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Accident avoidance by active intervention for Intelligent Vehicles

Driver Perceived Threat in Rear-End Collision Avoidance Situations – A Statistical Approach

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Agenda

- Objectives of Driver Behaviour Study
- Overview of Rear End Collision Avoidance
- Test Vehicle Setup & Clinic Overview
- Data Analysis
- Perceived Safety
- Conclusions

Objectives of Driver Behaviour Study

- For collision avoidance there is always a balance between early intervention by the systems and delaying the system reaction long enough until it is ensured that the driver will not (or is no longer able to) intervene.

- Determine the steering onsets when the driver avoids a rear end collision by steering.

- Determine preferred lateral distance and acceleration

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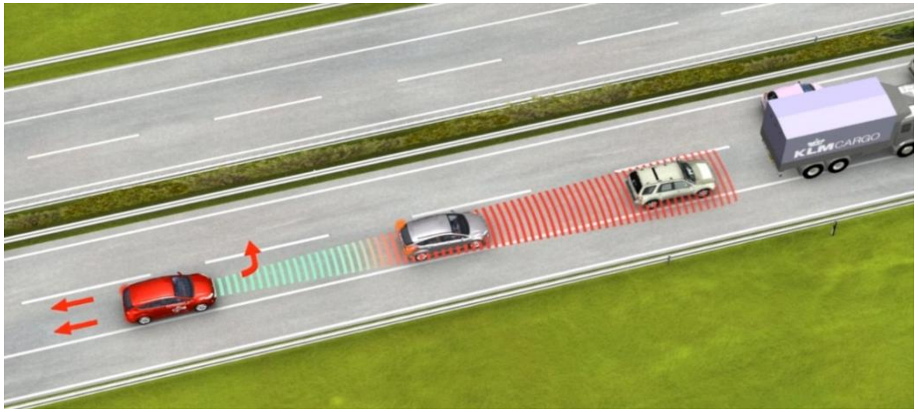
Overview of Rear End Collision Avoidance



- Collision avoidance functions
  are divided into four sub-functions:
  - lane change collision avoidance (LCCA)
  - side impact avoidance (SIA)
  - run off-road prevention (RORP)
  - rear end collision avoidance (RECA)
- Autonomous steering and/or braking intervention in case of imminent threat
- Evaluates the status of the host vehicle as well as of the surrounding traffic and environment by utilising different sensors (e.g. radar, camera and ultrasonic sensors and the digital map)

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Test Vehicle Setup & Clinic Overview

- Ford Focus, 2.0 L Diesel
- Automatic transmission
- Equipped with:
  - In-Vehicle sensors
    - yaw rate
    - lateral acceleration
    - longitudinal acceleration
    - steering angle
    - pedal position
  - Cameras monitors environment and driver
  - Differential GPS
  - Front and rear radar

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Test Vehicle Setup & Clinic Overview

Details of drivers participated in the clinic

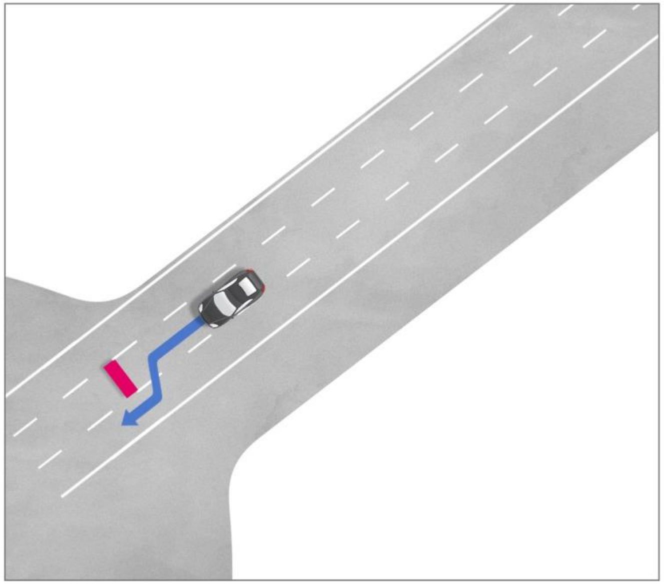
- 21 drivers + 4 experts
- Ford employees
- Age from 25-65 years
- 7 female and 18 male

Test Vehicle Setup & Clinic Overview

1	What is the last moment of steering perceived by driver?
2	How much torque and speed do they apply when steering?
3	What is the level of lateral acceleration?
4	How long does it take to control the vehicle after passing the obstacle?
5	What is the lateral distance to the obstacle when passing it?
6	How do driver parameters affect reaction (age, gender etc.)
7	How is the driver reaction affected by level of speed and dv?
8	What is the driver reaction time?

Test Vehicle Setup & Clinic Overview

- Experimantal Setup



Vehicle Dynamics Area (VDA) of Lommel Proving Ground

Test Vehicle Setup & Clinic Overview

- Experimental Setup – Driver Task

  - Steering manoeuvre as per table
  - Order of manoeuvre execution is randomized
  - Drivers were requested to conduct the manoeuvre as late as possible and not to brake during manoeuvre.

Velocity	Scenario		
Host vehicle speed [km/h]	FREE steering only	2 - LANES steering only	3 - LANES steering only
35	-	x	-
50	-	x	-
70	x	x	x
100	x	x	x
120	x	x	-

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Clinic in Progress

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Extract Information from Raw Data

1. The recorded data from sensors has been imported to matlab.

2. The automated script has been written to read, analyze and write metrics in excel sheet from matlab. The metrics are shown below in the table.

Collision Avoidance by Steering
Time to Collision(TTC)
Onset Distance
Onset Velocity
Lateral Acceleration
Lateral Displacement
Max. Torque
Max. Steering Wheel Angle
Max. Steering Wheel Velocity

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TTC - Deepdive

Factors:

1. No of Lanes
2. Drivers Skill level (Regular, Expert)
3. Driver Gender (Male, Female)
4. Vehicle Speed (35, 50, 70, 100, 120kph)

