THE INFLUENCE OF AGE, GENDER AND DELAY ON OVERTAKING DYNAMICS

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ABSTRACT

Overtaking is one of the most dangerous manoeuvres on two-lane rural highways. The most influential factors are related to drivers, so ITS and assistance systems are not yet common. This research is based on experimental data of overtaking manoeuvres collected using an instrumented passenger car, equipped with four cameras, laser rangefinders and a GPS tracker. This vehicle was driven along four different road segments in the surroundings of Valencia (Spain) at a speed slightly slower than the operating speed of each segment. Overtaking time and speeds were measured. Unlike previous work, the influence of human factor was also considered. Age and gender of overtaking driver, as well as time spent following were used to characterize this influence. More than 200 manoeuvres were recorded and the influence of driver characteristics and delay on gap acceptance, manoeuvre duration and speed differences have been analysed. Results show differences in behaviour between age and gender groups, since young male overtaking drivers have shown a more aggressive behaviour. Overtaking times were around 1 s lower than other drivers, while average speed difference was 4 km/h higher. Collected data and their analysis have provided a basis to review design criteria and to develop future assistance systems.

1. INTRODUCTION AND BACKGROUND

Overtaking manoeuvres improve the level of service of two-lane rural highways. To pass a slower vehicle, it is necessary to occupy the lane reserved to opposing traffic. Therefore, overtaking is one of the most dangerous manoeuvres on two-lane rural highways. Severity of accidents related to overtaking manoeuvre is significantly higher than other accident types [1].

Human factor is highly important in this manoeuvre, since it involves several complex decision processes. Drivers decide to overtake depending on which difference between their desired speed and the speed of leading vehicles would accept. Before starting the manoeuvre, a driver must check whether there is enough distance until the next opposing vehicle to safely complete the pass. Therefore, human factor influence is very strong [2]. Decisions to overtake are based on driver's style, driver's behaviour or preferences. It determines driver's impatience, perception of opposing vehicle speeds, or characteristics of overtaking and overtaken vehicle.

Existing geometric design and marking criteria define overtaking sight distance (OSD) as the distance needed to overtake a slower vehicle when an opposing vehicle is approaching. OSD estimations were based in different theoretical models [3, 4] which define the movement of the three vehicles involved in the manoeuvre: the overtaking vehicle (faster); the overtaken vehicle (slower); and the opposing vehicle. Usually, their trajectories were calculated using deterministic formulations.

However, many field studies showed a high dispersion in their results [5,6,7]. Those authors recorded overtaking manoeuvres. Trajectories and speeds of vehicles involved in overtaking manoeuvres were measured, but variables related to human factor were not usually considered, despite their potential influence on the overtaking process. Driving simulator based studies have confirmed its influence. Specifically, Farah [2] found that some overtaking variables, like overtaking time on left lane, varied between different age and gender groups. However, driving simulator was not validated with field data. It should be necessary, because risk perception could be different and screen resolution could modify the visibility of far vehicles.

Impatience of drivers in overtaking manoeuvres was also considered [8], using macroscopic data of traffic flow and a microsimulation model. It was concluded that longer delays made drivers to accept shorter overtaking gaps, although individual behaviour couldn't be analysed.

The complexity of this manoeuvre could explain why overtaking assistance systems are less developed than in other manoeuvres, such as lane changing or speed adaptation. Löwenau et al. [9] suggested a system to warn drivers where overtaking is not recommended, according to map data and previous driving behaviour. The system would provide information to drivers on a head up display, indicating sections where overtaking is recommended or should be avoided. However, only geometry of highways was considered and traffic conditions were omitted.

Hegeman et al. [10] designed different systems, but they were only tested using a microsimulation model. In this case, drivers would be provided with information about size of overtaking gaps in opposing traffic flow. Then, drivers would accept or reject that overtaking gap with help of this information. No technical development is presented, although threshold values and influence of percentage of users in a road are discussed from both safety and operational points of view.

An alternative design was considered by El Khoury [11]. In this case, a warning system located at a road segment where overtaking is forbidden was simulated, in order to avoid violations of road marking. Safety benefits where considered, although driver's overtaking behaviour is not considered itself.

