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# Driving Behavior Safety Levels: Classification and Evaluation

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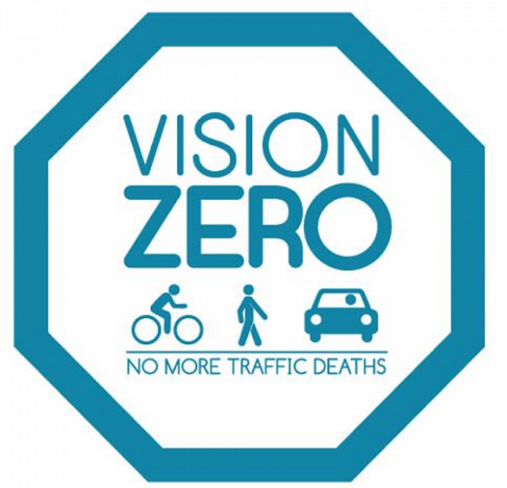
# Significance

- Traffic crashes: kill 1.35 million people/year all over the world, the eighth biggest cause of death.

- Separate target: 50% reduction in fatalities and serious injuries by 2030.

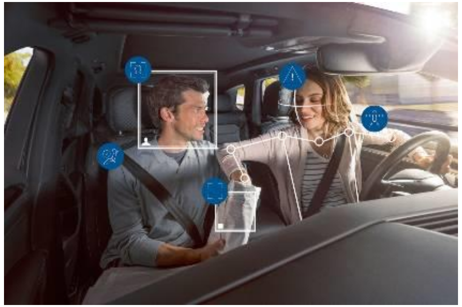
- Vision Zero: no deaths and serious injuries on European roads by 2050.

# Research problems

It is important to evaluate driving behavior safety levels in real-time for providing intervention warmings to further avoid the crash occurrence. Therefore,

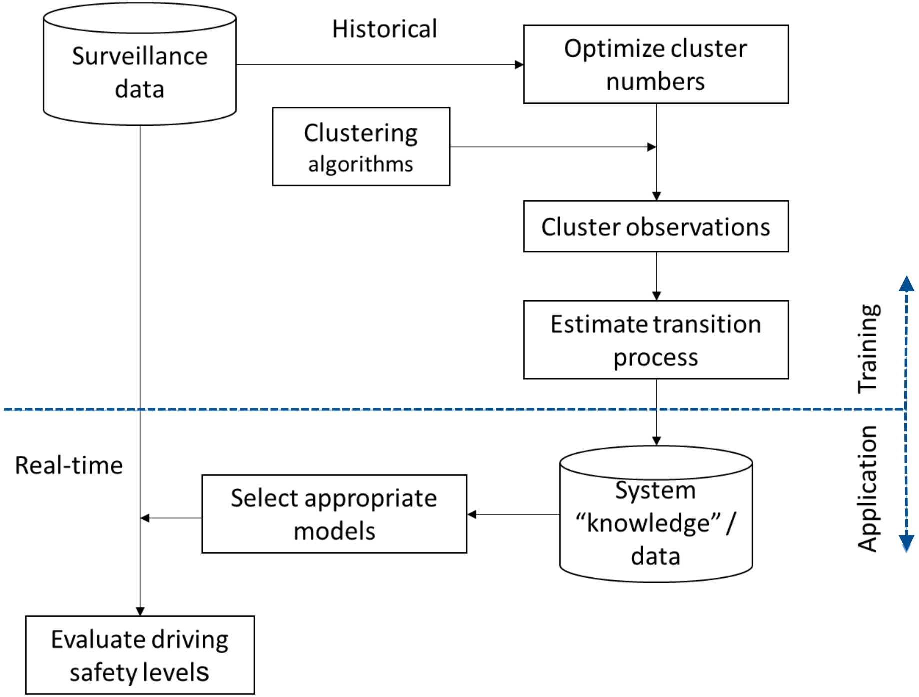
- How to develop a real-time classification and evaluation framework of driving behavior safety levels?
- How many safety levels are optimal for driving intervention warnings?



