Predictive Analysis of Crash Incidents in Hillsborough County

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# Abstract

Hillsborough County is a rapidly growing region located in southwest Florida and includes 3 incorporated cities: Tampa, Plant City, and Temple Terrace. As a region’s population grows, the demand on its transportation infrastructure and the importance of incorporating safety designs increases. Unintentional injury was the #3 leading cause of death in Florida during 2022 (Florida Department of Health, 2023). To help reduce or eliminate traffic fatalities and serious injuries, transportation authorities and international programs research and test various roadway designs to improve public safety. In addition, the state maintains a digital archive of all crash events for making data-driven decisions using prescriptive analytics. This initiative raises the question of how well can machine learning predict the severity of automotive crashes.

Using all crash events in 2023 within Hillsborough County, stepwise variable selection was performed to reduce dimensionality to 16 predictors and 1 binary response representing the case of an incapacitating event. Geographically, most crashes occurred along local roads when considering all crashes as well as only incapacitating events. This implies that while roadway safety is a high concern for all agencies, this is largely a concern for the 3 cities within Hillsborough County.

The response is naturally unbalanced in favor of not being involved in an incapacitating event and this can cause issues for model training and testing purposes, so the training data was handled using random over-sampling on the training data.

The results of 3 models were compared with and without the stepwise-selected predictors: logistic regression, random forest, and generalized boosting regression. Considering all predictors, logistic regression had a testing error of 0.2011 and specificity of 0.6860, random forest had a testing error of 0.0460 and specificity of 0.2479, and generalized boosting regression had a testing error of 0.0282 and a specificity of 0.0992. With stepwise predictors, logistic regression had a testing error of 0.1981 and specificity of 0.7101, random forest had a testing error of 0.0439 and specificity of 0.2810, and generalized boosting regression had a testing error of 0.0271 and a specificity of 0.0331.

# Introduction

Hillsborough County, located in southwest Florida, is home to a diverse population and a rapidly expanding network of roadway. Given its urban communities, tourism appeal, access to natural resources, and well-developed transportation network, the county sees substantial Average Annual Daily Traffic (AADT) levels on its roadways. Unfortunately, along with this traffic comes the risk of road accidents and crashes, posing challenges to public safety and transportation management. Hillsborough County’s population is rapidly growing and is expected to increase by 461,371 (+30.4%) from 2020-2050 (Plan Hillsborough, 2023), which causes roadway conditions to become more congested; and thus, increases the probability of traffic accidents occurring. The purpose of this report is to serve as a comprehensive examination of all crash data in Hillsborough County to offer valuable insights into the dynamics of traffic accidents to support safer roadways and communities.

Machine learning models trained on historical crash data can forecast the probability of future accidents along specific corridors or under certain conditions. Analyzing these events is crucial to recognize patterns, trends, and contributing factors, enabling authorities to prioritize safety improvements at specific locations. Many governments integrate principles from the Vision Zero initiative, aiming to eliminate fatalities and serious injuries in road traffic incidents, into their design strategies (Vision Zero Network, 2024). Predictive analytics enable stakeholders to incorporate best practices during the design phase, leveraging machine learning to comprehend spatial and temporal trends, pinpoint key crash contributors, and develop anticipatory models. By doing so, preventative measures can be integrated into transportation designs, mitigating the occurrence of crash events.

# Methodology

## Software

The project uses the programming language R version 4.3.2 (“Eye Holes”) for statistical analysis. In addition, ArcGIS Pro version 2.9 is used for generating maps and ArcGIS Online is used for creating an interactive dashboard for data exploration.

## Data Sources

Signal Four Analytics is a statewide geospatial crash analysis system developed and hosted by the University of Florida’s GeoPlan Center (University of Florida, 2024). This system receives data from Florida’s statutory custodian of records, the Florida Department of Highway Safety and Motor Vehicles (FLHSMV). The data used for this analysis was obtained on March 6, 2024, and filtered to all crash events in the year of 2023 within Hillsborough County.