Definition - TTC

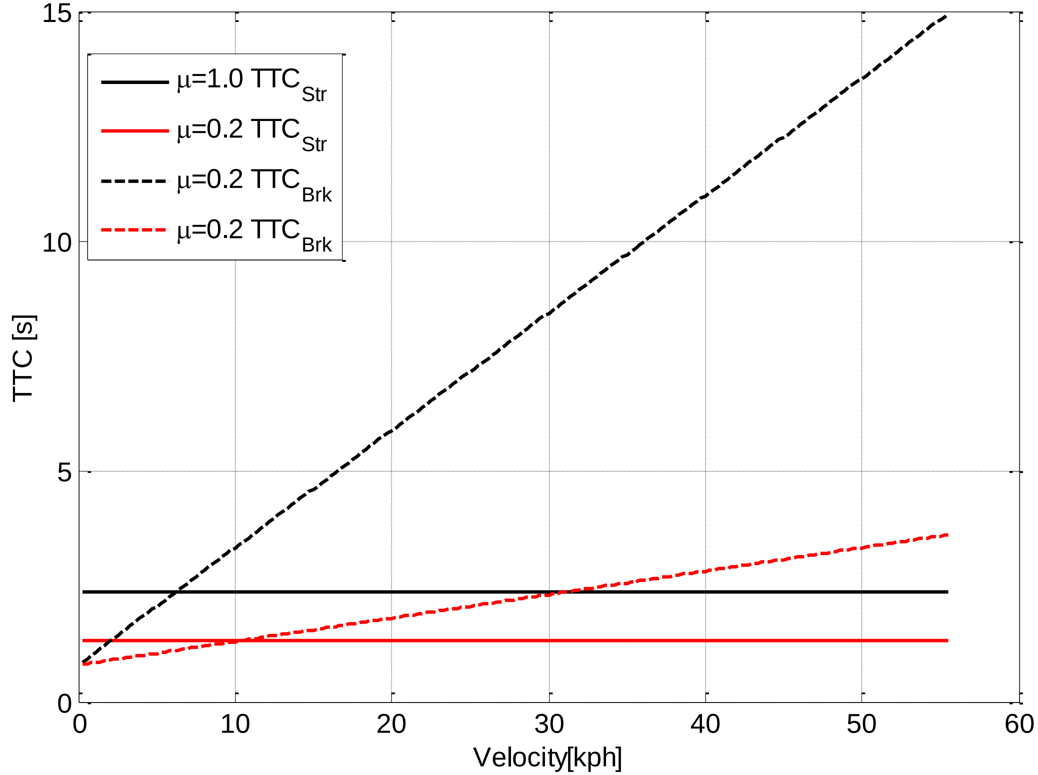
In research on Traffic Conflicts Techniques, Time-To-Collision (TTC) has proven to be an effective measure for rating the severity of conflicts.

TTC is defined as: "The time required for two closing vehicles to collide if they continue at their present speed and acceleration in the same lane".

$$TTC_{Str} = f(y_d, a_{lat}, \mu)$$

$$TTC_{Brk} = f(v, a_{long}, \mu)$$

where,
y_d = lateral deviation
a_{lat} = lateral acceleration
v = vehicle velocity
a_{lon} = long. Deceleration
µ = coefficient of friction



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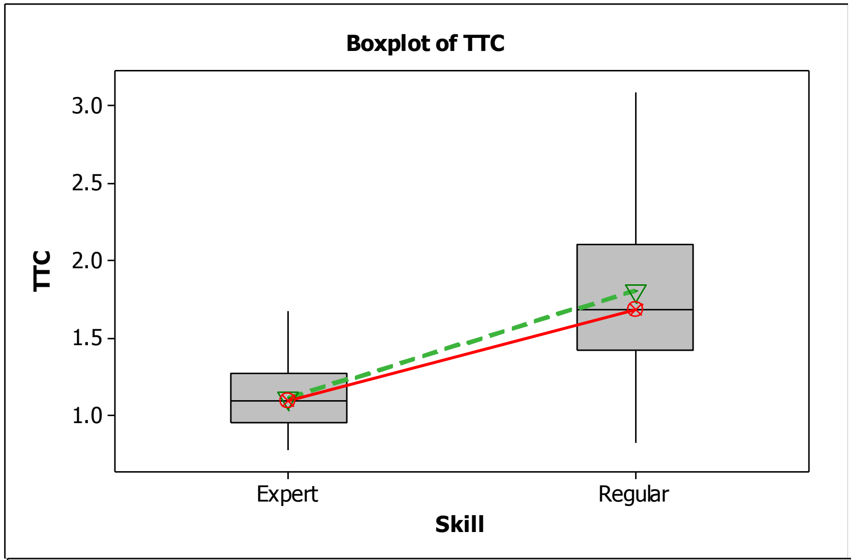
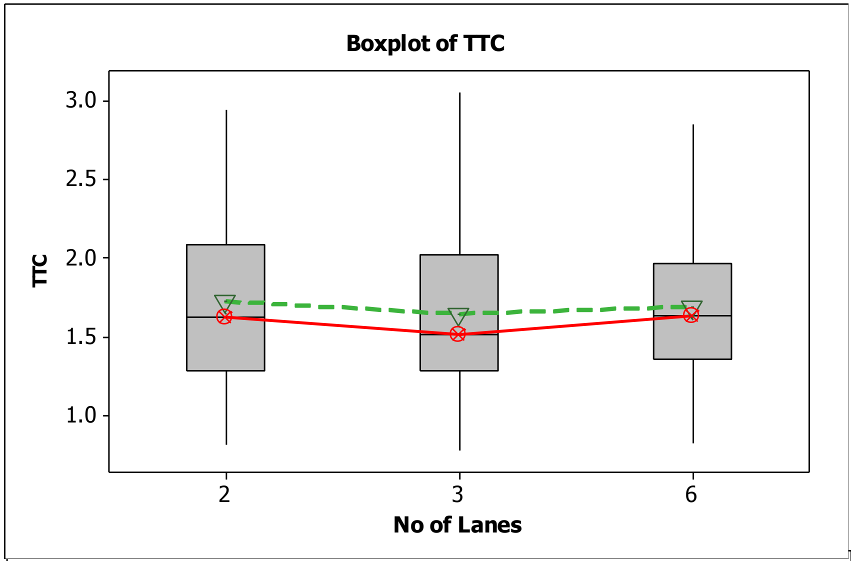
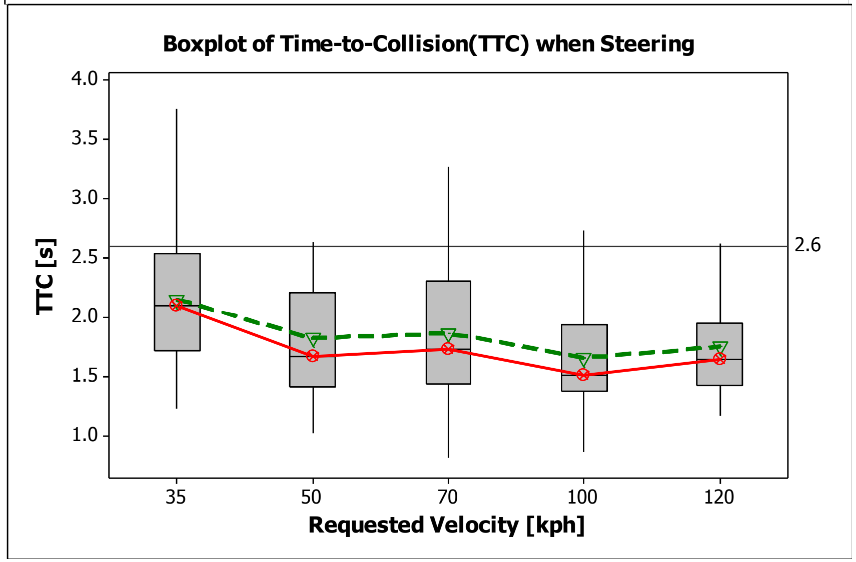
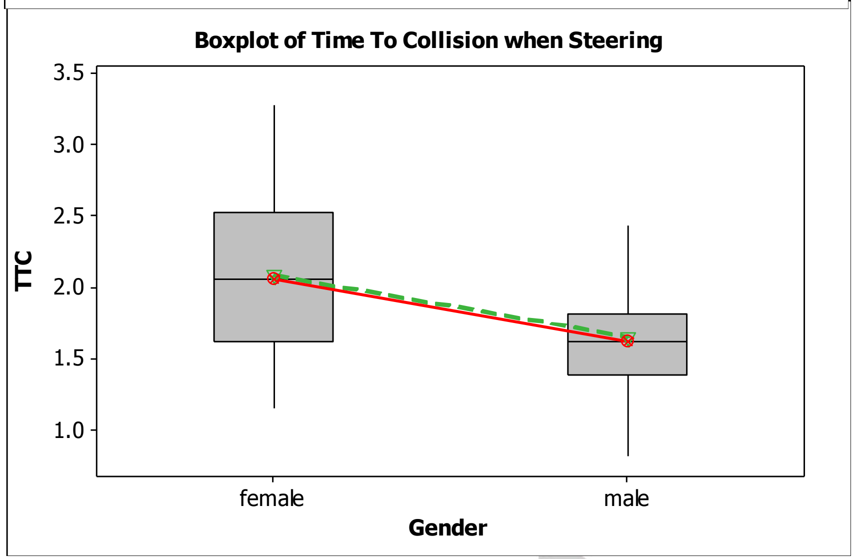
Effects of factors on TTC