# Methodology

## A. Overall framework

- **Training step:**
  - Find the optimal number of clusters
  - Identify the driving behavior safety levels
  - Estimate the transition process
- **Application step:**
  - Select the appropriate classification model
  - Evaluate the driving safety levels



# Methodology (continued)

## B. Clustering Algorithms

**K-means clustering** defines clusters by minimizing the total intra-cluster variation (known as total within-cluster variation). The total within-cluster variation is popularly defined as the sum of squared Euclidean distances between observations:

$$Total.D = \sum_{k=1}^{k} W(C_k) = \sum_{k=1}^{k} \sum_{x_i \in C_k} (x_i - \mu_k)^2$$

where $x_i$ is a driving behavior observation belonging to the cluster $C_k$, and $\mu_k$ is the mean value of the observations assigned to the cluster $C_k$.

# Methodology (continued)

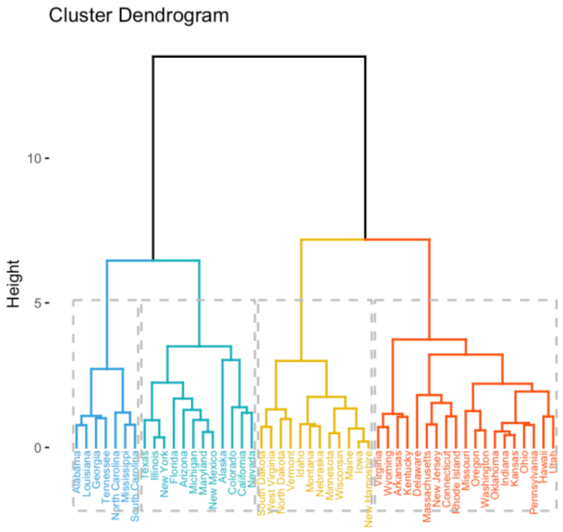
## B. Clustering Algorithms

**Hierarchical clustering** creates a hierarchy of clusters, and presents the hierarchy in a dendrogram to cluster multidimensional data sets, by evaluating dissimilarities of objects.

Agglomerative techniques: to build a hierarchy of clusters:

➢ The linkage method

The linkage method refers to the longest distance between two observations in each cluster, and its equation is $D_{12} = max_{ij}(X_i, Y_j)$ where $X_i$ and $Y_j$ are two observations.



# Methodology (continued)

## B. Clustering Algorithms

As **a model-based clustering,** the Gaussian Mixture Model (GMM) attempts to optimize the fit between the observed data and some mathematical model using a probabilistic approach.

First, a specific-form mixture of Gaussians is assumed, and the density of the GMM is:

$$f(x|\theta) = \sum_{m=1}^{M} \pi_m \varphi(x|\rho_m, \Sigma_m)$$

where $\varphi(x|\rho_m, \Sigma_m)$ is the density of a multivariate Gaussian random variable $X$ with mean $\rho_m$ and covariance matrix $\Sigma_m$, and $\theta = (\pi_1, \cdots, \pi_M, \rho_1, \cdots, \rho_M, \Sigma_1, \cdots, \Sigma_M)$.

Second, the parameters (i.e., mean and std) of this model are estimated by the Expectation Maximization (EM) algorithm.

# Methodology (continued)

## C. Evaluation Models of Driving Behavior Safety Levels

**Support Vector Machine (SVM)** establishes a separating hyperplane and a maximal margin free of training data by choosing a subset $SV \subset X$ called support vectors. The optimization problem is given:

$$\min \frac{\|w\|^2}{2} + C \sum_{i=1}^{n} \xi_i$$

Subject to: $y_i(w \cdot x_i + b) \geq 1 - \xi_i$

The SVs are used to calculate the normal vector $w$ on the hyperplane and the bias $b$ to fulfil the constraint on the optimization problem

# Methodology (continued)

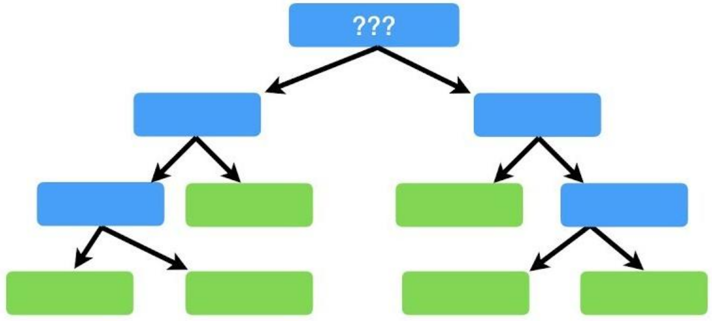
## C. Evaluation Models of Driving Behavior Safety Levels

A **decision tree (DT)** is a decision support algorithm that uses a tree-like model of decisions and their possible consequences to perform both classifications and regressions.

