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European Sight Distance in perspective - EUSight

Driving Experiment Report

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CEDR Call 2013: Safety
EUSight
European Sight Distances in perspective

Driving Experiment Report

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Executive summary

Part of the 'CEDR Transnational Road Research Programme Call 2013 Safety' is the research project European Sight Distances in perspective – EUSight. The objective of this research project is to conduct a detailed examination of the subject of stopping sight distance (SSD) and its role and impact on highway geometric design, taking into account differences (and similarities) between EU Member States. This research considers stopping sight distance from different (related) approaches: human factors ('the driver'), road characteristics, vehicle characteristics and environmental conditions (like wet, snow, ice, dark). Since SSD is related to many different aspects, multiple approaches and methodologies are needed to determine state-of-the-art parameter values.

Work package 5 of the EUSight study consists of a driving experiment. The driving experiment is to give additional insight in the driving behaviour of a large group of drivers, over a long period, in 'natural conditions' and in different EU Member States. Together with the results of tests under controlled conditions (derived from the literature review and the parameter study), an understanding of driving behaviour in relation to stopping sight distance (SSD) has been developed.

Drivers from 6 EU Member States (UK, Ireland, Germany, Belgium, The Netherlands and Romania), were asked to monitor their daily trips for 3 months by recording their speeds with a Smartphone app. Participants did not get instructions for their trips.

Most of the participants used an app which also collected video images. With this approach a large amount of individual driving data was collected from a (potentially) large network.
In total 69 people registered for the experiment and 37 participated (by collecting and providing data).

The driving experiment has attempted to evaluate driver behaviour in emergency braking situations in real-traffic conditions. Despite the 400 hours of collected driving data, real emergency manoeuvres (i.e. hard braking to avoid hitting an obstacle) according to the stopping sight definition were not recorded: in most cases a vehicle in front determined the braking behaviour of the participant.

Nevertheless, the results of the experiment have provided data on the deceleration rates and behaviour of events in which drivers had to slow down significantly (in most cases because of congestion).

Deceleration distributions of the 37 participants of the experiment show that deceleration rates larger than 4 m/s^2 seldom occur. In situations which require immediate response and a significant decrease of speed (at least 40 km/h), a typical maximum deceleration rate of 3-4 m/s^2 was found. Only in situations with short times-to-collisions short peaks of higher deceleration rates up to 6 m/s^2 and higher were noted. A value of 3-4 m/s^2 can be interpreted as a comfortable deceleration rate.

The distribution of deceleration rates of drivers participating from different countries is reasonably stable; the differences in the distributions per country are small. One has to bear in mind that the number of participants from Germany and Belgium are very small and conclusions cannot really be drawn from the results.

The results of the driving experiment are in line with the findings of the literature review. Literature on braking trials on test tracks (maximum braking performance) and other studies

on driving behaviour in emergency brake situations, confirm that a deceleration rate of 3-4 m/s^2 is a reasonable value for average deceleration rates from a traffic safety perspective:

- Cars without ABS, which are still present on EU member states motorways, are not capable of decelerating faster in worst case situations (wet road surface, low tyre tread depth, etc.)
- Driver work load and stress increases significantly with limited sight distances associated with higher deceleration rates.

The literature review underlines the risk of increasing the deceleration rate in the stopping sight distance definitions, because of the increased braking capabilities of modern cars; this will influence traffic safety in a negative way.

Deceleration rates between 3 and 4 m/s^2, which are incorporated in all the studied design guidelines of EU Member States, still seem to be appropriate values.

List of definitions

Driver eye height

The vertical distance between the road surface and the position of the driver's eye.

Obstacle

A stationary obstacle on the road that requires a stopping manoeuvre. Examples of obstacles are a stationary vehicle (represented by the tail lights of a car) and an obstacle on the road (lost load of a truck).

Perception-Reaction Time (PRT)

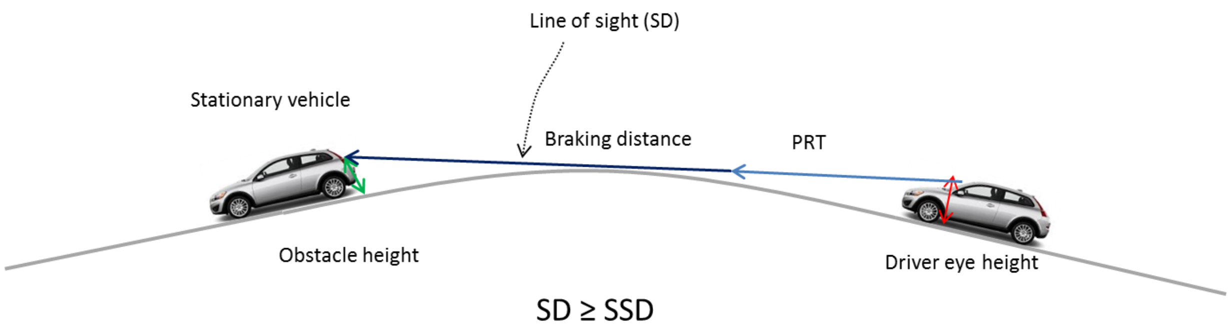
The time it takes for a road user to realize that a reaction is needed due to a road condition, decides what manoeuvre is appropriate (in this case, stopping the vehicle) and start the manoeuvre (moving the foot from the accelerator to the brake pedal).

Sight distance (SD)

This is the actual visibility distance along the road surface, over which a driver from a specified height above the carriageway has visibility of the obstacle. Effectively it is the length of the road over which drivers can see the obstacle, given the horizontal and vertical position of the driver and the characteristics of the road (including the road surroundings).

Stopping Sight Distance (SSD)

SSD is nothing more than the distance that a driver must be able to see ahead along the road to detect an obstacle and to bring the vehicle to a safe stop. It is the distance needed for a driver to recognise and to see an obstacle on the roadway ahead and to bring the vehicle to safe stop before colliding with the obstacle and is made up of two components: the distance covered during the Perception-Reaction Time (PRT) and the distance covered during the braking time.



1 Introduction

1.1 EUSight

In the process of road design, sight distances are of great importance for traffic flow and traffic safety. Adequate sight distance is needed to enable drivers to adapt speed to the alignment of the road; to stop in front of a stationary obstacle; to overtake a slower vehicle safely on a carriageway with two-way traffic; to reduce speed or to stop while approaching an intersection; to merge with (or cross) traffic at an intersection comfortably; and to process roadside information on traffic signs.

Part of the CEDR Transnational Road Research Programme Call 2013: Safety, is the research project European Sight Distances in perspective – EUSight. The objective of this research project is to conduct a detailed examination of the subject of stopping sight distance (SSD) and its role and impact on highway geometric design, taking into account differences (and similarities) between EU Member States. This research considers stopping sight distance from different (related) approaches: human factors ('the driver'), road characteristics, vehicle characteristics and environmental conditions (like wet, snow, ice, dark). Since SSD is related to many different aspects, multiple approaches and methodologies are needed to determine state-of-the-art parameter values.

1.2 Driving experiment

Work package 5 consists of a driving experiment. The driving experiment will give additional insight in the driving behaviour of a large group of drivers, over a long period, in 'natural conditions' and in different EU Member States. Together with the results of tests under controlled conditions (derived from the literature review and the parameter study), an understanding of driving behaviour in relation to stopping sight distance (SSD) was developed.

In this work package, drivers were asked to monitor their daily trips for 3 months by recording their speeds with a Smartphone app. Participants did not get instructions for their trips
With this approach we collect a large amount of individual driving data from a (potential) large network. This approach enables a comparison of driving behaviour between individual participants, and an evaluation of driving behaviour of an individual driver over the test period.

Because route choice is free during the test period, it is not possible to influence the road sections and conditions that are covered in this study. After the collection of the data, a selection of the relevant data has to be made. With GIS-based techniques, we select the situations in which drivers had to make a (emergency) stop.

In this report the plan of collecting and analysing individual driving data in EU-Member States is explained (sections 1-4). The results of the experiment are presented in section 5. A comparison with other studies on braking behaviour is commented in section 5. Section 6 contains the conclusions.

1.3 Study objective

The value of the deceleration rate in the formula for SSD should represent the actual deceleration of drivers on the road in case they have to stop for a stationary object or queue of vehicles.

To get insight in the distribution of actual deceleration rates, the driving experiment focusses on deriving deceleration rates of vehicles which have to come to a (near) standstill.

1.4 Methodology

The basic technical principles of the naturalistic driving experiment were as follows:

- An (existing) smartphone app was used to record GPS-based data, vehicle positions and vehicle speeds. Existing (freeware) app's, like Google My Tracks, have possibilities to collect such detailed data and use it for analysing speed profiles. These applications use the GPS-sensor of the smartphone.
- From the logged vehicle speeds, acceleration and deceleration can be calculated. Next, the distribution of deceleration rates is calculated.
- Together with GIS-data and road design characteristics (like road type, design speed, curve radius), the relationship between driving behaviour and SSD can be analysed (in combination with the driving conditions).
- Calculation algorithms to filter data for outliers (false measurements of the GPS-device) are also developed. Algorithms to select the emergency stop manoeuvres from the data are also programmed.
- Because driver behaviour can differ per country, the driving experiment was carried out in several countries: Five countries were selected:
  1. The Netherlands
  2. Germany
  3. UK
  4. Ireland
  5. Romania
- By combining speed and deceleration data with individual information of the participants of the experiment, relationships between driver and vehicle characteristics and driving behaviour can be analysed.

The results of this experiment are used as input for the determination of the deceleration rate in WP6 (Representative parameter values) and WP8 (Final report and implementation letter).

2 Smartphone app

2.1 Approach

Because the conditions in which drivers have to make an emergency stop influence the deceleration rate, it is important that these conditions are logged during the driving experiment. For instance, the weather conditions can influence the deceleration rate in cases where a driver has to stop for a stationary vehicle. Also the driving behaviour (speed and deceleration) of a leading vehicle can influence driving behaviour.

Because many factors influence driving behaviour and some of them cannot be derived from databases, the most appropriate method to incorporate driving conditions in this study is to make video recordings of individual trips.

Registration of video data requires a lot of data storage capacity and increases the work load of participants in the experiment. Also, the participants have to upload the data; this may cause some participants to withdraw or to stop registering trip data.

For this reason, participants of the experiment are offered two options:
- Standard option (no video)
- Advanced option (video)

Standard option
The standard option includes data collection with the Google My Track app. This app records time-based gps-positions and speed, but no video. In combination with data about the road network, emergency stops on freeways and highways can be selected. Based on the time of day of the emergency stop, it can be determined if the manoeuvre was conducted during daytime light conditions or at night.

Although not all conditions during emergency braking manoeuvres are known, it is possible to collect suitable data with this approach: with the large group of participants a better understanding can be given of the distribution of deceleration rates. From this distribution the average and maximum deceleration rates for emergency stops in different situations (initial speed, road type, day/night, etc.) can be derived.

Advanced option
The advanced option uses a smartphone app with video recording. Speed, position and video images are stored. From the database with speed profiles, the sections of the trips with an emergency stop are selected. The accompanying video images are used to review the conditions in which the driver made the emergency manoeuvre.

Using this approach, the distribution, average, and maximum values of decelerations rates were derived.

With the results of both approaches, conclusions can be drawn about the driving behaviour during emergency stops.

2.2 Standard option

In this section the 'standard option' of the naturalistic driving experiment using the Google My Tracks app (version 2.0.9) is described.

The major features of this app are:

- Google My Tracks is a free to use app (no installation costs) and is available in the Play Store (i.e. for Android smartphones). The app is not available for the iPhone.
- My Tracks records (time based) the GPS-position (latitude, longitude and height) of the smartphone/car.
- The recording interval of time based GPS-positions is 1 sec.

Figure 1 shows examples of Google My Tracks screenshots.

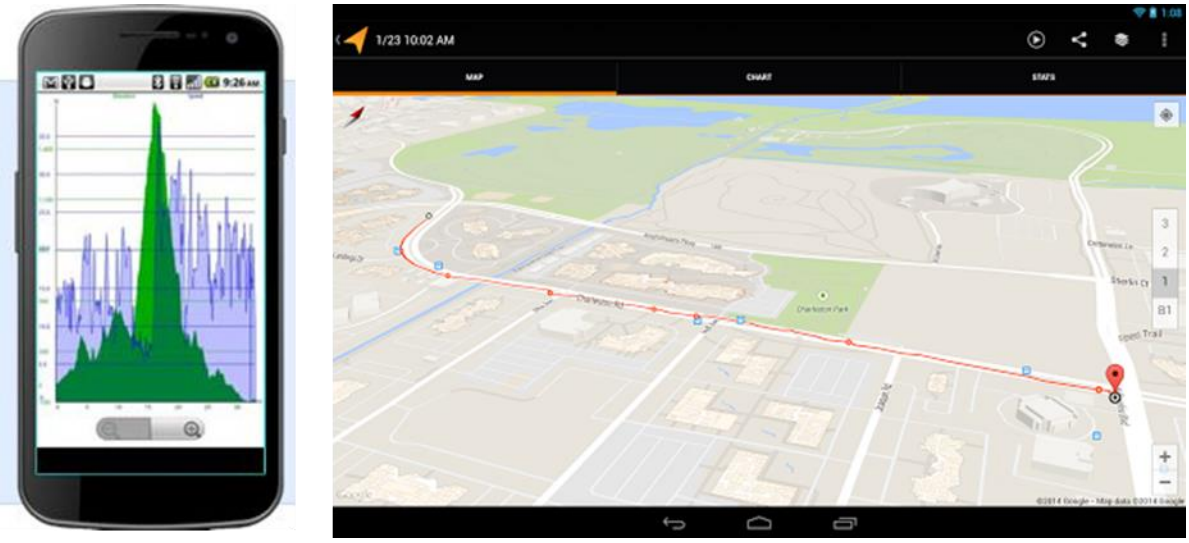


Figure 1: screenshot Google My Tracks app

2.3 Advanced option

For the advanced option, a number of free-of-charge apps (Ubipix, Daily Roads and AutoGuard) were tested, all based on the principle of collecting both GPS and video data. The app's were reviewed on the following criteria:

1. Possibilities for exporting data
2. User friendliness
3. Stability and reliability
4. Data storage
5. Battery power consumption

Overall the AutoGuard app (version 4.5.4) scored the best on these criteria and was chosen for this experiment. The major features of this app are:

- The app synchronises the GPS-data and the video images.
- The time interval for the GPS-data is adjustable with a minimum of 1 sec.
- The quality of the video-images (bit-rate, resolution, format) is adjustable.
- Also the length of the video recordings can be changed: in this way a series of shorter videos can be recorded from one trip.

- The app can be used in background-mode: the video recording is not shown on the screen of the smartphone and the smartphone can be used for other purposes.

The figure below shows a screenshot of the app.

Figure 2: screenshot AutoGuard app

3 Recruitment

3.1 Introduction

The experiment took place between October and December 2014. Participants from five countries (The Netherlands, Germany, UK, Ireland and Romania) were invited to participate in the experiment. The aim was to recruit 50 participants in each country.

This section describes the approach that was followed and summarizes the results of the recruitment of participants.

3.2 Recruitment strategy

Target groups
Because participants do not benefit from the experiment and they don't get a financial compensation for collecting and distributing data (only a phone cradle and battery charger is supplied), the recruitment strategy targeted people employed by the consortium partners. The assumption was that colleagues with an interest in traffic and transportation are more likely to participate than people without professional interest in this area. Also, a more direct and professional approach leads to a higher response.

Arcadis is an international consultant with offices in various countries: colleagues in the UK, Germany, Belgium and Romania were used as contact persons to recruit participants in those countries.

Additional to consortium partners, the partners of the PEB (Rijkswaterstaat, BASt, NRA, UK Highways Agency) were also invited to participate in the experiment.

Communication
To recruit participants the following resources were used:

- The Arcadis Europe intranet page
- The National intranet pages of Arcadis Netherlands, Germany, Romania and Belgium
- Invitations per e-mail to traffic and transportation related colleagues (Arcadis Netherlands, EC Harris/Arcadis UK, SWOV, TNO, The Highways Agency and the NRA)
- Publication in the digital newsletter of the Traffic and Transportation magazine of the Netherlands (Verkeerskunde). See Figure 3.
- The EUSight webpage (www.EUSight.nl).

Nieuwsbrief Abonneren Publiceren Adverteren Archief Contact Colofon Zoeken

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Naturalistic Driving onderzoek naar Europees weggedrag

vrijdag 3 oktober 2014 • redactie • 94x gelezen

Een consortium van TNO, SWOV, TRL,TU Darmstadt en Arcadis voert In opdracht van het CEDR (Conference of European Directors of Roads), een Europees onderzoek uit op het gebied van verkeersveiligheid en wegontwerp, onder meer met een 'naturalistic driving experiment'.