Although overtaking manoeuvre has been deeply studied, there is a variety of methodologies and results. As a result, existing design and marking criteria are not uniform among countries, and in most cases, they are based only in analytical formulation of the manoeuvre [12, 13]. Besides, there is a lack of observational data to study the influence of human factors on this manoeuvre.

2. OBJECTIVES AND HYPOTHESES

The main objectives of this research are, firstly, to develop a new methodology to study overtaking manoeuvres based on an instrumented vehicle, and secondly, to collect a sample of observed manoeuvres to characterize the effect of different human related factors.

The analysis was supported by several hypotheses. On one hand, driver's age and gender is thought to be a factor of overtaking decisions. Young drivers could overtake faster, accepting smaller overtaking gaps, and driving at higher speeds. It would be caused by their lower risk perception and shorter reaction times.

On the other hand, impatience could be the cause of a risky behaviour. Longer delays would made drivers perform overtaking manoeuvres accepting smaller gaps with lower safety margins.

3. METHODOLOGY

The proposed methodology is based on a new versatile instrumented vehicle, developed by the Highway Engineering Research Group of the Universitat Politècnica de València (Spain). The new instrumented vehicle was driven along two-lane rural highway segments at constant speeds, lower than the operating speed, in order to be overtaken by other drivers [14].

Previously, only few studies used an instrumented vehicle to study overtaking manoeuvres, considering only dynamic variables, such as trajectories and speeds [6]. With the new data collection system, the number of observed variables was increased. Human factor related variables were considered: age and gender of drivers of overtaking vehicles and their gap acceptance behaviour along the entire following process, and not only in single overtaking zones.

3.1. INSTRUMENTED VEHICLE DESIGN

Data collected using the new vehicle is a combination of video data, distances to other vehicles and positioning data (Figure 1). Video data is provided by four small digital cameras, which are installed inside the car. They cover the rear, left and front areas. Therefore, the whole trajectory of every overtaking vehicle is observed (Figure 2).

Relative distances between overtaking vehicle and the instrumented vehicle before and after performing an overtaking manoeuvre are collected by two laser rangefinders installed on rear and front bumpers. Position of the instrumented vehicle is registered by a 10 Hz GPS tracker.

As size of equipment is very small, it was not visible by other drivers. In fact, no unexpected or evasive actions were observed during the experiments.

Additional information, such as characteristics of overtaking vehicles, number of passengers and gender of overtaking drivers was registered by the co-driver of the instrumented vehicle. Age of overtaking driver was also estimated (in 5 years intervals) and written down during each manoeuvre by the co-driver. These additional variables are an improvement of existing previous methodologies, in order to get more detailed data of the phenomenon.

3.2. SITE SELECTION

The instrumented vehicle was driven along four highway segments. They were located in the surroundings of Valencia (Spain) and had the same posted speed limit (100 km/h) and cross section, as well as similar traffic volume. Each segment had different design speed, ranging from 80 to 120 km/h. 41 overtaking zones, marked with centre dash line, were located in those segments. A summary of characteristics of road segments is presented in Table 1.

The instrumented vehicle circulated at constant speed, slower than the segment operating speed, based on previous data [15]. In that study, overtaking manoeuvres were observed from a fixed point of view outside the road. Speeds of each overtaken vehicle were measured, among other variables. Then, the speed of the instrumented vehicle was fixed at different levels for each location based on the speed of overtaken vehicles (Table 1). Some locations show a high variability, so two different speed levels were chosen.

Highway	(1) CV-35	(2) CV-50i	(3) CV-50ii	(4) N-225
Length of section (km)	10.0	1.5	6.0	15.0
Design speed (km/h)	120	80	90	100
Traffic volume range (vph)	250 – 350			
Number of overtaking zones (m)	10	2	12	17
Cross section	3,5-m-wide lanes and 1,5–m-wide paved shoulders			
Speed of overtaken vehicle (km/h)	80 and 90	50 and 60	60 and 70	80
Number of manoeuvres	42	56	54	62
Number of analysed manoeuvres	25	27	23	29
Duration of observation (h)	4	4	4	6

Table 1. Site selection

3.3. DATA REDUCTION

Using this methodology, a total of 214 manoeuvres were observed, with an average frequency of 11 manoeuvres per hour. However, 66 of them were not considered since the overtaking vehicle was a truck, there was more than one overtaking and/or overtaken vehicle, or data about overtaking driver missed. As a result, every analysed manoeuvre involved only one passenger car or van overtaking the instrumented passenger car. No aborted manoeuvres were observed during data collection.

