Characterization and Prediction of Superload in Florida Using Gradient Boosting Machine Learning Algorithm

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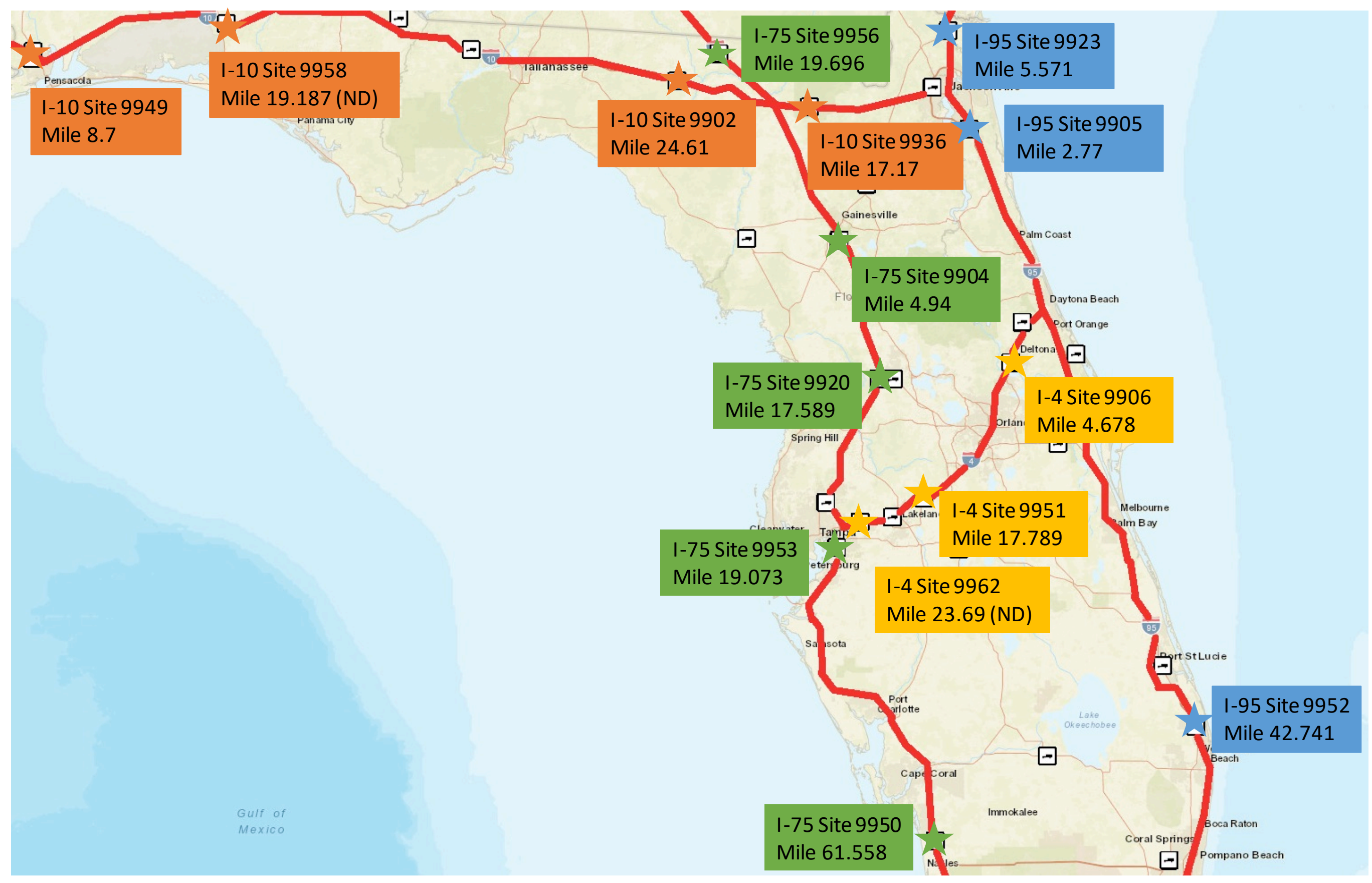
Introduction