The relationship between the outcome y and features x is

$$\hat{y} = \hat{f}(x) = \sum_{m=1}^{M} c_m I(x \in R_m)$$

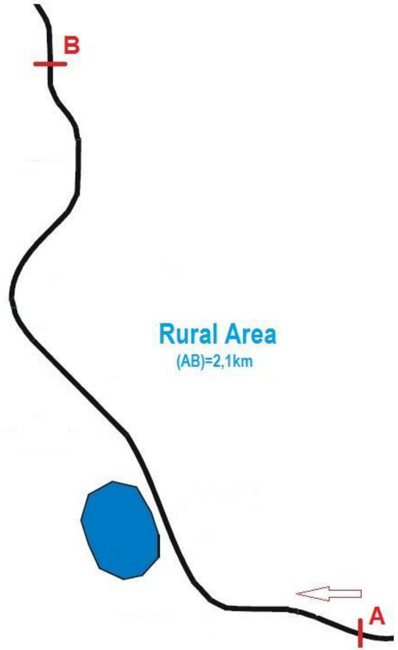
Each instance falls into exactly one leaf node (subset $R_m$). $I(x \in R_m)$ is the identity function that returns 1 if $x$ is in the subset $R_m$ and 0 otherwise. The predicted outcome is $\hat{y} = c_m$, where $c_m$ is the average of all training instances in leaf node $R_m$.



# Experimental Design and Data

## Experimental Design

- Driving simulator experiment
  - Undivided two-lane rural road
  - Length 2.1km, width 3m, zero gradient
  - Six trials for each driver
    - ✓ two traffic scenarios: moderate traffic conditions and high traffic conditions
    - ✓ three distraction conditions: no distraction, cell-phone conversation and conversation with passenger
  - 140 participants with a pathological condition
  - 120 participants with no known pathological conditions



# Experimental Design and Data (continued)

## Data

- Original data
  - Frequency: 33 to 50 milliseconds
- Aggregated data
  - 28 variables
  - Mean, std of
    - ✓ Vehicle direction, Left road board
    - ✓ Chosen gear, Brake pedal position
    - ✓ Steering wheel position in degrees
    - ✓ Motor revolutions, Time to line crossing
    - ✓ Headway distance, Headway time
    - ✓ TTC, etc.