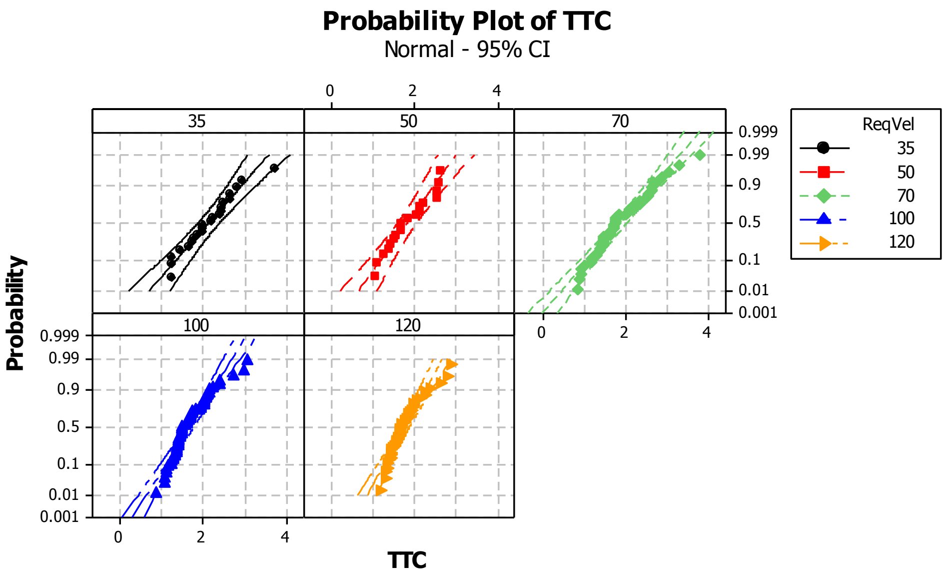


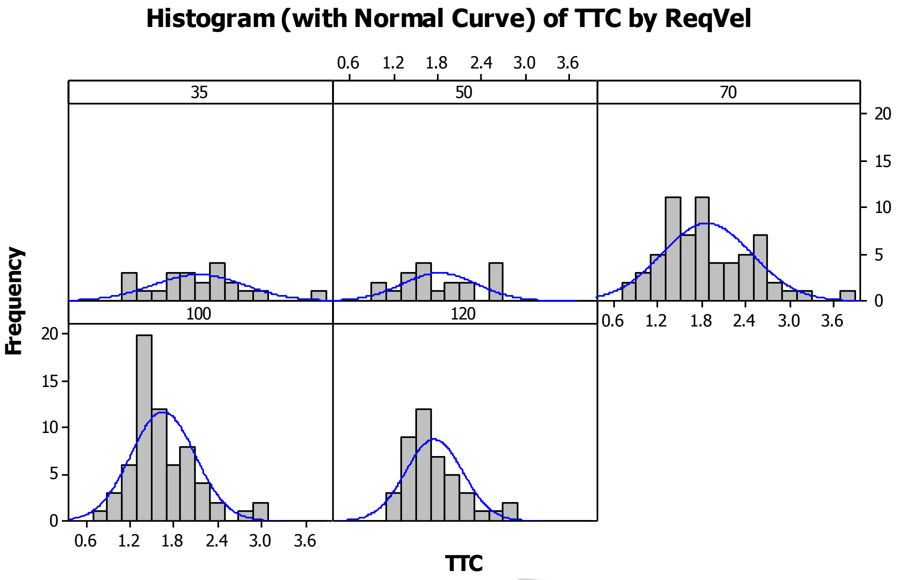


Understanding Raw data

- The metrics from time series data have been extracted.
- It is found that data is not in normal distribution at different factor levels.
- To compare metrics even at different factor levels it is required to transform the data in normal distribution at all factor levels.

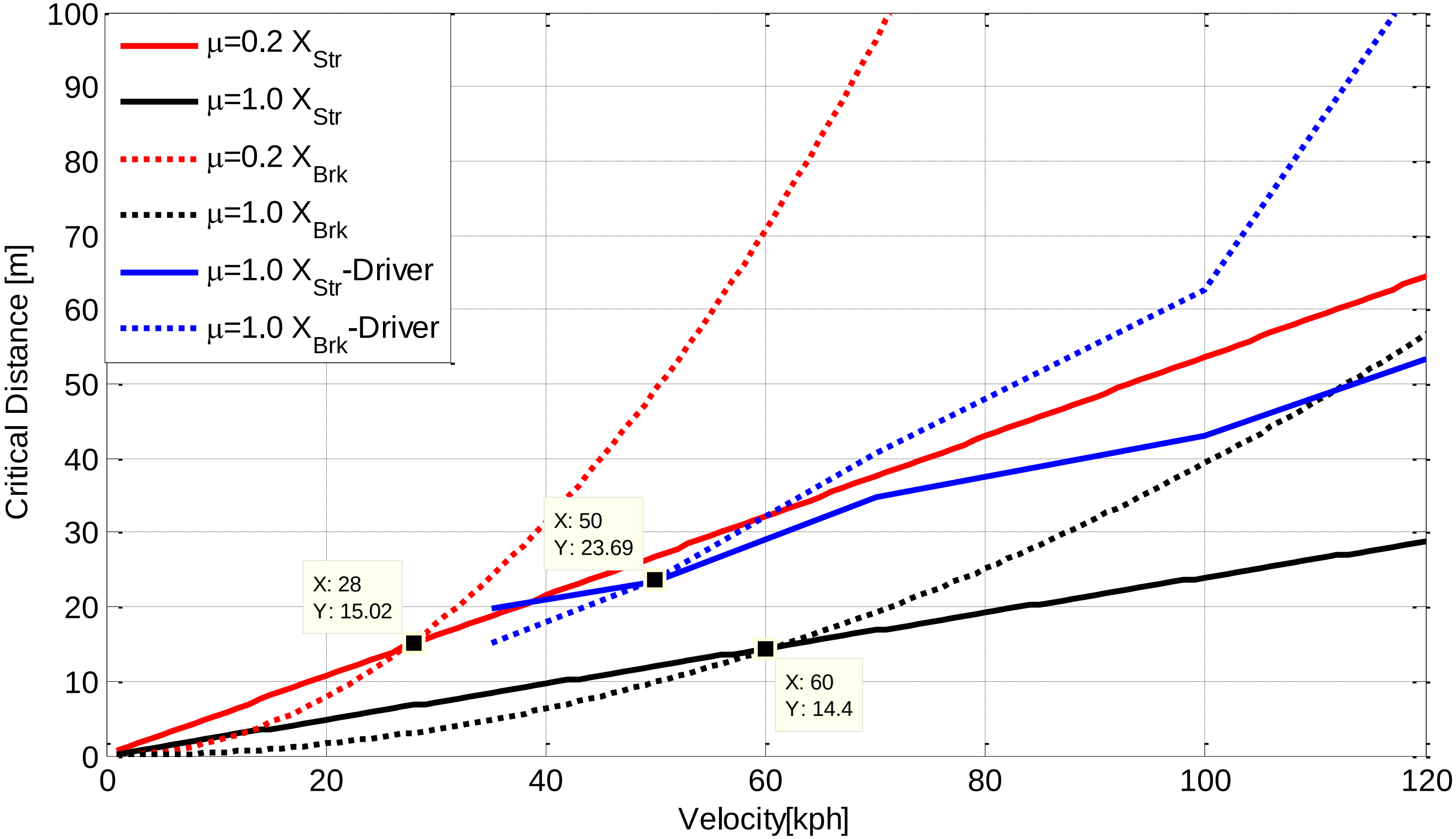
The distribution of TTC has been shown in probability plot & histogram





