International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 8 (2018) pp. 6052-6055

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.

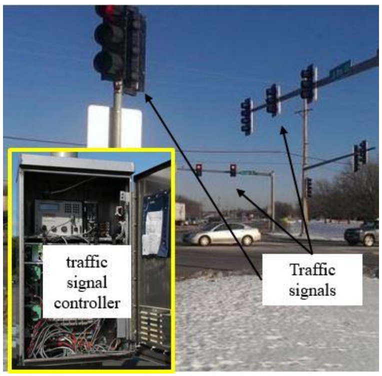


Figure 1. Traffic signals (traffic lights) and a traffic signal controller

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.

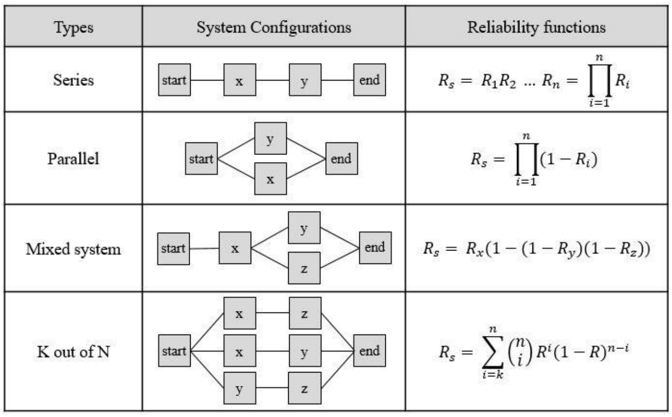


Figure 2. Reliability functions for typical system configurations

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 $\mathrm{R(t)} = P(T > t) = 1 - \int_0^t f(x)dx$. In reliability engineering, the exponential distribution is popularly used, and this paper also assumes that $f(t) = \lambda e^{-\lambda t}$, where the parameter λ (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.

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/m^2/day.

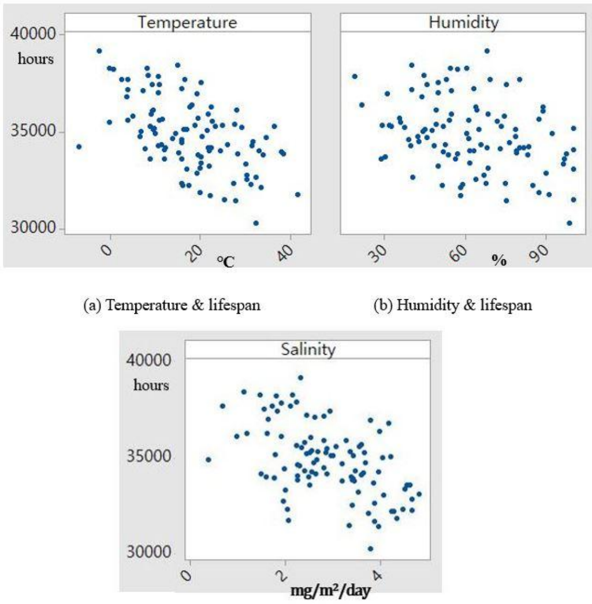
Multiple regression analysis is a useful tool when we are trying to develop a model for predicting a dependent or criterion variable from several independent predictor variables. In this paper, the dependent variable becomes the lifespan of a traffic signal controller. To construct a model predicting the lifespan of a traffic signal controller, we consider three environmental factors (temperature, humidity, and salinity) as independent variables. A traffic signal controller operates outdoors, and its lifespan is known to be closely related to the environmental factors. As a result of the multiple regression, we can obtain a regression equation explaining the relationships between the lifespan of a traffic signal controller and environmental factors. Once a regression equation is obtained, it can be very useful to make an effective maintenance plan for traffic signal controllers.

MULTIPLE REGRESSION FOR LIFESPAN ESTIMATION

To perform the multiple regression analysis of 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.

