Autonomous Vehicle (AV) Safety Analysis

-Nihit Hindlekar

This project explores failures and disengagements in Autonomous Vehicles (AVs) being tested on public roads in California. I have used the California Department of Motor Vehicles dataset for this project. I have done statistical and probabilistic analysis to evaluate how well the AI-driven decision and control of AVs works under a variety of conditions and developing insights into why/how they disengage.

As AVs have started interacting more directly with humans on public roads, the safety and resilience of AVs is a significant concern (Uber's [2] fatal accident, Tesla's [3] autopilot flaw) and must be thoroughly evaluated through analysis of data obtained during field-testing.
The California DMV mandates that all manufacturers testing AVs on public roads file annual reports detailing disengagements and accidents. A disengagement occurs when a failure in the AV system causes control of the vehicle to switch from software to the human driver.

In this project, I have studied the disengagement data from AV manufactures and analyzed the current state of AV safety.

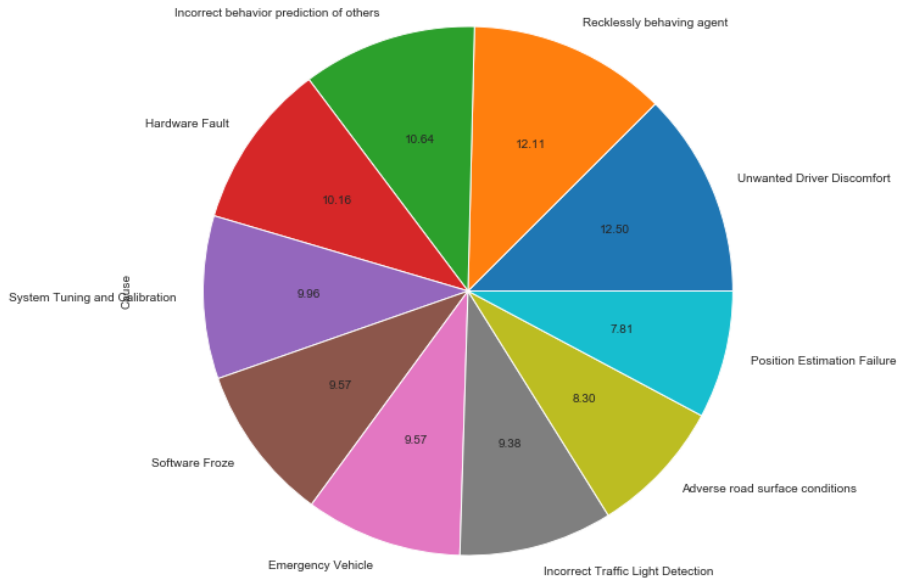
Dataset description:

mp1_av_disengagement.csv
This file lists the details of each disengagement that happened in AV testing.
mp1_av_totalmiles.csv
This file contains the total number of miles driven and other summary statistics by month.

Descriptive Analysis and Data Exploration:

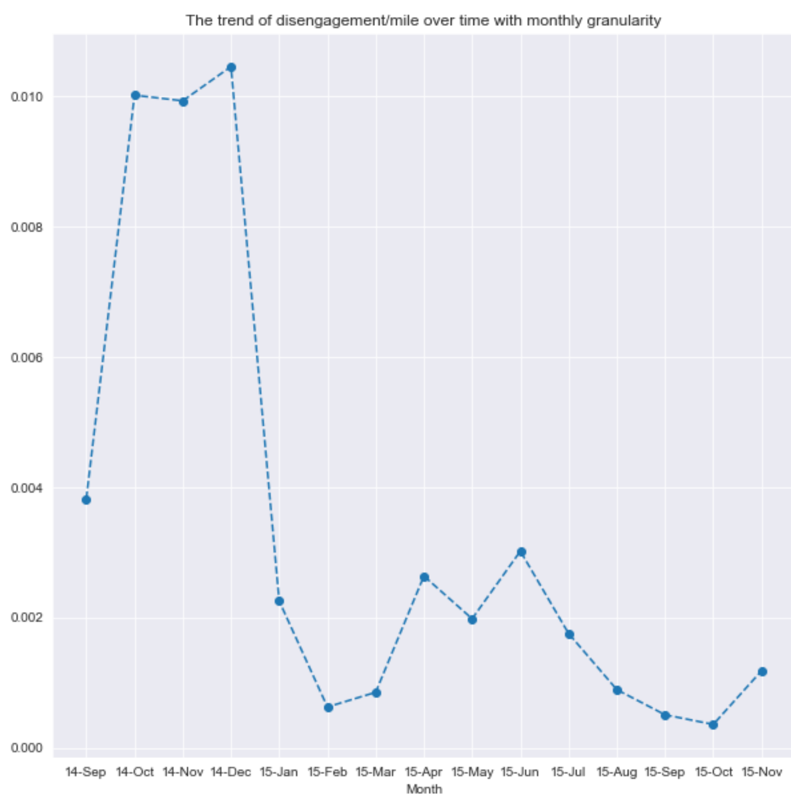
I found out the following:

- Total number of AV disengagements over the entire duration of available data = *1024*
- Number of unique months that have recorded AV disengagements = *15*
- List of unique locations of AV disengagements = *{urban-street, highway}*
- Number of unique causes for AV disengagements = *10*
- Number of missing values (NAs commonly occur in real world datasets) = *532*
- Pie-chart plot for the two top causes of disengagements



Based on a pie-chart, the two top causes of disengagements are **Unwanted Driver Discomfort** and **Recklessly Behaving Agent**

- Also plotting the graph of trend in disengagements/mile over time.

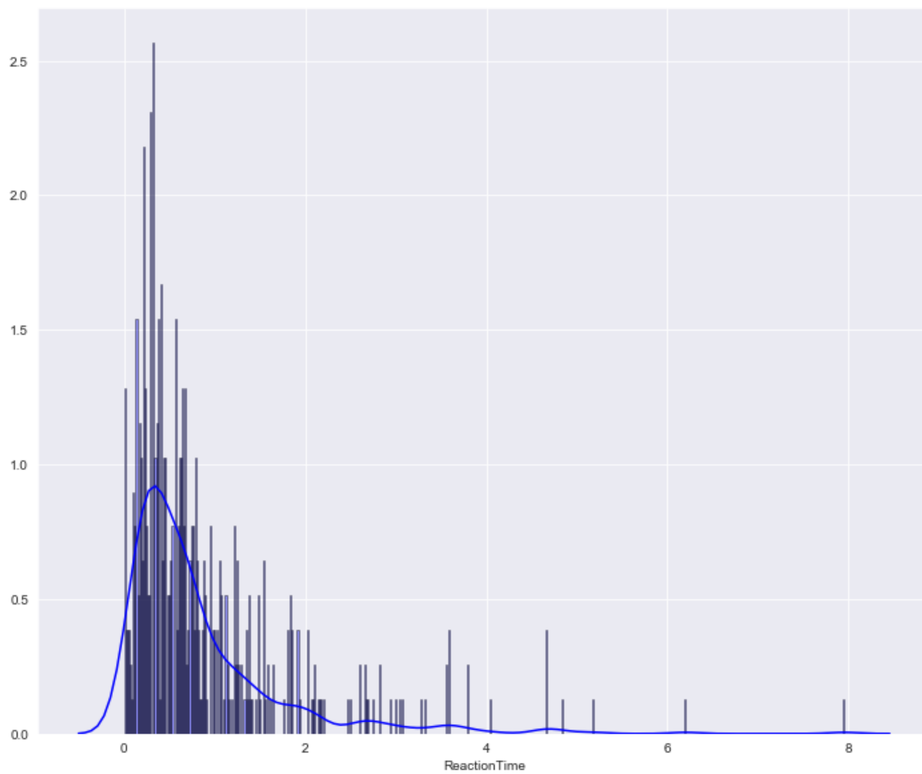


- The graph shows a decreasing trend of disengagements/mile over time. Therefore the AVs ***<u>show sign of maturity over time.</u>***