Due to the number of columns represented in Signal Four Analytics, only the following columns were considered in this analysis:

Table 1: Data Columns Used

|  |  |
| --- | --- |
| **Name** | **Description** |
| INCAPACITATING FLAG | Binary response whether the crash severity resulted in a serious injury/fatality or not derived from S4 CRASH TYPE SIMPLIFIED |
| PEAK | Peak traffic period derived from CRASH DATE AND TIME |
| TOTAL NUMBER OF VEHICLES | Count of all vehicles involved in the crash |
| TOTAL NUMBER OF PERSONS | Count of all persons involved in the crash (drivers, passengers, and non-motorists) |
| RURAL OR URBAN | Check if the traffic crash occurred inside the corporate limits of the city |
| ROAD SYSTEM IDENTIFER | This classification is used to identify the primary road system on which the traffic crash occurred |
| ROAD SURFACE CONDITION | This classification is used to identify the surface condition of the street, road or highway at the time of the traffic crash |
| S4 CRASH TYPE SIMPLIFIED | Crash type simplified for practitioners who desire less detailed crash types |
| S4 DAY OR NIGHT | To identify if the crash happened in the daytime or nighttime |
| S4 IS AGGRESSIVE DRIVING | To identify the presence of aggressive driving in the crash |
| S4 IS ALCOHOL RELATED | To identify the presence of alcohol by the driver in the crash |
| S4 IS CMV INVOLVED | To identify the presence of a commercial motor vehicle is involved in the crash |
| S4 IS DISTRACTED | To identify the presence of driving distraction in the crash |
| S4 IS DRUG RELATED | To identify if the crash is drug related due to refusal of drug test or positive drug test of driver |
| S4 IS HIT AND RUN | To identify if the crash is hit and run related |
| S4 IS INTERSECTION RELATED | To identify if the crash is intersection related |
| S4 IS LANE DEPARTURE RELATED | To identify the presence of lane departure in the crash |
| S4 IS SPEEDING RELATED | To identify if the crash is speed related |
| S4 TRAILER COUNT | Number of trailers in the crash |
| S4 MOTORCYCLE COUNT | Number of motorcycles in the crash |
| S4 MOPED COUNT | Number of mopeds in the crash |
| S4 BICYCLIST COUNT | Number of bicyclists in the crash |
| S4 AGING DRIVER COUNT | Number of aging drivers in the crash who are 65 or older |
| S4 TEENAGER DRIVER COUNT | The number of drivers involved in the crash whose age at time of crash is between 15 and 19 |
| S4 UNRESTRAINED COUNT | Number of motor vehicle occupants not using restraint system(s) at time of crash |

## Analytical Methods

This analysis uses machine learning to determine how well the severity of crash events can be predicted and if there are any regions with a statistically significant amount of crash events. Due to the nature of the data, it is anticipated the severity classification in the data raw data will be unbalanced as most crash events do not result in an injury, and that will be handled using techniques such as random over-sampling examples (ROSE) for the training datasets only to ensure each response factor has 2000 results. In addition, the time values are placed into bins for the peak traffic hours of AM Peak (M-F; 07:00 – 10:00), Mid Peak (M-F; 10:00-16:00), PM Peak (M-F; 16:00-19:00), Weekend (Sa-Su; 06:00-20:00), and Off Peak for all other values for compatibility between other transportation model results (Florida Department of Transportation Systems Forecasting and Trends Office, 2023).

This analysis uses the following models to predict the severity of crash events occurring events occurring:

* Logistic Regression (Logit): A probabilistic classification model used for binary classification. Suitable for scenarios when you need to understand variable relationships the probability of a particular outcome.
* Random Forest (RF): An ensemble bagging model that bootstrap aggregates multiple, independent decision trees using randomly sampled subsets of data and features to predict or classify data. This is beneficial for handling large datasets with high dimensionality and complexity.
* Generalized Boosting Regression (GBM): An ensemble gradient boosting model that iteratively builds decision trees and trains weak learners to correct the weights used by the previously models. Suitable for a wide range of supervised learning tasks when you can tolerate longer training times.

To measure performance, each model try will predict the response variable within the testing dataset and compared to the actual values to calculate the testing error.