The study is limited to those drivers which finally decided to pass, since only the dynamic of completed manoeuvres is analysed. However, there were a number of drivers which decide to follow the instrumented vehicle without overtake. There could be many different motivations that make drivers decide not to overtake, such as a conservative behaviour or the proximity of their final destination. Therefore, naturalistic observations like the present study are not sufficient to evaluate the overtaking desire.

During field study, time of each overtaking manoeuvre and characteristics of overtaking driver and overtaking vehicle were collected by the co-driver. After that, data reduction began with the identification of the starting point and the ending point of each manoeuvre, as well as every accepted or rejected gap during the entire following process.

Overtaking gaps were calculated as the difference between starting time of an overtaking opportunity (either starting an overtaking zone or crossing with an opposing vehicle) and crossing time between overtaking and opposing vehicles (Figure 3a). This was valid only for overtaking manoeuvres limited by the presence of opposing vehicles. Otherwise (Figure 3b), overtaking gaps were calculated taking into account the available sight distance at the starting point of the manoeuvre (point A), according to a previous work [14]. From point B, an opposing vehicle could appear at any time. So, overtaking gaps considered that a virtual opposing vehicle appeared from point B and its speed was equal to the design speed.

For each manoeuvre, distance between the instrumented vehicle and the overtaking vehicle was obtained from laser rangefinder data and position of instrumented vehicle was provided from GPS tracker. After that, speed of overtaking vehicle was calculated. Delay was estimated as the difference between the time spent following and the time travelling at design speed along the same distance.

The most representative variables are shown in Figure 4. In order to carry out a statistical analysis, a limited number of variables have been selected.

Selected dependent variables were:

- Accepted gap (Gap, t3 – t0). It evaluates driver's decision considering his or her estimation of required time to overtake with safety. Once a gap is accepted, it can be also considered as a factor, due to its influence in the following dependent variables.
- Overtaking time (t2 - t1). It measures the left lane occupation time.
- Average speeds difference (dV). It measures the speed of overtaking vehicle.
- Following distance at starting point of the overtaking (h1). It could be an estimation of impatience.

Following independent factors and their correspondent levels have been considered:

- Age of overtaking driver: two groups have been considered, based on previous research [2]: young drivers (under 30 years old) and old drivers (over 30 years old)
- Gender of overtaking driver: male or female.
- Starting mode: categorical variable describing how the manoeuvre is started. There are two groups:
    - Flying: overtaking vehicle doesn't reduce its speed before overtaking.
    - Accelerative: overtaking vehicle reduce its speed before overtaking, and must accelerate during the manoeuvre.

- Delay (s): continuous variable associated to each accelerative manoeuvre. (Delay equal to zero for flying passes).

Other conditions during data collection were: daytime, good weather and traffic volume around 250 vph. The effect of those other variables was not analysed.

4. ANALYSIS

A statistical analysis was carried out to study the influence of different variables on overtaking manoeuvres, in order to analyse the effect of human factor. After that, the results were compared to previous research.

4.1. AGE AND GENDER EFFECT

To analyse the influence of age and gender, a multifactor ANOVA was carried out for each dependent variable. The factors included in this analysis were: age, gender, the interaction of age and gender and starting mode (flying or accelerative). Normality of each dependent variable was checked before carrying out the analysis, using normal probability plots and Chi-square tests. Results of the analysis are presented in Table 2.

	Variable			
	Gap (s)	t2-t1 (s)	dV (km/h)	h1 (m)
Factor	F-ratio	F-ratio	F-ratio	F-ratio
Age	0.55	0.14	0.81	0.85
Gender	0.26	1.17	1.90	1.60
Age x Gender	0.76	4.23*	4.27*	0.16
Starting (0= accelerative, 1=flying)	6.82**	4.11*	24.66**	8.85**

*significant at the 0.05 level, **significant at the 0.01 level

Table 2. ANOVA of age, gender and starting mode

Gap, overtaking time, speed difference as well as following distance depend on the starting mode. This effect was significant in all independent variables. Differences on values of each variable are shown in Table 3. Flying manoeuvres represent a different behaviour: accepted gap was 4 s smaller, overtaking time was 1.1 s lower, speed difference was 9 km/h higher and following distance was 5 m longer.