Binnen het project wordt een zogenoemd 'naturalistic driving experiment' georganiseerd: 250 weggebruikers (verspreid over verschillende Europese landen) registreren gedurende drie maanden hun rijgedrag met een app op een smartphone. Dit komt overeen met het principe van een black box.

CEDR Conférence Européenne des Directeurs des Routes Conference of European Directors of Roads

Video-opnames

Voor de deelnemers zijn er een eenvoudige standaard opties waarin alleen de snelheid en positie worden vastgelegd. Daarnaast is er een 'advanced' optie waarbij de smartphone ook video-opnames maakt van een rit. Deelnemers aan de proef krijgen geen vergoeding, wel kunnen ze een houder voor de telefoon krijgen voor in de auto.

De proef start medio oktober en eindigt op 31 december. Op dit moment zoekt het consortium onder leiding van Arcadis naar deelnemers. Zie hier de oproep voor deelname. Voor meer informatie over de proef: www.EUSight.nl

Nieuwsoverzicht

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Meest gelezen nieuws in 2014 / 2015

- NS: stilte is geen regel maar service
- 'Gedrag van ouders werkelijke probleem bij schoolmobiliteit'
- Expats: 'Vechten voor plek op Nederlandse weg'
- Let op: een dove reageert niet op gerinkel en getoeter
- Norm voor verkeersborden in Nederland herzien

Figure 3: call for participation in Verkeerskunde magazine

- Approximately 1 month before the start of the experiment, the call for participation was published on the homepages and distributed by e-mail.
- The call for participation was accompanied by a short explanation of the CEDR-project and the naturalistic driving experiment.
- Participation in the experiment (and the collection of data) was encouraged with a reward: the participants collecting the most data received a reward (a €50 voucher for a web-store).
- The number of registrations was monitored on a daily basis. Because the number of registrations was below the required number of participants, colleagues were approached directly by mail or phone. Also colleagues from Belgium were invited to join the experiment.
- The installation and user guides for the app and for transferring data were published on the EUSight website.
- During the experiment, a helpdesk was available for the participants: they could report technical problems or submit questions to the helpdesk.

3.3 Recruitment results

Table 1 shows the results of the recruitment. Because not all people who registered for the experiment delivered data, a distinction is made between participants and registrations: the participants actually sent data.

Country	*Registrations*	*Participants*
The Netherlands	47	27
Germany	3	2
Belgium	2	2
Romania	2	1
UK	11	5
Ireland	4	0
	69	37

Table 1: Number of registrations and participants

Explanation:
- In total 69 people registered for the experiment and 37 participated.
- Despite extra calls for participation, the numbers of registrations stayed below expectation (which was 50 participants per country; the effort for participation in combination with the absence of profits for the participants, is the main reason for the low number of registrations.
- Only in The Netherlands was the number of required participants (almost) reached.
- Not all the registered participants provided data for the EUSight project: approximately 40% of the registrations did not send any data during the experiment (despite several reminders).
- Table 2 shows some more characteristics of the participants.

Characteristics	*Number*				*Total*
App	AutoGuard: 23	Ubipix: 9	My Tracks: 5		37
Gender	Male: 34	Female: 3			37
Age	20-30: 5	30-40: 14	40-50: 15	50-60: 3	37

Table 2: Characteristics participants

Because there were no participants from Ireland, an already available data set from this country was used in addition to the data recorded within this experiment.

The Irish data set contains over 20.000 km of driving data and was collected between 2012 and 2014. The data was collected by 2 drivers in 2012, 9 in 2013 and 13 in 2014.
The data was collected for reviews on the National Road Network. The drivers were not informed as to how to drive the road, and they are primarily middle aged professionals.
The data is captured using a range of devices and analysed with Ubipix.

Since the data from Ireland was not collected within this experiment, it was decided to use this data only for global analysis (see section 5).

4 Data processing

4.1 Introduction

This section describes the process from individual data collection to the analyses of the data. The different apps used are distinguished in this section.

4.2 Data collection

The participants of the experiment recorded their daily trips with a smartphone app. The participants who used an app with video-recording capabilities (AutoGuard, Ubipix), had to install their smartphone behind the windscreen. Those without a camera were simply mounted in a dashboard cradle.

Figure 4: Smartphone ready for video-recording

The user starts the recording before a trip and can stop the recording at any given moment. Video and GPS-data are stored on the SD-card of the smartphone. Figure 5 shows the data format of the GPS-data logging. At every time-step the speed and the position (longitudinal and lateral coordinates) are logged. The logging interval is 1s.

```
84
00:01:52,469 --> 00:01:53,463
Time: 7 Nov 2014 07:07:16
Type: Normal
Speed: 67.5
Lat.: 51.45526694
Lon.: -0.97885532

85
00:01:53,463 --> 00:01:54,463
Time: 7 Nov 2014 07:07:17
Type: Normal
Speed: 66.6
Lat.: 51.45543597
Lon.: -0.97876283
```

Figure 5: GPS-data logging AutoGuard

The video-data has a time-stamp, making it possible to synchronize the video-data with the GPS-data afterwards.

4.3 Data transfer

After recording a trip, a participant sent his (or her) data to the EUSight project; the apps do not have a functionality to transfer data to a central database automatically.

Because the video-files are large (approximately 400 Mb for 10 minutes), participants were recommended to transfer data with a Wifi or fixed internet connection, instead of transferring it directly via the mobile data connection.

The transferred data of the trips of the individual participants were stored on a server. The data of each trip were stored separately, making it possible to evaluate similarities and differences between participants and trips.

4.4 Data selection and evaluation

In total over 400 hours of driving data were collected during the 3 month experiment. Because participants did not get instructions when and where to collect data, the data sets also contain data of not (or less) relevant sections of trips; for example data of sections without deceleration.
To select emergency braking manoeuvres and to synchronize the GPS-data with the video-images, a custom made analysis tool was built.
Figure 6 shows a screen shot of the tool.

Figure 6: data evaluation tool EUSight

Part A of the tool interface contains the file import window; it shows the individual data files. A user can import several trip data files at one time. The lower part of the tool shows the speed and acceleration/deceleration characteristics of a trip ($\Delta v/\Delta t$); a blue bar corresponds with an acceleration and a red bar with a deceleration. In window C, the trip video is shown. Part D contains the position of the vehicle on a map. To facilitate the selection of emergency brake manoeuvres, the user can select a minimum speed or minimum deceleration (section E); only the trips that contain those minimum values are shown. It is also possible to export the data to a shapefile (GIS) or Excel.

4.5 Validation of smartphone app data

Introduction

To determine the accuracy of the speed and deceleration data collected with the smartphone apps, a test drive was carried out: for a short trip speed (and deceleration) data was collected simultaneously with a smartphone app and an instrumented test vehicle (see text box below). The speed and deceleration data of both sources are compared to get insight in the accuracy of the smartphone apps.

INCA

INstrumented CAr for on-the-road assessment and evaluation of driver behaviour

With growing traffic volumes and more advanced systems within cars and along the road, the driving task becomes more and more complex. In order to cope with congestion and reduced traffic safety, new road designs are being developed. Furthermore, systems that inform and support drivers or take over parts of the driving task are emerging both within cars and in infrastructure. How do these new concepts influence driver behaviour, workload and performance?

With TNO's INCA (INstrumented CAr) it is possible to test and evaluate the driving task and the driver's performance in real traffic. By on-line registration of driving speed, lateral position, driver actions and the relative distance and speed with respect to other cars, we assess driver behaviour in terms of speed choice, following behaviour, steering behaviour, looking strategy and workload. This on-the-road testing can be used for many different purposes, for example for the evaluation of (new) in-car systems, certain infrastructure elements, or general appreciation of driving circumstances.

In-car systems

In-car systems that inform or support drivers in their driving task may have a potential to increase road capacity and driving comfort, improve traffic safety and reduce energy consumption and environmental impact. For the effectiveness, however, it is essential that drivers are both able and willing to properly interact with these new systems. With TNO's INCA it is possible to evaluate the reactions of the driver to (combinations of) new in-car systems.

With respect to the direct interaction between driver and in-car systems, the INCA provides the options to present information on a visual display, acoustically or proprioceptively.

The proprioceptive information mode means that force feedback is given to the driver by means of an active accelerator or by means of an active steering wheel.

Data collection principles
For this test the AutoGuard app was used (version 4.5.10) on a Samsung S4 smartphone. Speed is logged every second with a resolution of 0.1 km/h =0.36 m/s (based on the GPS of the smartphone). The deceleration is not logged, but calculated from the speeds: the resolution for acceleration is delta V / delta t = 0.36/1 = 0.36 m/s^2.

INCA has two options for collecting driving data:
1. GPS: for position and speed, a RTK ('Real Time Kinematic') GPS is used. With respect to a fixed base station, this system realizes centimetre accuracy in positioning signals (1.96 Hz). This is considerably better performance than a standard GPS.
2. CAN bus: from the CAN bus of the vehicle, the velocity of all four wheels is logged separately (50 Hz). Since this CAN signal had a much higher sampling frequency and better resolution than the GPS signal, the CAN signal was used to calculate the acceleration/deceleration of the vehicle:
    - The CAN speeds are equal to what is shown on the speedometer, which is designed to be higher than the actual speed.
    - First, the average speed over the 4 wheels was determined.
    - A correction factor was derived by comparing the CAN speed and the GPS speed signals, using only portions of the data where the GPS was in RTK mode (i.e. not merely normal GPS or differential GPS) and speed was almost constant.
    - Next, the correction factor was applied to scale the CAN speed to the actual speed (speed shown on the speedometer).
    - This signal was differentiated and low-pass filtered to obtain the acceleration signal.

To compare the speed and acceleration profiles collected with AutoGuard and INCA, a test drive of 8 minutes was made. During this test drive medium to hard braking manoeuvres were performed.

Results

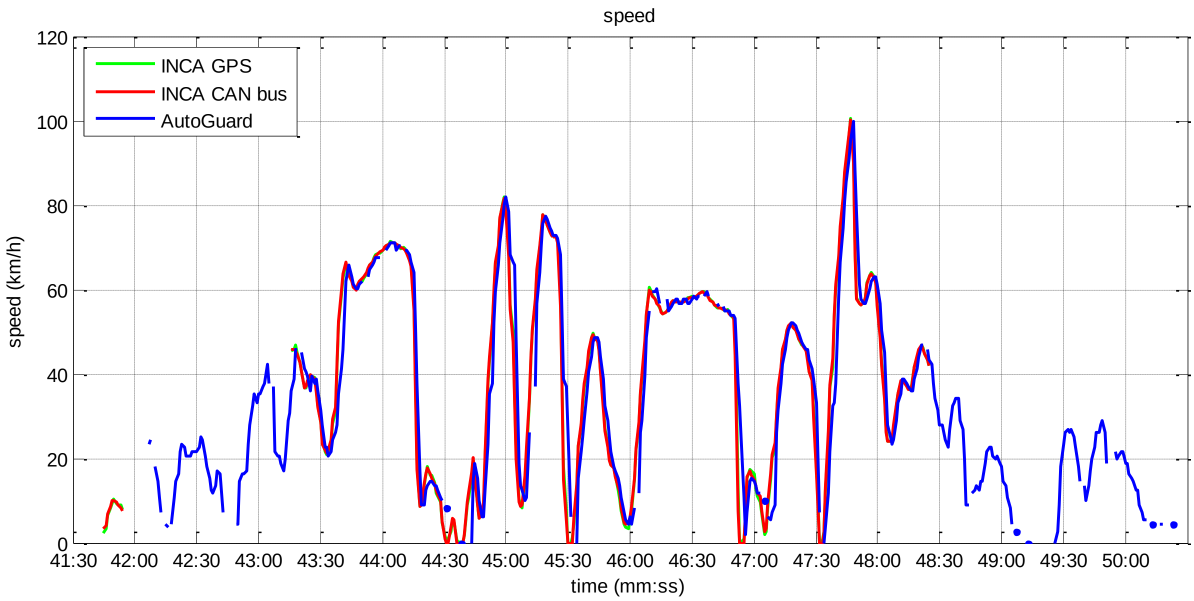


Figure 7 and Figure 8 show the speed profiles logged by AutoGuard and INCA (both GPS and CAN bus).

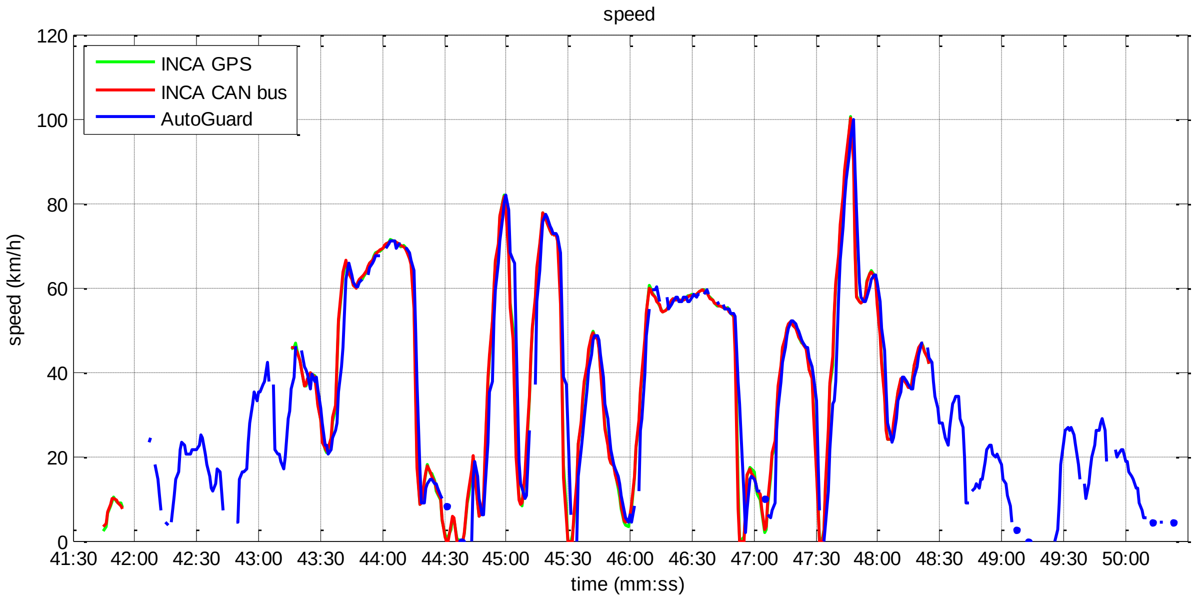


Figure 7: comparison of AutoGuard and INCA speed profiles

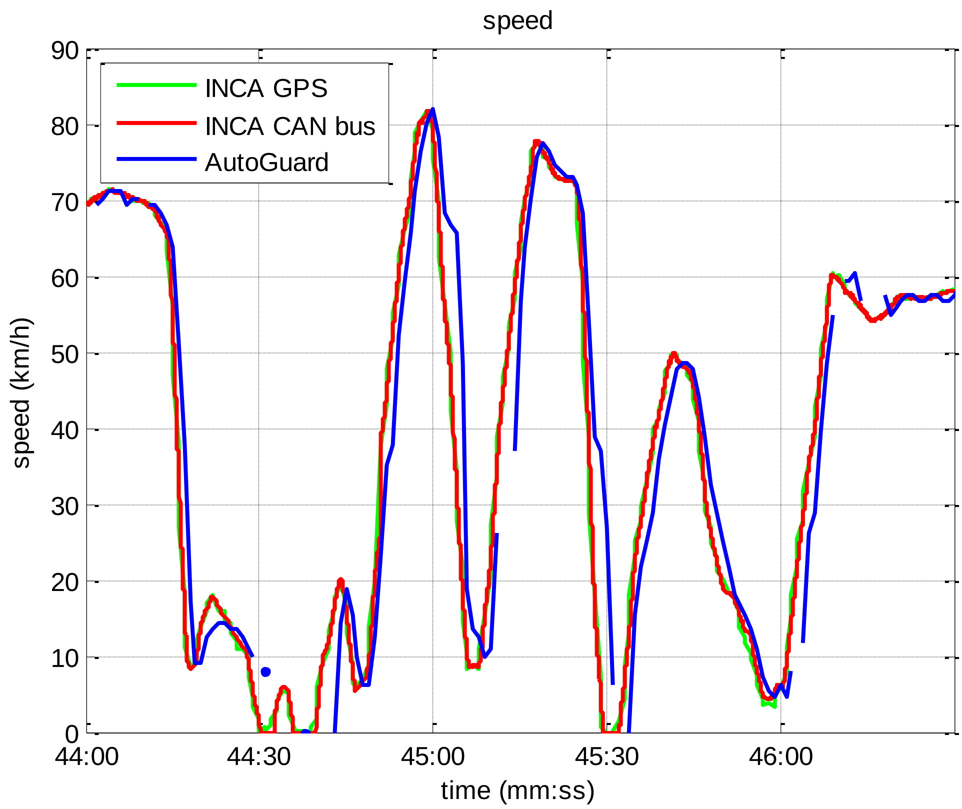


Figure 8: Detail of the logged speed profiles

The AutoGuard speed profile follows the speed profiles of INCA fairly good; the speeds are very close to the values logged by the INCA GPS system and the CAN bus. There seems to be a small time lag between the AutoGuard logging and the INCA logging (the AutoGuard logging is 1-2 seconds behind the INCA loggings).

