2020 Disaster Resilience Data Science Competition

Diurnal temperature variation effect on the bridge maintenance in Maryland

1. Introduction:

The state of Maryland has 5,402 bridges, averaging an age of 49.42 years. Due to global warming's effects, climate patterns may be different than those fifty years ago. Regarding bridge engineering, movement, or deformation caused by temperature variations may affect bridge service life and maintenance cost. In the current design code (AASHTO LRFD), the temperature change is considered to be a long-term effect, including yearly highest and lowest temperatures. However, the thermal effect causes bridges to expand and contract in the short-term as well due to daily temperature variation, which is not considered. The daily thermal movement causes cyclic loading on bridge elements, which may lead material to fatigue or potentially fail. The deck cracking and expansion joint clogging are the most common damages in bridge superstructures. If these damages are not detected and repaired in time, further significant damage may occur, leading the entire bridge system to fail, traffic systems to deteriorate, and potential for loss of human life.

This project collects the temperature data in the state of Maryland from the past forty years and creates the maximum daily temperature variation models based on the diurnal temperature data. Based on the temperature variation data, the movement of the bridge superstructure could be estimated by a long-term and continuous monitoring of bridge girders' displacement sensor shown in figure 2. This project would propose maintenance recommendations for bridges in Maryland to accommodate for those climate patterns.

This project collects forty years' worth of diurnal temperature data from four sites in Maryland, which are Cumberland, BWI, Salisbury, and Bethesda, to represent Zone 1, Zone 2, Zone 3 and Zone 4, respectively. All Maryland counties are also divided into four zones listed in Table 1 and shown in figure 1.

Zone 1 (Agricultural Non-Coastal): These counties are largely comprised of farmland with few smaller cities within them. These counties are located in the northwestern direction of the state of Maryland and are not adjacent to bodies of water. This area is mostly farmland but also has mountainous areas.

Zone 2 (Agricultural North Coastal): These northern counties are primarily flat farmland but have coastland in some parts of the county.

Zone 3 (Agricultural South Coastal): These southern counties are primarily flat farmland but have coastland in some parts of the county.

Zone 4 (Urban): These counties are the most urban of all the counties in Maryland. These counties have a large city with substantial suburban areas around them.

Zone/ Station	1 Cumberland	2 BWI	3 Salisbury	4 Bethesda
Number of Bridges	880	2161	519	1831
Counties	Allegany Washington Carroll Garrett	Baltimore (City) Kent Cecil Queen Anne Harford Caroline Anne Arundel	Wicomico Dorchester Somerset Worcester Talbot Calvert St. Mary Charles	Montgomery Prince George Howard Frederick