Level of factor starting mode	Count	Variable							
		Gap (s)		t2-t1 (s)		dV (km/h)		h1 (m)	
		Adjusted Mean	SE	Adjusted Mean	SE	Adjusted Mean	SE	Adjusted Mean	SE
flying	15	10.4	1.45	6.4	0.51	30.0	1.74	14.3	1.55
accelerative	133	14.3	0.63	7.5	0.22	21.1	0.76	9.5	0.66

SE: standard error

Table 3. Table of means by flying/accelerative manoeuvre

On the other hand, differences on independent variables caused by age and gender are shown in Table 4. Either the effect of age or gender was not significant, but interaction of them was significant at the 0.05 level in overtaking time t2-t1 and speed difference dV. This interaction influence is also shown in Figure 5.

Level of factor age x gender	Count	Variable							
		Gap (s)		t2-t1 (s)		dV (km/h)		h1 (m)	
		Adjusted Mean	SE	Adjusted Mean	SE	Adjusted Mean	SE	Adjusted Mean	SE
Male:									
Young	23	12.6	1.31	6.2	0.46	28.7	1.58	13.5	1.39
Old	94	12.7	0.84	7.2	0.30	24.4	1.02	11.8	0.91
Female:									
Young	16	13.0	1.52	7.5	0.50	23.7	1.69	11.4	1.52
Old	15	11.1	1.56	6.8	0.55	25.4	1.96	10.8	1.67

SE: standard error; statistically significant effects underlined

Table 4. Table of means by age/gender

According to the ANOVA results for age and gender effects, only the interaction was statistically significant. Interaction plots show that differences between young and old drivers are significant only for male drivers. Young male drivers overtake 1 s faster than older ones, with a 4 km/h higher speed difference. Female drivers did not show these difference.

4.2. DELAY EFFECT

On the other hand, effect of delay suffered by overtaking driver on overtaking time has been analysed using a multiple linear regression model. Only accelerative manoeuvres were considered, since flying passes don't have any delay.

Table 5 show the results of the regression model for the dependent variable overtaking time (t2-t1). Only statistically significant variables at the 0.05 level were included in the model. R-squared of the model was 50.5%.

Parameter	Estimate	Standard Error	t-Statistic	p-Value
CONSTANT (s)	10,53	0,60	17,44	0,0000
dV (km/h)	-0,21	0,02	-9,42	0,0000
Age (young = 0, old = 1)	-1,13	0,45	-2,52	0,0129
Delay (s)	-0,04	0,02	-2,04	0,0432
Age*Delay (s)	0,07	0,02	2,74	0,0071
h1 (m)	0,23	0,03	8,73	0,0000

p-values under 0.05 correspond to statistically significant factors

Table 4. Multiple linear regression model for overtaking time (t2-t1)

According to Table 5, overtaking time was affected by speed difference and following distance at the starting time of the manoeuvre. This is explained by dynamics of the overtaking vehicle trajectory. In addition to this, influence of age and delay, as well as its interaction, was significant. Equation 1 is the equation of the model for young drivers (Age equal to 0) and equation 2 for old drivers (Age equal to 1). It shows that delay coefficient is negative for young drivers (the longer the delay the shorter the overtaking time, with an increasing rate of 1 second each 25 seconds delay). Old drivers presented the opposite behaviour: the longer the delay the longer the overtaking time. Gender influence was not significant for the overtaking time regression model.

$$\text{Overtaking time (young drivers)} = 10.531 - 0.209\,dV - 0.039\,Delay + 0.228\,h1 \qquad (1)$$

$$\text{Overtaking time (old drivers)} = 9.403 - 0.209\,dV + 0.028\,Delay + 0.228\,h1 \qquad (2)$$

The effect of delay was not significant for the other previously considered dependent variables, such as accepted gap, speed difference or following distance.

5. DISCUSSION

Results of present study have been compared with previous research.