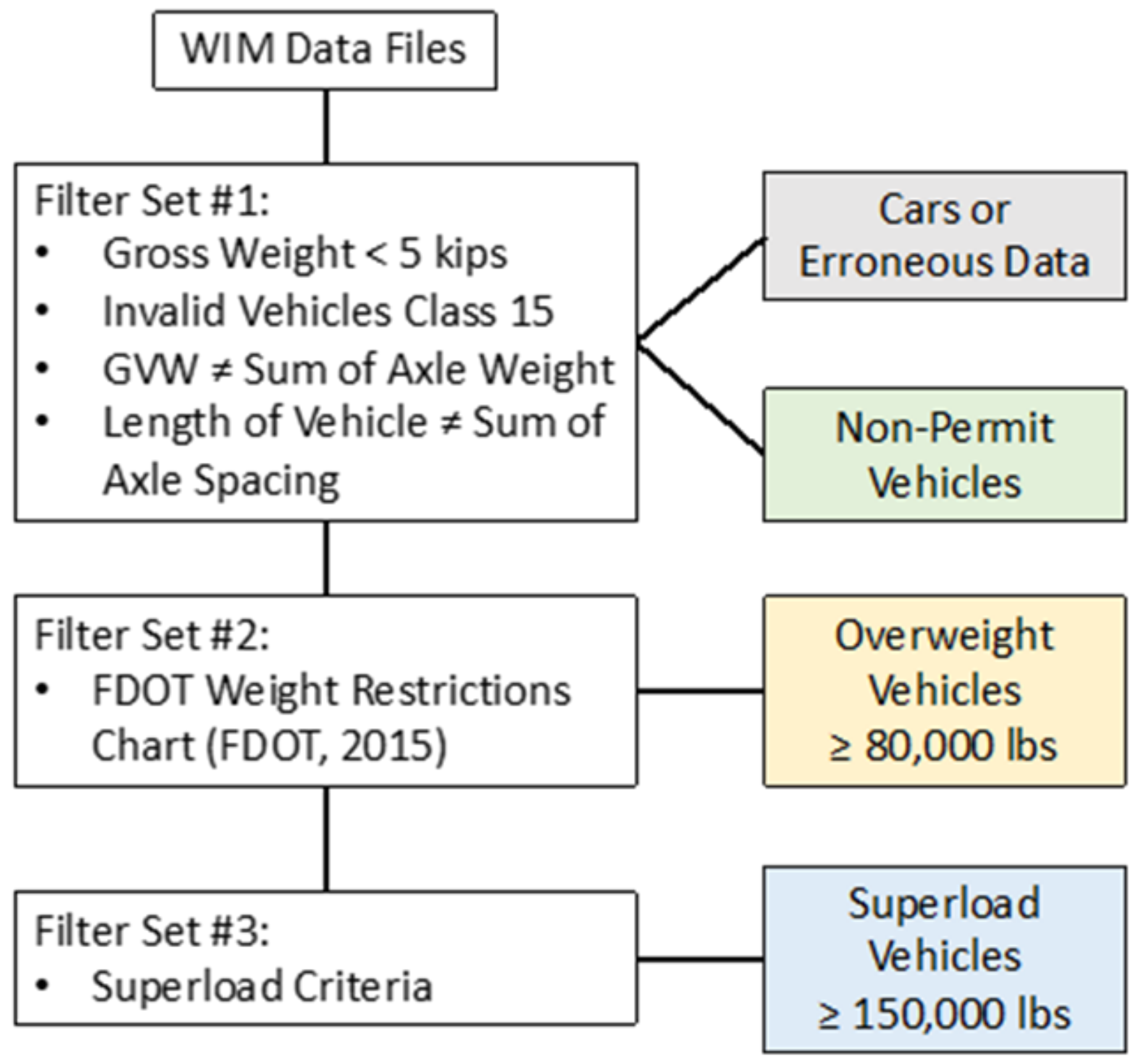
Highway agencies are responsible for protecting billions of taxpayer dollars invested in highway infrastructure. For the purposes of safety and system preservation, trucking operational characteristics (i.e., size and weight) are regulated using federal and state legislation and policies. The effect of truck loads on infrastructure is important in the effort of upgrading and maintaining transportation infrastructure. Over the past two decades, rapid advancement in trucking technology and increasing demands in freight transportation has led to longer and heavier vehicles traveling on the highway. Furthermore, in order to incorporate special needs from the industry, more irregular vehicles are utilized to transport heavy loads, including prestressed concrete girders, transformers, and wind turbine components. Thus, there is great need to better understand the characteristics of these heavy vehicles, called superload, and to develop a procedure to predict vital superload attributes for enhanced accuracy in the permitting process.

Florida Department of Transportation (FDOT) transtat office maintains an oracle database which stores per-vehicle, time-stamped Weigh-In-Motion (WIM) data collected from 31 existing permanent WIM stations. The collection of unbiased data and monitoring of truck movement, weight data, and axle configuration, provides the basis for understanding their impact on the state's highway infrastructure. In this study, the major focus was to develop an analytical procedure for the characterization and prediction of superload using advanced Gradient Boosting Machine (GBM) learning algorithms. This analytical procedure was specifically altered to accommodate the unique features of superload data. By applying the new procedure, the characterization of superload was performed for Florida WIM sites and the prediction of various key parameters, such as gross vehicle weight, average axle weight, and maximum axle weight, were accurately predicted using all parameters as well as limited vehicle configuration parameters.

Characterization of Superload

Among 31 WIM sites that FDOT operates, the research team selected 13 sites to represent the traffic loads from four major highways in the state of Florida. There are 4 sites on I-10, 3 sites on I-95, 5 sites on I-75, and 3 sites on I-4. The WIM data for each site was initially processed by following an author-developed procedure and the superload data was later utilized for characterization and prediction.