Figure 9 and Figure 10 show the derived acceleration and deceleration data.

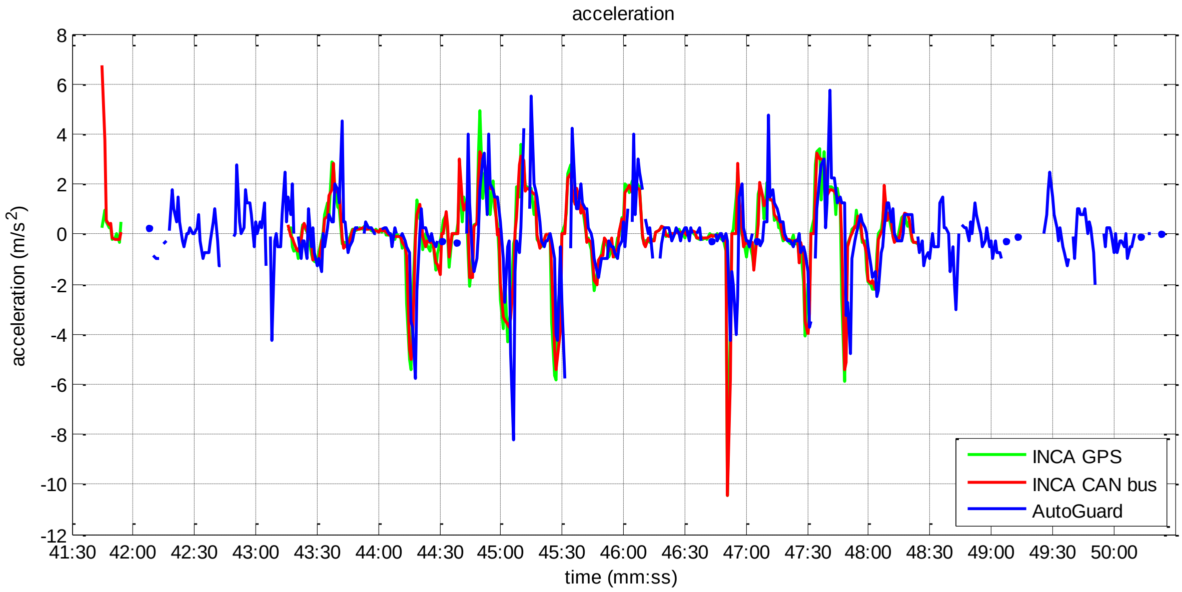


Figure 9: Comparison of AutoGuard and INCA acceleration profiles

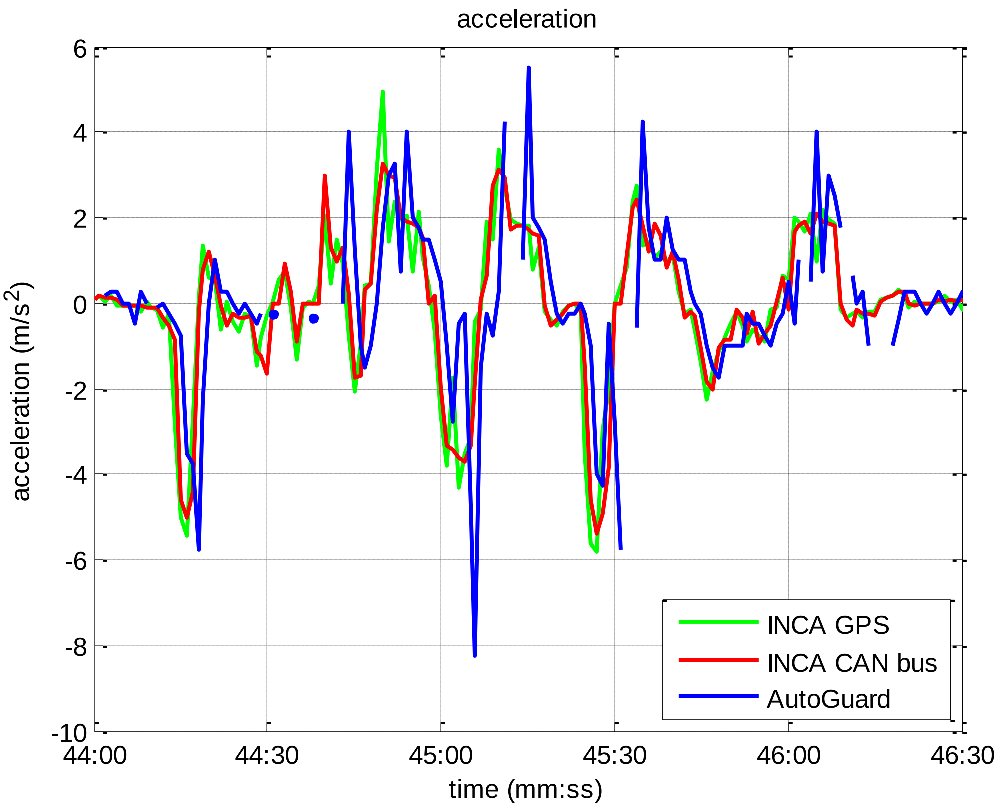


Figure 10: Detail of the logged acceleration profiles

Compared to the speed profiles, the acceleration profiles show larger differences between the different loggings. In case of hard brakings (and accelerations), AutoGuard is recording higher values than INCA, both the GPS-logging and the CAN bus logging.

In general, the absolute deceleration rates recorded with AutoGuard are in the same range as those of the instrumented vehicle.

Figure 11 shows the distribution of the deceleration rates recorded with INCA GPS, INCA CAN bus and AutoGuard.

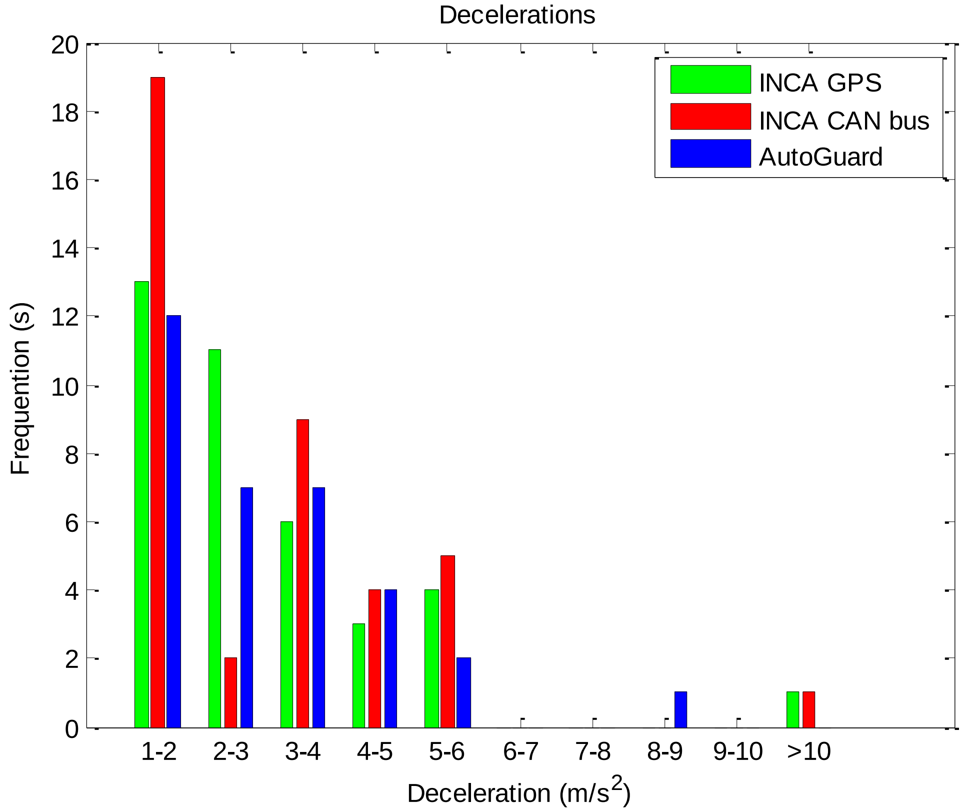


Figure 11: Distribution of deceleration rates of the test drive

Table 3 shows the average speeds and acceleration rates for the three systems and the average (absolute) differences between the AutoGuard and INCA speed and acceleration profiles (for each time stamp of the AutoGuard frequency the speeds and acceleration rates are compared).

System	Average speed [km/h]	Average speed difference per time step [km/h] (compared to AutoGard)	Average (absolute) acceleration [m/s²]	Average acceleration difference per time step [m/s²] compared to AutoGard
AutoGuard	42.18	---	1.068	---
INCA CAN bus	42.23	2.1	1.058	0.7
INCA GPS	42.24	2.1	1.057	0.8

Table 3: Comparison of AutoGuard and INCA test drive recordings

With respect to the application of the smartphone app data, the following conclusions can be drawn from this validation test:

1) Detailed analysis of individual braking manoeuvres (deceleration rates for 1 second intervals) should be regarded with caution; in some cases the app can log two high deceleration rates; and
2) For calculating average deceleration rates, the accuracy of the smartphone app is reliable enough. This also counts for distributions of deceleration rates of participants over the total of trips.

5 Data evaluation

5.1 Introduction

This section describes the results of the data analysis of the experiment.

Since data is collected during everyday trips without experimental control, a general evaluation is carried out; this gives an impression of the deceleration behaviour in all sort of conditions and situations. These results are later compared with results from braking trials, simulator studies and other driving experiments.

5.2 Global evaluation

From each individual driver, the distribution of the deceleration rates during all trips was analysed. The speed of a vehicle is recorded during a time interval of 1s; from these speeds, the deceleration rates were derived.

Figure 12 shows an example. The vertical axis corresponds with the total recorded deceleration time. For instance, this participant has braked in total 102 seconds with a deceleration rate of 3-4 m/s^2 during all of the trips. The decelerations rates smaller than 1 m/s^2 are left out of the analyses: these rates are not associated with (severe) braking, but with releasing the throttle.

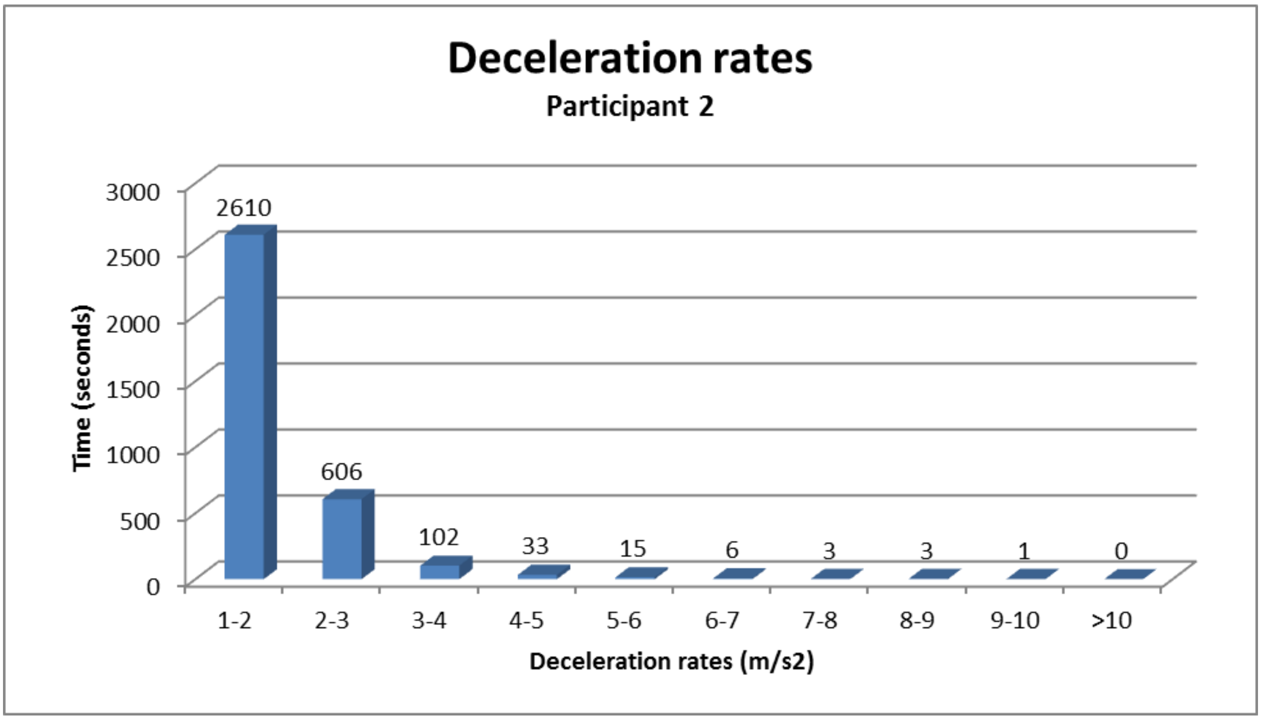
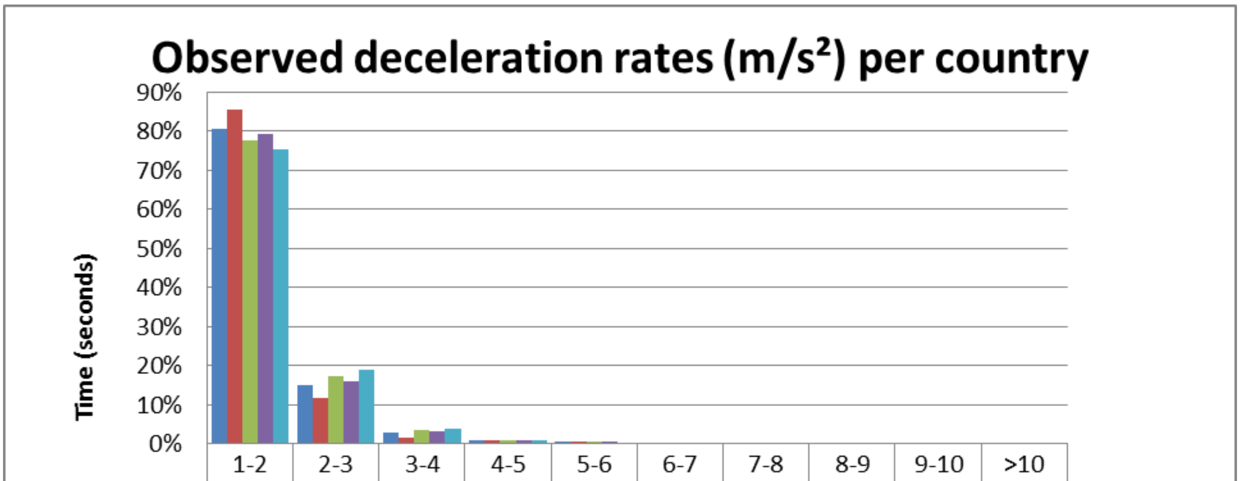


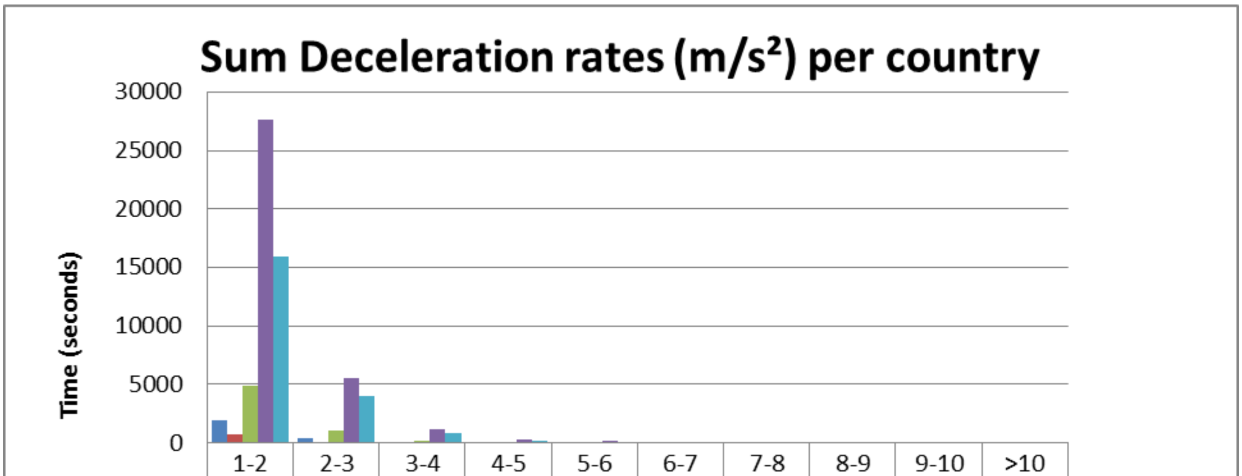
Figure 12: Example distribution of deceleration rates for an individual participant

Appendix A contains the deceleration distributions of all participants. From these individual distributions an overall distribution can be compiled. Figure 13 and Figure 14 show the distribution of all collected deceleration rates per country.