# Results

## Exploratory Data Analysis

The charts below represent the distribution of incapacitating events in 2023 by crash type and peak traffic period. For more details and charts, visit the interactive dashboard found [here](https://arcg.is/1KbDmv0).

Figure 1: Crash Location

A close-up of a map

Description automatically generated

The bin aggregate map shows that the majority of the crashes occur within city limits with linear tangents along the highways heading east towards Orlando and north towards Gainesville. A significant portion of all crashes occurred on local roadways with almost 3x more events than the next leading roadway system. This trend stays relatively true when considering only incapacitating events with the proportion dropping closer to 2x more than the next leading system.

Figure 2: Crash Summary

A collage of several graphs

Description automatically generated

These charts show that the majority of crashes are classified as rear ends and occur in the Mid Peak traffic hours. When specifically referring to incapacitating events, crossing over traffic while making a left turn shows to have the highest count of events with accidents involving pedestrians and rear ends being the next highest crash types in the off-peak hours when congestion is likely not as high; thus, allowing faster travel speeds. For crash types, most crashes are classified as rear end events, but when considering only incapacitating events, left turn, pedestrians, rear ends, and off-road were the most common.

Figure 3: Crash Time Series



A graph showing a blue line

Description automatically generated

A graph showing a red line

Description automatically generated

The plots above show the crash temporal trends. Overall, there is little to no seasonality when considering all crash severities with a dip in November. When focusing on incapacitating events, winter and fall months have more events compared to summer and spring that coincides with temporary transplants escaping the harsh winters in northern climates. There is also a notable spike in March that coincides with the spring break vacation. Holidays with an anticipated higher volume of traffic such as Independence Day and Halloween do not show to be significant based on these plots.

## Variable Selection

A stepwise regression with the penalty term k=2 degrees of freedom for an AIC method was used to reduce dimensionality by selecting only the predictors that contribute to the model’s performance. The final selection resulted in 15 predictors:

Table 3: Variable Selection Predictors

|  |  |  |  |
| --- | --- | --- | --- |
| TOTAL NUMBER OF VEHICLES | S4 CRASH TYPE SIMPLIFIED | S4 IS HIT AND RUN | S4 MOPED COUNT |
| TOTAL NUMBER OF PERSONS | S4 IS AGGRESSIVE DRIVING | S4 IS INTERSECTION RELATED | S4 AGING DRIVER COUNT |
| RURAL OR URBAN | S4 IS ALCOHOL RELATED | S4 IS LANE DEPARTURE RELATED | S4 UNRESTRAINED COUNT |
| ROAD SYSTEM IDENTIFER | S4 IS DRUG RELATED | S4 MOTORCYCLE COUNT |  |

## Logistic Regression

A logistic regression model was trained using a binomial distribution. The results of the prediction accuracy for the full model as well as the reduced model with only the stepwise predictors are shown below.

Table 4: Logistic Regression Confusion Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Logit** | N | Y |  | **Logit-SW** | N | Y |
| N | 3429 | 38 |  | N | 3439 | 35 |
| Y | 846 | 83 |  | Y | 836 | 86 |
| Test Error | 0.2011 |  |  | Test Error | 0.1981 |  |
| Specificity | 0.6860 |  |  | Specificity | 0.7101 |  |

## Random Forest

The Random Forest model was trained with the consideration for the importance of the predictors and the proximity measure among rows. The results of the prediction accuracy for the full model as well as the reduced model with only the stepwise predictors are shown below.

Table 5: Random Forest Confusion Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **RF** | N | Y |  | **RF-SW** | N | Y |
| N | 4164 | 91 |  | N | 4169 | 87 |
| Y | 111 | 30 |  | Y | 106 | 34 |
| Test Error | 0.0460 |  |  | Test Error | 0.0439 |  |
| Specificity | 0.2479 |  |  | Specificity | 0.2810 |  |

## Generalized Boosting Regression

The boosting algorithm was initially trained with 5000 trees, a shrinkage factor of 0.01, and interaction depth of 1, and 10 cross-fold validations. Cross-fold validations was used to find the optimal number of iterations to be used for prediction, which results in 4856 iterations. The results of the prediction accuracy for the full model as well as the reduced model with only the stepwise predictors are shown below.

