Multiple Regression to Estimate the Lifespan of a Traffic Signal Controller

Jimyoung Park, Joong Soon Jang, Sang C. Park*

Department of Industrial Engineering, Ajou University, San 5, Woncheon-dong, Yeongtong-gu, Suwon, Korea.
*Corresponding author

Abstract

This paper proposes a lifespan estimation methodology for a traffic signal controller. While most of previous research results on reliability have attempted to estimate the lifespan of an entire system by obtaining and combining each component reliability, the proposed methodology utilizes a multiple regression approach to the lifespan estimation of a traffic signal controller. Since a traffic signal controller operates outdoors, it is well known that the lifespan is seriously affected by the environmental factors. In this paper, we choose three major environmental factors, temperature, humidity, and salinity. According to the proposed methodology, the multiple regression analysis on the lifespan of a traffic signal controller has been performed by using a commercial software application. As a result, we obtain a regression equation which can provide the essential information to construct an optimized maintenance plan that maximize availability, or minimize life cycle costs.

Keywords: Multiple regression, Lifespan estimation, Reliability evaluation, Environmental factors

INTRODUCTION

A traffic signal (or stoplight) directs vehicular traffic by means of colored lights. Typically, there are three colored lights: 1) red for stop, 2) green for go, and 3) yellow for proceed with caution. There are many traffic signals at intersections to direct or control traffic. These traffic signals are electronically operated, and they are controlled by a ‘traffic signal controller’ mounted inside a cabinet. The objective of a traffic signal controller is to coordinate to ensure that traffic moves as smoothly and safely as possible (Runping 1994; Aslani et al., 2017; Araghi et al., 2015), by controlling connected traffic signals at intersections.

Typically, a traffic signal controller controls multiple traffic signals at an intersection, and is installed and operated outdoors, as shown in Figure 1. The service providers, who are responsible for the maintenance of a traffic signal controller, have two objectives; 1) maximizing the traffic handling capacity of roads via proper utilization of the traffic signal controller, and 2) maximizing the availability of the traffic signal controller via proper maintenance activities. This paper focuses on the second objective, maximization of the availability of a traffic signal controller. Since a traffic signal controller is directly related to the safety issues, it is very important to maximize the availability by minimizing the failure time.

![Figure 1. Traffic signals (traffic lights) and a traffic signal controller](image1)

For the effective maintenance, it is essential to perform the lifespan estimation of a traffic signal controller. Due to the importance of the lifespan estimation, there have been many research results on the reliability of a system which is the ability to function under the stated conditions for a specified period (Kim, 2018; Bowles, 1992; Lee et al., 2006; Jones and Hayes, 1999; Pecht et al., 2002). Let $T$ denotes the time to failure of a facility, and $f(t)$ is the probability distribution function of $T$. At this time, the reliability of the facility at time $t$ can be defined as the probability that the facility fails after time $t$ ($t > 0$), and the reliability function can be stated as $R(t) = P(T > t) = 1 - \int_{0}^{t} f(x)dx$. In reliability engineering, the exponential distribution is popularly used, and this paper also assumes that $f(t) = \lambda e^{-\lambda t}$, where the parameter $\lambda$ (a failure rate) is such that $\frac{1}{\lambda}$ is the mean time to failure. Figure 2 shows some reliability functions for four types of typical system configurations.

![Figure 2. Reliability functions for typical system configurations](image2)
Although, there have been many previous research results, most of them focus on the reliability evaluation of system with small number of components. A traffic signal controller is a large system with thousands of components, and these previous results cannot be effectively applied to a traffic signal controller. Multiple regression (Eslamian et al., 2016; Catalina et al., 2013; Hanley, 2016) is a statistical technique that predicts values of one variable (dependent or response variable) on the basis of two or more other variables (independent or predictor variables). The objective of this paper is to propose a multiple regression approach to estimate the lifespan of a traffic signal controller. The overall structure of this paper is as follows. Section 2 addresses the overall approach to the lifespan estimation of a traffic signal controller, and Section 3 provides a detailed description of the proposed multiple regression methodology. Finally, some concluding remarks are provided in Section 4.