	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10
Belgium	80.47%	15.01%	2.80%	0.96%	0.52%	0.24%	0.00%	0.00%	0.00%	0.00%
Germany	85.61%	11.67%	1.42%	0.71%	0.47%	0.12%	0.00%	0.00%	0.00%	0.00%
England	77.51%	17.35%	3.64%	0.98%	0.40%	0.13%	0.00%	0.00%	0.00%	0.00%
Netherlands	79.35%	15.82%	3.30%	0.96%	0.39%	0.13%	0.04%	0.00%	0.00%	0.00%
Ireland	75.33%	19.02%	3.92%	0.84%	0.32%	0.16%	0.06%	0.05%	0.05%	0.25%

Figure 13: Distribution of deceleration rates in percentages (for all data)[1]



	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10
Belgium	1894	353	66	23	12	6	0	0	0	0
Germany	726	99	12	6	4	1	0	0	0	0
England	4904	1098	230	62	25	8	0	0	0	0
Netherlands	27588	5502	1149	335	135	46	13	1	0	0
Ireland	15937	4025	829	178	67	34	13	11	11	52

Figure 14: Distribution of deceleration rates in seconds (for all data)

From these data it can be concluded that the majority of the braking manoeuvres have a typical deceleration of 3 m/s^2 or less: approximately 95% of the braking time has a deceleration rate between 1 and 3 m/s^2.

[1] *The data from Ireland was not collected with this experiment. False registrations are not filtered out of the Irish data set*

Higher deceleration rates are exceptional: only in 2-4% of the time the deceleration rate is between 3 and 4 m/s^2, deceleration rates above 4 m/s^2 occur only in less than 1% of the time braking occurs. The maximum deceleration rates recorded are in the range of 7-9 m/s^2. Drivers do not apply maximum deceleration, unless an emergency is forcing them to do so.

The volume of data varies widely between the countries; the data set of the Netherlands is significant, the data set of Germany is limited.

Despite the differences in the size of the data sets, the distribution of deceleration rates is similar for all the considered countries; the percentages are in the same order of magnitude.

5.3 Emergency braking

5.3.1 Introduction

During the experiment a large amount of driving data was collected. Because the participants in the experiment did not receive any instructions, the data had to be filtered and the data relating to emergency stops was identified and extracted.

In this section the results of all emergency brake manoeuvres are analysed. The driving behaviour during an emergency stop is investigated and the deceleration rates during these stops are determined.

5.3.2 Emergency brake definition

Guidelines
In work package 2 (WP2) the road design guidelines of several EU-member states were studied. Each of the guidelines studied contains parameter values for lateral coefficient of friction, from which the deceleration rate can be calculated given the perception reaction times.

Table 4 shows the lateral coefficients of friction (Van Petegem et al, 2015).

Country	tangential or braking coefficient of friction								
	50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	120 km/h	130 km/h
Denmark: straights (up) and horizontal curves (down)	0.377 0.33	0.377 0.34	0.377 0.35	0.377 0.35	0.377 0.36	0.377 0.36	0.377 0.36	0.377 0.37	0.377 0.37
France	0.46		0.44		0.40		0.36		0.32
Germany	0.377	0.377	0.377	0.377	0.377	0.377	0.377	0.377	0.377
Ireland	-	-	-	-	-	-	-	-	-
The Netherlands	0.48			0.41		0.36		0.32	
Switzerland: motorways (up) and other roads (down)		0.49 0.35		0.44 0.30		0.40		0.36	
United Kingdom (85 km/h instead 80 km/h)	-	-	-	-	-	-	-	-	-

Table 4: Braking coefficient of friction of EU road design guidelines (Van Petegem et al, 2015)

From the tangential coefficient of friction the average deceleration rate can be calculated for a stopping sight braking manoeuvre (acceleration of gravity multiplied by the tangential coefficient of friction): given the values in Table 4, the average deceleration rates (of design speeds of 100 km/h and above) vary from 3.1 m/s^2 (France and The Netherlands) to 3.9 m/s^2 (Switzerland).

Two other assumptions related to SSD are of relevance with respect to road design:
1. For calculating road geometric dimensions in relation to SSD (like curve radii), it is assumed that drivers start braking at the design speed (e.g. 120 km/h) and decelerate to a complete standstill. The deceleration rate in the guidelines should be regarded as an average deceleration rate.
2. With respect to the available sight distance, it is assumed that the view on the obstacle (braking light of a stationary vehicle, or object on the road surface) is not obstructed by a vehicle in between: the length of the field of view is at least equal to the stopping sight distance.

This assumption is illustrated in Figure 15. The available sight distance of the braking vehicle on the stationary truck, is equal to the SSD. There is no vehicle in between the braking vehicle and the stationary truck; in that case the driver would react on the vehicle in front and not on the stationary truck.

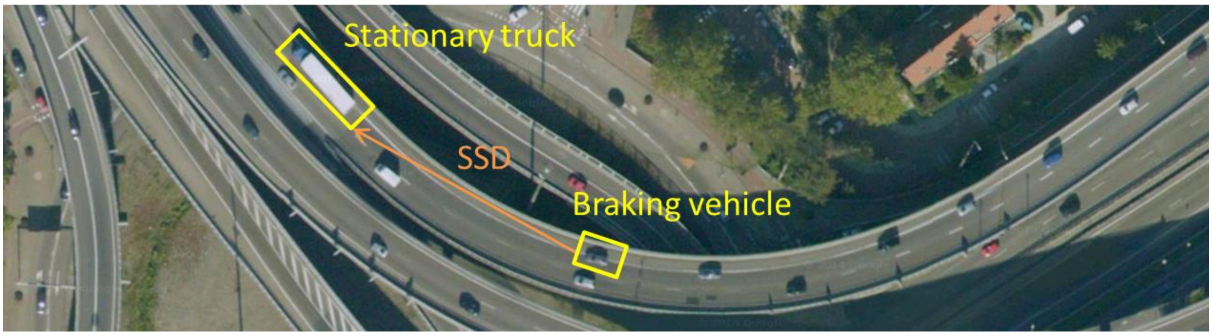


Figure 15: Example of ‘ideal’ SSD conditions (stationary object on stopping sight distance)

With regard to the selection of the driving data in SSD conditions, the following criteria can be derived:
- Speed profiles of mainline carriageways and interchange ramps of motorways;
- Deceleration rates of at least 3 m/s^2;
- Deceleration from the design speed of the road section to a standstill;
- Headway to the vehicle in front is larger than the stopping sight distance;

5.3.3 Selection of data
With the criteria presented in the previous section, the braking manoeuvres were selected from the data set. A quick-scan of the data showed that the ‘ideal SSD manoeuvre’ was not recorded during the test period: in most cases of emergency braking, the vehicle did not come to a complete standstill and the participants speed and deceleration was influenced by a vehicle in front (instead of a stationary object or vehicle).

Therefore it was decided to exclude the criterion for the minimum headway. The criterion for a deceleration from the design speed to a standstill was adjusted so that a speed drop of at least 40 km/h constituted an emergency stop.

5.3.4 *Selected data*

With the (modified) criteria, a selection of trips was made from all data. In total 32 brake events met the criteria (see Appendix B for details). Figure 16 shows an example of a brake event.

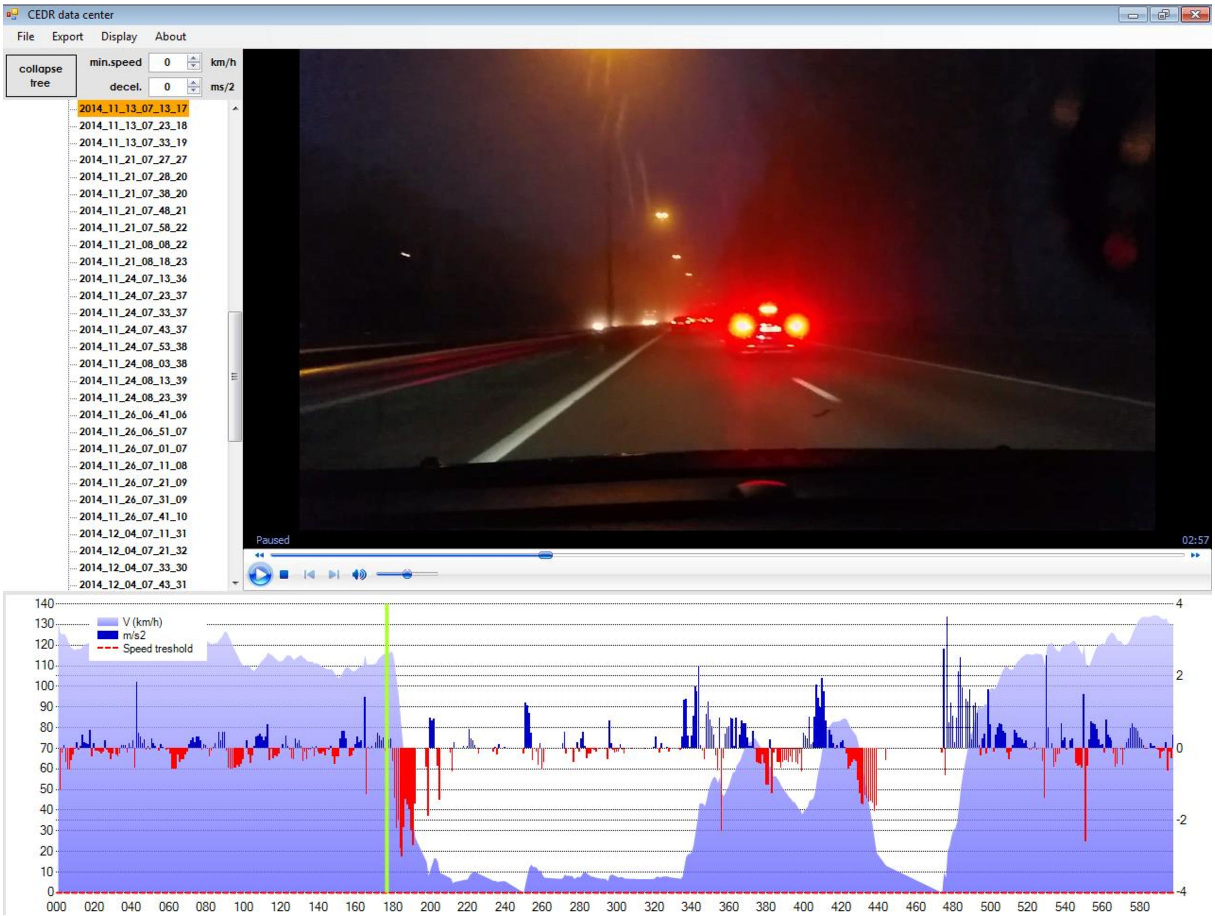


Figure 16: Example of recorded trip with emergency stop for a queue

This participant had an initial driving speed of approximately 120 km/h. As he approaches the tail of a queue he has to brake for the vehicle in front of him; the vehicle in front is not a stationary vehicle at stopping sight distance, but a vehicle that is also approaching the tail of the (stationary) queue. The speed of the queue is approximately 10 km/h.
Figure 17 zooms in to the emergency stop section of the trip.

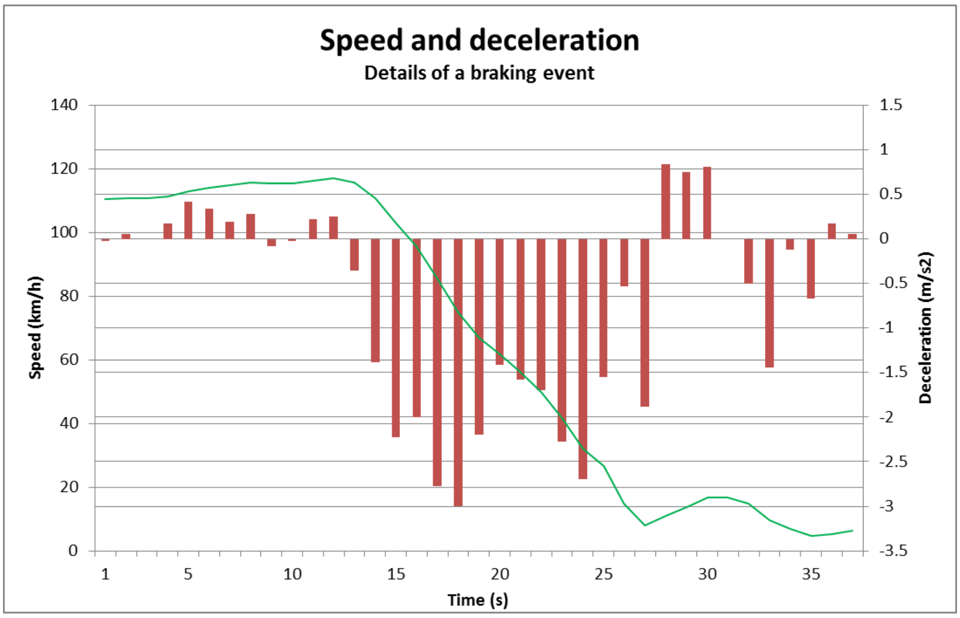


Figure 17: Details of emergency braking manoeuvre (speed in green line, deceleration in red bars)

For this braking manoeuvre it is clear that the deceleration rates are not constant during the braking manoeuvre. Initially, the participant brakes gently, then he brakes more severely with a maximum deceleration of about 3.0 m/s^2. The average deceleration rate is approximately 1.5-2.0 m/s^2.

Figure 18 shows the speed and deceleration profiles of 32 selected brake events (all with video recordings) that correspond to the criteria best. Table 5 summarizes the characteristics of the selected brake events.