Table 1. Stations and Maryland counties list

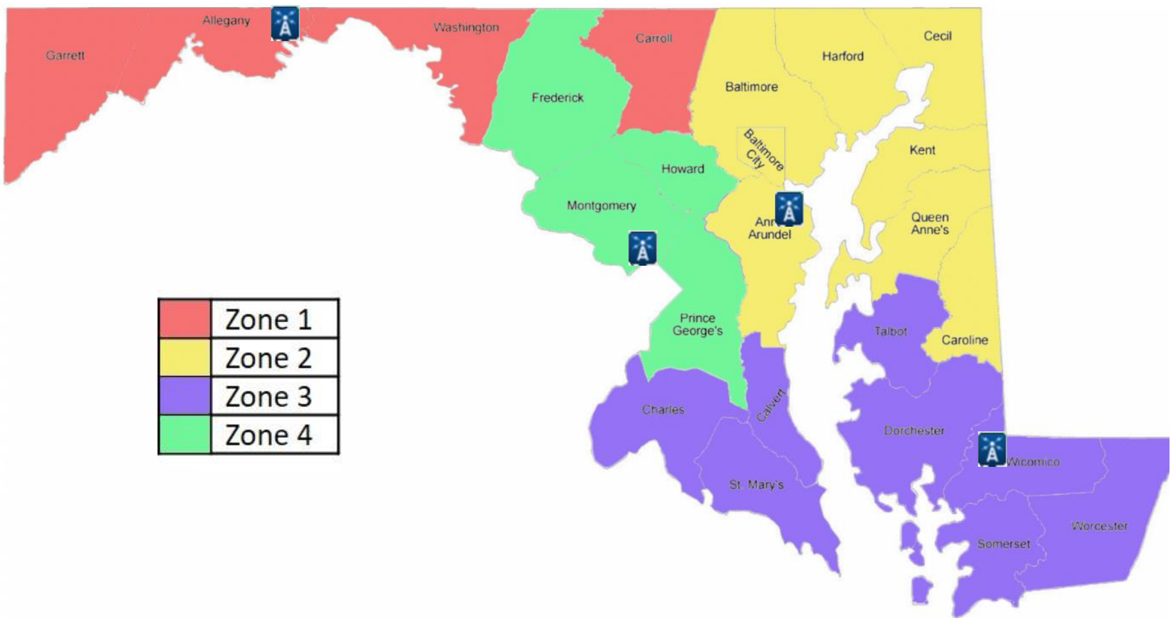

Figure 1. Maryland county map with zones and stations

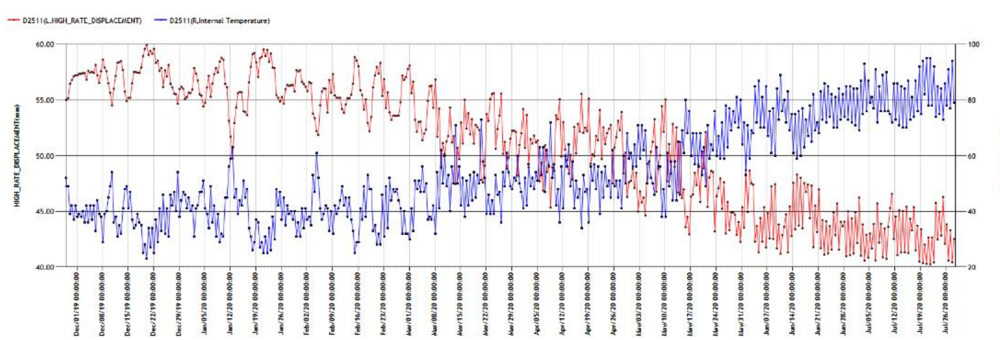

Figure 2. 11/28/19-7/28/20 Girder displacement and temperature monitoring in Zone 2

2. Analysis:

In order to see if the daily temperature change increases or decreases in the past forty years, the mean, mode, and median of the yearly temperature variation of four stations are plotted in figure 3. Since high-temperature variation is more critical to the thermal effect on

bridges, the count of the temperature variation above 20°F is plotted in figure 4. We perform a temperature variation frequency analysis and specifically focus on the difference between the highest and the lowest temperature in one day from 1979 to 2019. The annual maximum temperature variation series and the peak value of each year are indicated in the time-series plot shown in figure 5. We use the Generalized extreme value distribution to fit the annual maximum temperature variation data set because we are more interested in the occurrence of severe incidents. Based on the distribution, we estimate the possible maximal temperature variation associated with the return periods: 10, 100, and 500-year.
Generalized extreme value:

$$= f(x|k,\mu,\sigma) = \left(\frac{1}{\sigma}\right)\exp\left(-\left(1+k\frac{(x-\mu)}{\sigma}\right)^{-\frac{1}{k}}\right)\left(1+k\frac{x-\mu}{\sigma}\right)^{-1-\frac{1}{k}}$$

