Crash Reduction Analysis of Friction Enhancements in Georgia

Final Project: Special Research Problem CEE 4699

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# Abstract

# Introduction

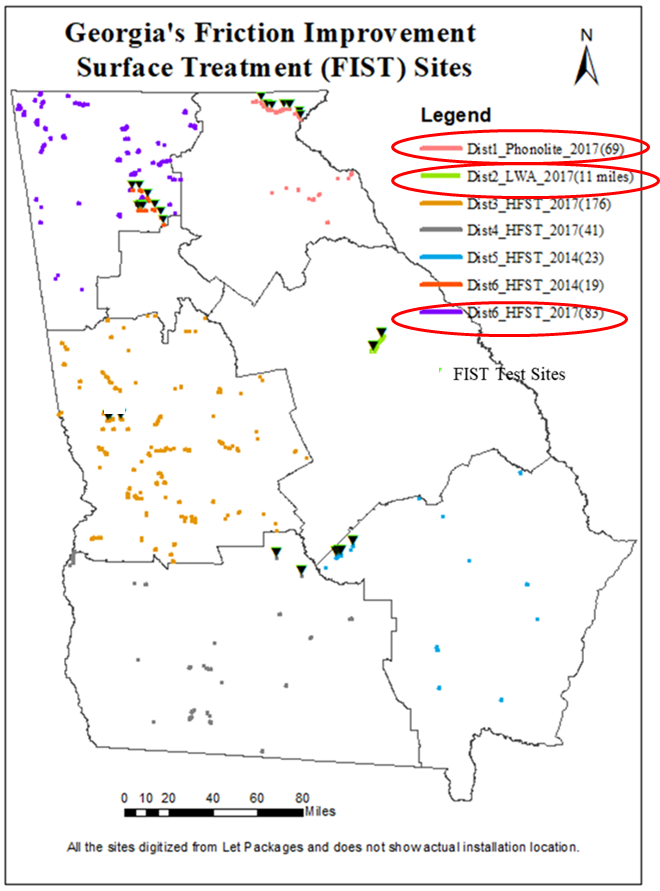
Curve-related crashes represent approximately 25% of all roadway fatalities, and roughly 70% of these crashes are due to roadway departures (ref). To mitigate roadway and lane departure crashes, a common treatment utilized is high friction surface treatment or HFST. HFST is rough aggregates bonded to a roadway surface with an epoxy known as calcined bauxite. HFST is a proven safety counter measure (ref FHWA). It is usually implemented alongside other safety treatments such as signage, rumble strips, etc. HFST and other friction improvements have been implemented in hundreds of sites in Georgia (ref HFST report GA). To analyze the effectiveness of friction improvements, the long-term friction of sites is often assessed and the crash reduction that occurred is assessed. Crash modification factors are a quantifiable measure of the crash reduction of a safety treatment.

Georgia has implemented HFST and two other friction improvements. These friction improvements are called Light weight aggregate (LWA) and phonolite. Light weight aggregate is an alternative aggregate used as a resurfacing material, and phonolite is an alternative epoxy-based friction improvement. Phonolite has been implemented in Wyoming and is often referred to as Wyoming Bauxite (ref HFST report).

Crash modification factors have not been developed in Georgia to assess the effectiveness of HFST and other implemented friction improvements. It is critical to develop CMFs for state specific conditions because the roadway environment between states is not necessarily the same, and different states have different strategies for the implementation of HFST. Additionally, no published CMFs have been developed for LWA and phonolite.

The objective of this study is to analyze the effectiveness of HFST and other friction improvements in Georgia. The various friction improvements are to be compared. Additionally, the crash types that HFST reduces the most of are assessed. Furthermore, relevant roadway characteristics that lead to a higher reduction in HFST are analyzed. This study uses Empirical Bayes and Naïve Bayes methods to develop crash modification factors, and a methodology is proposed to assess relevant crash types reduced and critical roadway characteristics that influence the effectiveness of HFST.