Initial speed	>120 km/h	100-120 km/h	80-100 km/h	<80 km/h	
	41% (13)	28% (9)	25% (8)	6% (2)	
Final speed	>60 km/h	40-60 km/h	20-40 km/h	0-20 km/h	
	22% (7)	16% (5)	16% (5)	47% (15)	
Speed drop	>100 km/h	80-100 km/h	60-80 km/h	40-60 km/h	20-40 km/h
	22% (7)	25% (8)	25% (8)	19% (6)	9% (3)
Max. decel. rate	1-2 m/s^2	2-3 m/s^2	3-4 m/s^2	4-5 m/s^2	5-6 m/s^2
	9% (3)	22% (7)	44% (14)	13% (4)	13% (4)

Table 5: Summary of characteristics selected brake events

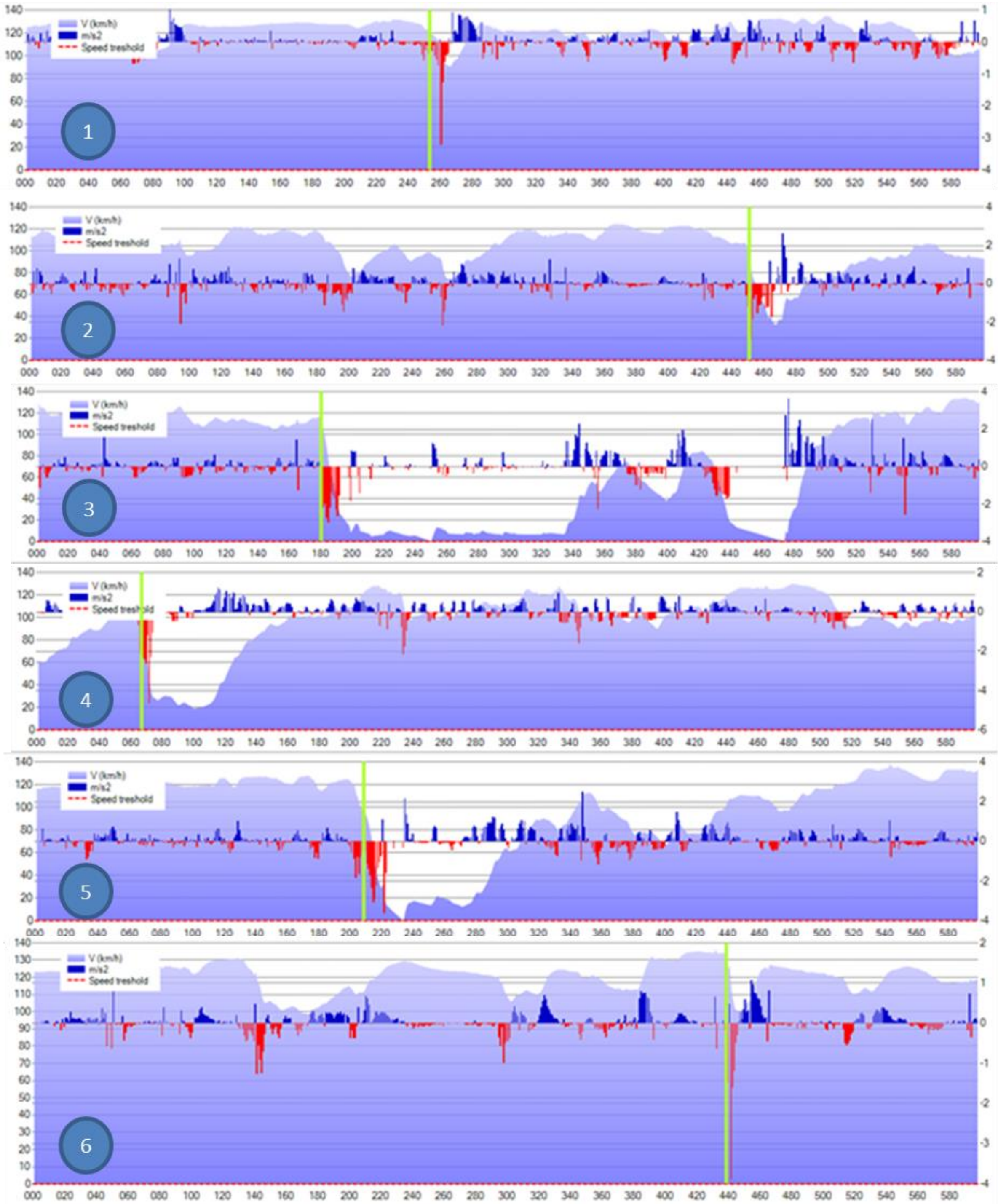


Figure 18a: Selected ‘emergency’ stops

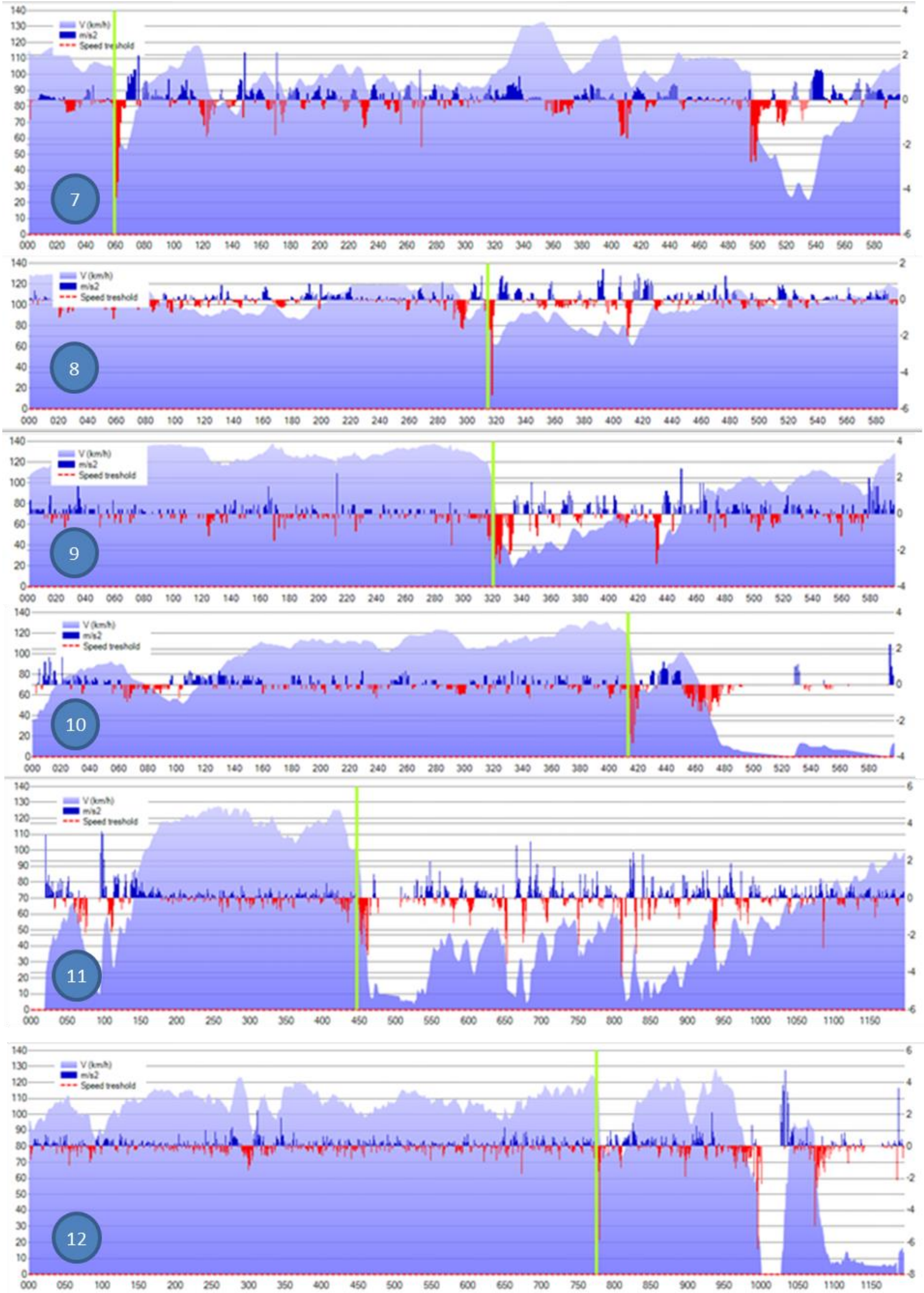


Figure 13b: Selected ‘emergency’ stops

*** *trip 17: in miles/hour****

Figure 13c: Selected ‘emergency’ stops

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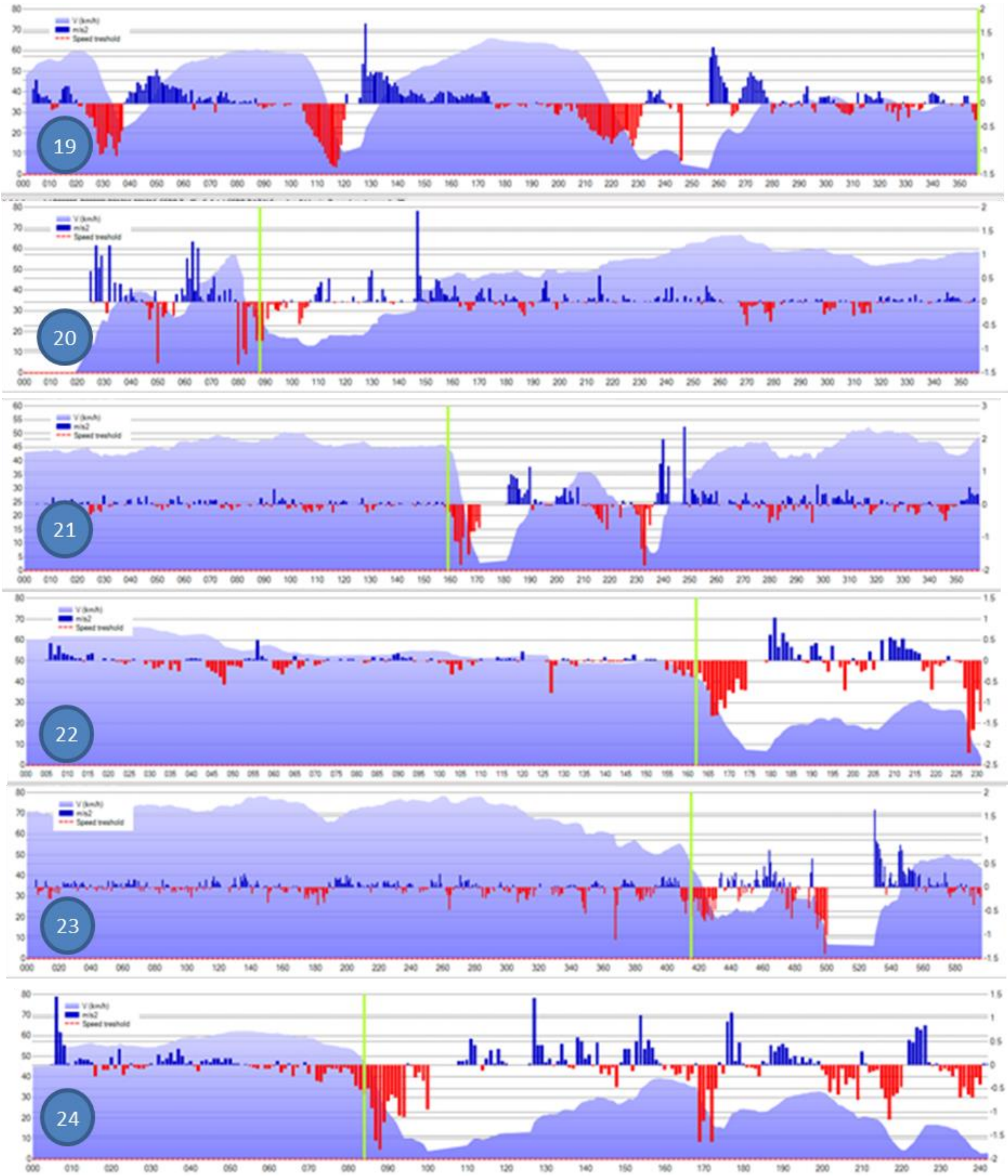

**** trip 19-24: in miles/hour****

Figure 13d: Selected ‘emergency’ stops

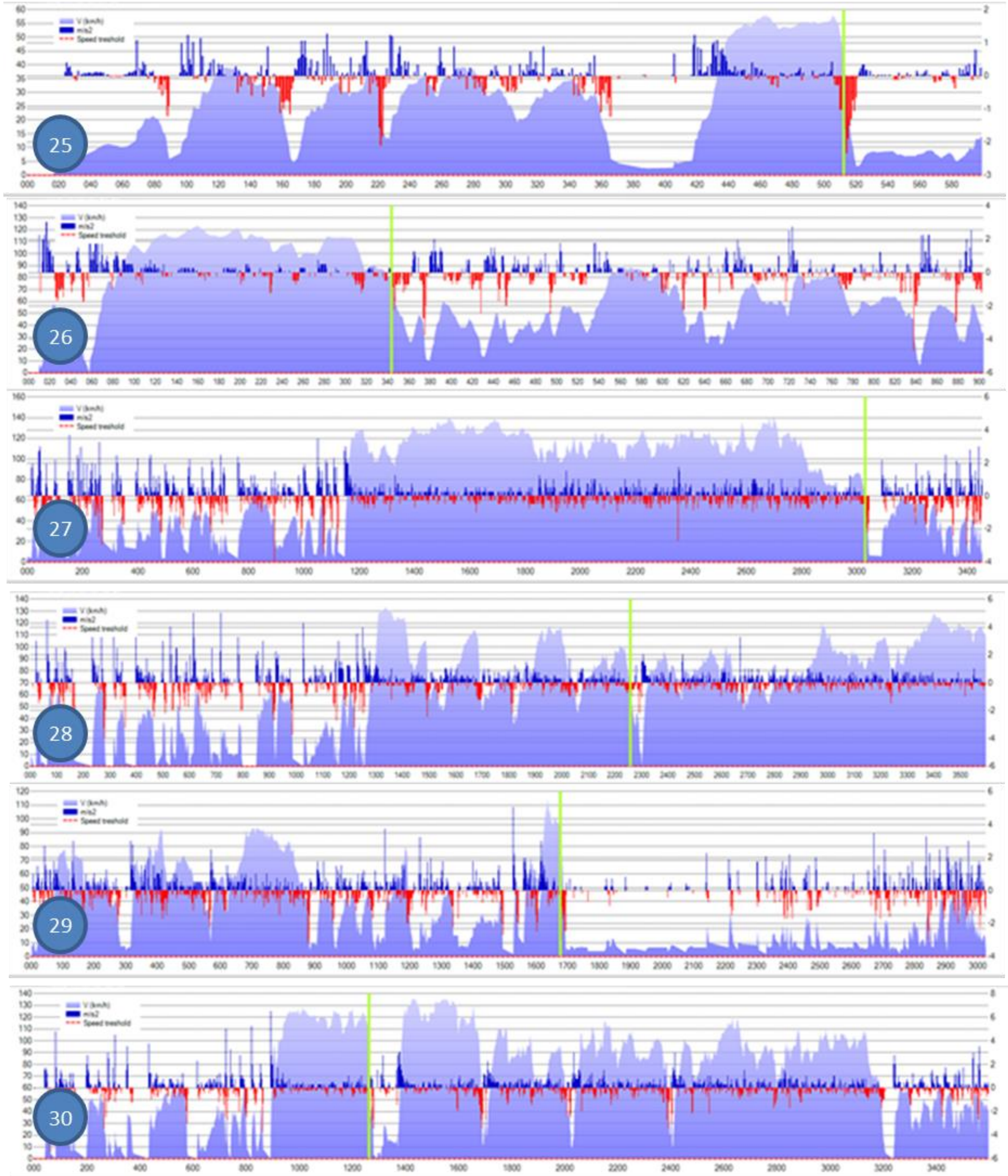

Figure 13e: Selected ‘emergency’ stops

**** trip 25: in miles/hour****

Comparing these selected trips, we can draw the following conclusions:

- The deceleration rate during emergency braking manoeuvres is not a constant factor; the variation of deceleration rates is large.
- In many braking manoeuvres, in which the driver comes to an (almost) complete standstill, a typical pattern emerges: first the driver brakes lightly, then brakes more firmly and finally brakes again lightly. Figure 19 shows an example of this typical pattern.

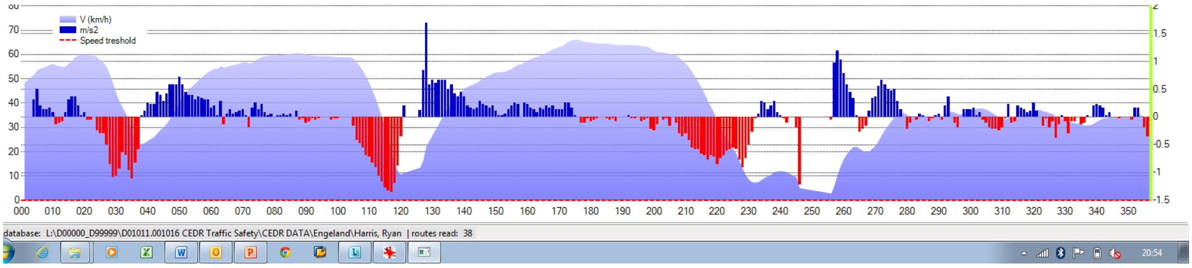

Figure 19: Details of emergency stop

- In most cases the participant does not slow down to a complete standstill; in most situations the speed at the end of the braking manoeuvre is 20-40 km/h.
- On average, the maximum deceleration rate in stopping manoeuvres does not exceed 3-4 m/s^2 with incidental peaks of 5-6 m/s^2.
- From the details of the braking manoeuvres (see Appendix B) it can be concluded that in most cases the participant is anticipating the (moving) vehicle in front and not the stationary vehicle at the tail of the queue. The SSD conditions described by the road design guidelines (i.e. an unobstructed view on the stationary obstacle) did not occur during this experiment.
- The deceleration rates participants apply depend on the necessity of braking firmly: with a decreasing time to collision, the deceleration rate increases.

5.3.5 *Quantitative analysis of emergency stops*

The deceleration distributions presented in section 5.2 are based on all driving data. The analysis presented in this section, represents the statistical characteristics of the emergency braking manoeuvre.

All the data were imported into a data analysing tool (Matlab): this tool enables using multi-criteria filtering of the data.

Figure 20 shows an example of an emergency braking selected in Matlab. The difficulty with describing the statistical characteristics of these manoeuvres is the selection of the criteria: when does an emergency braking manoeuvre exactly start and end? At the same time, the start and end conditions of the emergency braking manoeuvres, influence the average deceleration rates of the manoeuvre. In practice, the speed patterns of emergency braking manoeuvres are very diffused, making it difficult to choose unambiguous selection criteria.