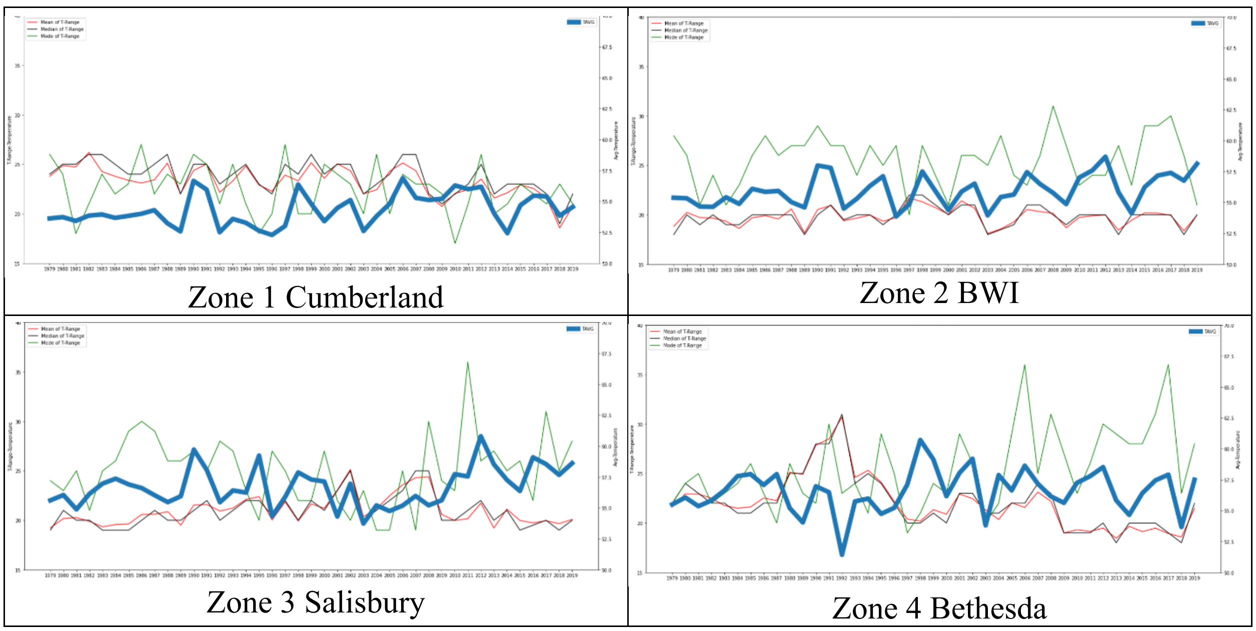

Figure 3. Mean, mode and median of yearly temperature variation

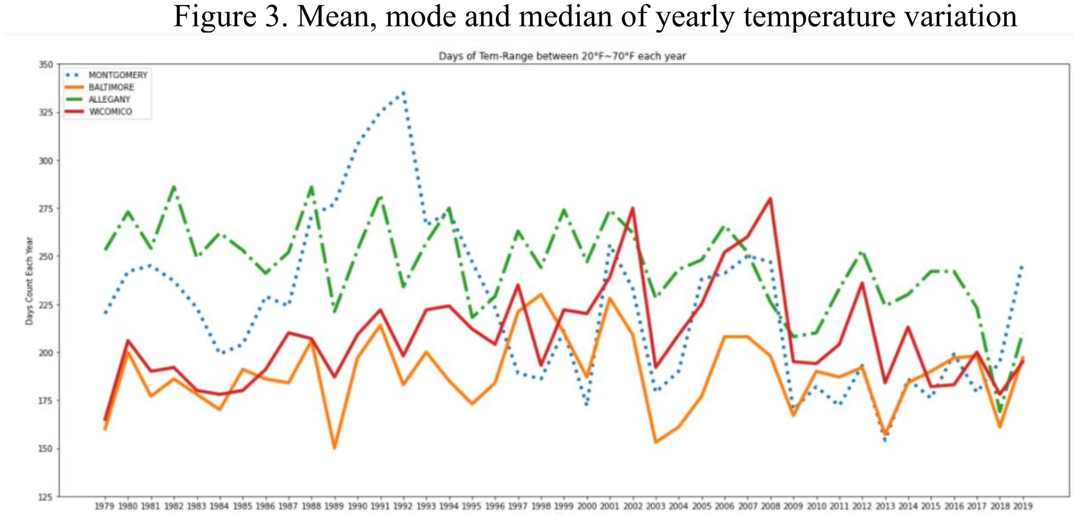

Figure 4. Yearly count of the temperature variation above 20°F