# Background



The three FISTs, HFST, phonolite, and LWA, ~

* FIST was implemented in GA in the locations above
* The locations circled in red are studied.
* Three treatments
  + Phonolite: detailed description of material
  + LWA: detailed description of material
  + Calcined bauxite (HFST): detailed description of material
* Discuss the three treatments implemented in ga and their number. Reference our HFST report
* Discuss life cycle of the three treatments
* Discuss David Merrits paper, and his methodology, what states did he do
* Mention that there is no published CMF for HFST in GA
* Note that though friction data was recorded, high quality friction data before and after HFST implementation is not available and is not considered
* Data used
  + Crash data comes from GDOTs Numetric
  + Roadway information comes from GDOT’s safety program
  + HFST locations are identified from a concurrent project (reference project)

# Methodology

## Spatial analysis:

Crash data was provided by the Numetric platform maintained by GDOT (ref), and curve data was provided by [source]. The crash data was formatted as a collection of points that included information such as the crash location, date of the crash, vehicles involved, and what the vehicles were doing as the collision occurred. The curve data was formatted as a collection of polylines, best described as connected lines, and included information such as the curve location, length, radius, deflection angle, ball-bank indicator reading, speed limit, advisory speed, and AADT.

There were some challenges with curve AADT, as the (more from Ron, I’m not sure of the exact details).

To separate crashes that occurred on curves from the rest of the dataset, a buffer was constructed around curves. These buffers had a width of 100 ft around the road and extended 500 ft beyond the road polyline to capture as many curve crashes that as possible, even if they had been mislabeled in location.

Photo example of buffer

After identifying which crashes occurred on curves, the remaining crashes were manually examined to determine whether the crash occurred because of the curve or if it occurred because of external factors, such as intersections located on the curve or animal collisions. Crashes that occurred due to external factors were removed from the data, and the remaining data would be used for the crash modification factor analysis.

* 1. Describe spatial analysis procedure to join curves to crashes.
  2. Describe some of the effort to attribute AADT to the curve. Describe the curve data availability.
  3. Curve data was developed from a Georgia tech application curve finder, which has given this research team a curve inventory on all GA state routes

## Naïve bayes approach to develop CMFs:

The first method used to quantify the crash reduction effects of FISTs in this study was the Naïve Bayes approach. The Naïve Bayes approach is a straightforward yet less accurate way of calculating CMFs as it simply uses average number of crashes per year after the treatment was implemented divided by the average number of crashes occurred before the treatment was implemented. In this study, the crash data from 2012 to 2020 was obtained from GDOT *Numetric* GIS, and the data of the year the FIST was implemented was abridged. For example, for district 6, HFST was implemented in 2016, thus, sum of crashes from 2012 to 2016 is divided by 4 (number of years between 2012 to 2015) to get average number of crashes per year before the HFST was implemented, and sum of crashes from 2017 to 2020 was divided by 3 (number of years between 2017 to 2020). Other than total CMF, other customized CMFs that are specific to different crash-related driver and road environment characteristics were also calculated to help researchers understand whether certain HFST has an unexpectedly good or poor effect on certain types of crashes that cannot be reflected through the total CMF. For example, a CMF on wet roads was calculated to see whether HFST would maintain a similar level crash reduction efficacy during rainy or snowy days.

Crash modification factor, or CMF, is used to assess the efficacy of different HFSTs in terms of percentage of crash reduction after the treatment. CMFs are calculated using the formula: . Thus, a CMF of 0.75 means that the treatment brings 25% crash reduction to the studied locations, and a CMF more than one means this CMF is not helping to reduce the crash in a specific studied area.

