A Study on the Prediction of Road Pavement Deterioration according to the Road Quality and ESAL

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Abstract. This study intends to analyze the pavement life data on the target area in consideration of load size and VI grade for determining the influence level. Here, VI grade is the road surface status investigation which indicates the defect status on the pavement surface, and the level of defect on the surface is divided into 7 grades, and these grades are divided into 3 grades again. For the case analysis, the road maintenance zone conducted by Daejeon Regional Construction Management Administration in 2011 was analyzed. For the classification according to the load, Low level for MESAL 0.0-0.10, Medium level for 0.11-0.30, and High level for over 0.31 are selected, and VI grades are classified as follows. (A level: 1(Good), B level: 2~3(Normal), C level: 4~7(Bad)) (Korea Institute of Construction Technology, 2010). The analysis result shows that the reliability of road pavement decreases according to the road quality and accumulated ESAL, the reliability of road decreases as the accumulated ESAL is higher even if the road quality is same. And also, the reliability of road decreases as the level drops even if the ESAL is same.

Keywords: Cox Model, ESAL, Pavement Management System, VI, Pavement Life

1 Introduction

The most fundamental analysis for preparing the decision making measures and analyzing LCCA to plan and maintain the pavement project efficiently in consideration of these economic feasibility and safety is the prediction of the reliable pavement life, and the pavement life (performance) is influenced by various factors such as traffic volume, weather, pavement strength, performance period, ratio of large vehicles and flatness. Especially, the traffic load characteristic, weather and the thickness of the foundation have a great influence on the pavement life (Yoo, 2002; Loizos et al., 2005; Yang et al., 2005).

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Many study results showed that the load strength such as the size of ESAL has a
greater influence on the pavement life than the absolute value such as annual average
daily traffic volume (AADT) (Kwon, 2002; Gharibeh et al., 2003).
And, ESAL is accumulated on the road pavement, and as a result, the road quality
will drop and the road life will decrease over time.
Therefore, this study intends to determine the influence level of the accumulated
ESAL and the road quality on the road life using the Cox model.

2 Cox Model

The Cox model or Proportional Hazards model introduced by Cox has been used in
the biomedicine or medicine field, but it can be also used for the accelerated-life test.
The purpose of the Cox model is to obtain the relationships between life and vari-
ous stresses that influence on the life.
Especially, the Cox model is often used in the case that a number of variables
(stresses) is considered. And its another advantage is that the interaction between
stresses considered can be obtained easily. The Cox model assumes that the hazard
rate of the stress in a level and the hazard rate of the stress in another level don’t
change over time. Therefore, the Cox model is also called as the Proportional Hazards
model.
Let be the stress variables, then is the hazard rate function in life distribution,
when . The basic Cox model is same as Formula (1).

\[
h(t; x_1, \ldots, x_j) = h_0 \cdot \exp(\alpha_1 x_1 + \cdots + \alpha_j x_j)
\]

The basic hazard rate function and coefficients are estimated from the life data.
The distribution of basic hazard rate function can be assumed from the Cox model
and it can be predicted with the non-parametric method. Eq. (1) has no segment value
and replaces instead. The corresponding reliability function is as Eq. (2).

\[
R(t; x_1, \ldots, x_j) = [R_0(t)]^{\exp(\alpha_1 x_1 + \cdots + \alpha_j x_j)}
\]

When \( x_1 = x_2 = \cdots = x_j = 0 \), the reliability function is as Eq. (3).

\[
R_0(t) = \exp \left[ - \int_0^t h_0(u)du \right]
\]

And, the Proportional Hazards function and the reliability function for the Weibull
Distribution are as Eq. (4)~(5).

\[
\begin{align*}
h(t; x_1, \ldots, x_j) &= \frac{\beta}{\gamma} \left( \frac{t}{\gamma} \right)^{\beta-1} \exp(\alpha_1 x_1 + \cdots + \alpha_j x_j) \\
R(t; x_1, \ldots, x_j) &= \exp \left[ - \left( \frac{t}{\gamma} \right)^{\beta-1} \exp(\alpha_1 x_1 + \cdots + \alpha_j x_j) \right]
\end{align*}
\]
3 Result analysis using the Cox model

The life of pavement section means the number of years from the beginning of the new pavement performance to the time right before the pavement coating due to the destruction, and in case of the coated pavement, it means the number of performance years right before the next coating or re-pavement (Kwon, 2002).

In this study, the pavement life data for the national highway under the jurisdiction of the Daejeon Regional Construction Management Administration is used.

For the classification of pavement sections maintained in 2011 according to the load, Low level for MESAL 0.0-0.10, Medium level for 0.11-0.30, and High level for over 0.31 are selected, and VI grades are classified as follows (A level: 1, B level: 2~3, C level: 4~7) (Pavement Management System).

The reliability analysis of road pavement is carried out with the Cox model (Proportional Hazards model) using the history data. The life data regression analysis of the MINITAB which is the statistics software is used for the Cox model analysis. The Cox model can be analyzed also with non-parametric method, but the Proportional Hazards model for the Weibull distribution is used in this study. For the convenience in the analysis, Low (0), Medium (1) and High (2) are substituted for the accumulated ESAL, and A level (0), B level (1) and C level (2) are substituted for the VI.

The following expression can be induced from the MINITAB result.

$$\hat{Y}_p = \alpha_0 + \alpha_1 \cdot x_1 + \alpha_2 \cdot x_2 + \alpha_3 \cdot x_1 x_2 + \sigma \varepsilon_p$$

Here, x1 and x2 are VI and ESAL respectively, and $\alpha_0$ is segment, and $\alpha_1, \alpha_2, \alpha_3$ are coefficients. And, $\sigma = 1 / \text{shape}$, and the shape parameter of Weibull distribution $\beta$ is 3.3219.

The Proportional Hazards model assumes that the influence of the stress variable on the Hazard rate is constant regardless of time. In order to examine the proportionality assumption, ln(-lnR(t)) curve which is called duplex log of reliability function or log-log conversion is used. Figure 2 shows the duplex log of the reliability function. If the curves in the graph don’t intersect and are parallel to each other as the result of this study, it is considered that the proportionality of hazard rate exists.

![Fig. 1. Cox model probability](image1)

![Fig. 2. Cox model diagnosis graph](image2)
In this study, performance regression model was developed using road pavement reliability due to road quality and cumulative ESAL, as shown in figure 3.

Fig. 3. Prediction of Reliability on the Road Payment according to ESAL and road quality by time

4 Conclusion

In this study, in order to predict the deterioration of road pavement according to the road quality and ESAL, the influence of the road quality and ESAL is analyzed using the pavement life data from the target areas by considering the load size and VI level. For the case analysis, the pavement life data of the section under the jurisdiction of the Daejeon Regional Construction Management Administration maintained in 2011 is analyzed.

The analysis result shows that the reliability of road pavement decreases according to the road quality and accumulated ESAL, the reliability of road decreases as the accumulated ESAL is higher even if the road quality is same.

And also, the reliability of road decreases as the level drops even if the ESAL is same.

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