Instrumented vehicle data has been also obtained by Carlson et al [6]. This research was carried out on a two-lane rural highway where overtaking was allowed along 75 per cent of road length. Researchers drove an instrumented passenger car at 88, 96 and 104 km/h in order to be passed by other drivers. 105 overtaking manoeuvres were analysed. Overtaking time and overtaking vehicle speed were calculated for each manoeuvre. Results are compared to present study.

Figure 6 shows overtaking times as a function of overtaken vehicle speed. In both studies, 15th, 50th and 85th percentiles are plotted. For overtaken vehicle speeds between 80 and 90 km/h (registered in both studies) overtaking times of present study were more than 1.5 s under times measured by Carlson et al. Average speed differential measured by Carlson et al. was 19 km/h and in present study, 21 km/h.

However, neither overtaking gaps nor overtaking driver characteristics were measured by Carlson et al. [6].

Farah [2] considered human factor variables in a driving simulator experiment. Its results have been compared to present study, although methodology and highway geometry were different. Farah analysed the influence of age and gender of 100 Israeli drivers (69 male and 31 female, 54 young and 46 old) on overtaking decisions.

Age	Gender	Overtaking time (s)			
		Present study		Farah [2]	
		Observed mean	Standard deviation	Mean	Standard deviation
Young	Male	6.3	3.57	6.9	0.53
	Female	7.5	3.58	7.1	1.56
Old	Male	7.7	3.48	7.3	0.68
	Female	7.9	3.75	8.9	3.04

Table 5. Comparison with previous research (Farah, [2])

Differences shown in Table 5 are equivalent to present study, since young male drivers overtook in less time than old and female. Differences between groups in driving simulator data are higher, while dispersion of overtaking times is lower.

In addition to this, shorter following distances were measured for younger age groups, in accordance with the present study. No influence of delay and impatience was studied.

Finally, the results have been compared to a previous study [10], which proposed different thresholds for overtaking assistant systems. This work discussed values for an assistant system threshold between 8 s and 14 s. This threshold would be the minimum acceptable gap to perform an overtaking manoeuvre with safety.

A threshold of 8 s corresponded to the 20^{th} percentile of accepted gaps, while a threshold of 14 s corresponded to the 60^{th} percentile (Figure 7). It means that 20% or 60% of overtaking manoeuvres were under the threshold of the proposed assistance system, and consequently not recommended by it.

6. CONCLUSIONS

Overtaking is one of the most complex manoeuvres on two-lane rural highway. It involves several decision processes and it is affected by highway, driver, vehicle, traffic and environment. This causes a high variability of situations and requires observational data, since neither analytical formulations nor driving simulation could explain accurately the phenomenon.

This work has developed an experimental methodology, which can be used to analyse in detail the overtaking manoeuvre based on an instrumented vehicle. This is a versatile methodology, since it can be adapted to different vehicles and can be used anywhere. The number of variables and accuracy is higher than previous techniques, thanks to the use of four video cameras, laser rangefinders, and observations made by the co-driver.

An average of approximately 11 manoeuvres per hour can be recorded when the vehicle is driven along two-way rural roads of traffic volumes around 250 vph. For this work a field study was carried out to record 214 manoeuvres.

Data of these manoeuvres has been analysed to characterize the influence of human factor related variables. The effect of age and gender was considered, dividing the sample into different groups. Young and old male drivers showed a different behaviour, characterized by their overtaking time (young drivers 1 second shorter) and their speed difference (young drivers 4 km/h faster).

Flying overtaking manoeuvres, with delay equal to zero were characterized by 1.1 s shorter overtaking times and 9 km/h higher speed differences. Following distance was 5 m longer too.

The effect of delay was considered in order to test if impatience of drivers could affect their behaviour. This effect has been observed in young drivers, who tend to overtake faster if the delay was higher. On the other hand, older drivers passed slower when they had suffered longer delays.

The results were compared with previous research. Overtaking data collected with other instrumented vehicle showed differences in measurements of left lane occupation time. In present study, overtaking times were shorter. Consequently, a high variability of overtaking variables should be expected if highway, drivers or environment varies. A driving simulator study found similar effects of age and gender of overtaking driver on overtaking times. Young male driver's group showed also the most aggressive behaviour. Lastly, a recent proposal of overtaking assistant system was compared with recorded data. Observed behaviour must be an additional criterion to design and calibrate those systems. Higher values of the gap thresholds would provide a very conservative assistance to drivers, which probably affected traffic operation. Lower values could be dangerous for those drivers which only accept larger gaps. Further work will be necessary to extend the sample size, including the study of overtaking manoeuvres with an instrumented heavy vehicle and under different traffic volumes.

