it can consider and process multiple dependent variables at the same time. In addition, it can clearly analyze the influence of a single variable on the entire system and the relationship among variables [20].

A lot of research studies on structural equation models have been carried out in China and abroad, and fruitful research results have been obtained [21–26]. Because the SEM has the characteristics of processing multiple dependent variables simultaneously, it makes up for the shortcomings of traditional statistical methods such as regression analysis and covariance analysis. This makes the model a new method for multivariate statistical analysis and is widely used in economics, psychology, social sciences, and other disciplines. In recent years, with the increasing complexity of research issues in transportation disciplines and the need to describe the complex causality among multiple variables, more and more scholars have introduced structural equation models into the field of transportation. Based on the data collected in Chengdu, China, Chen and Li established a structural equation model to analyze the important factors affecting public transport choices and proposed the corresponding improvement measures [27]. Based on different types of disease data collected from the long-term pavement performance database, Chen et al. considered various types of diseases as potential variables and used the structural equation model to solve the causes of different pavement diseases and the influence of other factors on the overall pavement diseases [28].

On the basis of referring to the existing achievements, this paper analyzes the causes and mechanism of pavement diseases based on the data of pavement diseases in the seasonal frozen area. Exploratory factor analysis method is used to determine the main disease types affecting pavement damage. Furthermore, a SEM is established to quantitatively analyze the relationship between pavement damage and diseases, and finally, identify the critical diseases that accelerate the pavement damage and take the corresponding maintenance measures in a timely manner. This greatly increases the service life of the pavement and reduces maintenance costs.

This paper attempts to develop a new mathematical model (structure equation model) and apply it to the relationship among pavement diseases, which has not been done by previous researchers. The research area of this paper is 36 military airports in the seasonal frozen area. At present, no one has studied the relationship among the diseases of the military airports in the seasonal frozen area and has not quantified the impact of the diseases on the pavement damage. Through the analysis of the solution results of the structural equation model, it is found that the fitting degree conforms to the recommended value, and the path coefficient reaches the significance level, which verifies the

research hypothesis proposed in this paper. The research results of this paper have military application value. This paper quantitatively analyzes the relationship between the disease and the pavement, identifies the key diseases that accelerate the destruction of the pavement, and determines the key content of the maintenance of the military airport pavement.

The following sections are organized as follows: Section 2 presents the methodological overview and approach based on the SEM. Section 3 introduces the principle and construction process of the SEM. Section 4 designs a questionnaire based on the research in Section 3 and tests the reliability and validity of the questionnaire. In Section 5, the model is solved. By analyzing the relationship among variables, the weak effect relationship among variables is removed, and the SEM is rebuilt. In Section 6, the fitting degree and hypothesis test of the original model and the modified model are verified, and the relationship and mechanism of cement concrete pavement diseases are analyzed. Conclusions are presented in the final section.

2. Methodology Research

The research method and the technical route of this paper are shown in Figure 1, which can be divided into four steps:

The first step: this paper first introduces the basic principle of the SEM. Based on the data collection of 36 military airports in 12 provinces, such as Heilongjiang province, Jilin province, and Liaoning province, this paper analyzes the types of diseases that affect the pavement damage and constructs the evaluation indexes and specific questions of airport pavement damage. Based on the above analysis, the structural equation is used to construct the model of the pavement damage relation, and the research hypothesis is proposed.

The second step: on the basis of the following five principles of questionnaire design [29], the questionnaire is designed by the Likert scale 5-point method. The questionnaire contains two parts: basic personal information and cement concrete pavement damage information. The first part is the basic personal information, including gender, age, educational background, occupation, and position. In order to ensure the professionalism and effectiveness of the collected questionnaire data, 60% of the total respondents are technical personnel, who engaged in pavement maintenance, and they have more than 5 years of work experience. The administrative leadership of the pavement maintenance department accounts for 20%, and they are familiar with the pavement conditions of the airport. Pilots account for 20%. They are users of the pavement, and they know more about the wear of the plane on the pavement. Obtaining data from them is more in line with the actual situation of the airport pavement. The second part is related information of pavement damage. Questionnaires are collected from staff of 36 military airports. Then, the reliability and validity of the questionnaire are analyzed by SPSS24.0

software to ensure the internal consistency and reliability of the data. If the reliability and validity of the questionnaires are high and they meet the requirements, AMOS22.0 software can be used to calculate and test the SEM through confirmatory factor analysis. The path coefficients among variables can be obtained, and the relationship among variables can also be analyzed.