	C1 Temperature	C2 Humidity	C3 Salinity	C4 Life-span
1	18.7166	28.979	3.33551	35334.7
2	21.9258	49.823	3.52554	33240.7
3	15.7016	74.689	4.45213	32355.0
4	13.8022	60.881	2.24480	34652.3
5	21.5175	47.210	4.19027	35084.1
6	17.3096	84.931	4.25811	32240.6
7	14.4493	60.173	2.63704	34891.7
8	36.2169	32.396	2.50164	35299.1
9	3.5923	43.561	4.14939	36792.1
10	8.7354	51.357	3.65344	35288.2
11	15.9519	51.067	4.22091	32203.8
12	21.5595	68.255	2.78399	35892.8
13	30.2916	66.503	1.94822	32760.0
14	9.4832	78.242	3.41545	35136.9
15	15.6942	62.756	2.42855	37216.1
16	41.5375	90.862	2.04214	31737.8
17	27.8125	74.855	3.94046	31458.0
18	6.7200	44.150	4.02133	35011.2
19	9.1381	88.691	2.51097	36056.7
20	-0.2230	35.535	2.85316	35484.6
21	10.6359	49.676	1.61152	37050.5
22	27.9625	64.093	0.94790	36118.9
23	16.8704	100.000	4.04499	33077.9
24	22.3352	80.045	1.46132	34193.9
25	24.8283	31.379	2.66369	35348.9
26	15.8742	75.966	1.96387	34459.8
27	31.4067	39.367	2.54473	34287.8
28	29.9996	96.158	1.97310	33314.5
29	10.8097	75.095	1.80228	37452.4
30	32.8935	63.003	1.57981	34032.4
31	17.5663	88.471	1.60685	36280.6
32	3.7728	52.748	2.08456	37700.2
33	24.3944	78.727	3.36468	34035.2
34	11.2489	65.480	3.46209	34338.8
35	33.4091	58.094	3.73309	32117.4
36	-2.4281	67.784	2.30324	39163.0
37	30.1491	63.704	3.38503	32532.2
38	10.8398	53.899	3.53773	35608.8
39	16.3745	79.759	0.65697	37706.6
40	3.7769	60.969	3.05732	35612.6
41	-0.2389	54.245	2.13874	38298.6
42	19.0607	89.592	4.65468	32876.6
43	22.5894	71.598	2.31666	35532.7
44	16.8218	64.947	2.93873	35110.6
45	32.1847	40.078	3.85777	32653.5
46	19.8193	87.113	4.32976	31836.7
47	19.3064	35.193	3.57620	35729.2
48	0.6959	56.707	1.78342	38255.5
49	-7.0554	83.485	3.61250	34227.1
50	6.5496	78.512	3.66522	34768.1
51	15.0071	78.642	3.40831	33910.9
52	17.9831	21.221	3.96191	36375.5
53	38.3022	56.849	2.23954	33876.7
54	20.3863	42.031	2.57031	34769.4
55	9.4813	49.051	1.88451	36119.9
56	33.8459	53.416	3.17120	33809.6
57	37.8325	51.512	1.73821	33944.7
58	3.9144	39.915	2.80052	37170.2
59	27.3920	67.333	2.02116	32331.2
60	8.7096	28.386	4.59408	33574.6
61	19.7884	68.189	4.78574	33121.8
62	21.8844	61.304	2.47994	34023.9
63	27.5671	48.725	2.53626	35381.3
64	23.1204	73.047	2.82366	35280.1
65	10.6907	18.573	1.89444	37866.3
66	29.1605	37.163	2.42627	35227.7
67	4.9385	74.358	2.38625	35804.4
68	9.9625	92.083	0.34938	34903.6
69	7.5567	72.882	3.57210	34120.7
70	15.6674	56.096	4.54330	33587.1
71	11.9208	96.577	2.49857	33596.6
72	25.9339	52.148	2.38947	34310.8
73	8.1584	60.046	1.44080	38305.2
74	2.3674	68.915	1.70902	37691.9
75	8.9581	54.573	3.25043	35911.7
76	15.7507	38.610	2.27813	34588.9
77	34.5525	45.622	3.17663	34723.1
78	10.5760	48.101	3.94207	34301.2
79	12.2686	67.689	2.86384	34194.7
80	20.1061	29.955	3.83694	33683.2
81	28.2418	97.180	3.38179	33884.3
82	19.1326	30.638	3.76615	36974.3
83	22.4051	63.692	1.17393	36288.2
84	32.1891	98.588	3.77328	30281.0
85	25.1949	100.000	3.32060	31480.7
86	14.9297	39.976	1.09517	38474.4
87	8.3676	44.304	2.22429	37940.3
88	16.2051	44.892	2.98558	35123.9
89	7.2543	54.567	2.59586	37113.8
90	20.0727	61.383	4.49438	33374.8
91	9.7386	100.000	1.77205	35175.4
92	22.0947	58.147	3.85178	31709.2
93	31.6892	42.269	2.79022	34477.7
94	31.0709	58.865	4.64496	32260.1
95	20.0575	49.636	1.52627	37530.9
96	21.7103	81.361	2.62477	34172.0
97	19.3634	82.827	3.43246	33800.0
98	11.3890	87.268	2.20484	35651.4
99	9.3320	45.355	2.91358	37460.2
100	11.8807	100.000	2.22904	34052.7