Break Even Point for Steering & Braking

With out system and vehicle response delay



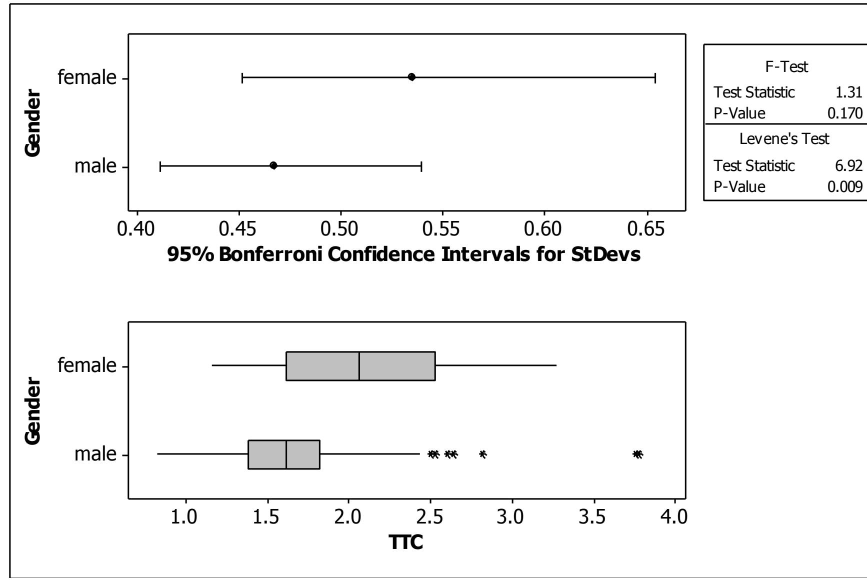
Spread of TTC

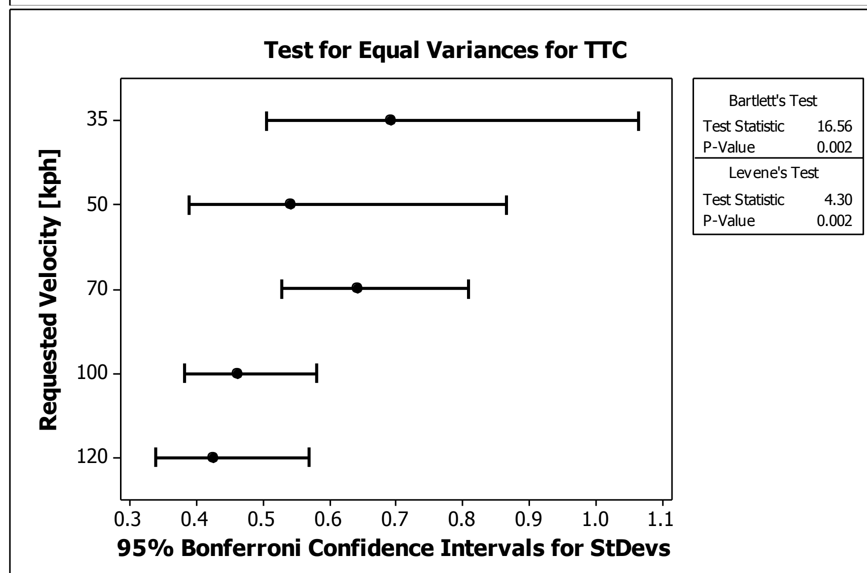
Variances in TTC @ speed & gender

$H_0 : \sigma_{30kph} = \sigma_{50kph} = \ldots = \sigma_{120kph}$
$H_a : \sigma_{30kph} \neq \sigma_{50kph} = \ldots \neq \sigma_{120kph}$

Bartlett test : For normal data
Levene's test : For non- normal data

There is significant variance of TTC @velocity. The related p-value is less than 0.05 so reject H_0.





Inference:

- ✓ The variance in TTC is not same at different velocity.
- ✓ The variance in TTC for male and female for all velocity is same.

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TTC – Velocity Difference

The hypothesis :

$H_0 : \mu_{35kph} = \ldots = \mu_{120kph}$

$H_a : \mu_{35kph} \neq \ldots \neq \mu_{120kph}$

```
 Individual 95% CIs For Mean Based on Pooled StDev
Level    N    Mean   StDev   ------+---------+---------+---------+---
 35     22  0.7247  0.2962                   (--------*---------)
 50     19  0.5634  0.2889     (----------*---------)
 70     64  0.5702  0.3344          (-----*----)
100     65  0.4755  0.2483   (-----*----)
120     43  0.5392  0.2071       (------*------)
                             ------+---------+---------+---------+---
                                 0.48      0.60      0.72      0.84
Pooled StDev = 0.2785
```

Hsu's Multiple Comparison with Best

Metrics/Vehicles	TTC (P-value = 0)		
	L	C	U
35kph	-0.0317	-0.1545	0.3067
50kph	-0.3542	-0.1613	0.0317
70kph	-0.3067	-0.1545	0.000
100kph	-0.4011	-0.2491	0.000
120kph	-0.3470	-0.1855	0.000

Inference:

1) The mean of transformed TTC is different from atleast one set.
2) The variation of TTC is 1.32s

Tukey's Test – pairwise comparison of TTC

```
ReqVel =  35 subtracted from:

ReqVel     Lower   Center     Upper   --+---------+---------+---------+-------
 50      -0.4012  -0.1613    0.0787      (-----------*-----------)
 70      -0.3438  -0.1545    0.0349         (---------*----------)
100      -0.4381  -0.2491   -0.0602    (----------*---------)
120      -0.3863  -0.1855    0.0153       (----------*----------)
                                      --+---------+---------+---------+-------
                                     -0.40     -0.20     -0.00      0.20


ReqVel =  50 subtracted from:

ReqVel     Lower   Center    Upper   --+---------+---------+---------+-------
 70      -0.1934   0.0068   0.2069             (----------*---------)
100      -0.2877  -0.0879   0.1119         (----------*----------)
120      -0.2353  -0.0243   0.1868           (-----------*---------)
                                     --+---------+---------+---------+-------
                                    -0.40     -0.20     -0.00      0.20


ReqVel =  70 subtracted from:

ReqVel     Lower   Center    Upper   --+---------+---------+---------+-------
100      -0.2296  -0.0947   0.0403              (-----*------)
120      -0.1821  -0.0310   0.1200                (------*-------)
                                     --+---------+---------+---------+-------
                                    -0.40     -0.20     -0.00      0.20


ReqVel = 100 subtracted from:

ReqVel     Lower  Center    Upper   --+---------+---------+---------+-------
120      -0.0870  0.0636   0.2142                     (------*-------)
                                    --+---------+---------+---------+-------
                                   -0.40     -0.20     -0.00      0.20
```