* 1. Simple before and after.
  2. This was utilized to get a preliminarl look at the crashes and identify which crash types EB cmfs should be developed for

## Development of prediction models.

* 1. 5 prediction models are developed.
  2. Say potential variables used.
  3. Models assessed based on goodness of fit,p-value of variables, and preliminary basis of a concurrent study to develop high quality SPFs for network screening purposes (reference my paper)
  4. SPFs are developed for rural curves in GDOT districts 1,2, and 6 the dependent variable of the spf is the crash frequency on each curve

## Use Empirical Bayes Method to develop high quality CMFs

A flaw of the Naïve Bayes method is that the effects of external factors such as changes in traffic volume or other time trends on CMFs are not accounted for. The Empirical Bayes Method can address these time trend factors in the calculations of CMFs by not just using observed crashes on a curve but by also using the predicted number of crashes generated by the prediction models. These predicted numbers of crashes are used to represent the number of crashes that should’ve occurred had the FIST not been applied to the curve, and the observed crashes are essentially weighed against these predictions to adjust the CMF.

For example, a curve that had a FIST implemented but also a significantly higher traffic volume could possibly observe a higher number of crashes after the FIST. Using a Naïve Bayes approach, the number of crashes would suggest that the FIST caused an increase in crashes. However, using an Empirical Bayes approach would weigh the observed crashes against the prediction—which would predict that crashes should increase due to increased traffic and not because of the FIST—and thus decrease the final calculated CMF accordingly.

To weigh the observed (O) against the predicted (P) crashes, the two values are first combined into an expected (E) number of crashes for both before and after FIST. The expected number of crashes before the FIST is found using a weight *w* and the following equation:

The weight *w* can be calculated by using *k*, the dispersion of the prediction model, and the following equation:

The expected number of crashes after the FIST is found using the following equation:

The variance (*V*) of the expected crashes after is then found using the following equation:

Lastly, the final CMF is calculated:

CMFs using the Empirical Bayes approach were calculated for the phonolite/Wyoming bauxite treatment and HFST. Multiple CMFs were calculated, depending on which crash filters were applied before calculation: the filters included 1) all crashes, 2) single vehicle crashes, 3) crashes with the “Negotiating a curve” maneuver, and 4) crashes with wet road conditions.

* 1. This is done to account for changes in traffic volume over time
  2. Describe the methodology and equations used in detail

## Model CMFs as functions of the roadway environment

* 1. CMF is the dependent variable
  2. In a linear model various characteristics are assessed

# Results

## Naïve Bayes CMFs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | CMF | Crash frequency before  implementation  (2013-2016) in crashes/year | Crashes after implementation  (2018-2020) in crashes/year | CMF Value |
| Phonolite/Wyoming Bauxite | All Crashes | 41.75 | 40.00 | 0.9581 |
| Single Vehicle | 27.25 | 24.67 | 0.9052 |
| Curve | 27.25 | 20.67 | 0.7584 |
| Wet Road | 8.75 | 9.33 | 1.0667 |
| LWA | All Crashes | 5 | 6.33 | 1.2667 |
| Single Vehicle | 3.75 | 3.67 | 0.9778 |
| Curve | 0.33 | 1.00 | 0.3333 |
| Wet Road | 1 | 0.25 | 4.0000 |
| HFST | All Crashes | 167.00 | 113.67 | 0.6806 |
| Single Vehicle | 111.50 | 61.33 | 0.5501 |
| Curve | 117.00 | 72.00 | 0.6154 |
| Wet Road | 56.25 | 26 | 0.4622 |

## 

## Developed SPFs:

Table number: Total Crashes SPF Coefficients

|  |  |  |  |
| --- | --- | --- | --- |
| Label | Estimate | Divided by number of years | P value |
| Intercept | -4.345000 | -0.543125 | < 2e-16 \*\*\* |
| Divided road | 0.332100 | 0.0415125 | 1.32e-08 \*\*\* |
| Natural log of deflection angle | 0.247400 | 0.030925 | 2.67e-11 \*\*\* |
| Length | 0.000221 | 2.76375E-05 | 1.18e-10 \*\*\* |
| Natural log of AADT | 0.649600 | 0.0812 | < 2e-16 \*\*\* |
| Dispersion | 1.233000 |  | |
| Years | 8 |
| R2 | 0.491146 |