The third step: if an exogenous latent variable (variables that are not affected by other variables in the model but affect other variables) has weak ability to measure the endogenous latent variable (variables that are always affected by other variables in the model), the exogenous latent variable should be removed. It is necessary to modify the model and reuse AMOS22.0 software to calculate the SEM. After the model results are obtained, the statistical index is used to evaluate the fit between the model and the data to verify the rationality of the SEM. At the same time, the significance of the path coefficient is analyzed to check whether the assumed path is consistent with the real data. In addition, the direct and indirect effects among variables are analyzed.

The fourth step: finally, the correlation coefficient between the pavement damage and the disease is obtained, and the critical diseases that accelerate the pavement damage are determined.

3. Construction of the Pavement Disease Model Based on the Structural Equation

3.1. Structural Equation Model. As a method to establish, estimate, and test the causal relationship model, SEM can deal with the interaction between observed variables and potential variables as well as among potential variables and quantify the interaction among them. The model integrates path analysis and factor analysis. Not only can multiple potential variables be considered at the same time, allowing measurement errors among them, but also the relationship among potential variables can be constructed to analyze the direct and indirect effects among variables [30].

The SEM is mainly composed of two elements of variables and the relationship among variables. According to the different characteristics of variables, it can be divided into observed variables and potential variables. Observed variables are directly measurable variables, while potential variables cannot be directly measured and can only be measured indirectly by observed variables. Latent variables can be divided into exogenous variables and endogenous variables. Exogenous variables are not affected by any other variables, but they will affect other variables. Endogenous variables are affected by other variables and are mostly used as dependent variables [31].

In terms of variable relationships, a complete SEM includes a measurement model and a structural model. The measurement model measures the relationship between observed variables and latent variables. The structural model analyzes the causal relationship among the latent variables and the parts of the model that cannot be explained by other variables.

FIGURE 1: The framework of research methodology.

The equation of the measurement model is

$$\begin{aligned}x &= \Lambda_x \xi + \delta, \\ y &= \Lambda_y \eta + \varepsilon,\end{aligned}\quad (1)$$

where x is a vector composed of exogenous observed variables; ξ is a vector composed of exogenous latent variables; Λ_x is the factor load matrix of the exogenous observed variable x on the exogenous latent variable ξ ; y is a vector composed of endogenous observed variables; η is a vector composed of endogenous latent variables; Λ_y is the factor load matrix of the endogenous observed variable y on the endogenous latent variable η ; δ is the error vector of the exogenous variable; and ε is the error vector of the endogenous variable.

The equation of the structural model is

$$\eta = B\eta + \Gamma\xi + \zeta, \quad (2)$$

where η is a vector of endogenous latent variables of order $m \times 1$; ξ is a vector of exogenous latent variables of order $n \times 1$; B is the coefficient matrix of the endogenous latent variable η ; Γ is the coefficient matrix of the exogenous latent variable ξ ; ζ is the $m \times 1$ order residual vector, which is the unexplained part of the equation; and m and n are positive integers [22].

3.2. Pavement Disease Model Construction

3.2.1. Variable Design. At present, there are few studies on the mechanism of pavement diseases in military airports in seasonal frozen areas. The only work mainly focuses on the classification of pavement diseases, the causes of diseases, and the corresponding maintenance measures. This paper focuses on the quantitative research on the conversion mechanism of pavement diseases and their mutual influence and discusses the critical diseases that accelerate the pavement damage. Based on the existing theoretical research results and the data of cement concrete pavement damage in the military airport in the seasonal frozen area obtained through practical investigation, the following main factors influencing pavement damage were summarized:

- (1) Joint diseases: in the daily use of cement concrete pavement, due to the erosion of the aircraft load and the natural environment (especially, the freeze-thaw cycle and frost heave), concentrated stress will be generated at the joints. In the long run, the joint is broken and damaged under the action of concentrated stress, and surface water is easy to infiltrate through the damaged joint. Furthermore, under the effect of repeated changes in temperature, it is further damaged due to thermal expansion and contraction, causing other diseases. Around the joint, it is easy to produce joint cracking, joint opening, mud, corner peeling, and other diseases, resulting in the joint to be a part of the cement concrete pavement that is prone to damage [32].
- (2) Surface diseases: due to the large temperature difference between day and night in the seasonal frozen

area, the temperature change causes thermal expansion and contraction of the pavement panel, and the temperature stress causes fine cracks on the pavement. If it is not maintained in time, external moisture such as natural precipitation and snow-melt water will invade the pavement through microcracks. Moreover, under the repeated action of the freeze-thaw cycle, the local pavement materials will be loose, which will lead to slight surface erosion until obvious peeling damage [12].

- (3) Vertical diseases: in the seasonal frozen area, under the unfavorable geological and hydrological conditions, water in the soil foundation under the pavement panel will migrate under the action of temperature gradient due to the fall in temperature in autumn and winter. During the migration process, water condenses into ice due to temperature, which causes the soil base to swell up. When it reaches a certain level, it will lead to the misalignment of the pavement panel. With the occurrence of joint diseases, surface water percolates along the joint to the soil foundation under the pavement panel. As a result, the water content of the soil is too large, and the frost heaving effect increases sharply. Furthermore, the uneven frost heaving occurs on the pavement panel, resulting in the formation of plate bottom emptying and interplate slip. Plate bottom voidage and interplate slip occur frequently in the airport cement concrete pavement in the seasonal frozen area. The increase in the amount of the interplate slip will accelerate the damage rate of the pavement, which in turn leads to the deterioration of the interplate slip. This can create a vicious circle [9].
- (4) Repair diseases: repair diseases refer to small patches and large patches. The small patch refers to the repair of the partially damaged surface. The large patch refers to a pavement surface that is repaired after excavation of the initial pavement due to the addition of underground pipelines and other facilities. Patch is more prone to secondary damage than the initial surface, that is, secondary damage, so it is classified as a pavement damage type [11].
- (5) Fracture diseases: in airports with severe pavement damage, there are often more plate fracture diseases. When there are many small cracks on the pavement and they are scattered in various parts of the concrete, the cracks continue to grow and deepen under temperature stress, aircraft load, and other natural factors, slowly connected to each other, resulting in a decrease in the bearing capacity of the soil foundation. At this moment, surface diseases such as surface cracks and surface peeling appear on the pavement surface. The effect of the external conditions on the cement concrete is strengthened, the cracks continue to expand and deepen, and the strength of the concrete continues to decline, resulting in the interplate slip and other diseases. With the continuous comprehensive effect of

external conditions, structural damage such as plate corner fracture, plate fracture, and even plate fragmentation will eventually occur [13].

Therefore, based on the multilevel features of pavement damage, this paper divided the factors affecting pavement damage into five exogenous latent variables: joint disease, surface disease, vertical disease, repair disease, and fracture disease. The interaction of these five factors will accelerate the pavement damage and reduce the service life of the pavement. The collected data of 36 military airfields were statistically sorted out from the aspects of surface appearance quality and flatness, and the performance test data of these airfields were analyzed. Some diseases that have a small impact on the pavement (less occurrences) were eliminated, and many diseases that affect the pavement damage were obtained. The characteristic description and typical legends of diseases are shown in Table 1. On this basis, 11 observed variables were designed. In this paper, the damage evaluation indicators and specific questions of the cement concrete pavement of the military airport in the seasonal frozen area were constructed, as shown in Table 2. It can be seen from Table 2 that the SEM has a total of 6 potential variables and 11 observed variables.