7. ACKNOWLEDGMENTS

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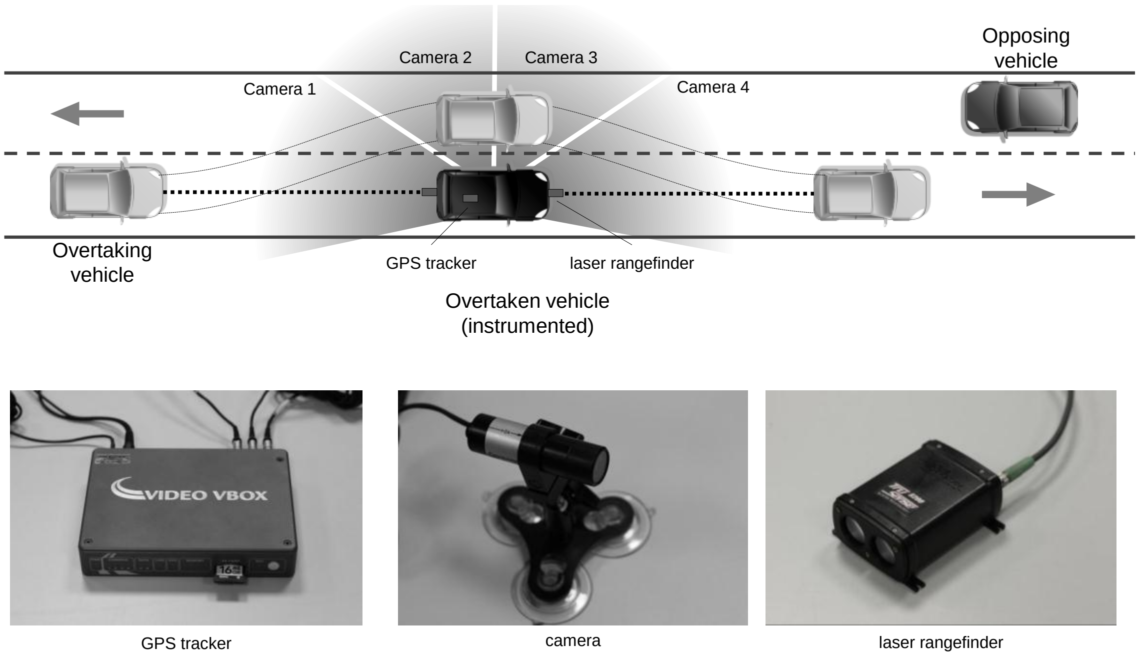