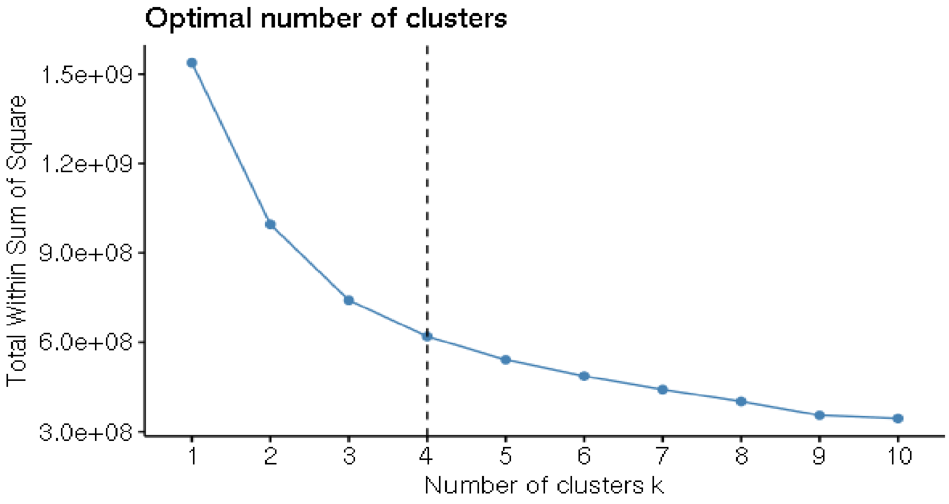
| No | Variables | Description |
|---|---|---|
| 1 | age | Driver's age |
| 2 | LateralPosition | Average distance to the right road board (m) |
| 3 | StdevLateralPos | Standard deviation of distance to the right road board (m) |
| 4 | AverageSpeed | Average speed (km/h) |
| 5 | StdevSpeed | Standard deviation of speed (km/h) |
| 6 | RspurAverage | Average track of the vehicle from the middle of the road (m) |
| 7 | StdRspur | Standard deviation of track of the vehicle from the middle of the road (m) |
| 8 | RalphaAverage | Average direction of the vehicle compared to the road direction in degrees |
| 9 | StdRalpha | Standard deviation of direction of the vehicle compared to the road direction in degrees |
| 10 | BrakeAverage | Average brake pedal position (%) |
| 11 | StdBrake | Standard deviation of brake pedal position(%) |
| 12 | GearAverage | Average chosen gear (0 = idle, 6 = reverse) |
| 13 | StdGear | Standard deviation of chosen gear (0 = idle, 6 = reverse) |
| 14 | RpmAverage | Average motor revolutions in 1/min |
| 15 | StdRpm | Standard deviation of motor revolutions (1/min) |
| 16 | HWayAverage | Average headway, distance to the ahead driving vehicle (m) |
| 17 | StdHWay | Standard deviation of headway, distance to the ahead driving vehicle (m) |
| 18 | DleftAverage | Average distance to the left road board (m) |
| 19 | StdDleft | Standard deviation of distance to the left road board (m) |
| 20 | WheelAverage | Average steering wheel position in degrees |
| 21 | StdWheel | Standard deviation of steering wheel position in degrees |
| 22 | TheadAverage | Average time to headway, i.e. to collision with the ahead driving vehicle (s) |
| 23 | StdThead | Standard deviation of time to headway, i.e. to collision with the ahead driving vehicle (s) |
| 24 | TTLAverage | Average time to line crossing, time until the road border line is exceeded (s) |
| 25 | StdTTL | Standard deviation of time to line crossing, time until the road border line is exceeded (s) |
| 26 | TTCAverage | Average time to collision (all obstacles) (s) |
| 27 | StdTTC | Standard deviation of time to collision (s) |
| 28 | Crash_number | Number of crashes during the driving interval |

# Results

## A. Optimizing Driving Behavior Safety Level

K-means clustering

- ✓ According to the location of the bend (knee) in the plot, the optimal number of driving behavior safety levels is four



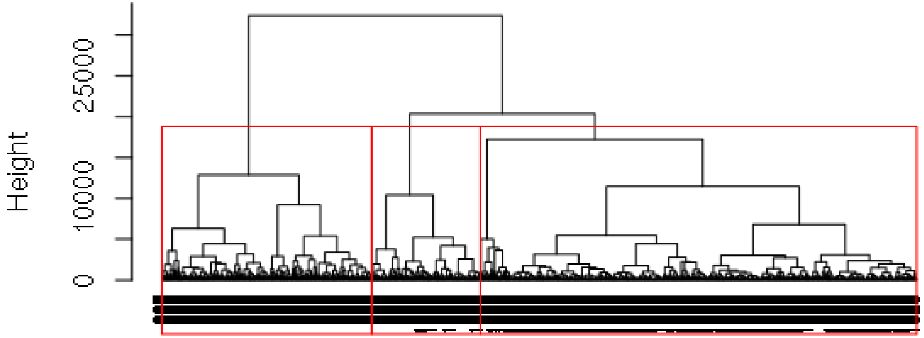

Optimal number of clusters based on k-means clustering

# Results (continued)

## A. Optimizing Driving Behavior Safety Level

Hierarchical clustering

- ✓ The Ward's minimum variance method to perform agglomerative clustering.
- ✓ The optimal number of state levels of driving behavior safety is found to be three.