Table number: Single Vehicle Crashes SPF Coefficients

|  |  |  |  |
| --- | --- | --- | --- |
| Label | Estimate | Divided by number of years | P value |
| Intercept | 2.878000 | 0.35975 | < 2e-16 \*\*\* |
| Divided road | -0.270400 | -0.0338 | 3.95e-08 \*\*\* |
| Natural log of deflection angle | 0.141300 | 0.0176625 | 0.000409 \*\*\* |
| Length | 0.000408 | 5.09625E-05 | < 2e-16 \*\*\* |
| Natural log of AADT | 0.378700 | 0.0473375 | < 2e-16 \*\*\* |
| Natural log of BBI | 0.146800 | 0.01835 | 5.22e-07 \*\*\* |
| Speed limit and advisory speed difference | 0.015740 | 0.0019675 | 1.43e-05 \*\*\* |
| Dispersion | 2.604400 |  | |
| Years | 8 |
| R2 | 0.323600 |

Table number: Curve Crashes SPF Coefficients

|  |  |  |  |
| --- | --- | --- | --- |
| Label | Estimate | Divided by number of years | P value |
| Intercept | -5.882000 | -0.73525 | < 2e-16 \*\*\* |
| Divided road | -0.269500 | -0.0336875 | 2.59e-06 \*\*\* |
| Natural log of deflection angle | 0.630000 | 0.07875 | < 2e-16 \*\*\* |
| Length | 0.000093 | 1.16363E-05 | 0.0198 \* |
| Natural log of AADT | 0.497900 | 0.0622375 | < 2e-16 \*\*\* |
| Natural log of BBI | 0.254800 | 0.03185 | 4.94e-14 \*\*\* |
| Speed limit and advisory speed difference | 0.006123 | 0.000765375 | 0.1264 |
| Dispersion | 2.046300 |  | |
| Years | 8 |
| R2 | 0.422435 |

Table number: Wet Road Crashes SPF Coefficients

|  |  |  |  |
| --- | --- | --- | --- |
| Label | Estimate | Divided by number of years | P value |
| Intercept | -5.932000 | -0.7415 | < 2e-16 \*\*\* |
| Natural log of deflection angle | 0.245500 | 0.0306875 | 8.02e-05 \*\*\* |
| Length | 0.000219 | 0.000027425 | 3.33e-05 \*\*\* |
| Natural log of AADT | 0.654000 | 0.08175 | < 2e-16 \*\*\* |
| Speed limit and advisory speed difference | 0.021210 | 0.00265125 | 0.000286 \*\*\* |
| Dispersion | 0.887400 |  | |
| Years | 8 |
| R2 | 0.295964 |

1. Summary of SPFs used:
   1. Coefficients,
   2. P-values,
   3. R^2
   4. Dispersion ratio

## Empirical Bayes CMFs

The summary of the calculated Empirical Bayes CMFs is shown below in table number. No Empirical Bayes CMFs were calculated for curves in District 2 with LWA FIST due to the lack of sufficient data. In tables number and number, separate Empirical Bayes CMFs were calculated for curve groups in District 1 and 6 with certain AADTs and numbers of crashes before the use of a FIST.

Table number: Summary Table of Calculated Empirical Bayes CMFs

|  |  |  |  |
| --- | --- | --- | --- |
|  | Filter | Empirical Bayes CMF | Standard Deviation |
| Phonolite/Wyoming bauxite | All crashes | 0.9163 | 0.1427 |
| Single vehicle crashes | 0.8576 | 0.1642 |
| Curve crashes | 0.7172 | 0.1372 |
| Wet surface crashes | 0.8616 | 0.2752 |
| HFST | All crashes | 0.6719 | 0.0521 |
| Single vehicle crashes | 0.5421 | 0.0513 |
| Curve crashes | 0.6065 | 0.0562 |
| Wet surface crashes | 0.4454 | 0.0592 |