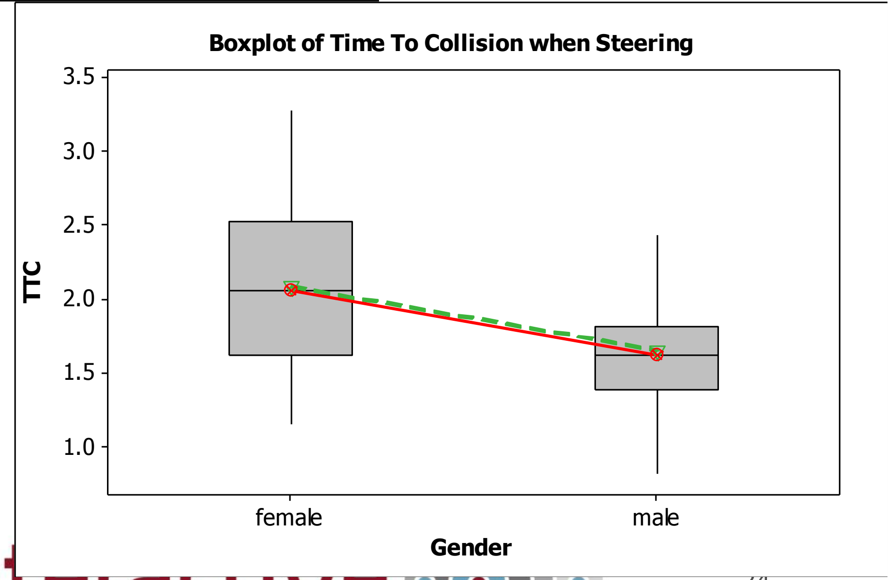
TTC – Gender Differences

Two-Sample T-Test and CI: TTC, Gender

```
Two-sample T for TTC

Gender     N   Mean  StDev  SE Mean
female    75  2.084  0.535    0.062
male     138  1.655  0.466    0.040


Difference = mu (female) - mu (male)
Estimate for difference:  0.4289
95% CI for difference:  (0.2899, 0.5679)
T-Test of difference = 0 (vs not =): T-Value = 6.08  P-Value = 0.000
DF = 211
Both use Pooled StDev = 0.4915
```

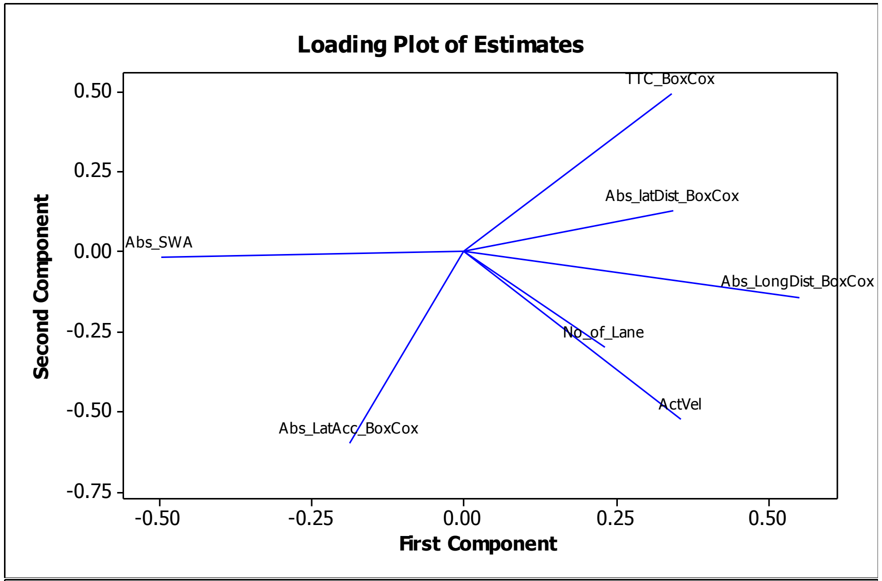


Inference

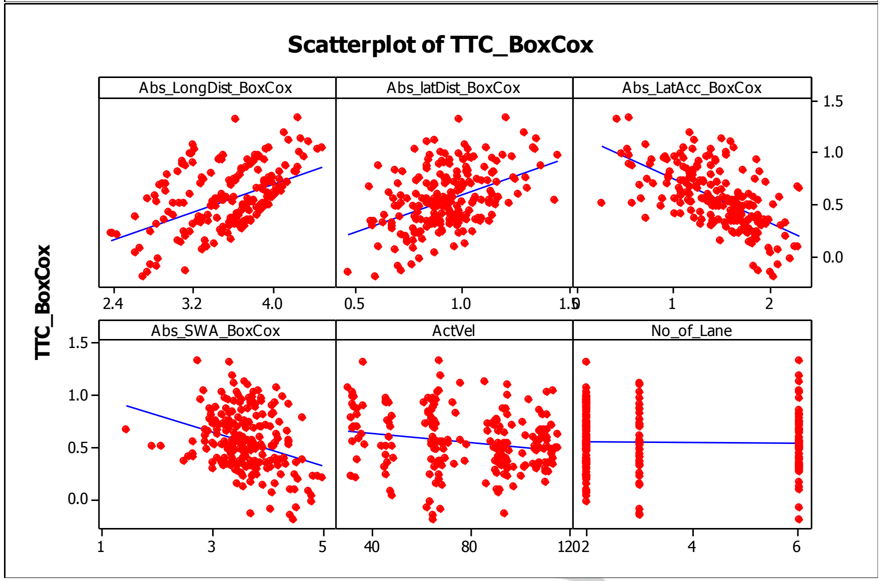
- ✓ Previously, we have seen that variances are equal.
- ✓ There is sufficient evidence exist that mean TTC for male and female exist.
  - ➢ p-values <0.05 &
  - ➢ CI does not include zero.
- ✓ The estimated difference is 0.43s(approx)

Regression of TTC among Estimates

Statistian's View



Engineer's View



Summary of TTC findings

Criteria	Conclusions
Velocity	1. Theoretically, TTC for steering is independent of vehicle velocity. 2. Practically, it is found that the only difference in TTC exist between 35kph and 100kph for steering. 3. The break-even point for steering and braking is 60kph at 14.5m without system delay. 4. The break-even point for steering and braking is 40kph at 14.5m with system delay. Summary of TTC findings 5. The break-even point for steering and braking is 50kph at 24.0m for drivers.
Enviro	1. The number of available free lanes does not affect TTC.
Driver	1. Beautiful gender take significantly more TTC than the handsome gender. 2. The ascending driving skills reduces the required TTC.