WIM Data Files

Filter Set #1:
- Gross Weight < 5 kips
- Invalid Vehicles Class 15
- GVW ≠ Sum of Axle Weight
- Length of Vehicle ≠ Sum of Axle Spacing

Cars or Erroneous Data

Non-Permit Vehicles

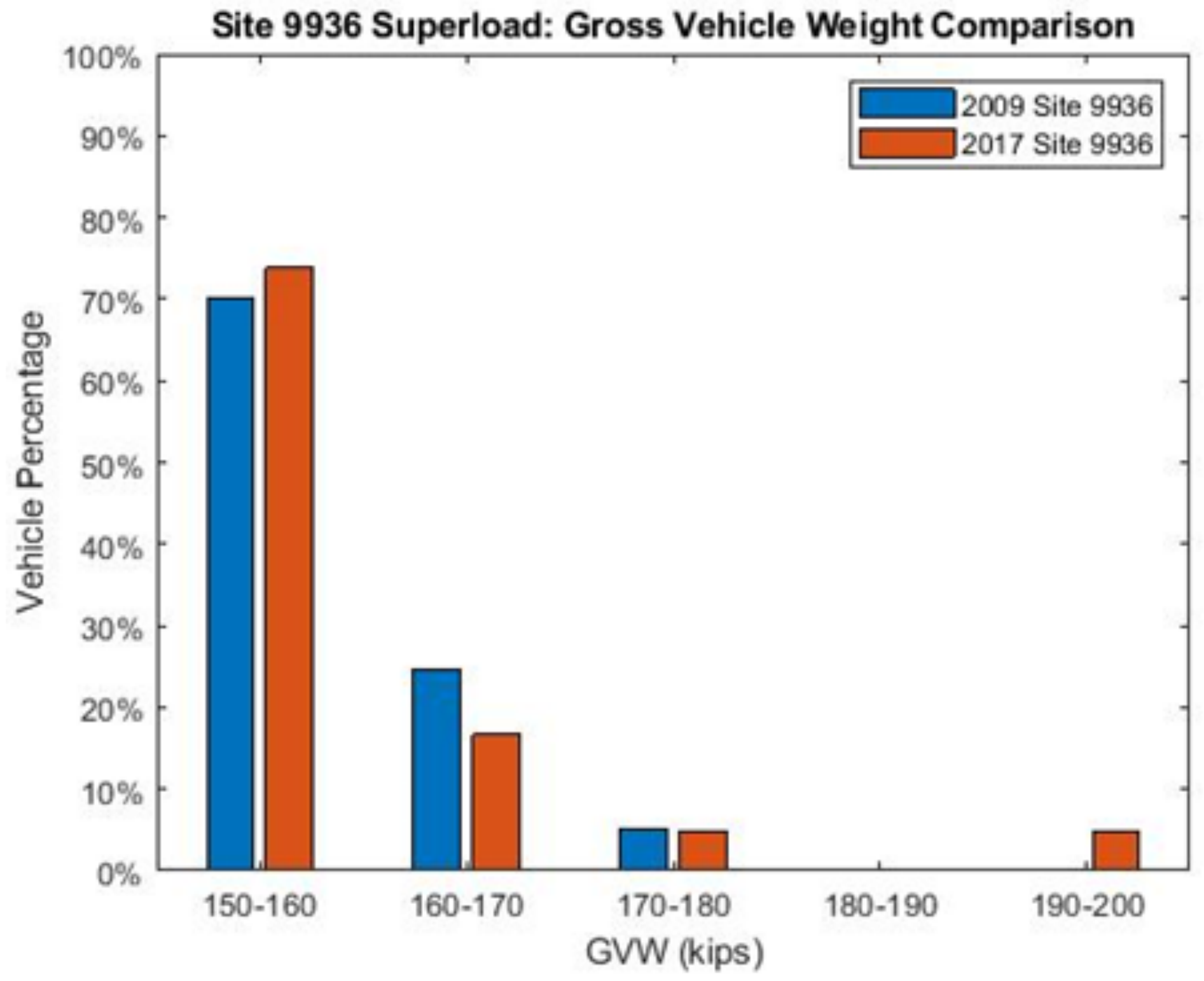
Filter Set #2:
- FDOT Weight Restrictions Chart (FDOT, 2015)