3.2.2. Model Assumptions. After the analysis in Section 3.2.1, joint disease, surface disease, vertical disease, repair disease, fracture disease, and pavement damage were selected as the core latent variables of the pavement damage model. Also, eight research hypotheses were proposed for the conceptual model:

Hypothesis 1 (H1): joint diseases have a positive impact on pavement damage

Hypothesis 2 (H2): surface diseases have a positive impact on pavement damage

Hypothesis 3 (H3): vertical diseases have a positive impact on pavement damage

Hypothesis 4 (H4): repair diseases have a positive impact on pavement damage

Hypothesis 5 (H5): fracture diseases have a positive impact on pavement damage

Hypothesis 6 (H6): joint diseases have a positive impact on surface diseases

Hypothesis 7 (H7): surface diseases have a positive impact on vertical diseases

Hypothesis 8 (H8): vertical diseases have a positive impact on fracture diseases

According to the pavement disease data of 36 military airports in the seasonal frozen area collected by our survey, as well as the relevant literature at present, we find the characteristics of the deterioration mechanism of cement concrete pavement diseases, which are as follows: first slow then fast, from surface to interior, from nonstructural diseases such as joint diseases and surface diseases, and finally to structural diseases such as vertical diseases and fracture diseases. So, we set the last three hypotheses. We have also

done a lot of research studies on whether repair diseases have a direct impact on other diseases. In this paper, by investigating military airports in the seasonal frozen area, it is found that most of the airports have repair diseases. However, due to the uncertainty of the location of the repaired local pavement, they may have an impact on joint diseases, surface diseases, and vertical diseases, so it is impossible to make hypotheses in the model. Moreover, there are not many studies on repair diseases that may affect joint diseases, surface diseases, and vertical diseases, and the effect mechanism is still unclear. Therefore, the hypothesis that repair diseases will have direct effects on joint diseases, surface diseases, and vertical diseases is not considered in this paper.

4. Data Collection and Analysis

4.1. Questionnaire Design and Implementation. The questionnaire design should follow five principles: (1) rationality, that is, the questionnaire must be closely related to the subject of the survey; (2) logicity, there should be no logical errors among problems; (3) clarity, the setting of the problem should be clear and not ambiguous; (4) noninductive, the description of the problem should be neutral and should not be inductive. (5) It is easy to organize and analyze. The design of the questionnaire should consider the data to facilitate analysis and processing. Based on the above principles, the questionnaire in this paper was designed based on the airport pavement damage assessment indicators constructed in Table 2. The questionnaire contained two parts: basic personal information and cement concrete pavement damage information. The first part is the basic personal information, including gender, age, educational background, occupation, and position. In order to ensure professionalism and effectiveness of the collected questionnaire data, 60% of the total respondents are technical personnel, who engaged in pavement maintenance, and they have more than 5 years of work experience. The administrative leadership of the pavement maintenance department accounts for 20%, and they are familiar with the pavement conditions of the airport. Pilots account for 20%. They are users of the pavement, and they know more about the wear of the plane on the pavement. Obtaining data from them is more in line with the actual situation of the airport pavement. The second part is related information of pavement damage, that is, the specific items listed in Table 2. In this study, the Likert scale 5-point method was used to determine the score. The answer to the question was set to strongly agree, agree, not necessarily, disagree, and strongly disagree. And the corresponding values are 5, 4, 3, 2, and 1.

Due to the complexity of the natural conditions in the seasonal frozen area, the variety of damage forms and the complexity of the deterioration factors of pavement performance are caused. Moreover, a large number of military airports in China are located in the seasonal frozen area. Therefore, it is typical to choose the seasonal frozen area as the research area in this paper. This paper took the questionnaire as the data source of the case study. Military airports in more than 10 provinces including Hebei,

TABLE 1: Characteristic description and typical legends of pavement diseases.

Pavement disease types	Feature description	Typical legend
Joint filler damage	Under the combined effect of environmental and load factors, the joint filler loses its elasticity and plugging effect.
Corner peeling	It refers to the damage caused by cutting the plate thickness at an oblique angle instead of through the plate thickness at the edge and corner of the plate.
Mud	Base material is deposited near the joints or cracks.
Surface crack	There are shallow cracks on the plate surface that do not penetrate the thickness of the plate. This kind of crack does not affect the bearing strength of the plate.
Surface peeling	Spalling, exposed stones, and potholes on the surface of the plate, which damage the flatness of the pavement surface.
Interplate slip	Uneven vertical displacements at the joints of adjacent plates.
Void at the bottom of the panel	Significant plate movements as aircraft wheels pass near cracks.
Secondary disease of the patch	Local repairs on the plate.
Plate fragmentation	It refers to the cracks that run through the thickness of the plate in the noncorner of the plate, forming more than 4 broken pieces, which have completely lost the original bearing capacity.
Plate fracture	There are cracks in the vertical and the horizontal direction that penetrate through the thickness of the plate. Usually, there are 1 or 2 cracks, which cause the plate to crack into 2 or 3 pieces.
Plate corner fracture	There are cracks through the thickness of the plate at the corner of the plate. The corner of the plate is broken. The side length of the corner is 1/10~1/2 of the plate length, about 50~100 cm.