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Lateral Acceleration – deep dive

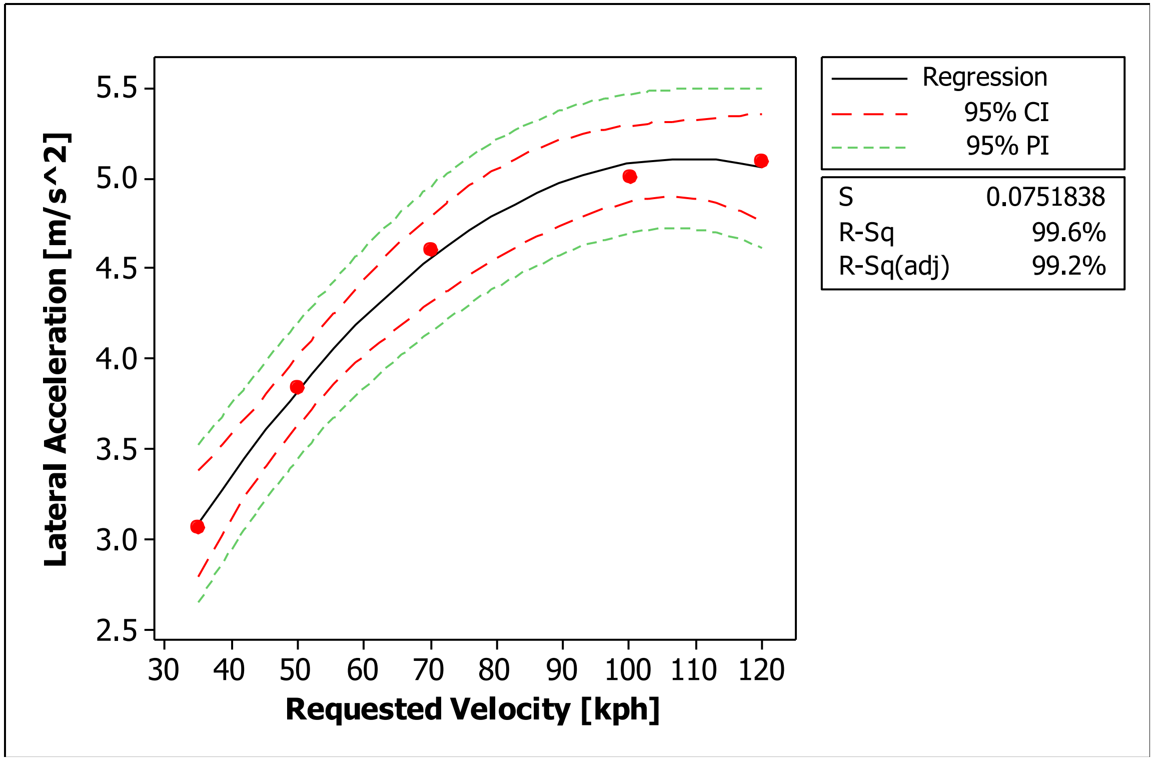
Factors:

1. No of Lanes (2,3,Free(6))
2. Drivers Skill level (Regular, Expert)
3. Driver Gender (Male, Female)
4. Vehicle Speed (35, 50, 70, 100, 120kph)

Regression – Latacc vs velocity

The lateral accelerations achieved by drivers has quadratic relationship with velocity.

$$a_{mean} = 0.693 + 0.0815v - 0.000376v^2$$



Lateral Distance – deep dive

Factors:

1. No of Lanes (2,3,Free(6))
2. Drivers Skill level (Regular, Expert)
3. Driver Gender (Male, Female)
4. Vehicle Speed (35, 50, 70, 100, 120kph)

Summary of lateral displacement findings

Criteria	Conclusions
Velocity	1. Lateral displacement has equal variance is all velocities 2. The lateral distance targetted by driver at different velocities are not significantly different from each other
Enviro	1. The number of available free lanes does affect lateral displacement. 2. 2 lanes or 3 lanes scenario has no significant difference 3. Free space and 2 lanes or 3 lanes scenario is significantly diferent by 1.1m
Driver	1. Beautiful genders take significantly more lateral distance than the handsome genders by 1.16m 2. The ascending driving skills reduces the required lateral distance.

Longitudinal Distance - Deepdive

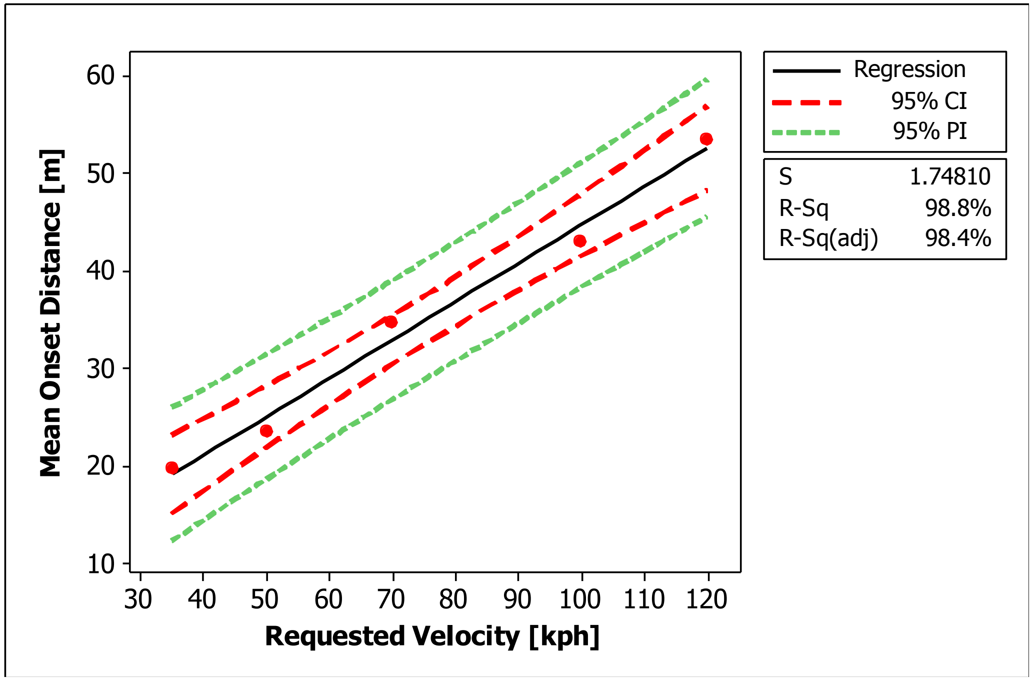
Factors:

1. No of Lanes (2,3,Free(6))
2. Drivers Skill level (Regular, Expert)
3. Driver Gender (Male, Female)
4. Vehicle Speed (35, 50, 70, 100, 120kph)

Regression

Regression among onset distance and vehicle velocity

$$x_{onset} = 5.352 + 0.03937v$$



Summary of longitudinal distance findings

Criteria	Conclusions
Velocity	1. Longitudinal distance has equal variance is all velocities 2. The longitudinal distance targetted by driver at different velocities are significantly different from each other execpt between 35kph and 50kph
Enviro	1. The number of available free lanes does effect longitudinal distance. 2. 2 lanes or 3 lanes scenario has no significant difference 3. Free space and 3 lanes scenario is significantly diferent .
Driver	1. Beautiful genders take significantly more longitudinal displacement than the handsome genders by 10m 2. The ascending driving skills reduces the required longitudinal displacement by 13.7m