Figure 1. Field study design

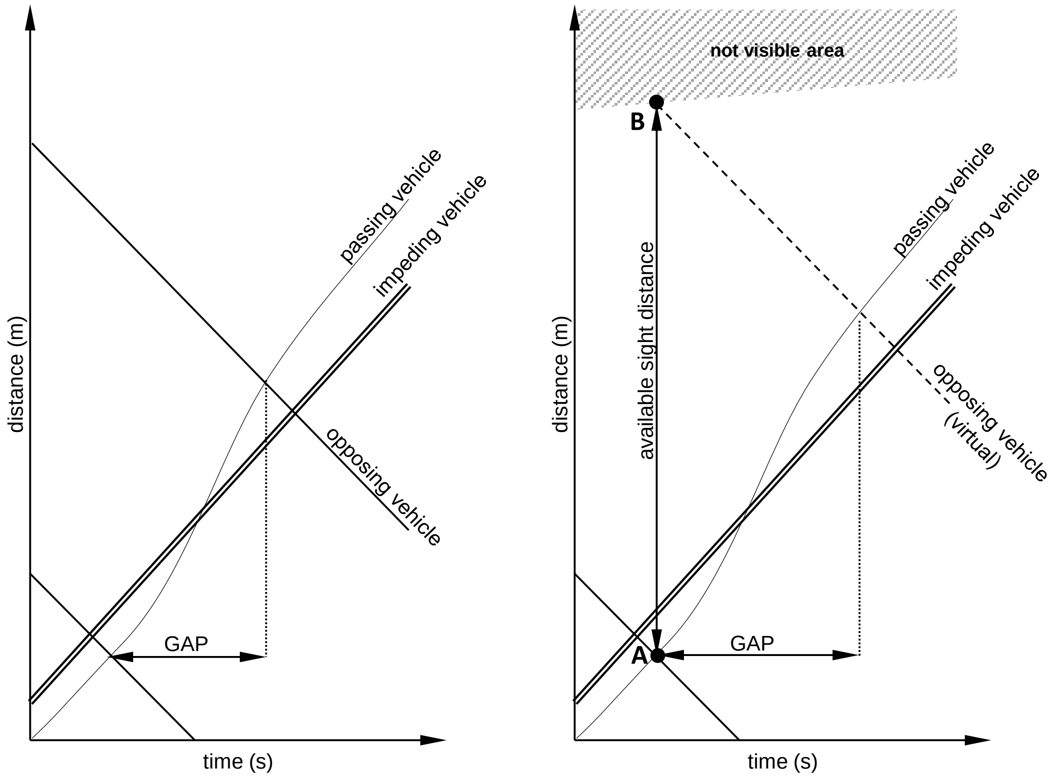
Camera 1: rear view, overtaking start

Camera 2: rear left view

Camera 3: fron left view

Camera 4: front view, overtaking end

Figure 2. Instrumented vehicle recorded images



(a) Opposing vehicle limited overtaking **(b) Sight distance limited overtaking**

Figure 3. Calculation of overtaking gaps

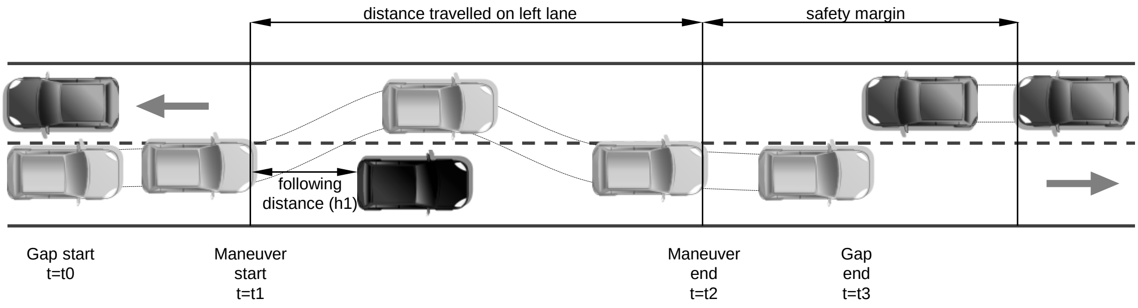


Figure 4. Overtaking manoeuvre variables

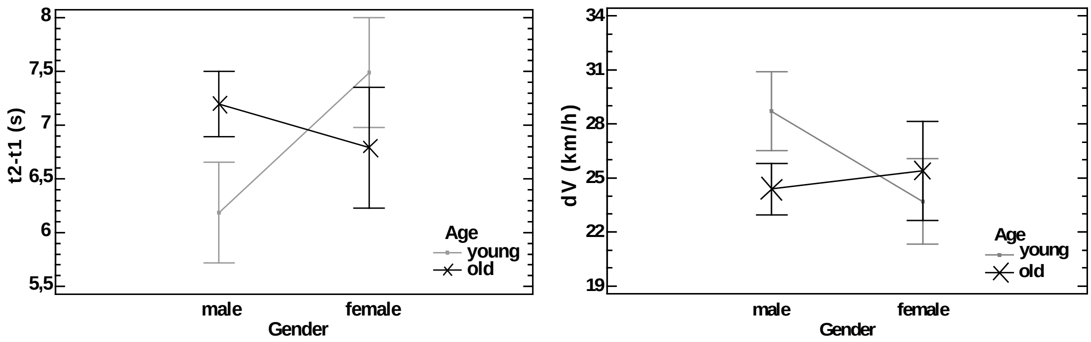


Figure 5. Interaction plot for overtaking time (t2-t1) and speed difference (dV)