Table number: District 1 Phonolite Empirical Bayes CMFs for differing curve characteristics

|  |  |  |
| --- | --- | --- |
|  | CMF (s.e.) | |
|  | AADT ≤ 2000 | AADT > 2000 |
| Crashes Before Treatment ≤ 3 | 0.5341 (0.1922) | 1.1770 (0.3518) |
| Crashes Before Treatment > 3 | 1.0573 (0.6163) | 0.7727 (0.2028) |

Table number: District 6 HFST Empirical Bayes CMFs for differing curve characteristics

|  |  |  |
| --- | --- | --- |
|  | CMF (s.e.) | |
|  | AADT ≤ 2000 | AADT > 2000 |
| Crashes Before Treatment ≤ 3 | 0.8679 (0.1614) | 0.9558 (0.2090) |
| Crashes Before Treatment > 3 | 0.4568 (0.1095) | 0.5717 (0.0585) |

## Influential factors

* Display Jiashu’s Model of CMF vs roadway enviornemtn
* Display R^2
* Display p-values
* Display coefficients
* Covid effects

# Discussion

## Use of EB method

Through the methods explained in the methodology, the EB method helped account for the correlation between the general increase of traffic and the general increase of crashes on the monitored curves. Thus, the adjusted CMFs were lower than the original naïve Bayes method CMFs, and the EB method realized more benefit of the FISTs. As seen in tables number and number, this trend holds true for all CMFs calculated regardless of FIST or the type of crash filter, and the greatest benefits to CMFs were seen for phonolite—especially in the CMF for wet road crashes, which improved from a naïve CMF of 1.0667 to an EB CMF of 0.8616.

However, the standard deviations for the phonolite EB CMFs are greater than the difference between the EB CMFs and the naïve CMFs, indicating that the gains made through using the EB method aren’t statistically significant.

* Discuss how EB method accounts for changes in traffic volume over time and how the CMFs changed slightly because of this. Therefore rmore benefit of HFST was realized

## CMF model

* Discussion of the interpretation of the model. Discuss the signs of the coefficients
  + 2 factors were identified as important. Prior crash AADT and prior crash frequency roadways with high aadt and low crash frequency did not realize as much benefit form HFST.
  + The curve characteristics were not significant variables. The only change in the CMF model we could account for was prior crash frequency and traffic volume

After finding that prior crash frequency and average AADT were the only significant variables for the EB CMFs, curves in District 1 and District 6 were organized into four groups based on these variables. Each curve was assigned an AADT rating, which would be either low AADT (≤ 2000 vehicles per day) or high AADT (> 2000 vehicles per day), and a prior crash frequency rating, which would be either low prior crash frequency (≤ 3 crashes in the years before FIST) or high prior crash frequency (> 3 crashes in the years before FIST).

## Different materials

Out of the three materials presented in this report, HFST by far performed the best. The Empirical Bayes CMFs show that HFST reduces crashes of all types by about 33%, and even more significantly, that it reduces wet road crashes by about 55%. Phonolite was significantly less effective, with its Empirical Bayes CMFs suggesting that it reduces crashes of all types by less than 9%. These findings correlate to the friction performance of these materials over time found in that report that was done before this (ref). There were no conclusive findings for the performance of LWA, however, due to the lack of crash data.

* HFST good
* LWA TBD
* Phonolite bad but traffic volumes increased and EB realized the benefits more

## Crash Types

Discuss the 5 that we moved forward with to make high quality CMFS

## COVID-19

There were initial concerns that the decreased traffic volume during the COVID-19 pandemic would cause significant changes to the calculated CMFs. However, after comparing EB CMFs that included data from the year 2020 to EB CMFs that excluded said data, only a minimal difference was noticed, suggesting that the sample size of the data was large enough to mitigate the effect of possible traffic volume variations during the pandemic. Since crashes are rare events, it is more advantageous to utilize more years of data, and thus data from the year 2020 was utilized to increase the sample size of data after treatment to at least three years of data.

# Conclusion

Summary:

Limitations:

Future research Needs