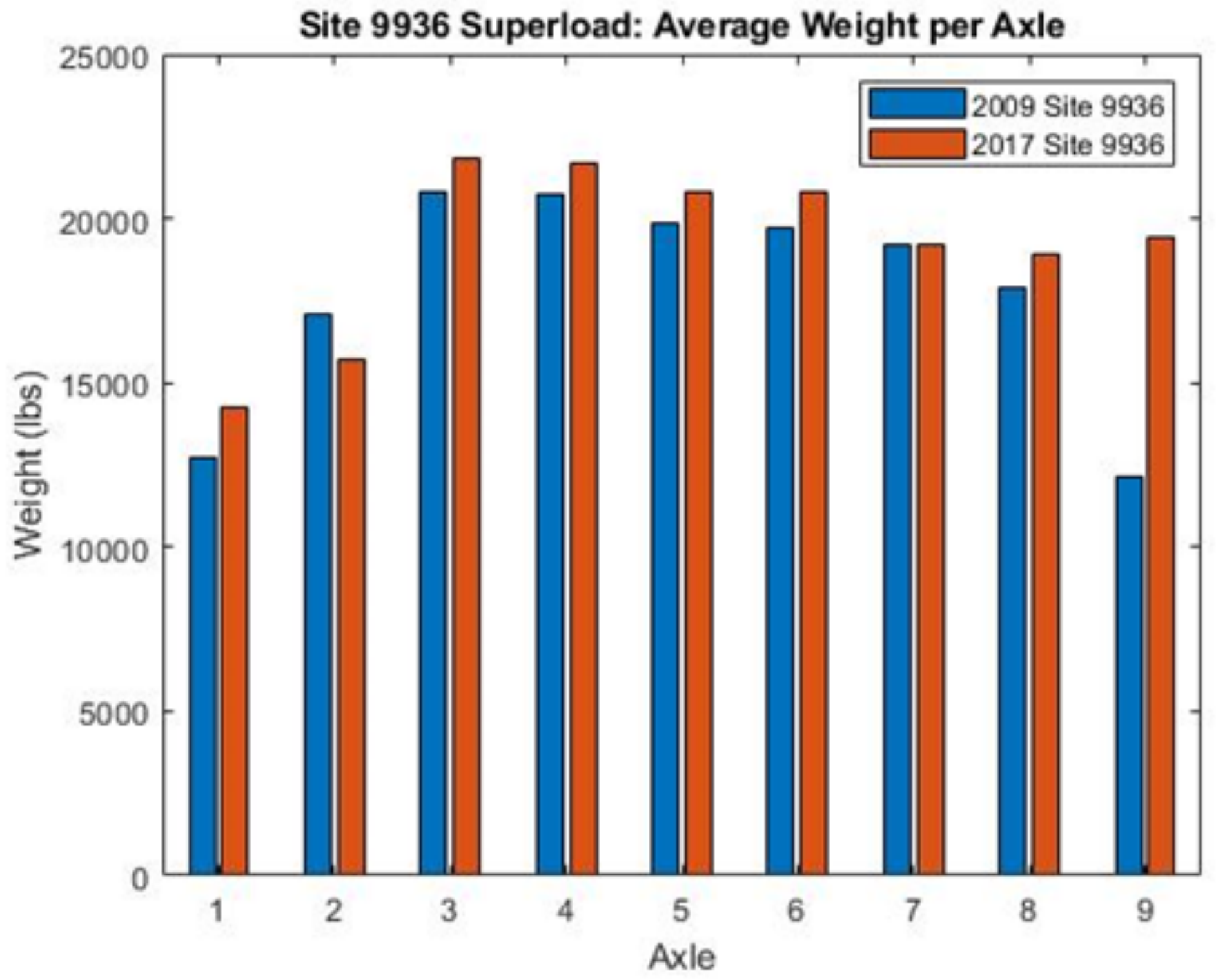
Overweight Vehicles ≥ 80,000 lbs

Filter Set #3:
- Superload Criteria

Superload Vehicles ≥ 150,000 lbs

Superload vehicles have their own distinct attributes that differ from other permitted vehicles, thus presenting a need to better understand trends for these extremely heavy vehicles. The characterization was performed using a procedure to discover trends in the data set. Superload is generally composed of seven or more axles, yet the majority of superload from site 9936 were 8 or 9 axle vehicles. The majority of superload travels between 60-69 mph. It also revealed that 52% of superload are 8-axle vehicles and 44% of superload are 9-axle vehicles. Superload vehicle length displayed a larger variation, with 45% of vehicles under 100 feet and 35% greater than 300 feet.





Superload displayed an increase in GVW between 150-160 kips in 2017. The results displayed heavier axle weights for nearly all axles on site 9936 in 2017. The axle with the biggest increase was axle 9 and the heaviest axles were axle 3 and axle 4, with axle weight of about 21,000 pounds. This means that there are increasing numbers of superload vehicles as well as increasing axle weights for these vehicles.