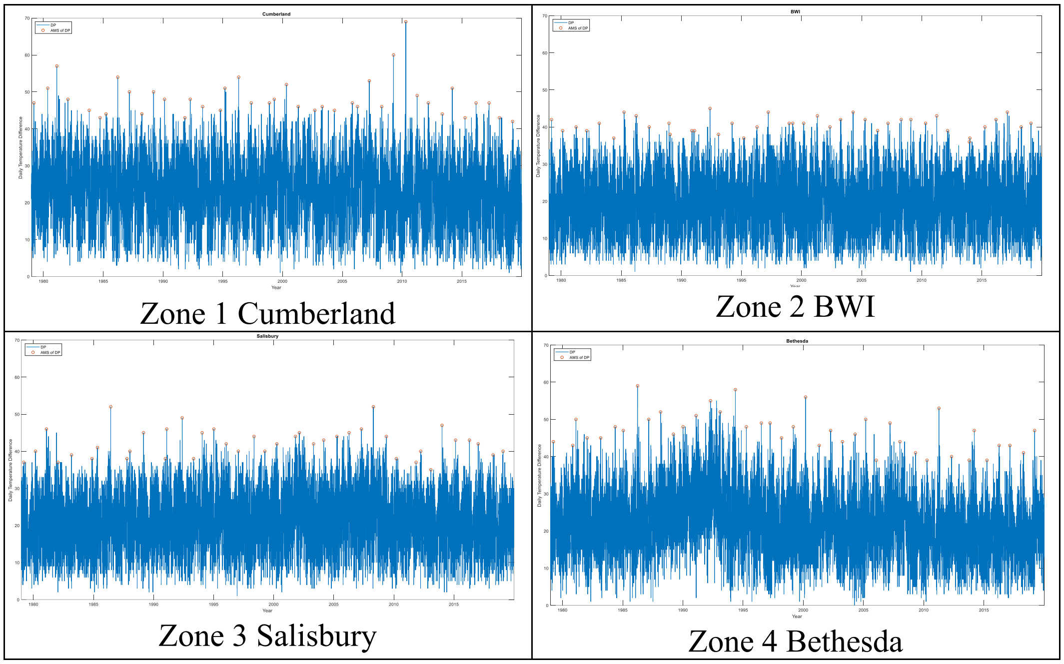

Figure 5. Time-series of daily maximal temperature variation

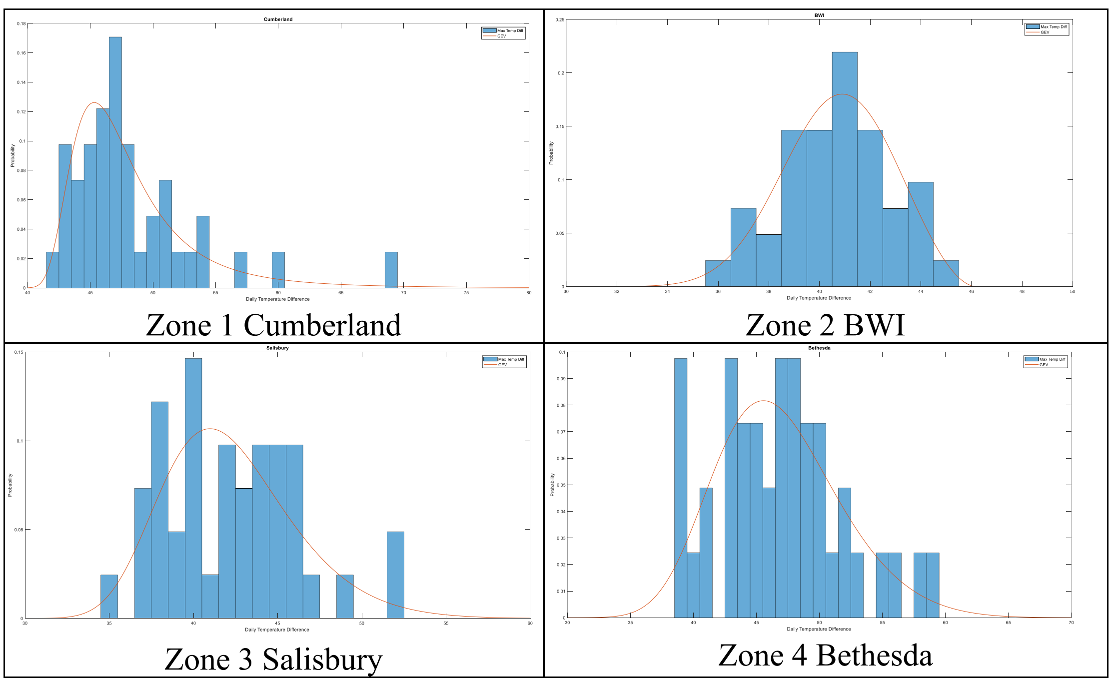

Figure 6. Normalized Freq diagram of annual max temperature variation w/ fitted PDFs