My understanding based on the above descriptive analysis:

If the AV suddenly disengages, there may not be enough time for the human to react. It is also possible, that the human is not sufficiently attentive while in the AV because of reliance on the technology. To understand the human alertness level, I have measured the reaction time of the human driver in the field.

The plot for the probability distribution of reaction times.



The distribution closely resembles **Weibull distribution**. It is highly intuitive to assume that the reaction time must be some generalized form of the exponential distribution, as after any disengagement, at every moment either the driver takes over the contol (hits) or does not take over the control (misses). As there must be a lower bound for any human to react to an incident, we see an initial dip. So, the Weibull distribution, which is a generalized exponential distribution, best fits the actual distribution.

I also computed the average reaction time as below:
a. For the entire duration of the dataset

- The average reaction time for the entire duration of the dataset = ***0.93 sec***

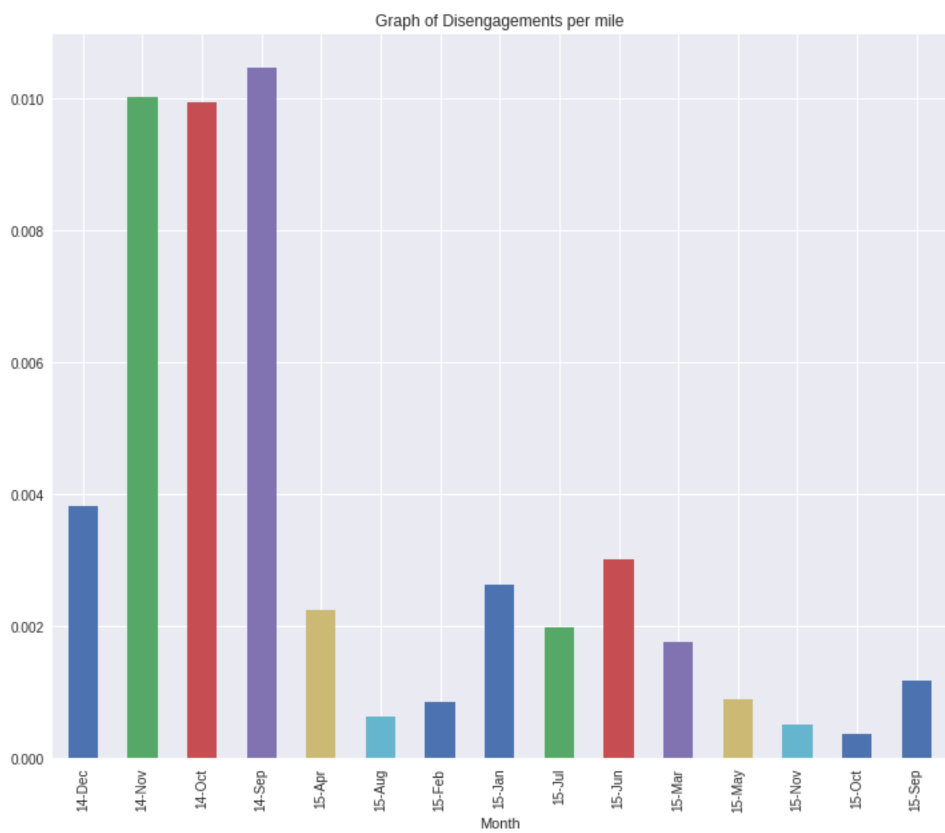
b. For the entire duration of the dataset differentiated by the location of disengagement

- Location
  highway 1.48000
  urban-street 0.92865

Comparing Reaction times in Human and AV cars:
It is known that the mean reaction time for humans in non-AV cars is 1.09 seconds [4].