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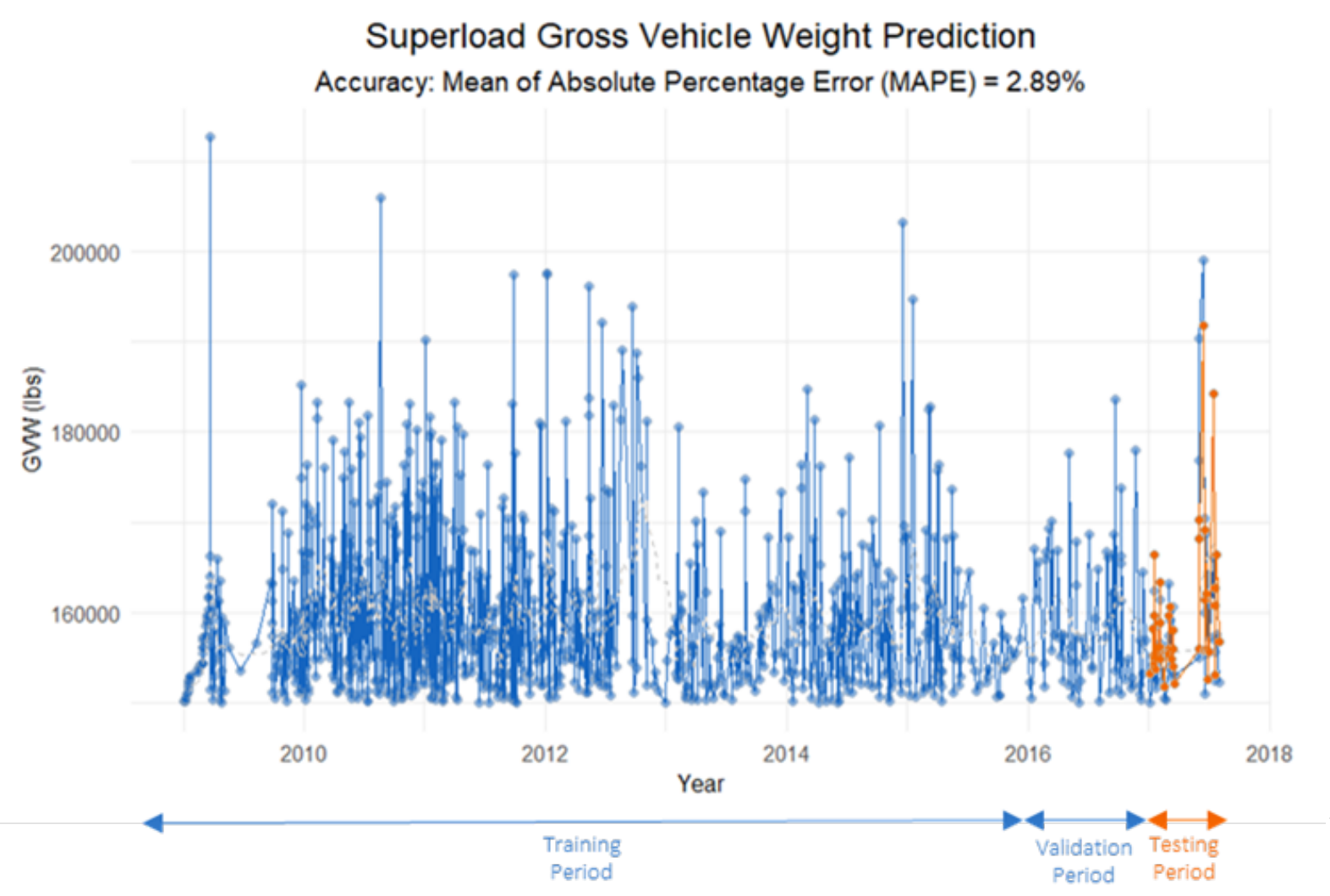