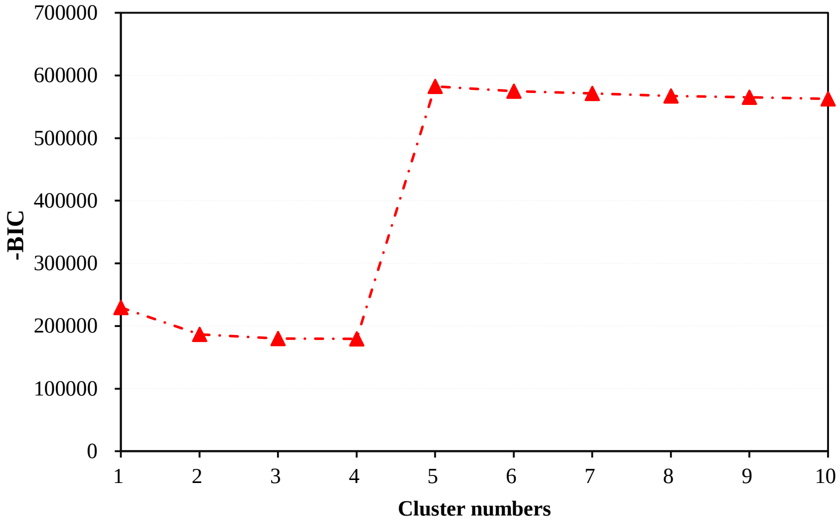

Cluster dendrogram of hierarchical cluster analysis

# Results (continued)

## A. Optimizing Driving Behavior Safety Level

A model-based clustering --Gaussian mixture model (GMM)

- ✓ Bayesian Information Criterion (BIC) is an important index to find the number of clusters by selecting the best clustering model and it uses the likelihood and a penalty term to guard against overfitting.
- ✓ The optimal number of driving behavior safety levels is four

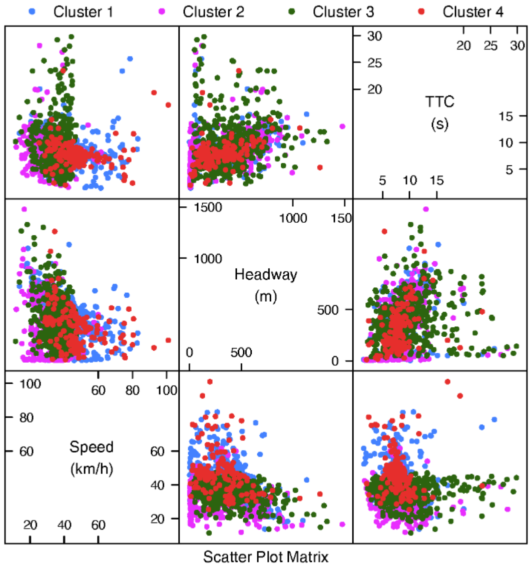



Optimal number of clusters based on GMM

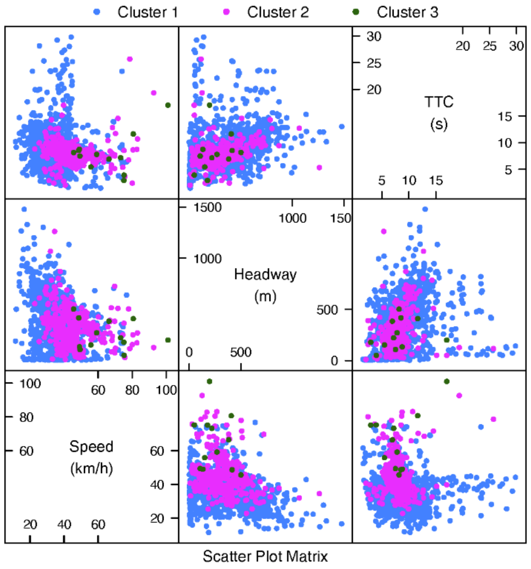
# Results (continued)

## B. Clustering and Classification

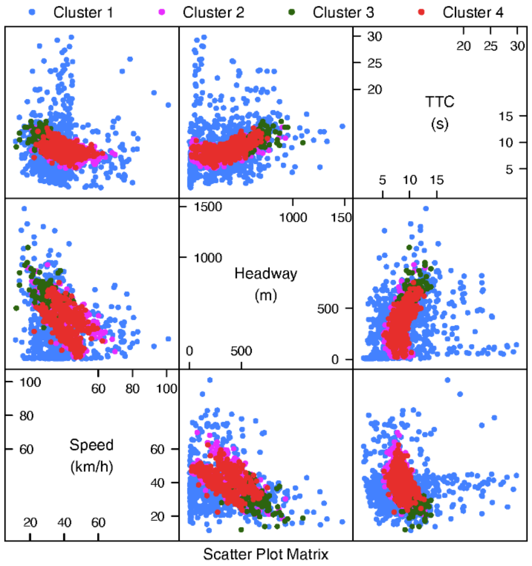
K-means clustering




Hierarchical clustering




Gaussian mixture model (GMM)