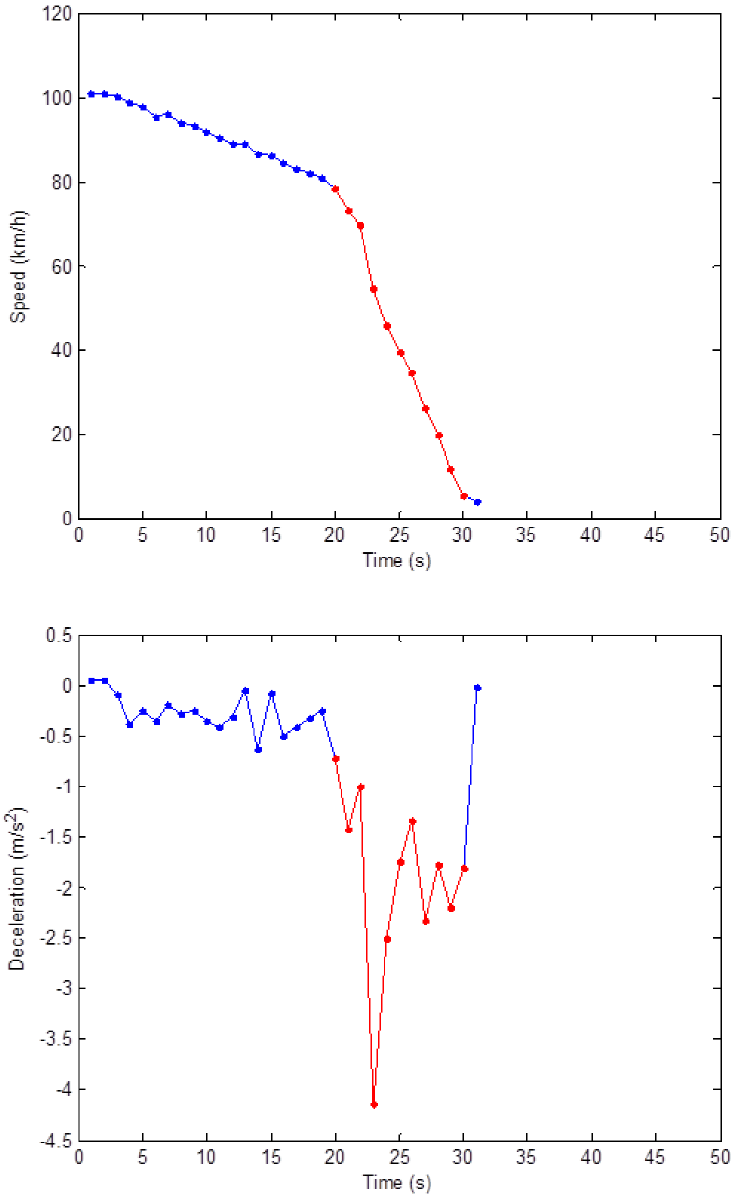

Figure 20: Example of emergency braking manoeuvre

To deal with this difficulty of determining selection criteria, several sets of criteria were applied in Matlab and the sensitivity of the results was tested.

		Run										
Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Speed drop (km/h)		40	40	40	40	45	45	45	40	40	40	40
Minimum decelation (m/s2)		-3.5	-3.0	-2.5	-2.0	-3.5	-3.0	-2.5	-3.0	-3.0	-3.0	-3.0
Minimum decelation, start and end point (m/s2)		-	-	-	-	-	-	-	-0.3	-0.5	-0.7	-1.0
Avarage deceleration rate												
cluster 1	130-90 km/h	-1.27	-1.18	-1.07	-0.98	-1.23	-1.16	-1.06	-1.57	-1.73	-1.90	-2.35
cluster 2	90-60 km/h	-1.29	-1.19	-1.10	-1.01	-1.30	-1.20	-1.11	-1.61	-1.78	-1.92	-2.20
cluster 3	<60 km/h	-1.46	-1.32	-1.16	-1.03	-1.59	-1.40	-1.22	-1.89	-2.05	-2.26	-4.08
Number of braking manoeuvres												
cluster 1	130-90 km/h	165	263	438	673	155	242	399	242	242	242	242
cluster 2	90-60 km/h	291	490	835	1237	262	443	754	443	443	443	443
cluster 3	<60 km/h	171	263	458	731	117	184	310	184	184	184	184

Table 6: Average deceleration rates of braking manoeuvres

Explanation:

- The combination of speed drop and minimum deceleration rate are basic criteria for selecting the emergency braking manoeuvres. Speed drop varies from 40 to 45 km/h, the minimum deceleration rate from 2.5 to 3.5 m/s^2.
- Some braking manoeuvres start with very light braking in the beginning; the blue part of the deceleration graph in Figure 20 illustrates this behaviour. The impact of leaving this part of the manoeuvre out of the analysis was studied by including minimum start and end decelerations rates (run 8-11). This means that only the red part of the deceleration graph is included in determining the characteristics of braking manoeuvres.
- The criteria influence the number of deceleration manoeuvres that remain from the data set; with higher minimum deceleration rates and larger speed drops, the number of manoeuvres decreases.
- The number of braking manoeuvres in Table 6 is related to the braking manoeuvres on all types of road. In general the manoeuvres of cluster 1 (initial speed 130 – 90 km/h) refer to manoeuvres on motorways, those in cluster 2 to highways and those in cluster 3 to urban roads (or minor rural roads). Of course it is possible that participants had an initial speed below 90 km/h (because of a queue).
- It can be concluded that the average deceleration rate on urban roads (or minor rural roads) is higher than that on highways and motorways.
- When excluding the light braking stages (beginning and end) of the total braking manoeuvre (runs 8 to 11), the average deceleration rate on motorways rate varies from 1.57-2.35 m/s^2. This relatively low rate can be explained from the fact that not only the emergency brake situations are included in this selection: but also, for instance, the manoeuvres in which a driver takes an off ramp and has to stop for a traffic light.

Figure 21 shows the distribution of deceleration rates based on run 10 (speed drop 40 km/h, minimum deceleration rate 3.0 m/s^2 and minimum deceleration rates at the start and the end of 0.7 m/s^2).

The proportion of deceleration rates larger than 3 m/s^2 is approximately 15%; at lower speeds this proportion is somewhat higher; and at higher speeds somewhat lower.

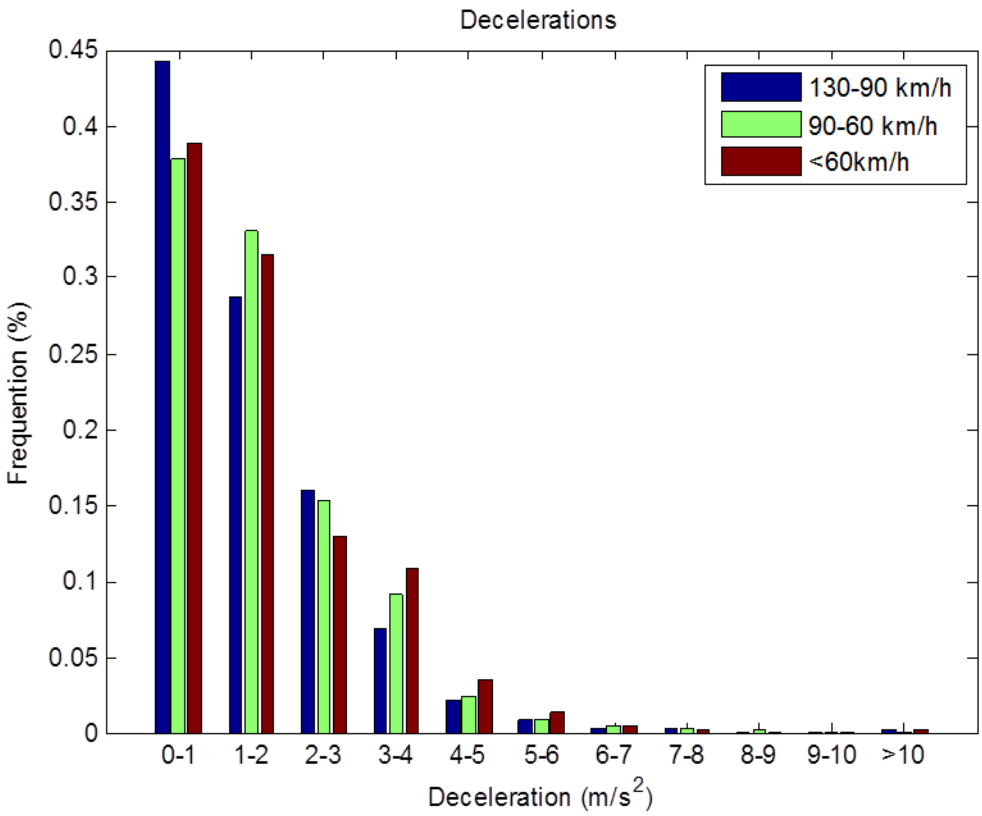

Figure 21: Distribution of deceleration rates in emergency brake situations for 3 categories of initial speeds

6 Comparison with other studies

6.1 Introduction

The driving experiment has given insight in the behaviour of drivers in (emergency) brake events. Because an event that meets the exact conditions of SSD road design guidelines is not present in the collected data, it is desirable to include results of other studies when considering recommendations for an appropriate deceleration rate. Studies on deceleration behaviour on test tracks and in driving simulators can add extra underpinning evidence for parameter choices to be made later in the project. These study approaches also have their own limitations (e.g. with respect to the representativeness of the driving behaviour compared to open road conditions), but together with the results of the driving experiment the different approaches can give a good overall picture.

This section presents studies related to deceleration characteristics.

6.2 Literature review

6.2.1 Stopping Sight Distance Discussion Paper

In this publication all parameters of stopping sight distance are discussed (Layton and Dixon, 2012). The backgrounds of the US road design guidelines (A Policy on Geometric Design of Highways and Streets, also known as The Green Book, published by the American Association of State Highway and transportation Officials (AASHTO)) are presented, including related studies. The results are derived from a literature review; no tests or experiments were carried out.

The current US road design guidelines (AASHTO ‘Green book’) use a design deceleration rate of 3.4 m/s^2. This value is considered as a comfortable deceleration rate and not based on a maximum deceleration rate related to the coefficient of friction.

The AASHTO Green Book (2011) refers to a study by Fambro et al.: most drivers decelerate at greater than 4.5 m/s^2 when decelerating for an unexpected condition. This corresponds to a pavement coefficient of 0.46, which cannot be provided by many wet surfaces.

The standard deceleration rate of 3.4 m/s^2 proposed first in the 2001 Green Book has been retained. This is expected to accommodate 90% of all drivers, and require an available pavement coefficient of friction of 0.35. Most wet bleeding asphalt surfaces and wet polished concrete roadways should provide this frictional resistance.

6.2.2 A study on driver behaviour during braking on open road

Data of three experiments were analysed in order to study drivers’ behaviour when braking and to find the better means to trigger active safety devices (Kassaagi and Brissart, 2003). Given the experimental complexity, the cost and the availability of the trial only the accident situations concerned rear-end crashes (unexpected obstacles on the roadway ahead of the leading vehicle) were studied. Regarding open road experiments, about a hundred volunteers (women and men of various ages) drove around 100 km in the Paris area. More than 14,000 braking events were recorded and studied. The analysis of these events allowed the links between the actions of the drivers and the potentially dangerous or dangerous driving situations to be underlined.

Further, two experiments were conducted by LAB (Laboratory of Accidentology and Biomechanics) in a driving simulator and on a test track to study the behaviour of drivers during obstacle avoidance situations (or rear-end crashes). For these tests, the drivers were recruited from the general public. They were told they were participating in a test concerning vehicle “ergonomics”. At the end of the test, the driver was surprised by the triggering of a potential crash situation. His (or her) actions on the car’s controls were recorded and synchronized with dynamic parameters and video.

Five critical scenarios (four in the driving simulator and one on the test track), according to accidentologic studies, were tested. The four rear-end accident configurations tested in the simulator were:

- a vehicle leaving a parking space in an urban area and merging into the subject’s lane;
- a vehicle stopped on the other side of a crest;
- a vehicle driving at reduced speed on the other side of a crest;
- a vehicle decelerating, then braking strongly after having been followed for 500 m in an urban area.

On the test track the subjects had to follow a vehicle pulling a trailer [3]. The potential crash situation was caused by releasing the trailer decelerating at 7 m/s^2. The release was triggered from a relative distance of 17 m and at a speed of 70 km/h.

In emergency situations, drivers operate with a reflex behaviour in an open loop mode: the perceptive bias in the simulator has no effects on the initial avoidance reactions (reaction time, brake pedal hit…). At this time the drivers are not yet expecting to feel the effect of their action. The lack of deceleration feedback is therefore not disturbing. This is no different during the control phase, when drivers are in a close loop mode: generally 500 ms after the braking action beginning. The drivers tend to brake harder because they do not feel the deceleration in the simulator. In order to analyse this control phase it is necessary to perform experiments on a test track. This phenomenon becomes a source of bias when studying “normal” braking.

A literature review showed that drivers in emergency situations were a long way from using the maximal capacities of their vehicles. For example, during an emergency braking, 52% of the drivers have not reached the ABS regulation release situation.

The results on the test track show that the slightest modification of the initial conditions of the crash scenario (like driver’s attention or obstacle kinematics), has a strong impact on the driver behaviour during an emergency situation: the driver is thus extremely sensitive to the parameters of the situation, and can react quickly according to these totally different operations.

Paradoxically, at first sight the reaction of the driver in an emergency braking situation does not seem to have an influence on its result (avoidance/accident). In fact, the consequences of the good reactions of the drivers are masked by the effects of the initial parameters (distance to obstacle and speed of the vehicle), of the steering wheel manoeuvre, as well as by the compensation of the long reaction times (often linked to an error of attention)and by more energetic actions.

From the experiment on the open road different braking situations were distinguished. The atypical events on braking pedal behaviour were studied in detail. On the whole, 58 braking events were observed in the video and selected based on certain criteria, such as the high brake force or the pedals’ speed, as well as the perception of the observer (who sat next to the subject). All the “atypical” braking situations were classified into 3 categories:

- The normal situations: the subject seems to master the vehicle and not to be surprised. For example : arriving to a stop sign or a give up the access or a roundabout, parking manoeuvres, driving in a row at low speed in an urban area, navigation, merging in a row, arriving very quickly at traffic lights, braking in a bend;
- The potentially dangerous situations: the subject is surprised but the situation or its evolution makes it unnecessary to initiate emergency braking. For example: traffic lights perceived at the last moment or pass into red, no-entry sign seen late, a stop sign seen late, in a bend;
- The truly dangerous situations: the subject is surprised and a reaction of the driver is necessary because the situation is truly dangerous at the moment of it commencing. For example: priorities to the right or vehicle coming in the opposite direction. The analysis of these situations shows that a fast action on the brake pedal is most of the time connected to the perception of a potential danger, notably when the speed of the car is higher to about 20 km/h. This explains the will of the driver at the moment of the brake pedal hit: he might want to stop or to be able to make it quickly. However any fast hit of the brake pedal does not lead automatically to braking with high deceleration rates. During potentially dangerous and dangerous situations, this is explained by the favourable evolution of the situation or by the better interpretation of the situation by the driver. To illustrate this result, let us quote as an example a driver approaching a priority to the right situation where another vehicle appears suddenly. The driver generally reacts by releasing the accelerator and engaging the brake pedal. If another vehicle stops, the driver re-evaluates the situation, stops braking and follows his path normally.

The speed at which a driver engages the brake pedal is generally synonymous with a potentially dangerous or dangerous situation for the driver when the car’s speed is higher than about 20 km/h. This fast action at the moment that the brake pedal hit denotes the will of the driver to stop or at least to be ready to stop quickly (notably in case of surprise after “distraction”, or in case of a poor interpretation of the situation). Variables describing the brake pedal hit are, unsurprisingly, the most efficient variable to trigger an EBA (emergency brake assist).

Fast hits of the brake pedal are not always followed by hard braking when the potentially dangerous and dangerous situations evolve favourably. In spite of the relatively rapidly changing driving situations, the diagnostics and the actions of the drivers change as fast as those situations. Some driving situations, for example traffic lights which change to orange, are considered as potentially dangerous by some drivers who reach decelerations superior to 5 m/s², whereas the real danger could be relatively low.

6.2.3 Deriving of a relation between friction, speed and stopping sight distance based on real deceleration manoeuvres

The goal of this study, carried out by Van der Sluis, is to establish the correlation between skid resistance, velocity and stopping sight distance for road design purposes based on actual decelerations (Van der Sluis, 2002).

In a first step, tests were performed in which a vehicle travelling with different selected speeds is brought to a halt on wet road sections with various skid resistance properties.

Through the variation of initial speed, vehicle type, tyre tread depth and braking system (with or without ABS) the most important influences on vehicle deceleration can be assessed.

From these test results, correlation curves were derived between skid resistance (measured with SCRIM) and "mean fully developed deceleration"(MFDD).