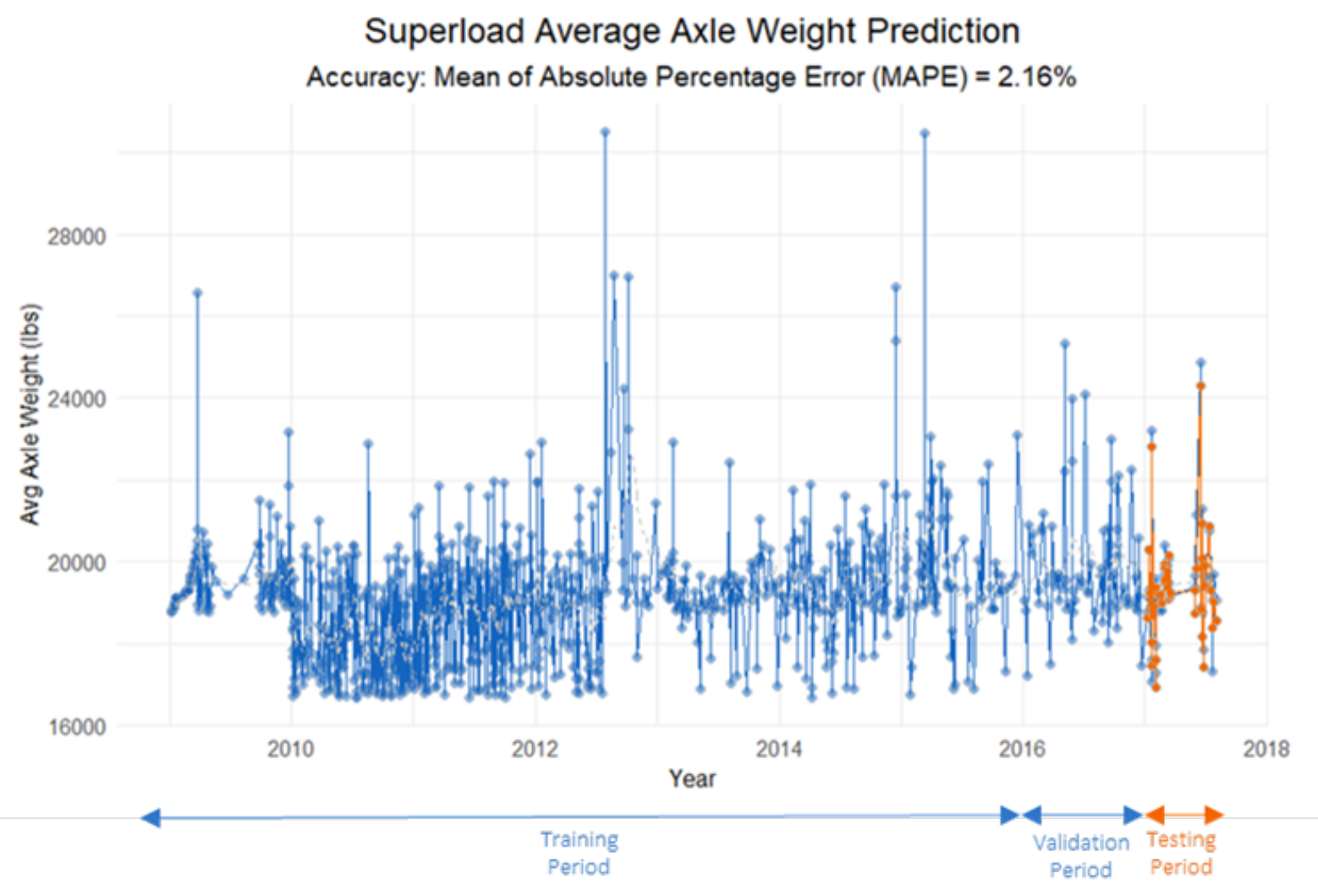
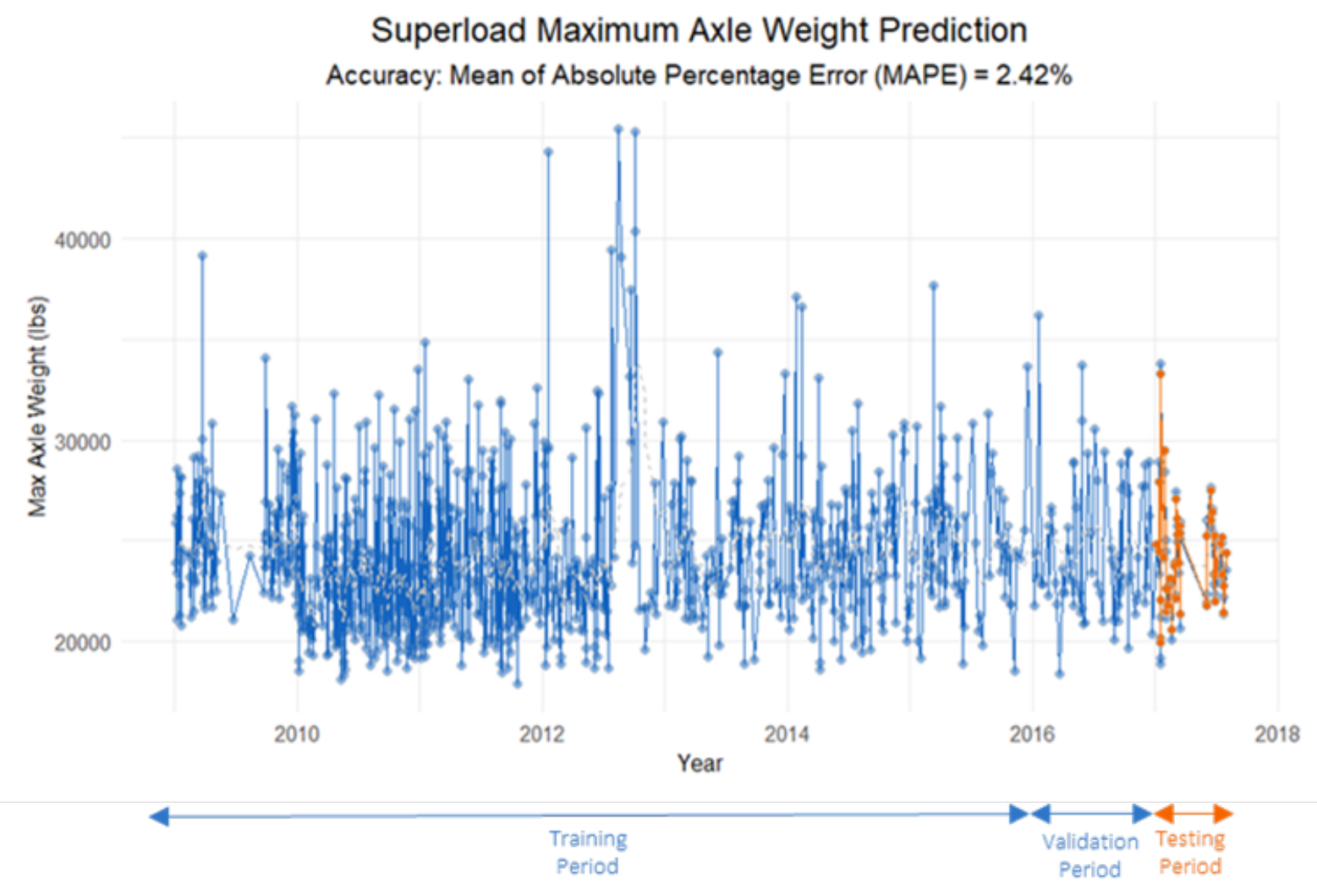
Prediction of Superload