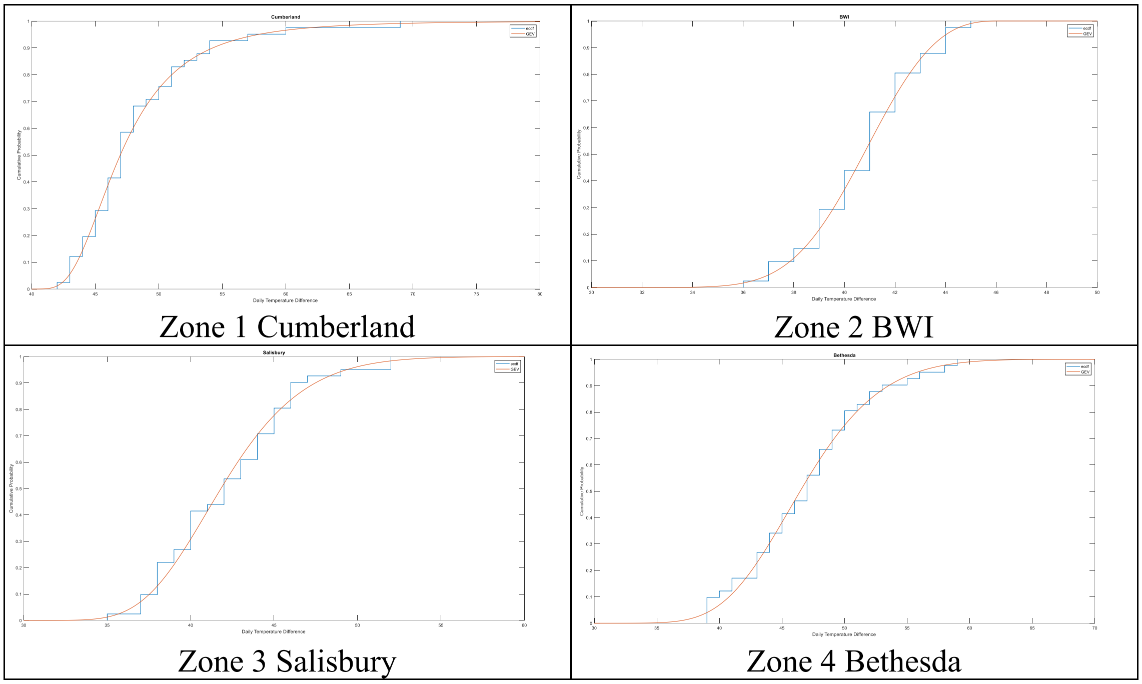

Figure 7. eCDF of the annual max temperature variation along with the fitted CDFs

3. Conclusion

According to the yearly mean, median, and mode plot of four stations, there are fluctuated trends and insignificant trends to show the number of high-temperature change increases or decreases from the past forty years. Based on the forty years diurnal temperature variation of four stations, the maximal temperature variation of the 10, 100 and 500-year return period are listed in Table 2. The highest temperature variation in one day is more likely to happen in zone 1. There are the most bridges in the urban area, and relatively high-temperature variation is more likely to happen there than in the north and south coastal area. However, there is a potential blind spot of using daily highest and lowest temperatures that temperature change may vary continuously over a 24-hour time range, shown in figure 2. In figure 5, some PDF distribution seems not to be consistent with the bar chart pattern. More data set might be helpful to enhance fitting accuracy. There is a common scenario among four zones. March, April, and May cover 35% to 42% of the temperature variation above 30°F. September and October cover 23% of temperature variation above 30°F in the zone 1, but 19% to 23% above 30°F temperature variation occurs from October to November in the zone 2, 3 and 4. The state's DOT may schedule bridge inspection during or after this high probability period. More budget on maintenance cost is needed in zone 1 because more frequent cyclic load caused by larger thermal expansion or contraction may cause bridge elements to fatigue sooner. For the girder movement monitoring, there is about 5% of 243 days that the daily temperature changes exceed 20°F. The girder of the superstructure with a roller-roller bearing condition is released horizontally, and the girder movement is from 4.3 to 7.36 (mm) when the temperature changes above 20°F. According to the 10-year return period data, the highest movement of girder may reach 15 mm in 24 hours. This movement could be applied in the finite element software to evaluate structural tolerance due to thermal effect when an extreme incident occurs.

Return Period	1. Cumberland	2. BWI	3. Salisbury	4. Bethesda
10 Years	54.25 °F	43.40 °F	47.46 °F	53.52 °F
100 Years	68.06 °F	44.97 °F	53.02 °F	59.94 °F
500 Years	82.01°F	45.50 °F	56.07 °F	63.19 °F

Table 2. Maximal temperature variation of the return period

4. Reference:

[1] ENCE 433/633 – Assessment of Natural Hazards for Engineering Applications, Michelle Bensi, 2019.
[2] Monitoring fatigue life in concrete bridge deck slabs, Newhook, J., Limaye, V, 2007.
[3] AASHTO LRFD 2012 Bridge Design Specifications 6th.
[4] NCHRP 20-07/106 - Thermal Movement Design Procedure for Steel and Concrete Bridges, Charles W. Roeder.
[5] Generalized Extreme Value Distribution, MATLAB.
[6] https://www.ncdc.noaa.gov/cdo-web/search?datasetid=NORMAL_DLY

5. Team member info:

Kuang-Yuan Hou (vtmac23@gmail.com)
Ph. D Candidate, Civil & Environmental Engineering

Po-Hsun Chiu (Lucaschiu840118@gmail.com)
Master student, Business Analytics

Lena Bakalian (bakalian@terpmail.umd.edu)
Undergraduate, Civil & Environmental Engineering