Steering Torque – Deep Dive

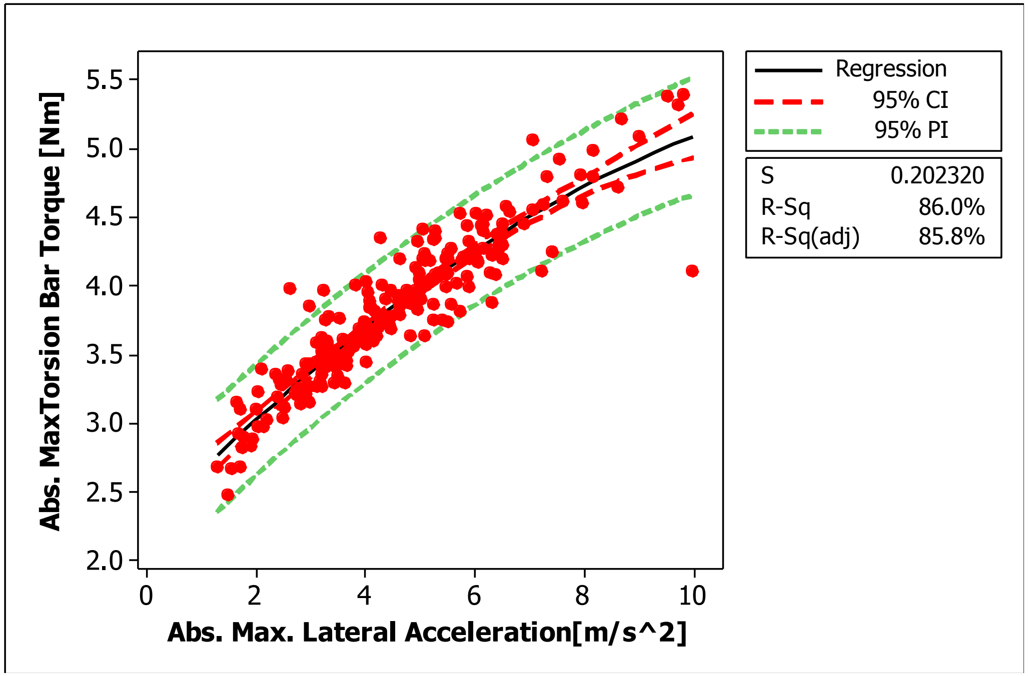
Factors:

1. No of Lanes (2,3,Free(6))
2. Drivers Skill level (Regular, Expert)
3. Driver Gender (Male, Female)
4. Vehicle Speed (35, 50, 70, 100, 120kph)

Regressions

The regression among steering wheel torque and lateral acceleration is shown below

$$Tbar_{trq} = 2.262 + 0.04074 a_y - 0.01246 a_y^2$$



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Perceived Safety - Questionnaire

The responses of the drivers to the questionnaire form a natural order. It is a natural option to fit a ordinal logistic regression model.
The questionnaire has 5 levels of safety feel to choose after each maneuver.

- How safe or unsafe did you feel during the last maneuver?

	very	somewhat	neither	somewhat	very	
Unsafe	❒	❒	❒	❒	❒	**Safe**
Scale	1	2	3	4	5	

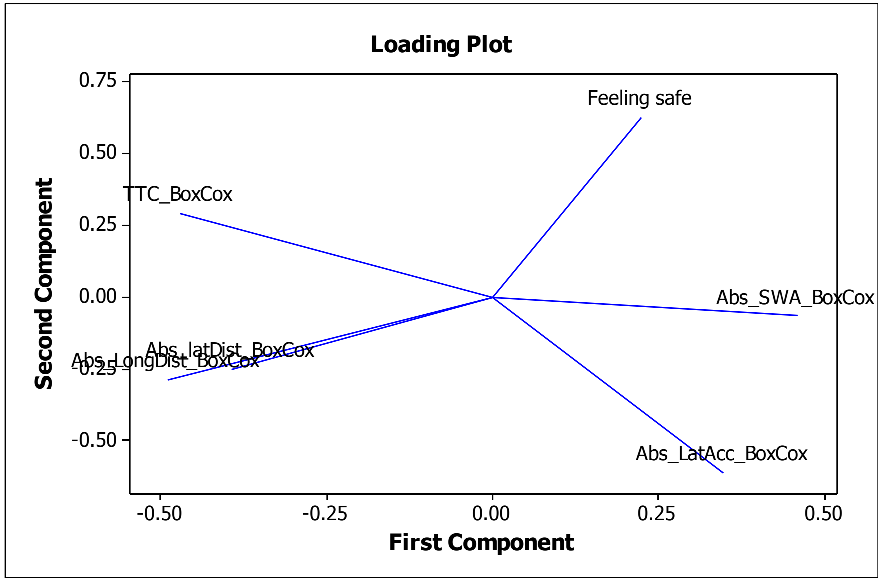
Attribute data – Feeling safe

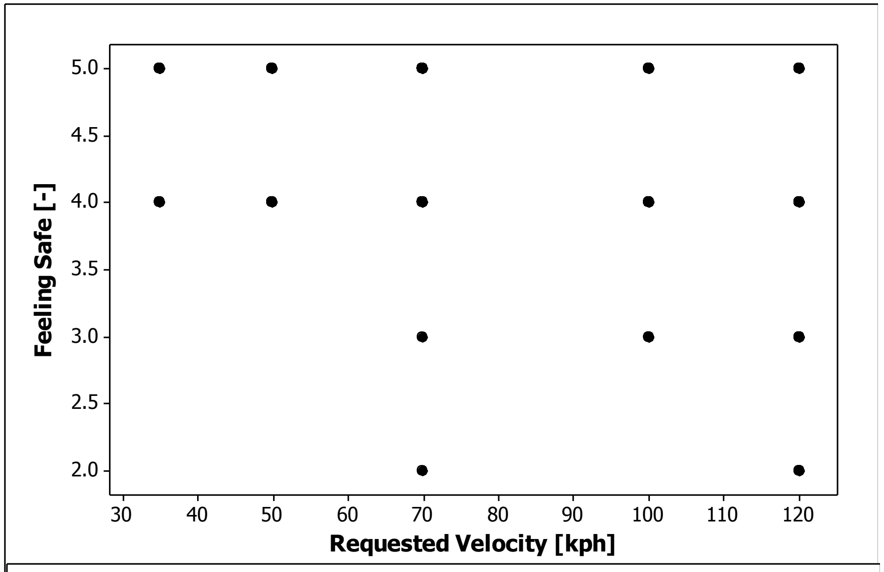
The rating scale is not explored by drivers!