Table 6: Boosting Confusion Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **GBM** | N | Y |  | **GBM-SW** | N | Y |
| N | 4273 | 117 |  | N | 4260 | 109 |
| Y | 2 | 4 |  | Y | 15 | 12 |
| Test Error | 0.0271 |  |  | Test Error | 0.0282 |  |
| Specificity | 0.0331 |  |  | Specificity | 0.0992 |  |

Table 7: GBM-Stepwise Relative Influence

|  |  |
| --- | --- |
| **Value** | **Rel. Influence** |
| S4 MOTORCYCLE COUNT | 44.08 |
| S4 MOPED COUNT | 31.22 |
| S4 CRASH TYPE SIMPLIFIED | 9.93 |
| TOTAL NUMBER OF VEHICLES | 6.38 |
| S4 UNRESTRAINED COUNT | 2.61 |
| S4 AGING DRIVER COUNT | 2.27 |
| TOTAL NUMBER OF PERSONS | 1.61 |
| ROAD SYSTEM IDENTIFER | 0.96 |
| RURAL OR URBAN | 0.43 |
| S4 IS HIT AND RUN | 0.20 |
| S4 IS DRUG RELATED | 0.17 |
| S4 IS AGGRESSIVE DRIVING | 0.12 |
| S4 IS LANE DEPARTURE RELATED | 0.01 |
| S4 IS ALCOHOL RELATED | 0.01 |
| S4 IS INTERSECTION RELATED | 0.00 |

In addition, each predictor’s relative influence was calculated and is shown in the table above. This table shows 95% of the relative influence of determining if a crash event is incapacitating or not using boosting is made up of number of motorcycles, number of mopeds, crash type, number of vehicles, and number of unrestrained passengers.

# Conclusion

When comparing the results of these models, it’s important to understand what metric is more important based on the background of the data. Testing error can give you a good sense of how well the model predicts overall across all classes. In this example, generalized boosting regression with all predictors showed the lowest testing error at 0.0271 while logistic regression with all predictors had the highest at 0.2011. However, crash data is naturally unbalanced being skewed in favor of not having an incapacitating event. Specificity measures the proportion of actual negative results that are correctly identified by the model, meaning how many incapacitating events were correctly identified as such. This is important when the cost of false positives is high such as life-threatening events. Logistic regression with stepwise predictors had the highest specificity of 0.7101 and generalized boosting regression with all predictors had the lowest of 0.0331.

The results of this analysis show that there are challenges when using machine learning and data collected from FLHSMV and provided by Signal Four Analytics. Human driving behavior has a lot of randomness that might be a challenge to model. Also, when dealing with situation with heavy consequences such as providing details to an officer after an accident, information may be withheld or fabricated to protect themselves and potentially avoid financial burdens. There are also predictors not included in this analysis that could potentially increase the performance. A binary indicator whether speeding was involved was included in the analysis, but there is a significant difference between going 5mph over the speed limit than going 50mph over the speed limit. Real-time travel metrics obtained from a car’s On-Board Diagnostics (OBD2) can provide valuable insight into what the machine was experiences at the time of the crash.

## Lessons Learned

I found this topic very interesting because it is using real data that affects everyone in Hillsborough County. During this project, I learned how challenging it is working with unbalanced data. There are different techniques on how to handle it, whether it’s over-sampling, under-sampling, or synthetic sampling, and they each have their weaknesses and can decrease your model’s performance if not used correctly, such as generating too many synthetic samples. I also had to learn how to navigate unbalanced data on a database with over 40,000 records, so code efficiency and finding the right train/test splitting size with cross-validation was a new challenge that sample datasets don’t have. I also found the discrepancy between which model is better based on what performance metric is used a valuable insight as I’m sure it’s very tempting to just look at overall accuracy and the model with the highest accuracy as the best model. However, incorrectly predicting a crash event as incapacitating when it is non-incapacitating likely results in additional safety measures and isn’t as nearly as costly of an error as missing an incapacitating event all together since that could have saved someone’s life. I plan on submitting this to either a journal or publish on Medium, so please let me know if there was anything else I could have explained better.

# References

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# Appendix