TABLE 2: Evaluation indicators of airport pavement damage.

Latent variables	Observed variables	Specific questions and corresponding options (the scores of options are 5 to 1 from left to right)
Joint diseases (Joi)	Joint filler damage (Joi1)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the joint filler? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
	Corner peeling (Joi2)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the corner peeling? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
	Mud (Joi3)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by mud? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
Surface diseases (Sur)	Surface crack (Sur1)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the surface crack? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
	Surface peeling (Sur2)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the surface peeling? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
Vertical diseases (Ver)	Interplate slip (Ver1)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the interplate slip? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
	Void at the bottom of the panel (Ver2)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the void at the bottom of the panel? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
Repair diseases (Rep)	Secondary disease of the patch (Rep1)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the secondary disease of the patch? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
Fracture diseases (Fra)	Plate fragmentation (Fra1)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the plate fragmentation? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
	Plate fracture (Fra2)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the plate fracture? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
	Plate corner fracture (Fra3)	Do you agree that timely maintenance can greatly improve the service life of the pavement when the pavement is damaged by the plate corner fracture? ☐ Strongly agree ☐ Agree ☐ Not necessarily ☐ Disagree ☐ Strongly disagree
Pavement damage (Pav)	—	—

Shandong, and Liaoning were investigated. Thirty-six sample airports (numbered 1–36) were selected, and questionnaires were issued and recovered. The distribution of the 36 airports is shown in Figure 2.

It can be seen from Figure 2 that most of the airports are in the range of the seasonal frozen area, while some airports are in the nonseasonal frozen area (#33, #34, #35, and #36). In order to ensure that the collected data can reflect the characteristics of the seasonal frozen area as fully as possible, questionnaires collected from the four airports of #33, #34, #35, and #36 were excluded in this paper. A total of 1,532 questionnaires were distributed, 68 invalid questionnaires were excluded, and 1,464 valid questionnaires were in total.

4.2. Reliability and Validity Test. Reliability refers to the degree of consistency in the results of repeated measurements of the same object using the same method. The greater the reliability of the questionnaire, the smaller the measurement error and the more stable and reliable the measurement results. The commonly used method to test

reliability is Cronbach's α . When Cronbach's α value is greater than 0.700, it indicates that the questionnaire has high reliability [33].

Validity refers to the degree to which measuring tools or means can accurately measure the things to be measured. The higher the validity is, the more consistent the measurement results are with the content to be examined. There are three types of validity: content validity, criterion validity, and structure validity. Generally, the structural validity of the questionnaire is analyzed. Structural validity refers to the degree of correspondence between the measured structure and the theoretical structure. It is generally believed that the Kaiser–Meyer–Olkin (KMO) value of the sample data should be greater than 0.5, and the chi-square value of Bartlett's spherical test is significant, indicating that the validity of the questionnaire is high [33].

In this paper, the actual data obtained from the questionnaire were used. Based on SPSS24.0 software, Cronbach's α was used to test the reliability of the data, and KMO test and Bartlett spherical test were used to test the structural validity. The calculation results are shown in Table 3. The

FIGURE 2: Distribution of sample airports.

TABLE 3: Reliability and validity test results.