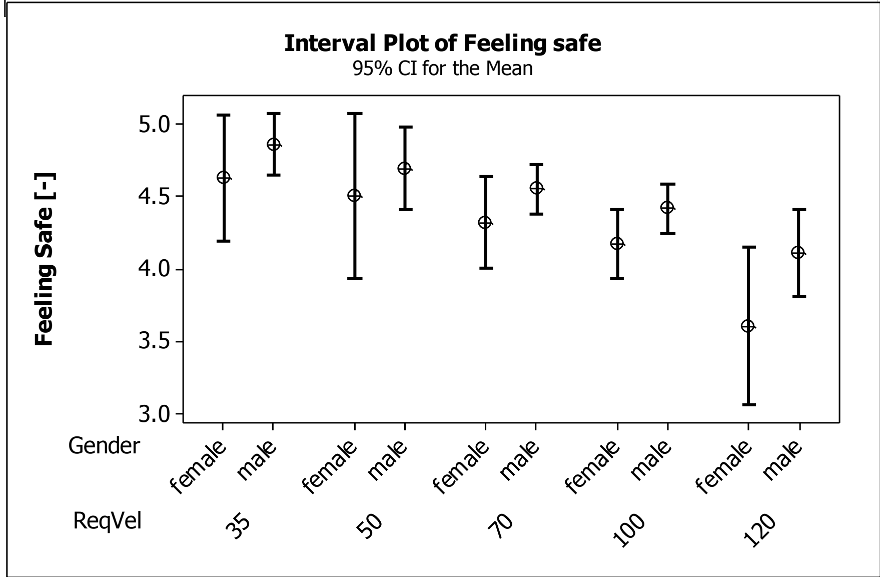
Variable	Value	Count
Feeling Safe	2	4
	3	13
	4	98
	5	98

Strong influence: Lateral Distance, Longitudinal Distance

Weak Influence : TTC







Estimate Model

Odds and Odd ratios are very informative way of expressing the relationship between categorical varaibles.

Odds is defined as the probability of an event occuring divided by probability of the event not occuring

$$odds = \frac{p}{1-p}$$

Suppose we have ***k*** ordered levels of our categorical variable (Safety feel) ***k*** = 5, The proportional Odds model is :

$$\ln \frac{p_1 + p_2 + \cdots + p_i}{p_{i+1} + \cdots + p_k} = b_{0k} + b_1 x_1 + b_2 x_2 + \cdots + b_p x_p$$

Note that $\boldsymbol{b}_{0k}$ is different for each level of categorical variable.

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Significant Factors in OLR

The factors chosen to be part of ordinal regression model are as
- Time to Collision
- Lateral Distance
- Longitudinal Distance
- Lateral Acceleration
- Steering Wheel Angle

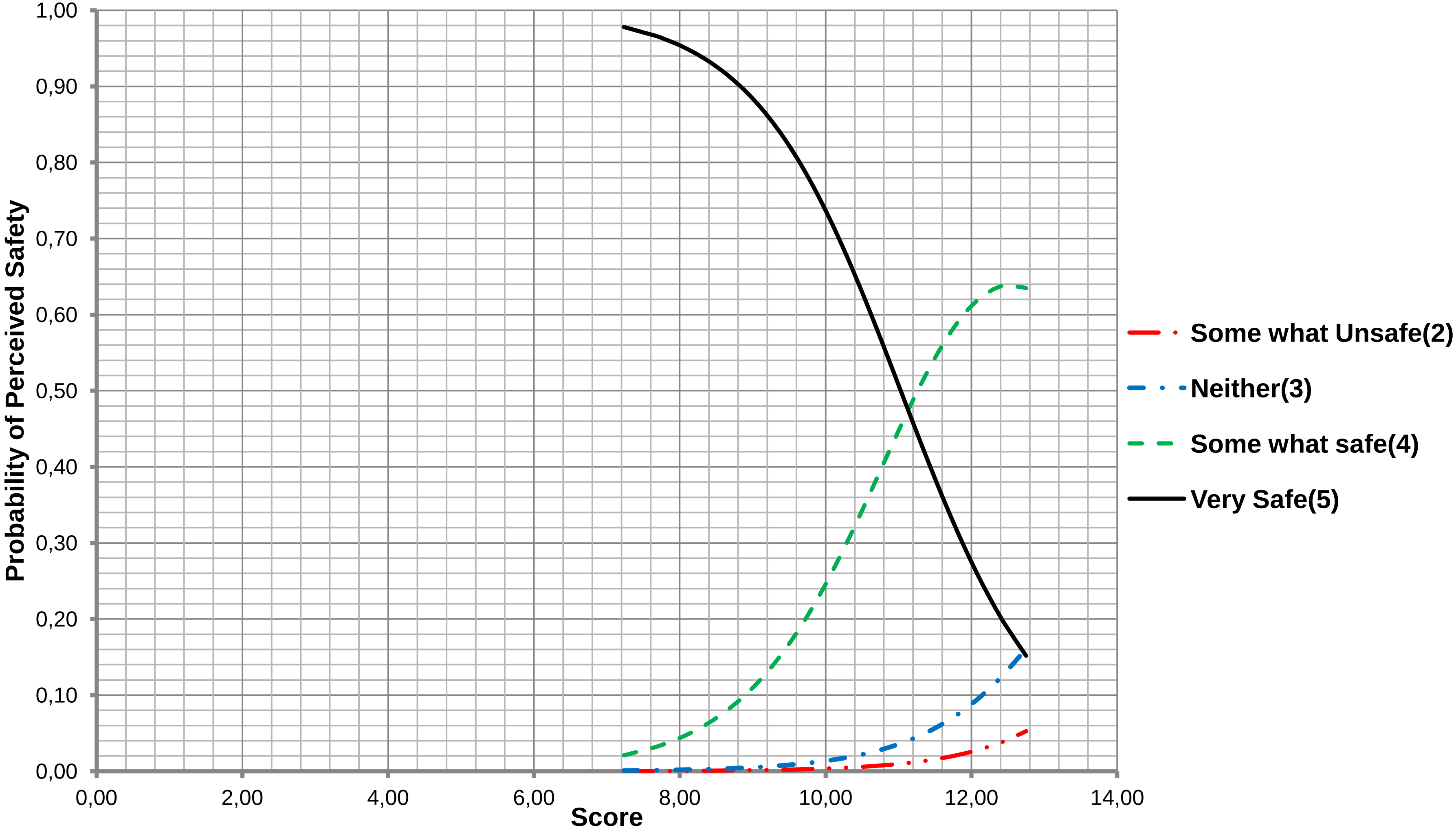
Only the factors with small p-values has significant effect on „Safety feel".

Small p-values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Const(1)	-15.6640	4.61745	-3.39	0.001			
Const(2)	-14.0564	4.59080	-3.06	0.002			
Const(3)	-11.0319	4.54698	-2.43	0.015			
TTC_BoxCox	-2.27400	1.26578	-1.80	0.072	0.10	0.01	1.23
Abs_latDist_BoxCox	3.95001	0.987757	4.00	0.000	51.94	7.49	359.97
Abs_LongDist_BoxCox	2.18964	1.05043	2.08	0.037	8.93	1.14	70.00
Abs_LatAcc_BoxCox	-0.164366	0.975453	-0.17	0.866	0.85	0.13	5.74
Abs_SWA_BoxCox	0.340979	0.761455	0.45	0.654	1.41	0.32	6.26

Probability of Perceived Safety



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Conclusion

1. The driver clinic really shows the threat that can be accepted by driver with out feeling unsafe.

2. Ordinal logistic regression shows the fit of the driver response to the engineering metric.

3. Lateral acceleration preferred by drivers is saturated to 0.5g.

4. The steering torque required to do manoeuvres is linearly increasing with increasing lateral acceleration.

5. TTC for steering is constant for all velocity which is matching with enginnering findings.

6. The system delay compensation is required during autonomous system intervention to avoid getting the break even point below the driver perceived break even point.

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Accident avoidance by active intervention for Intelligent Vehicles

Thank you.

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SEVENTH FRAMEWORK PROGRAMME

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