By performing the hypothesis test at 0.05 significance level, we found out the mean reaction time for humans in AV cars to be *significantly different from Non-AV cars.*

Next, plot the probability distribution for disengagements/mile with monthly granularity.



From the above plot it can be concluded, the distribution fits a Bimodal Distribution.
As seen above, contains two distinct humps or peaks with a valley separating them. Each peak is a local maximum since they represent the highest values relative to the data points immediately surrounding them. The valley between these peaks is called a local minimum. And such kind of distribution with two peaks is generally called a **Bimodal distribution.**

Probabilistic Analysis of AV Disengagement

Given that AV technology uses sensors like camera and LiDAR whose performance may vary under different lighting and weather conditions, it became paramount to understand if AVs are able to cope with the change in the environment (sensor performance). The dataset provided has disengagement measurements under different weather conditions which helped me understand the same.

To perform further analysis, I have made the following assumptions:
1) Only one disengagement per mile.
2) Weather either cloudy or clear. The probability of a day being clear in California is 72% [5].
3) The AV is equally likely to drive on a cloudy day as on a clear day.

Based on the above assumptions, I found the following:

- The probability of disengagement per mile on a cloudy day = 0.005902
- The probability of disengagement per mile on a clear day = 0.0005195
- The probability of an automatic disengagement per mile on a cloudy day = 0.002806
  and the probability of an automatic disengagement per mile on a clear day = 0.0002639
- Using Poisson Distribution, we get that the probability of having more than 150 disengagements in 1000 miles is 1.17 * 10^-23 which is almost zero so it is highly unlikely.

Next, I found the following conditional probabilities based on our assumptions:

a. Conditional probability of high reaction time on a cloudy day

- $P(Reaction > 0.5 | AutoDis, Cloudy)$ = 0.54292

b. Conditional probability of high reaction time on a clear day

- $P(Reaction > 0.7 | AutoDis, Clear)$ = 0.38541

c. Then I found the probability of Accident using theorem of total probability and applying Bayes Theorem

- The desired value of $P(Accident)$ = 0.0004998

Model Building and Evaluation

I am predicting the causes of latest unknown disengagement using a Naïve Bayes classifier.
NB classifier because the assumptions of Naïve Bayes classifier involve that the predictors are independent of each other which holds true in this case.

I did some research to find out the main causes of disengagements in AVs,

Though there are 10 different causes for disengagement, I found out that the 3 main causes for accidents/disengagements are - (i) Controller, (ii) Perception System, and (iii) Computer System.

	Disengagement Cause	Class
1	Incorrect behavior prediction of others	Controller
2	Recklessly behaving agent	Controller
3	Unwanted Driver Discomfort	Controller
4	Adverse road surface conditions	Perception System
5	Emergency Vehicle	Perception System
6	Position Estimation Failure	Perception System
7	Incorrect Traffic Light Detection	Perception System
8	System Tuning and Calibration	Computer System
9	Hardware Fault	Computer System
10	Software Froze	Computer System

I am using these 3 classes as the labels in the NB model.

Next Steps Taken:

- Firstly, I categorized all disengagement causes in 3 classes – Controller, Perception System and Computer System.
- Performed 80-20 standard split of the data into training and test sets.
- Defined a function "naive_bayes" to train a Naïve Bayes classifier.
- I got a training accuracy of 79.89%.
- After performing cross-validation by taking 5 random 80-20 splits, I achieved a cross-validation test accuracy of 81.41%.

References

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4. S. S. Banerjee et al., "Hands off the wheel in autonomous vehicles? a systems perspective on over a million miles of field data," in 2018 48th Annual IEEE/IFIP International Conf. on Dependable Systems and Networks (DSN), June 2018

5. https://www.currentresults.com/Weather/California/annual-days-of-sunshine.php