Latent variables	Number	Cronbach's alpha	KMO	Sig
Joint diseases	3	0.883	0.871	0.000
Surface diseases	2	0.778	0.737	0.000
Vertical diseases	2	0.861	0.835	0.000
Repair diseases	1	0.896	0.866	0.000
Fracture diseases	3	0.832	0.789	0.000
Total	11	0.965	0.973	0.000

results show that the overall Cronbach's α value of the questionnaire is 0.965, which is greater than 0.800. Cronbach's α value of each part meets the requirements of more than 0.7, which indicates that the questionnaire has high consistency and reliability. The KMO value of the data meets the requirements of more than 0.7, and Bartlett's spherical test is significant (Sig value is 0.000), indicating that the structure validity of the questionnaire is good. Therefore, the reliability and validity of the survey data are desirable, which is suitable for further research.

5. Model Solution and Modification

5.1. Model Solution. In this paper, AMOS22.0 software is used to calculate the SEM through confirmatory factor analysis, and the full path diagram of influencing factors of pavement damage is obtained, as shown in Figure 3.

In order to test whether the critical diseases affecting the pavement damage proposed in this paper fit the actual data, this section uses the confirmatory factor analysis method in the SEM to gradually screen out the critical diseases affecting the pavement damage.

The data shown in Figure 3 are the result of the original model calculation. From the standardized coefficients among the variables in the original model, we can see the strength of the relationship and interaction among the variables. According to the model output results, the effect of fracture diseases on pavement damage is only 0.059, and the effect of repair diseases on pavement damage is only 0.061. It is the weakest influence effect among all the factors, indicating that fracture diseases and repair diseases have weak

FIGURE 3: Full path diagram and calculation results of the original model.

measuring ability on the pavement damage. This is because the critical diseases affecting pavement damage are not necessarily the most serious diseases but must be at the key nodes in the deterioration process of pavement disease, which play a leading role in the deterioration of the relationship among the entire pavement diseases. The damage degree of this critical disease is not necessarily very serious. However, if unchecked, more types and numbers of diseases will be generated after long-term deterioration, which will seriously damage the function of the pavement structure. Therefore, the two potential variables of fracture diseases and repair diseases were removed, and the main factors affecting pavement damage were screened out as joint diseases, surface diseases, and vertical diseases.

5.2. Model Modification. The weak effect relationship among variables was removed, and the modified model was recalculated. The impact path diagram is shown in Figure 4, and the direct, indirect, and total effects are shown in Table 4.

6. Result Analysis

6.1. Model Fit Verification. The goodness of model fitting can evaluate the fitting degree between the model and the data to verify the rationality of the structural equation model. According to the different characteristics of each statistical test, it can be divided into three categories: absolute fit measures, incremental fit measures, and parsimonious fit measures. These indicators can be obtained through the AMOS software output table [34]. In this paper, six common indexes, normed chi-square (χ^2/df), parsimony goodness-of-fit index (PGFI), root-mean-square error of approximation (RMSEA), comparative fit index (CFI), normed fit index (NFI), and goodness-of-fit index (GFI), were used to test the fitting degree between the model and the original data. The fitting accuracy of the original model and the modified model was evaluated, respectively. The results are shown in Table 5. If χ^2/df value is less than 1, it

FIGURE 4: Modified path diagram and model calculation results.

TABLE 4: Standardized direct, indirect, and total effects.

	Joint diseases	Surface diseases	Vertical diseases
<i>Joint diseases</i>			
Direct effect	na	na	na
Indirect effect	na	na	na
Total effect	na	na	na
<i>Surface diseases</i>			
Direct effect	0.138	na	na
Indirect effect	0	na	na
Total effect	0.138	na	na
<i>Vertical diseases</i>			
Direct effect	0	0.109	na
Indirect effect	0.015	0	na
Total effect	0.015	0.109	na
<i>Pavement damage</i>			
Direct effect	0.174	0.296	0.283
Indirect effect	0.045	0.031	0
Total effect	0.219	0.327	0.283

Note. "na" denotes "not applicable."

indicates that the model is overadapted. If χ^2/df value is greater than 3, it indicates that the model is not well adapted. χ^2/df value between 1 and 3 indicates that the model is well adapted [30]. RMSEA less than 0.08 indicates a good fit [35]. The other fitting indicators are larger than their respective reference values, indicating that the model has a good fit, and the closer it is to 1, the better the fitting degree is [30, 35, 36].