Figure 3. Collected data from a simulation model



(a) Temperature & lifespan (b) Humidity & lifespan

(c) Salinity & lifespan

Figure 4. Relationship between lifespan & temperature, humidity, and salinity

Figure 3 shows a data set generated from a simulation model, and it includes 100 instances. Each instance includes temperature (℃), humidity (%), salinity ($mg/m^2/day$), 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, 'Minitap'.

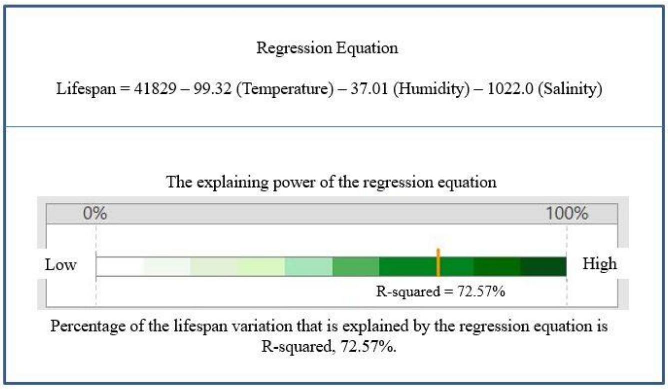


Figure 5. Result of the multiple regression analysis

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 'Lifespan = 41829-99.32(Temperature)-37.01(Humidity)-1022.0(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.

ACKNOWLEDGEMENT

This work was supported by a grant (17CTAP-C129828-01) from Infrastructure and transportation technology promotion research program funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCE

[1] Araghi S, Khosravi A, Creighton D (2015) Intelligent cuckoo search optimized traffic signal controllers for multi-intersection network. Expert Systems with Applications; 42: 4422-4431

[2] Aslani M, Mesgari M, Wiering M (2017) Adaptive traffic signal control with actor-critic methods in a real-world network with different traffic disruption events. Transportation Research Part C; 85: 732-752

[3] Bowles JB. (1992). A survey of reliability-prediction procedures for microelectronic devices, IEEE Transactions on Reliability 41(1):2-12.

[4] Catalina T, Lordache V, Characaleanu B. (2013). Multiple regression model for fast prediction of the heating energy demand, Energy and Buildings, 57: 302-312.

[5] Cho KH, Jang JS, Park SC. (2017) NHPP model based reliability growth management of a hybrid DC-DC converter, International Journal of Applied Engineering Research, 12(17): 6919-6928.

[6] Eslamian SA, Li SS, Haghighat F. (2016). A new multiple regression model for predictions of urban water use, Sustainable Cities and Society, 27:419-429.

[7] Hanley JA. (2016). Simple and multiple linear regression: sample size considerations, Journal of Clinical Epidemiology, 79:112-119

[8] Jang JS, Park SC. (2017). A reliability model for a wafer FAB, Cogent Engineering, 4:1-10

[9] Jones, J. and Hayes, J. (1999). A Comparison of electronic reliability prediction models, IEEE Transactions on Reliability, 48(2): 127-134.

[10] Kim H (2018) Maximization of system reliability with the consideration of component sequencing. Reliability Engineering & System Safety; 170: 64-72

[11] Lee, S. W., Han, S. W. and Kim, W. D. (2006). Reliability evaluation system of electronics components, Key Engineering Materials, 326 (328): 569-572.

[12] Pecht, M., Das, D. and Ramakrishnan, A. (2002). The IEEE standards of reliability program and reliability prediction methods for electronic equipment, Microelectronics Reliability, 42(9): 1259-1266.

[13] Runping Z. (1994) A new model for delay at isolated-signal control. IFAC Proceedings Volumes; 27(12): 909-911