Deceleration rates according to the German Guideline RAS-L were compared to measured values on road surfaces with different friction coefficients (derived from literature review, and based on road system performance, not on driving behaviour). The measurements with ABS show higher deceleration rates than the guidelines (see Figure 22).

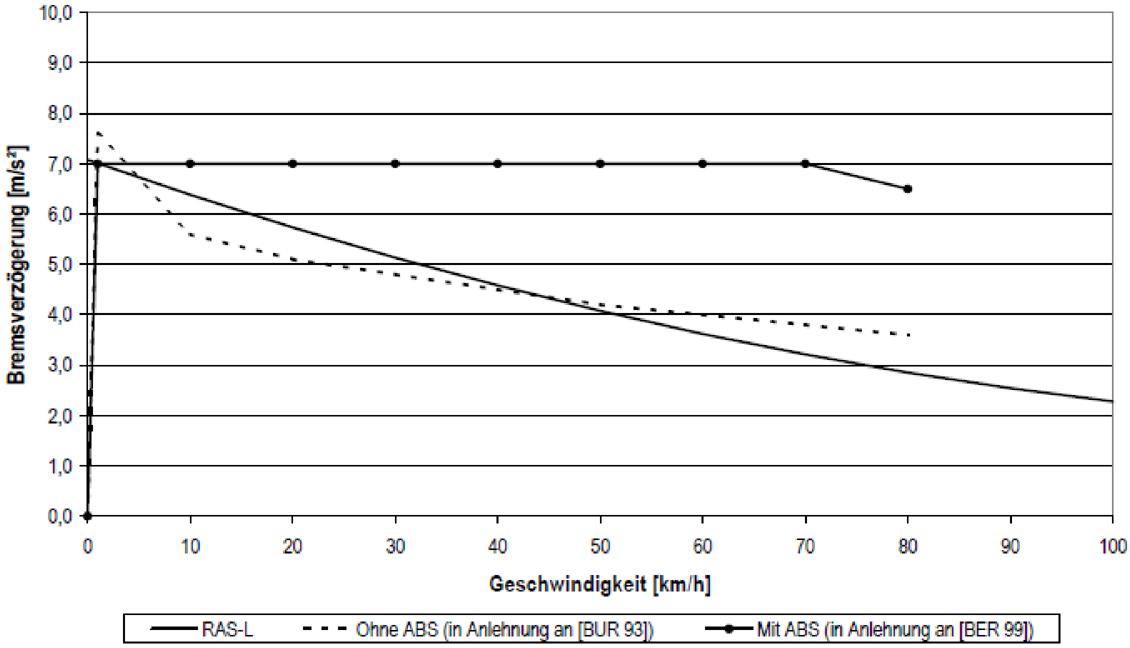

Figure 22: Deceleration (Bremsverzögerung) according to the German Guideline (RAS-L) compared with measured values with and without ABS

In this study, emergency braking manoeuvres were conducted in various test conditions (under wet road surface conditions). Several vehicle types were used on different road sections. The road sections were in most cases closed road stretches of motorways; the skid resistance of these stretches represented the skid resistance of the motorway network in practice better than the skid resistance of closed test tracks (because of the low traffic volume on test tracks).

The test driver was asked to stop his vehicle as quickly as possible.

Table 7 shows an example of the results of tests on one road stretch. Note, that there is a significant difference in maximum deceleration rates between vehicles with and without ABS.

Fahrzeugtyp	Versuchs-abschnitt	$\mu_{SCRIM, 80}$	Ausgangs-geschwindigkeit [km/h]	ABS	MFDD [m/s²]
Ford Mondeo 4 mm Profil-tiefe	Feld 1	0,318	80	•	-6,40
		0,315	100	•	-6,60
		0,327	130	•	-
		0,315	80		-4,52
		0,323	100		-4,24
		0,327	130		-
	Feld 2	0,718	80	•	-8,89
		0,722	100	•	-8,35
		0,723	130	•	-8,65
		0,720	80		-6,59
		0,725	100		-5,91
		0,719	130		-5,31
Ford Mondeo 2 mm Profil-tiefe	Feld 1	0,318	80	•	-6,40
		0,315	100	•	-6,31
		0,327	130	•	-6,00
		0,315	80		-5,08
		0,323	100		-4,26
		0,327	130		-3,55
	Feld 2	0,718	80	•	-8,14
		0,722	100	•	-7,94
		0,723	130	•	-7,43
		0,720	80		-6,79
		0,725	100		-6,31
		0,719	130		-4,71

Table 7: Example of MFFD (deceleration) measured on a test track (Münster-Nord, BAB A1)

The relationship between the longitudinal coefficient of friction and the deceleration rate (MFFD) was evaluated using a linear regression analysis. Figure 23 and Figure 24 show that the longitudinal coefficient of friction has a significant effect on the deceleration performance; low coefficients of friction restrict the maximum deceleration rate. Also, the absence of ABS has a major impact on the deceleration capabilities of a vehicle.

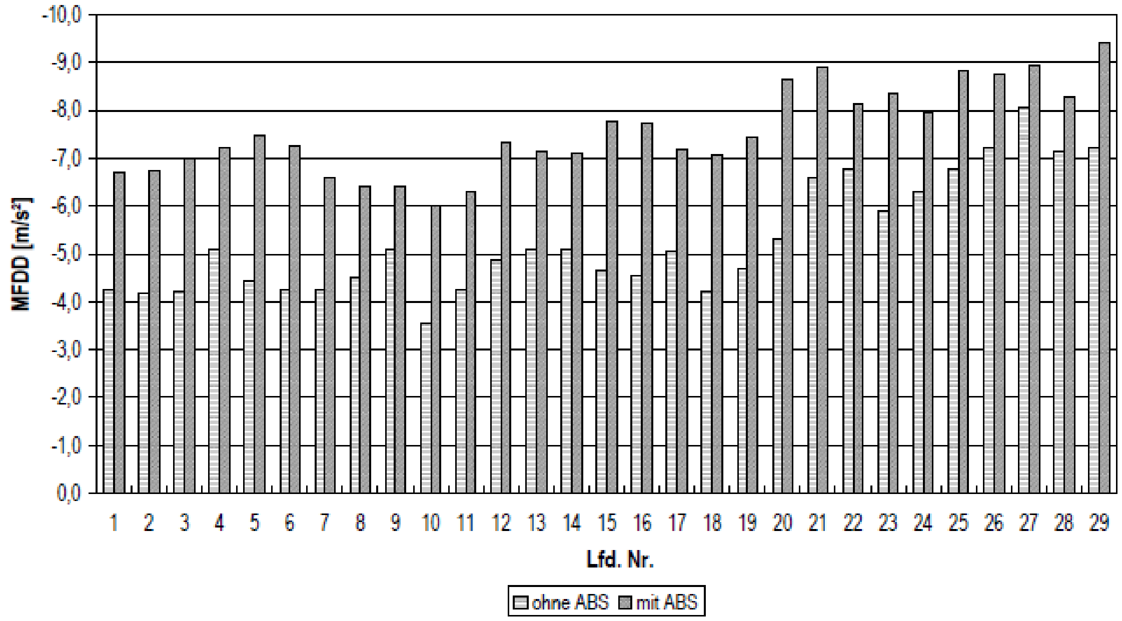

Figure 23: Deceleration rates (MFDD) as a function of the longitudinal coefficient of friction (left 'low', right 'high' for different initial speeds, with and without ABS

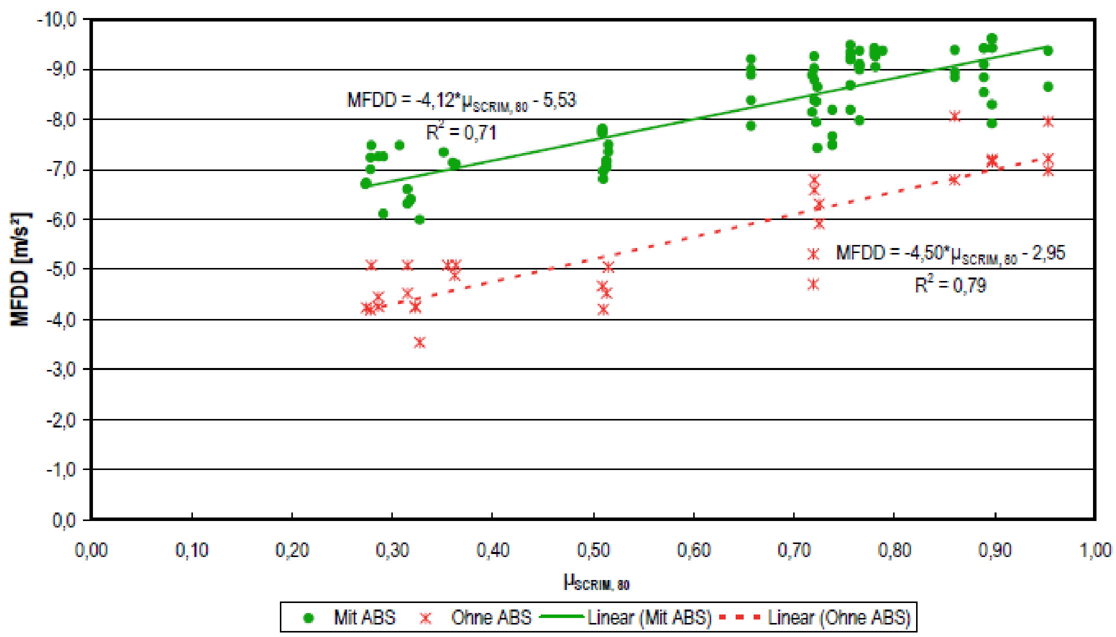

Figure 24: Deceleration rate (MFDD) as a function of the longitudinal coefficient of friction (μ_{scrim})

Furthermore Figure 25 shows the impact of the initial speed of an emergency stop on the average deceleration rate, distinguishing ABS and no ABS. The effect of the ABS is again substantial; the initial speed is less significant.

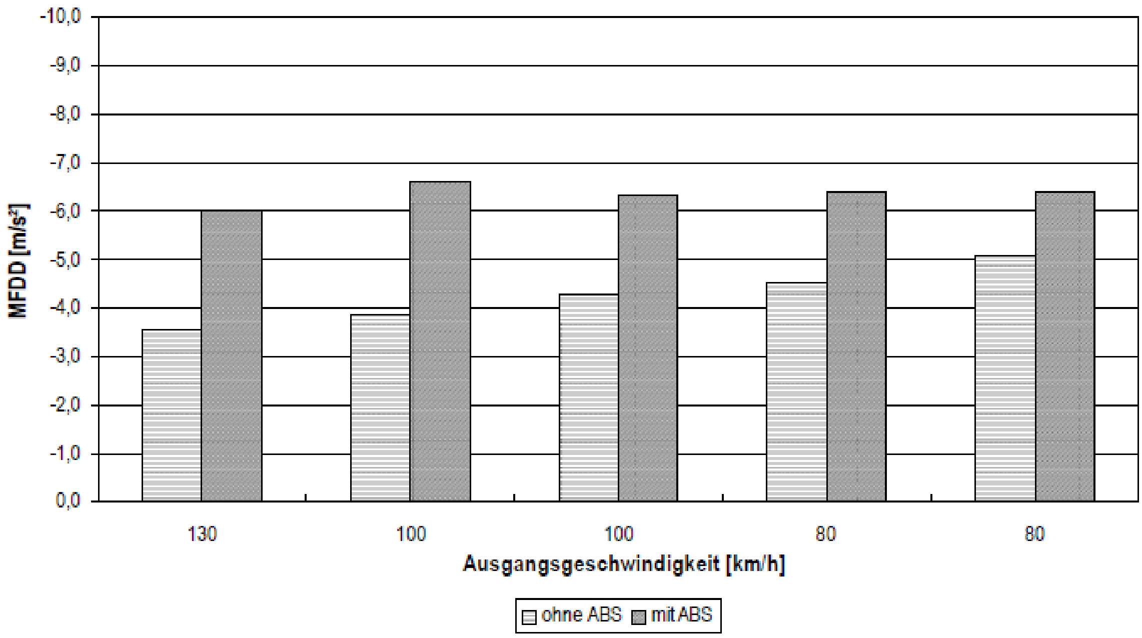

Figure 25: Deceleration rate (MFDD) as a function of the initial speed (test track BAB A1, field 1, longitudinal coefficient of friction of 0.327, Ford Mondeo with tire tread depth 4mm)

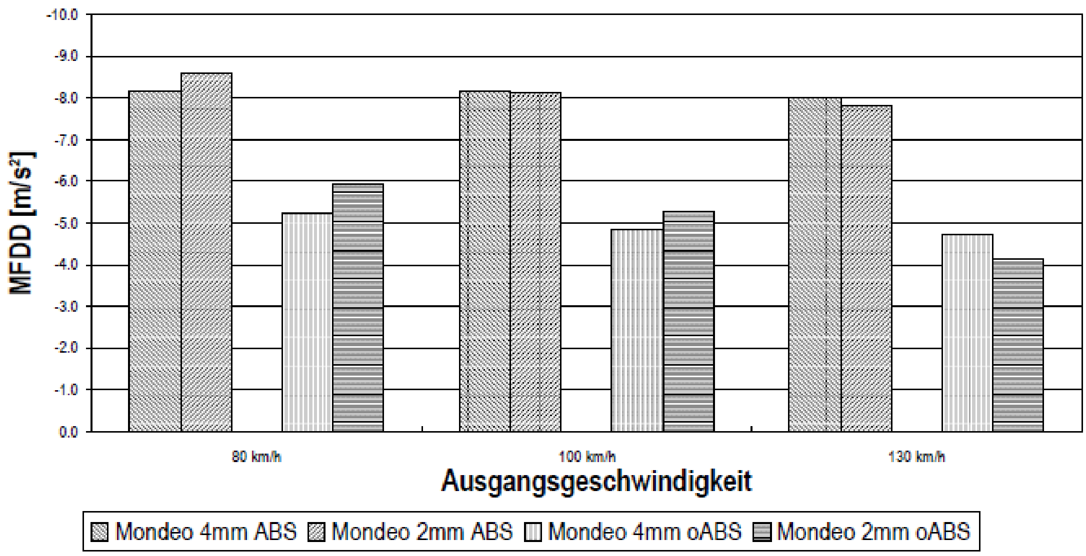

Figure 26: Deceleration rate (MFDD) as a function of the initial speed, tire tread depth and presence of ABS

Figure 26 shows the combined effect of the tyre tread depth and ABS on the average deceleration rate. With lower tyre tread depths, the deceleration rates decrease more with increasing speeds than the higher tread depths. Speed has a greater effect on deceleration rates of vehicles with lower tyre tread depths.

6.2.4 Braking distance, friction and behaviour. Findings, analyses and recommendations based on braking trials

The Danish Road Directorate conducted a study to gain insight into the braking behaviour among non-professional drivers (and professional drivers) and their braking distance at different speeds (Greibe, 2007). In order to assess the present method for calculating braking distances, a series of controlled braking trials were conducted with a total of 22 test drivers. All vehicles used were equipped with ABS.

Two types of braking manoeuvres were trialled:

- An emergency stop, where the vehicle is brought to a complete standstill as quickly as possible
- A normal braking action, the so-called 'comfort braking action' where the vehicle is brought comfortably to a standstill.

Table 8 shows the test parameters:

Test parameter (and number of levels)		
Speed	(3)	80, 110 and 130 km/h
Friction	(3)	road sections with friction in the range 0.4 – 0.8
Road surface	(2)	wet and dry roadway
Vehicle	(2)	small and medium-sized car (representative of Denmark)
Tyre type	(1)	Ordinary new summer tyres

Table 8: test parameters in the measurement programme

After examining several potential locations, three test tracks were selected. On each test track, the section in which the brake was to be applied was precisely defined and marked with cones during the braking trials. On test track 1, the same section was used for both dry and wet braking. On test track 2 and test tracks 3, two separate sections were used that were an immediate extension of each other for dry and wet braking, respectively.

The non-professional drivers test was only performed braking manoeuvres on one of the three test tracks. Thus, none of these drivers are represented more than once in the measurement programme. On test track 1 and 2, 2 and 4 non-professional test drivers, respectively were used, while on test track 3, 10 non-professional test drivers were used. A total of 6 professional test drivers were used (instructors of the Danish traffic police). Unfortunately it was not possible to include the same professional drivers on all three test tracks.

Each driver performed only one emergency stop for one combination of speed, braking type manoeuvre and road surface (wet or dry). The sequence of trials varied over the test drivers. Not all drivers performed emergency stops from 130 km/h; several drivers did not feel confident performing the manoeuvre at this speed.

Table 9 shows the total number of braking manoeuvres performed.