It can be seen from the results of the fitting index that GFI in the original model is 0.882, which does not meet the requirement of greater than 0.9. The NFI is 0.806, which barely meets the requirement of greater than 0.8. For the modified model, GFI is 0.913, which meets the requirements. Furthermore, compared with the original model, the other indexes all better meet the requirements of goodness of fit, and the adaptation of the modified model is better. It further illustrates that the modified measurement index is more reasonable, and the fitting degree of the modified model and data is higher.

6.2. Hypothesis Test Results. In order to test whether the assumed path is consistent with the real data, a significance analysis of the path coefficient is required. The path coefficient results of the original model and the modified model are shown in Table 6. The standard error (SE), critical ratio (CR), and significance of each path are also included in the table.

To test whether the path coefficient in the model is significant, it needs to be judged by critical ratio or significance p value. "****" in the output report means that p is less than 0.001. When the significance probability value $p > 0.001$, the value will be directly displayed in the p column. The critical ratio is the ratio of the parameter estimate to the standard error. When the absolute value of CR is greater than 2.58, the parameter estimate reaches a significant level of 0.01 [37]. As can be seen from Table 6, for the original model, the path coefficient of the effect of repair diseases on the pavement damage is 0.061, and the path coefficient of the effect of fracture diseases on the pavement damage is 0.059. Neither of them reached a significant level of 0.01, indicating that fracture diseases and repair diseases have weak ability to measure pavement damage. For the modified model, the standard load coefficients of joint diseases, surface diseases, and vertical diseases on the pavement damage are 0.174, 0.296, and 0.283, respectively, all of which have significant positive effects. Moreover, the standard load coefficient of joint diseases on surface diseases is 0.138, and the standard load coefficient of surface diseases on vertical diseases is 0.109, all of which have significant positive effects. Therefore, all five hypotheses have been verified.

6.3. Direct and Indirect Effects. It can be seen from Table 6 that the total effects of joint diseases, surface diseases, and vertical diseases on the pavement damage are all positive values, indicating that the joint diseases, surface diseases, and vertical diseases have a positive impact on pavement damage. Among them, joint diseases and surface diseases have both direct and indirect effects on pavement damage.

The correlation (0.219) between joint diseases and pavement damage is the sum of (i) the direct effect (0.174) of joint diseases on pavement damage and (ii) the indirect effect ($0.045 = 0.138 * 0.296 + 0.138 * 0.109 * 0.283$) of joint diseases on pavement damage through surface diseases and vertical diseases. The correlation (0.327) between surface diseases and pavement damage is the sum of (i) the direct effect (0.296) of surface diseases on pavement damage and (ii) the indirect effect ($0.031 = 0.109 * 0.283$) of surface diseases on pavement damage through vertical diseases. The total effects are ranked from high to low in the order of surface diseases, vertical diseases, and joint diseases. It indicates that the surface diseases are the critical diseases that affect the pavement damage. Therefore, in order to improve the service life of the pavement, it is necessary to start from joint diseases, surface diseases, and vertical diseases that affect the pavement damage and focus on the surface diseases and vertical diseases to take effective methods and measures.

TABLE 5: Model fit measures for the original and modified SEM models.

Measures	Fit index	Acceptable level	Original model	Modified model
Absolute fit measures	Normed chi-square (χ^2/df)	$1 < \chi^2/df < 3$ reflects a good model fit	2.863	2.516
	Goodness-of-fit (GFI)	GFI > 0.90 reflects a good model fit	0.882	0.913
	Root-mean-square error of approximation (RMSEA)	RMSEA < 0.08 reflects a good model fit	0.068	0.065
Incremental fit measures	Comparative fit index (CFI)	CFI > 0.90 reflects a good model fit	0.923	0.927
	Normed fit index (NFI)	NFI > 0.80 reflects a good model fit	0.806	0.831
Parsimonious fit measures	Parsimony goodness-of-fit index (PGFI)	PGFI > 0.50 reflects a good model fit	0.62	0.69

TABLE 6: Path coefficients for original and modified SEM models.