Superload has substantial impacts on Florida's infrastructure, consequently there is great need for state agencies to accurately predict vital characteristics of these vehicles. Analyses were performed using the WIM data throughout Florida to determine the GVW, maximum axle weight, and average axle weight for superload recorded from 2009 to 2017 at site 9936 on I-10. Two scenarios were presented in the following analysis: 1) superload prediction using all non-calculated WIM data values and 2) superload prediction using only spacing parameters. The spacing parameters not only provided the worst-case error, but also is the most realistic for what is specified and most accurate on a superload permit. The low mean absolute percentage error (MAPE) that resulted from the procedure and optimized GBM algorithm proves it is a powerful approach for the prediction of weight-based superload characteristics given all other parameters. A visual representation of the GBM model accuracy is shown in the following figures with the predictions from the testing period shown in orange.

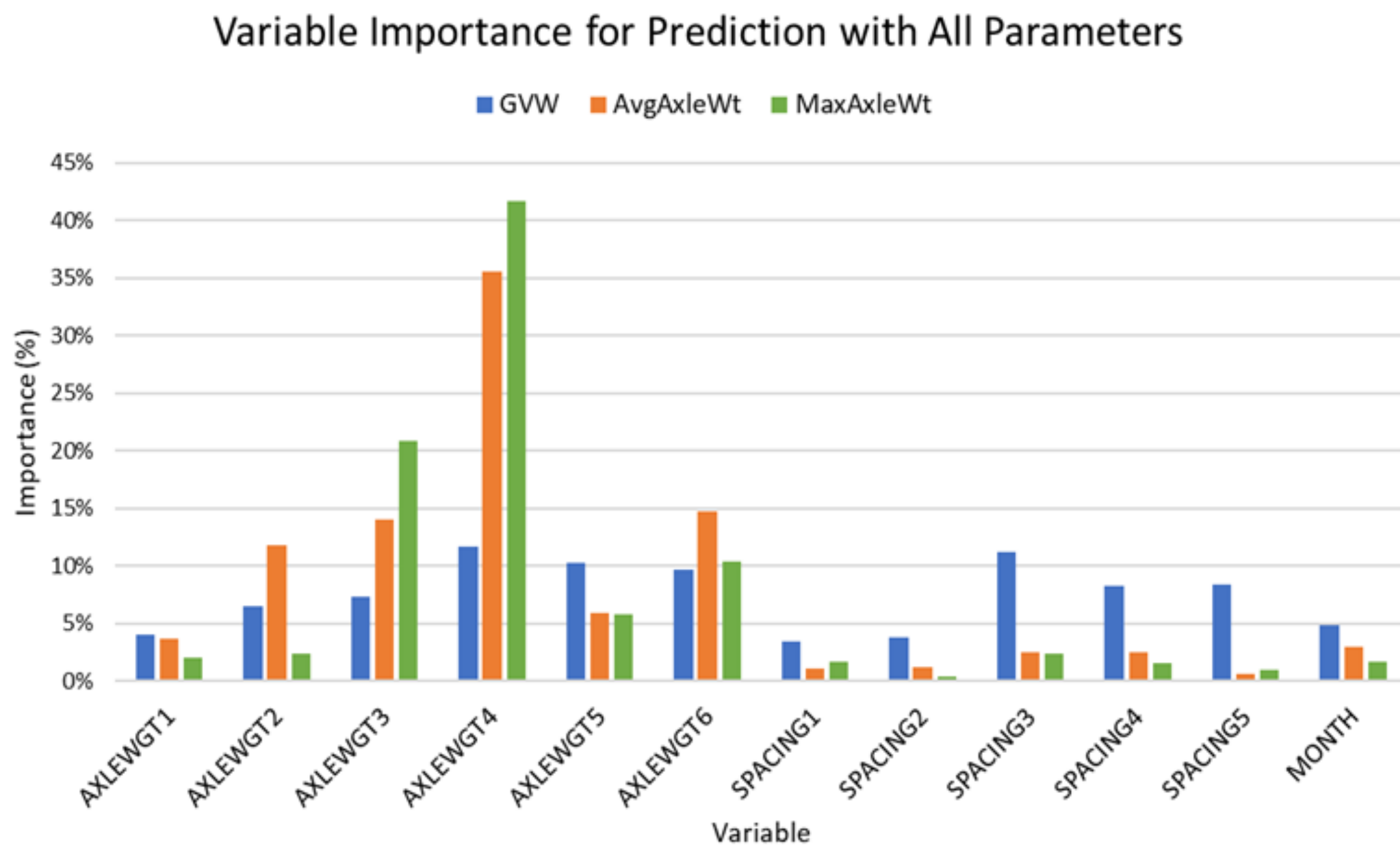


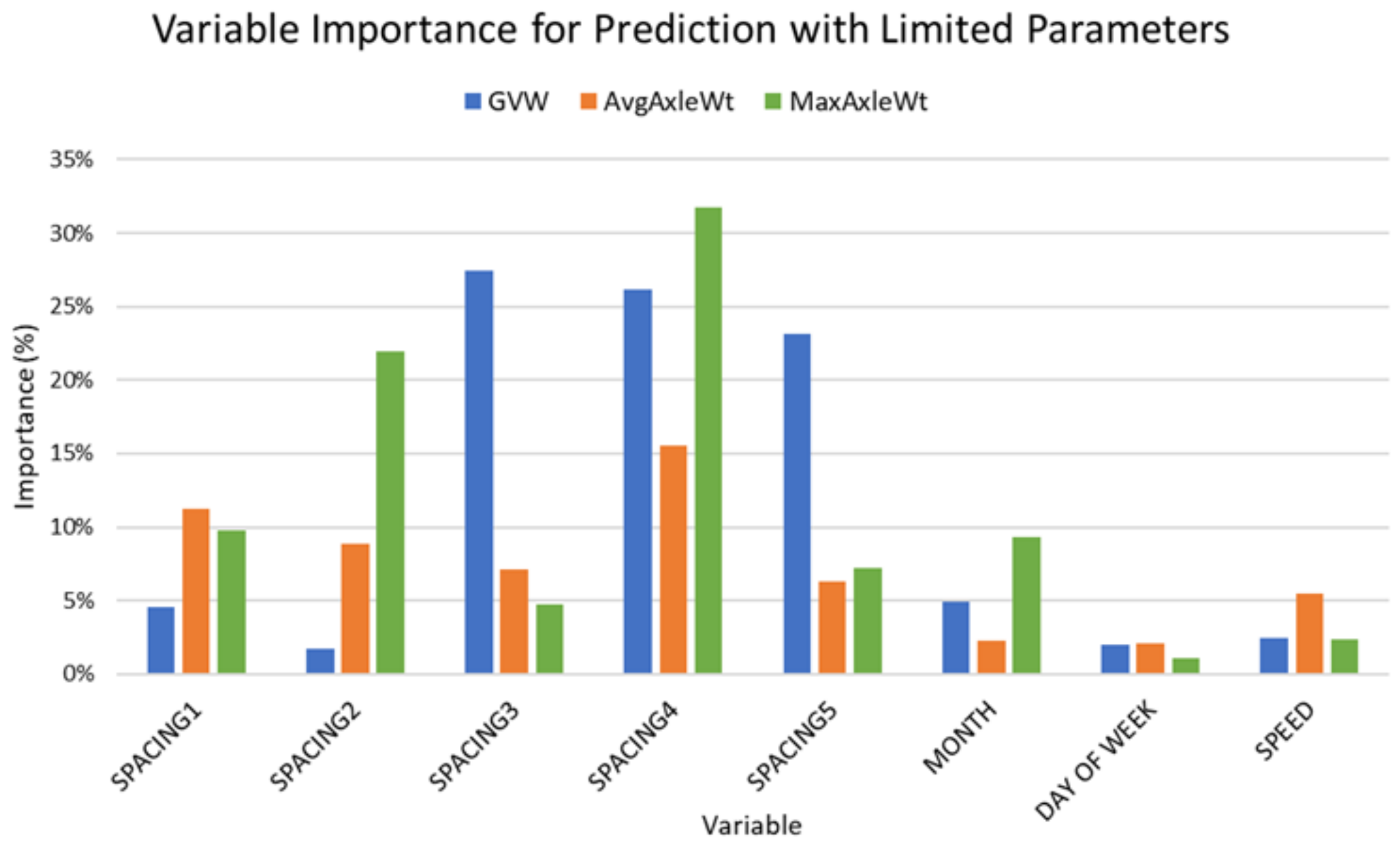




Predicted Parameter	MAPE with All Parameters	MAPE without Spacing Values	MAPE without Axle Weights
Gross Vehicle Weight	2.89%	3.32%	3.60%
Average Axle Weight	2.16%	2.37%	5.02%
Maximum Axle Weight	2.42%	2.44%	9.40%

The prediction using all parameters for GVW, average axle weight, and maximum axle weight produced a MAPE of 2.89%, 2.16%, and 2.42%, respectively. For the second scenario, the axle weights were excluded from the prediction to provide a realistic scenario for actual permit applications. Using limited parameters, only the spacing values, the prediction for GVW, average axle weight, and maximum axle weight resulted in MAPE of 3.60%, 5.02%, and 9.40%, respectively. Overall, these vital parameters determining the effects of superload can be accurately predicted with only truck configuration available. The parameter importance for each prediction variable was extracted from the GBM algorithm. The most important parameter using all attributes for each prediction was AXLEWGT4 (12%, 36%, 42% for GVW, average axle weight, and maximum axle weight, respectively) and was of highest importance for the prediction of maximum axle weight. AXLEWGT3 and AXLEWGT4 are of the heaviest axles, therefore the prediction coincides with the algorithm findings. The GVW prediction without axle weights was most dependent on SPACING3 (28%), SPACING4 (26%), and SPACING5 (23%), which are dependent of the trailer configuration and varies based on availability and transportation needs.





Summary and Conclusions

- ❑ The developed analytical procedure could conduct the characterization of superload data. The characterization revealed that the majority of superload are class 13 vehicles, travel between 60-70 mph, and are composed of 8 (52%) or 9 (44%) axles. Both maximum axle weights and average axle weights were lesser for vehicles with 9 axles compared to vehicles with 8 axles. From 2009 to 2017, there was an increase in vehicles with GVW between 150-160 kips and 190-200 kips. In addition, nearly all axle weights displayed an increase in 2017, while axles 3 and 4 were the heaviest.
- ❑ The GBM model yielded MAPE of 2.89%, 2.16%, and 2.42% for GVW, average axle weight, and maximum axle weight prediction, respectively, utilizing parameters such as year, classification, speed, axle weights, and spacing values. The GVW prediction displayed a 3.60% MAPE after eliminating the axle weight parameters, proving that it can be predicted accurately without the axle weights. For average axle weight and maximum axle weight, a 5.02% and 9.40% MAPE, respectively, was recorded after removal of axle weights. This level of high accuracy indicates the developed procedure and optimized GBM algorithm is a promising approach for prediction and forecasting of superload into the future.
- ❑ The most vital parameters for the GBM algorithm prediction of the GVW, average axle weight, and maximum axle weight given all parameters is AXLEWGT4. Given only spacing parameters, the variables of utmost importance include SPACING3 for GVW, and SPACING4 for both average axle weight and maximum axle weight.

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