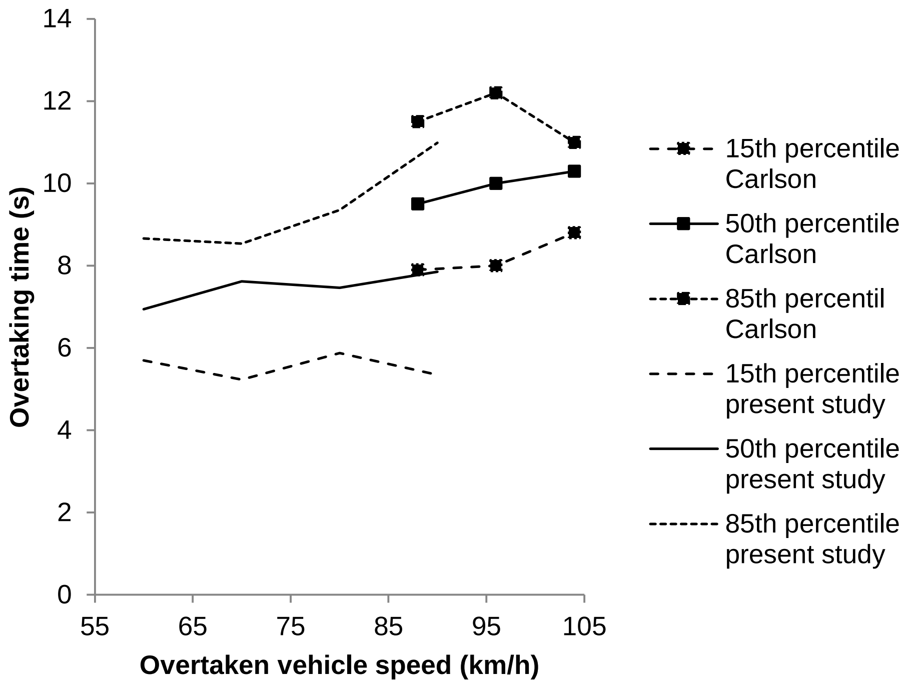


Figure 6. Comparison with previous research (Carlson et al. [6])

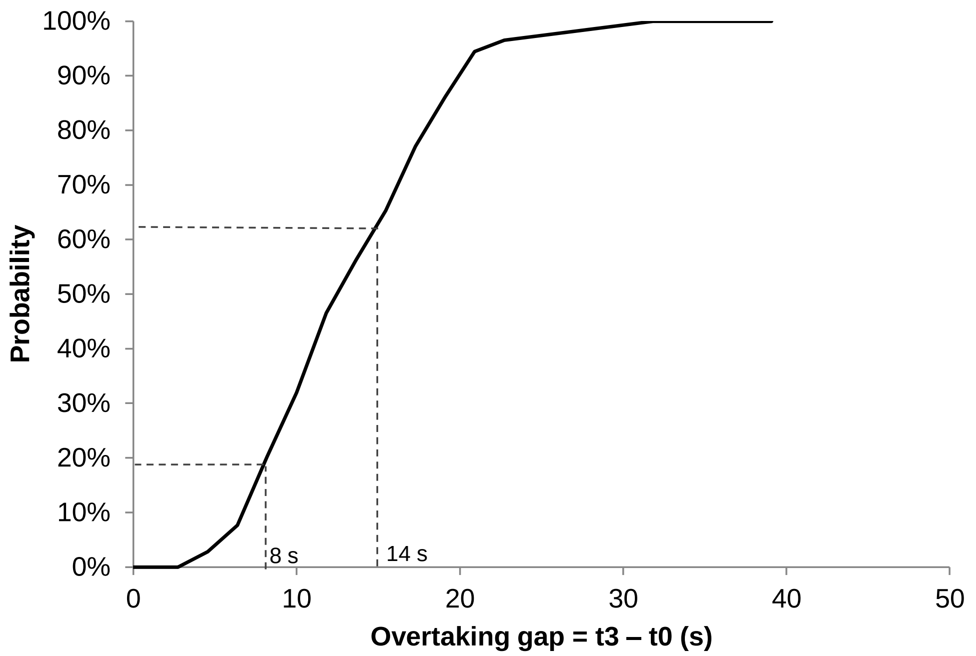


Figure 7. Comparison with previous research (Hegeman et al. [10])