Hypothesized paths	Original model				Modified model			
	Estimate	SE	CR	<i>p</i>	Estimate	SE	CR	<i>p</i>
H1: pavement damage ← joint diseases	0.162	0.035	4.588	***	0.174	0.036	4.793	***
H2: pavement damage ← surface diseases	0.245	0.048	5.064	***	0.296	0.053	5.544	***
H3: pavement damage ← vertical diseases	0.203	0.042	4.793	***	0.283	0.057	4.924	***
H4: pavement damage ← repair diseases	0.061	0.043	1.378	0.182	na	na	na	na
H5: pavement damage ← fracture diseases	0.059	0.046	1.242	0.216	na	na	na	na
H6: surface diseases ← joint diseases	0.084	0.022	3.778	***	0.138	0.038	3.592	***
H7: vertical diseases ← surface diseases	0.118	0.029	4.028	***	0.109	0.026	4.152	***
H8: fracture diseases ← vertical diseases	0.068	0.019	3.538	***	na	na	na	na

Note. ****p* value < 0.001. “na” denotes “not applicable.”

It can be seen from Figure 4 that the factor loading values of the surface crack and surface peeling on surface diseases are 0.88 and 0.80, respectively. It shows that the surface crack and surface peeling have a greater impact on surface diseases. In the same way, the factor loading values of the interplate slip and void at the bottom of the panel on vertical diseases are 0.82 and 0.75, respectively. It shows that the interplate slip and void at the bottom of the panel have a greater impact on vertical diseases. Therefore, in the study of surface diseases and vertical diseases, special attention should be paid to the prevention and treatment of diseases such as surface crack, surface peeling, interplate slip, and void at the bottom of the panel. This can greatly extend the service life of the pavement with less maintenance costs.

7. Conclusions

Affected by the natural environment such as freeze-thaw cycles and frost heaves, the causes and deterioration mechanisms of cement concrete pavement diseases in seasonal frozen areas are more complicated. In China, the seasonal frozen area is widely distributed, with a large number of military airports, and the disease characteristics are complex and representative. In this paper, the deterioration process of the diseases and the relationship among the diseases were analyzed, which is helpful to find the critical diseases to accelerate the damage of the airport pavement. Therefore, targeted prevention and treatment can greatly

increase the service life of the pavement and reduce maintenance costs.

For this purpose, a questionnaire was designed and tested for reliability and validity. Through exploratory factor analysis and the structural equation model, the influencing factors of pavement damage and their mutual causality were identified and quantified. The results prove that the modified model has better fitting degree than the original model and meets the requirements; joint diseases, surface diseases, and vertical diseases have positive and significant influence on pavement damage; surface diseases are the main factors that accelerate the pavement damage and are the critical diseases in the deterioration of pavement diseases followed by joint diseases and vertical diseases. In this paper, the key content of pavement maintenance was determined, which can provide decision support for pavement maintenance managers. For the maintenance of the cement concrete pavement in the seasonal frozen area, the following suggestions were put forward:

- (1) Strengthen the prevention and control of surface diseases: as a midterm disease, the surface disease is the latent stage of the disease and has formed a potential destructive force to the pavement. Especially, when the surface crack and surface peeling disease occur, the pavement surface should be repaired in time. Otherwise, pavement damage will accumulate faster than the early stage, and pavement defects will increase. It gradually evolves into vertical

disease and fracture disease, with extremely rapid loss of service life.

- (2) Delay the process of transformation to surface disease: each type of pavement disease is deteriorated and transformed on the basis of the former disease, and the trend of this transformation always exists. The critical to prolong the service life of the pavement is to delay the transformation of one disease to another more serious disease. Therefore, it is necessary to delay the process of joint disease to surface disease, so as to improve the service life of the pavement and reduce the maintenance cost.

The parsimony for the proposed SEM model in this study is promised, and all of the hypothesized paths are based on well-known empirical research and supported by real-world data. However, there are some limitations in this study. These data come from military airfields in the seasonal frozen regions of Hebei, Shandong, and Liaoning provinces, whose applicability outside these regions is uncertain. Moreover, the critical diseases of accelerating pavement damage obtained in this paper are also different from place to place, which are only for reference. In practical application, corresponding adjustments should be made according to the characteristics of different regions.

Data Availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available because they contain information that could compromise the privacy of research participants.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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