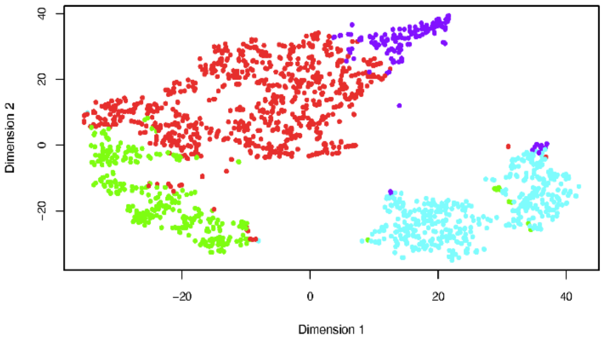


# Results (continued)

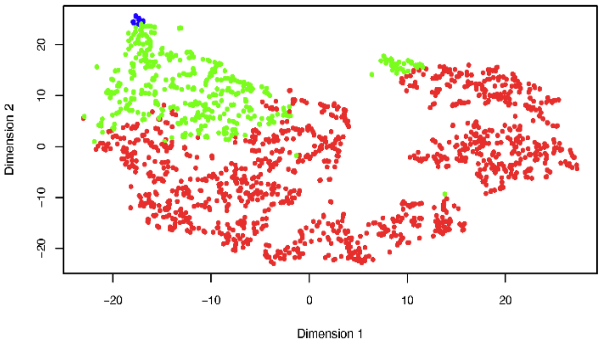
## B. Clustering and Classification

- T-SNE is used to visualize the clustering results.
- T-SNE is extremely useful for visualizing high-dimensional data with a dimensionality reduction method.

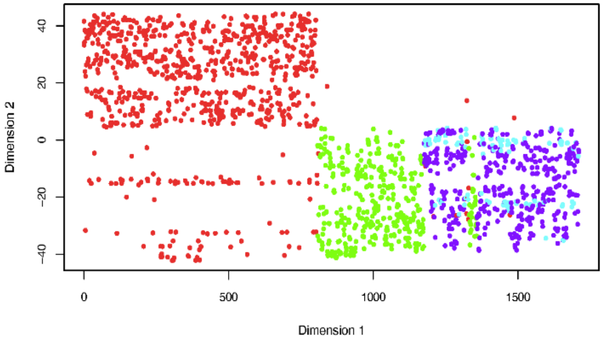
K-means clustering




Hierarchical clustering




Gaussian mixture model (GMM)



# Results (continued)

## B. Clustering and Classification

- The k-means algorithm is the best according to the evaluation indices.

Comparing three clustering algorithms

| Index | K-means | Hierarchical cluster | GMM |
|---|---|---|---|
| **The within clusters sum of squares** | 6.2E8 Best | 11.3E8 | 11.6E8 |
| **The average silhouette width** | 0.341 Best | 0.176 | -0.0239 |
| **Calinski-Harabasz index** | 843.4 Best | 310.2 | 182.9 |
| **Dunn index** | 0.0266 Best | 0.0240 | 0.0071 |

# Results (continued)

## C. Driving Behavior Safety Level Evaluations

- 80 SVM models:
  - ✓ Eight different gammas (i.e. 0.001, 0.01, 0.1, 0.5, 1, 2, 5, 10)
  - ✓ Five different costs (i.e. 0.01, 0.01, 1, 10, and 100)
  - ✓ Two kernel functions (i.e. radial and linear)

- The developed SVM models can well identify the driving behavior safety levels in the dataset (The total accuracy > 93.0%)

Results of SVM models

| Parameters | K-means clustering scenario | Hierarchical clustering scenario | GMM scenario |
|---|---|---|---|
| **Kernel** | Linear | Radial | Linear |
| **Gamma** | 0.001 | 0.01 | 0.001 |
| **Cost** | 10 | 10 | 100 |
| **Number of Support Vectors** | 110 | 165 | 107 |
| **Best performance** | 0.0251 | 0.0485 | 0.0169 |
| **Total Accuracy** | 97.3% | 93.4% | 98.7% |