2. APPROACH TO LIFESPAN ESTIMATION OF A TRAFFIC SIGNAL CONTROLLER

Most of previous studies on reliability have attempted to estimate the lifespan of an entire system by obtaining and combining each component reliability (Cho et al., 2017; Jang and Park, 2017). These methods, however, are difficult to apply to complex systems consisting of thousands of components. To relieve the difficulties, we propose a multiple regression approach to the lifespan estimation of traffic signal controller. Since a traffic signal controller is installed and operated outdoors, the lifespan is significantly depends on the environmental conditions. Although, there are various environmental stresses (temperature, salinity, humidity, vibration, and radiation) affecting to the lifespan of a traffic signal controller, this paper chooses three major environmental factors, temperature, humidity, and salinity. In the case of temperature (℃) and humidity (%), it is well known that the operating temperature and humidity affect the reliability of electronic components. The third factor, airborne salinity, refers to the content of gaseous and suspended salt in the atmosphere. The salt, deposited on the metal surface, accelerates the metal corrosion. Usually, the airborne salinity is measured in terms of deposition rate in units of mg/m²/day.

Multiple regression analysis is a useful tool when we are trying to develop a model for predicting a dependent or criterion variable from several independent predictor variables. In this paper, the dependent variable becomes the lifespan of a traffic signal controller. To construct a model predicting the lifespan of a traffic signal controller, it is necessary to collect data from real world. To collect such data, we need to implement a real time monitoring system into a conventional traffic signal controller. The monitoring system needs to have sensors monitoring environmental factors including temperature, humidity, and salinity. At this time, the monitoring system should be able to detect the failures of a traffic signal controller while collecting the environmental information. After the monitoring system is built, it is necessary to accumulate data for several years. In reality, however, it is very difficult to obtain such real data, so we generate a dataset through a simple simulation model.

![Figure 3. Collected data from a simulation model](image-url)

![Figure 4. Relationship between lifespan & temperature, humidity, and salinity](image-url)
Figure 3 shows a data set generated from a simulation model, and it includes 100 instances. Each instance includes temperature (°C), humidity (%), salinity (mg/m³/day), and lifespan (hours). Figure 4 shows three graphs, representing the relationship between lifespan of a traffic signal controller and the three environmental factors. As shown in Figure 4, we can observe that negative relationships between the lifespan and the three environmental factors. For the multiple regression analysis, we employ a commercial software application, 'Minitab'.

The result of multiple regression analysis on the lifespan of a traffic signal controller is shown in Figure 5. The regression equation shows the effect of the three environmental factors (temperature, humidity, and salinity) on the lifespan of a traffic signal controller which operates outdoors during the entire life cycle. As shown in Figure 5, the regression equation becomes \( \text{Lifespan} = 41829 - 99.32(\text{Temperature}) - 37.01(\text{Humidity}) - 1022.0(\text{Salinity}) \), and the R-squared value is 72.57% which represents the percentage of the lifespan variation that is explained by the regression equation. Generally, the larger R-squared value means the better explanatory power of the regression equation. In this way, we can obtain the regression equation estimating the lifespan of a traffic signal controller, and this information plays a vital role in preparing an optimized maintenance polices that maximize availability, or minimize life cycle costs.

DISCUSSION AND CONCLUSIONS

Traffic signals are controlled by a traffic signal controller mounted inside a cabinet, and a traffic signal controller operates outdoors during the entire lifespan. Since the unexpected failures of a traffic signal controller may cause various safety issues, it is very important to estimate the lifespan of a traffic signal controller. Most of previous studies on reliability have attempted to estimate the lifespan of an entire system by obtaining and combining each component reliability. These methods, however, are difficult to apply to complex systems consisting of thousands of components.

To relieve the difficulties, this paper proposes a multiple regression approach to the lifespan estimation of traffic signal controller. Since a traffic signal controller operates outdoors, it is well known that the lifespan of a traffic signal controller is seriously affected by the environmental factors. Although, there are various environmental stresses (temperature, salinity, humidity, vibration, and radiation) affecting to the lifespan of a traffic signal controller, this paper chooses three major environmental factors, temperature, humidity, and salinity. According to the proposed methodology, we perform the multiple regression analysis of the lifespan of a traffic signal controller by using a commercial software application. As a result of the multiple regression analysis, we obtain a regression equation explaining the effect of the three environmental factors (temperature, humidity, and salinity) on the lifespan of a traffic signal controller. The regression equation can provide the essential information to construct an optimized maintenance plan for traffic signal controllers.

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