# Results (continued)

## C. Driving Behavior Safety Level Evaluati

- Models have good performances
- The SVM models perform better than the decision trees (DT)

Model accuracy in k-means clustering scenario

| Model | Clustered | Predicted | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | True | False |
| SVM | 1 | 95 | 7 | 2 | 8 | 84.8% | 15.2% |
| | 2 | 1 | 126 | 3 | 0 | 96.9% | 3.1% |
| | 3 | 0 | 2 | 232 | 0 | 99.1% | 0.9% |
| | 4 | 0 | 0 | 3 | 35 | 92.1% | 7.9% |
| | Total | | | | | 94.9% | 5.1% |
| DT | 1 | 43 | 0 | 0 | 0 | 100.0% | 0.0% |
| | 2 | 15 | 106 | 0 | 15 | 77.9% | 22.1% |
| | 3 | 8 | 0 | 84 | 3 | 88.4% | 11.6% |
| | 4 | 0 | 0 | 0 | 238 | 100.0% | 0.0% |
| | Total | | | | | 92.0% | 8.0% |

Model accuracy in hierarchical clustering scenario

| Model | Clustered | Predicted | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | True | False |
| SVM | 1 | 374 | 14 | 0 | 96.4% | 3.6% |
| | 2 | 8 | 114 | 1 | 92.7% | 7.3% |
| | 3 | 0 | 0 | 3 | 100.0% | 0.0% |
| | Total | | | | 95.5% | 4.5% |
| DT | 1 | 371 | 11 | 0 | 97.1% | 2.9% |
| | 2 | 20 | 107 | 1 | 83.6% | 16.4% |
| | 3 | 0 | 0 | 4 | 100.0% | 0.0% |
| | Total | | | | 93.8% | 6.2% |

Model accuracy in GMM scenario

| Model | Clustered | Predicted | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | True | False |
| SVM | 1 | 252 | 0 | 0 | 0 | 100.0% | 0.0% |
| | 2 | 2 | 117 | 0 | 0 | 98.3% | 1.7% |
| | 3 | 1 | 0 | 24 | 3 | 85.7% | 14.3% |
| | 4 | 1 | 0 | 4 | 110 | 95.7% | 4.3% |
| | Total | | | | | 97.9% | 2.1% |
| DT | 1 | 240 | 2 | 0 | 2 | 98.4% | 1.6% |
| | 2 | 0 | 120 | 0 | 0 | 100.0% | 0.0% |
| | 3 | 0 | 0 | 24 | 3 | 88.9% | 11.1% |
| | 4 | 0 | 0 | 14 | 108 | 88.5% | 11.5% |
| | Total | | | | | 95.9% | 4.1% |

# Results (continued)

## C. Driving Behavior Safety Level Evaluatio

- The combination of developed SVM and GMM slightly outperforms the other combined algorithms

Model accuracy in k-means clustering scenario

| Model | Clustered | Predicted | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | True | False |
| SVM | 1 | 95 | 7 | 2 | 8 | 84.8% | 15.2% |
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Model accuracy in GMM scenario

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| | Total | | | | | 95.9% | 4.1% |

Model accuracy in hierarchical clustering scenario

| Model | Clustered | Predicted | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | True | False |
| SVM | 1 | 374 | 14 | 0 | 96.4% | 3.6% |
| | 2 | 8 | 114 | 1 | 92.7% | 7.3% |
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| | Total | | | | 95.5% | 4.5% |
| DT | 1 | 371 | 11 | 0 | 97.1% | 2.9% |
| | 2 | 20 | 107 | 1 | 83.6% | 16.4% |
| | 3 | 0 | 0 | 4 | 100.0% | 0.0% |
| | Total | | | | 93.8% | 6.2% |

# Discussions and Conclusions

- Driving safety could be clustered into several levels: ideally four.

- The k-means algorithm is the best according to the evaluation indices

- Models have good performances in these three clustering scenarios
  - The total accuracy > 92.0%

- The combination of developed SVM and GMM outperforms the other combined algorithms
  - The SVM models perform better than the decision trees, respectively

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# Driving Behavior Safety Levels: Classification and Evaluation

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