Braking manoeuvre		Non professionals test drivers dry	Non professionals test drivers wet	Prof. test drivers dry	Prof. test drivers wet
Emergency	80 km/h	29	23	12	12
	110 km/h	26	23	12	12
	130 km/h	16	8	12	12
	Total	71	54	36	36
Comfort	80 km/h	18	-	-	-
	110 km/h	8	-	-	-
	Total	26	-	-	-

Table 9: number of braking manoeuvres performed

The braking trials were conducted on both dry and wet road surfaces. The wet road was achieved with the aid of a water truck, which dispersed water onto the braking section immediately before each braking trial.

It was not possible to measure the exact water volume on the road surface for the braking trials. Based on the observed volume of water consumed, the number of trials performed and the dispersal area, the calculated volume dispersed by the truck was 1.3-1.6 litres/m^2. If the water could be assumed to remain in situ, this equated to a water membrane of 1.3-1.6 mm on the braking section.

Due to the road's cross slope, some of the water would naturally run off the road again before the trial was conducted. Typically it took a couple of minutes between the water truck dispersing the water and performing the braking trial was performed.

Table 10 and Table 11 shows the measured deceleration rates for professional and non-professional drivers.

		Dry Fiat	Dry Opel	Dry Av.	Wet Fiat	Wet Opel	Wet Av.
1 – Holbæk	80	8.5	8.1	8.3	7.1	7.3	7.2
	110	8.5	8.4	8.4	-	7.5	7.5
	130	8.6	8.5	8.5	7.1	7.7	7.4
2 – Odense	80	8.5	7.9	8.2	7.4	7.3	7.4
	110	8.6	8.1	8.3	7.7	7.7	7.7
	130	8.7	8.5	8.6	7.8	7.8	7.8
3 - Værløse	80	8.1	8.1	8.1	8.3	8.3	8.3
	110	9.0	8.4	8.7	8.5	8.8	8.7
	130	8.9	8.3	8.6	8.7	8.4	8.5
Average		8.6	8.3	8.4	7.8	7.9	7.9

Table 10: average deceleration rates (m/s^2), professional drivers

		Dry		Dry Av.	Wet		Wet Av.
		Fiat	Opel		Fiat	Opel	
1 – Holbæk	80	8.0	7.8	7.9	7.0	-	7.0
	110	7.8	8.5	8.3	7.0	-	7.0
	130	-	8.7	8.7	7.0	-	7.0
2 – Odense	80	8.0	7.9	8.0	7.0	-	7.0
	110	8.5	-	8.5	7.5	-	7.5
	130	8.2	8.5	8.3	7.6	-	7.6
3 - Værløse	80	6.6	6.6	6.6	6.9	6.5	6.7
	110	7.3	6.9	7.1	7.4	6.7	7.0
	130	8.4	6.9	7.4	8.3	8.4	8.3
Total		7.5	7.2	7.4	7.2	6.8	7.0

Table 11: average deceleration rates (m/s^2), non-professional drivers

The average deceleration rates for non-professional were quite consistent on wet surfaces; the deceleration varies from 7-8 m/s^2. On the dry surface the average deceleration rate was approximately 0.5 m/s^2 higher and the spread is somewhat larger.

Professional drivers are capable of decelerating about 1 m/s^2 harder.

Also the comfort braking manoeuvres were measured: the non-professional test drivers were required to bring the vehicle to a comfortable stop. The trials were conducted on dry road at 80 km/h and in few instances at 110 km/h.

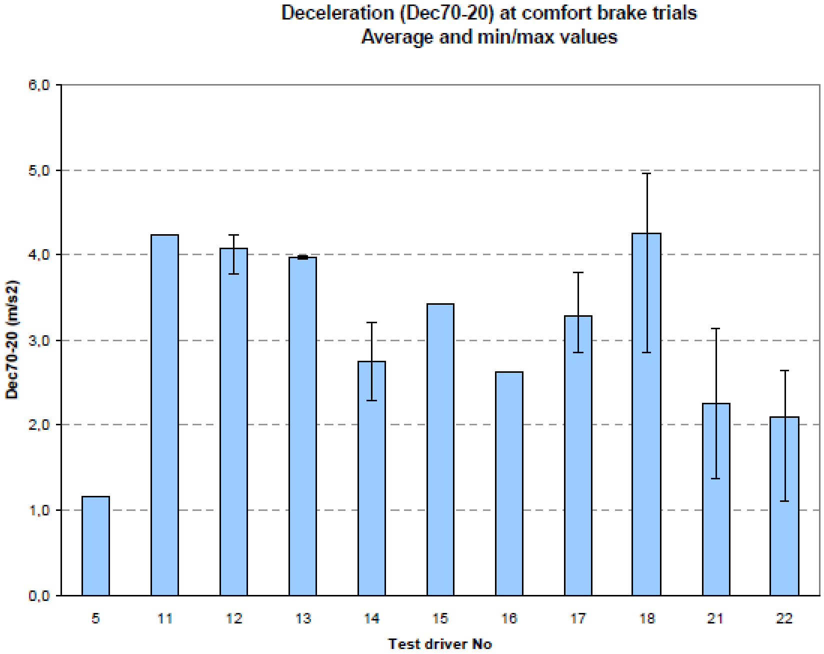

Figure 27: Recorded values for comfortable deceleration rates (from 70-20 km/h)

Overall, the average Dec_{70-20} was recorded at 3.2 m/s^2. The spread in the deceleration rate was large. Figure 28 shows the distribution of deceleration rates.

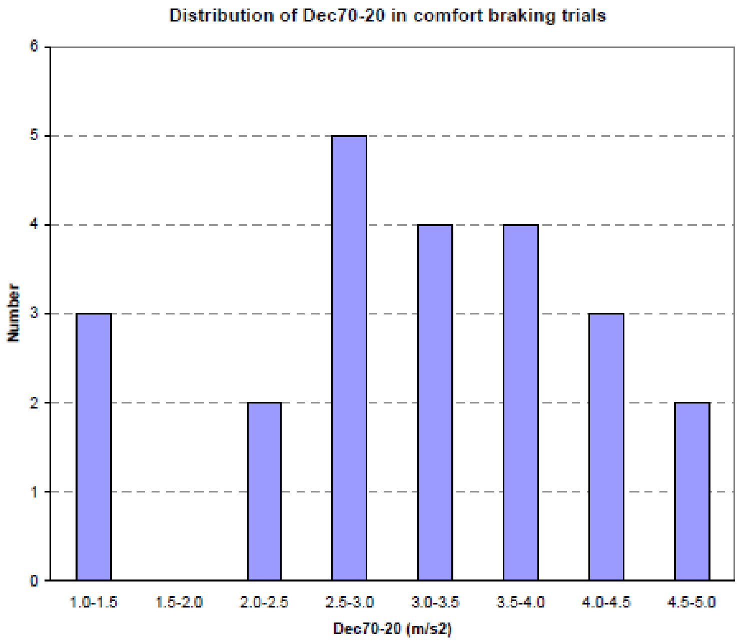

Figure 28: Distribution of comfortable deceleration rates (from 70-20 km/h)

Table 12, Table 13, Table 14 and Table 15 show the influence of other parameters on braking distance:

- The tyre type influences the braking distances for a margin of approximately -10% to +15%;
- Winter tyres increase the braking distance on average 10-15% (compared to summer tyres);
- With higher tread depths, there is little influence on the braking distances. Low tread depths (under 2 mm) result in a significant increase in the braking distance.

	Braking distance (m)			
Tyre size	Av.	Min	Max	[min., max.] in %
175/70 R13	45 m	42 m	51 m	[-7% ,+14%]
195/65 R15	49 m	41 m	49 m	[-9%, +9%]

Table 12: Recorded braking distances for different tyre types

Road surface	Average	Min/max in %
Dry	approx. 10%	[0-20%]
Wet	approx. 15%	[5-35%]

Table 13: Increased braking distance with winter tyres compared with summer tyres

Tread depth	Braking distance
8 mm	28.8 m
4 mm	30.3 m
1.6 mm	37.8 m

Table 14: Braking distance for different tread depths

Parameter	Effect in relation to:	[min/max]	Av.	Av. in relation to measure-ment programme
Make of tyre	Average tyre	-10% - +10%	+0%	+0%
Winter tyre	Summer tyre	+5% - +35%	+15%	+15%
Tread depth 1.6 mm	8 mm	+0% - +50%	+25%	+25%
Make of car	Average car	-10% - +10%	+0%	+0%
Loaded	Non-loaded	-10% - +15%	+4%	+4%

Table 15: Effects of parameters on braking distance on wet road

On the basis of the findings from the measurement programme, a new set of recommended braking distances for use in Denmark was drafted.

New recommended values for braking distances were provided on the basis of the following considerations:

- The braking distance should reflect worst case scenario road conditions, which equate to wet road with low friction. Low friction was set at 0.4, which is consistent with friction requirements for roads in operation. Wet road is assumed to be in the same state as that during the measurement programme, i.e. clean, but with a water membrane of approx. 1mm.
- The braking distance should reflect the braking capabilities of a vehicle whose braking capabilities are at the weak end of the scale among ordinary cars, but which otherwise conform to legal brake, tread pattern requirements, etc.
- The braking distance should reflect the braking behaviour found among the worst performing drivers (among non-professional) travelling on the roads.
- The braking distance assumes that the vehicle is fitted with ABS brakes.

Professional test drivers were able to achieve a deceleration rate of approximately 6.5 m/s^2 under these conditions. By far the majority of the non-professional test drivers produced braking distances 0-20% longer than the professionals. It is assumed that the weakest half of the non-professional drivers have a braking distance 30% longer than the professionals.

The braking distance for a legal vehicle in which the braking capability is poor due to worn and poor tyres, poor brakes, etc. is set (rounded figures) at 45% longer than the observed braking distances for the test cars used in the measurement programme.

The recommended braking distances correspond to an average deceleration of 3.7 m/s^2.

6.2.5 Driver Braking Performance in Stopping Sight Distance Situations

Introduction
Stopping sight distance (SSD) has featured in the design of roadways for more than 50 years (TranSafety, 1997). The American Association of State Highway Officials (AASHTO) first proposed a common model for predicting SSD. The model remains a simple chaining of constant deceleration after an allowance of lag time for the driver to detect a hazard and initiate the braking manoeuvre. While the model itself has remained relatively unchanged, the term "lag allowance" has been changed to "brake reaction time" (the estimate of the perception-reaction time (PRT) for braking to occur), and the initial time of 2 to 3 seconds has been changed to a constant 2.5 seconds.

Research suggests, however, that this time-tested model is ready for change, to a model "that has its roots not in theory or engineering judgement but in actual performance of real people in real vehicles on real roads." Like virtually all experimental researchers studying human behaviour, those researching driver behaviours are confronted by the problem of subject awareness--the idea that subjects in a research experiment behave differently when they know they are being observed and evaluated. To overcome that problem, researchers have tried pure "covert observation" (when drivers do not know they are being observed), but success in measuring driver performance has been limited at best.

New braking research prompts the question: "How do real drivers behave in emergency situations when SSD is a significant factor?"

A comprehensive braking performance study was carried out to evaluate driver behaviour in emergency situations (Fambro et al, 2007). A variety of braking scenarios were studied using nine test drivers; a later phase of the study involved volunteer drivers using either their own, or a test, vehicle.

Surprise Braking Manoeuvres
Drivers were given a few practice runs to acquaint themselves with the course and its conditions before experiencing "a completely unexpected barrier that suddenly sprang up from the pavement in their path." The "barrier" was suspended from an arm concealed in a two-inch (5-cm) wide trench in the pavement. Attached to the arm was a monofilament line. When pulled tight, the line unfolded a piece of cloth displaying four stop signs. Researchers activated the barrier device with a garage door opener. The hydraulic unit that operated the equipment was hidden behind traffic barrels at the side of the road.

The drivers' approach speed was 55 miles per hour (88.5 km/hr), with the barrier timed to be visible 210 feet (64 m) ahead of the vehicle assuming a 1-sec driver reaction time and pavement friction of 0.80. By allowing such a short time in which to respond, researchers hoped drivers would brake rather than try to evade the barrier. The barrier gave way without damage to the vehicle if a driver threatened to hit it. Ten of the drivers braked and hit the barrier, and two drivers showed no reaction and drove right through the barrier--one mistook it for a finish line; the other had no explanation.

Expected Braking Manoeuvres

All drivers experienced the unexpected braking scenario before researchers exposed them to expected braking scenarios. Twenty-six drivers used a test vehicle from Texas Transportation Institute (TTI), and twelve used their own vehicles. Males and females of various ages participated. For the expected braking-manoeuvre experiments, subjects drove at 55 mph. Researchers asked them to stop as quickly as possible once they saw the bright LED light come on--an event that might or might not occur. Both wet and dry pavement surfaces were used, as well as straight roadway and horizontal curves. Drivers knew only that braking was likely to occur on most trials.

On-Road Braking Manoeuvres

A section of rural two-lane roadway ("asphaltic concrete in moderate to poor condition") was used for the on-road portion of the testing. Researchers asked drivers to drive as they would normally on such a road. A pickup truck was parked perpendicular to the road in an entrance drive to a pasture; the pickup was loaded with cardboard drums. At first, drivers drove past the pickup. Later they were instructed to turn around and travel back the same way. Upon a signal from the test vehicle, one barrel rolled from the pickup onto the roadway. To lend credibility to the scenario, a researcher posing as a farmer was unloading the barrels when this "accident" occurred. The barrel was released (on the driver's right side) when the test vehicle was 75 feet from the pickup. The posted speed in this section of the roadway was 45 mph, which again allowed approximately a one-second response time for the driver to begin braking.

Braking performance

Under expected-stop conditions, research shows drivers generally exert an average steady braking force of -0.35 g. This amount of braking force seems comfortable for drivers. Computing constant braking force (deceleration) over the length of the stopping distance in these tests, researchers found that under surprise conditions drivers maintained an average of -0.63 g (standard deviation 0.08) in TTI vehicles and -0.55 g (standard deviation 0.07 g) in their own vehicles.

Many wet pavement surfaces will not provide the high levels of braking force cited above. AASHTO assumes a braking force (coefficient of friction) of 0.28g in its formula for computing stopping sight distance at 70 mph and a pavement friction of 0.40 for 20 mph. Table 2 compares steady braking performance for test subjects under Expected and Surprise conditions while driving TTI vehicles or their own vehicles.

Condition	**Car**	**No.**	**Mean**	**STD**	**25th***	**95th***	**99th***
Expected	TTI	38	-0.53	0.08	-0.61	-0.36	-0.29
Surprise	TTI	38	-0.63	0.08	-0.71	-0.38	-0.29
Expected	Own	12	-0.54	0.11	-0.69	-0.24	-0.13
Surprise	Own	10	-0.55	0.07	-0.65	-0.35	-0.27

***** Percent tolerance estimates conservative since distribution is truncated and positively skewed

Table 16: Braking characteristics (deceleration in g)

Analysis of a typical braking run revealed that drivers reached a maximum braking force on a wet pavement of almost -0.6 g within 5 seconds. The data showed that drivers of TTI cars averaged -0.91 g (with a standard deviation of 0.08 g) maximum deceleration, while those driving their own vehicles averaged a peak deceleration of -0.74 g (with a standard deviation of 0.09 g).

6.2.6 Possible deceleration rates in relation to skid resistance

Research by Von Loeben was carried out to create insight in the appropriate deceleration rate and the impact on road design parameters. This contribution to the 'Colloquium for experts in roads' (Karlsruhe, 2004), contains the results of emergency brake test trials on a test tracks under with several parameter variations (Von Loeben, 2004):

- Tyre type and tyre tread depth
- Vehicle class (3 classes)
- ABS (with and without)
- Speed (70, 100 and 130 km/h)
- Water layer (0.3, 0,7 and 1.0 mm)

Table 17 presents the test programme.

	Fahrzeug	Fahrzeug A (Kleinwagen)					Fahrzeug B (untere Mittel-klasse)			Fahrzeug C (Mittelklasse)		
	ABS	ja			nein		ja			ja		
Reifentyp / Profilhöhe	V[km/h]	70	100	130	70	100	70	100	130	70	100	130
P3	2 mm	X	X	X	X	X						
P3	5 mm	X	X	X								
P3	8 mm	X	X	X	X	X						
BB	7 mm	X	X	X								
P6	2 mm						X	X	X	X	X	X
P6	5 mm						X	X	X	X	X	X
P6	8 mm						X	X	X	X	X	X
P6H	5 mm									X	X	X
M+S	7 mm						X	X	X			
MXH	5 mm						X	X	X			
MXH	7 mm						X	X	X			
SP	7 mm									X	X	X
SPE	7 mm									X	X	X

Wasserfilmdicken:
0,3 mm
0,7 mm
1,0 mm

Table 17: test programme

Figure 29: test track

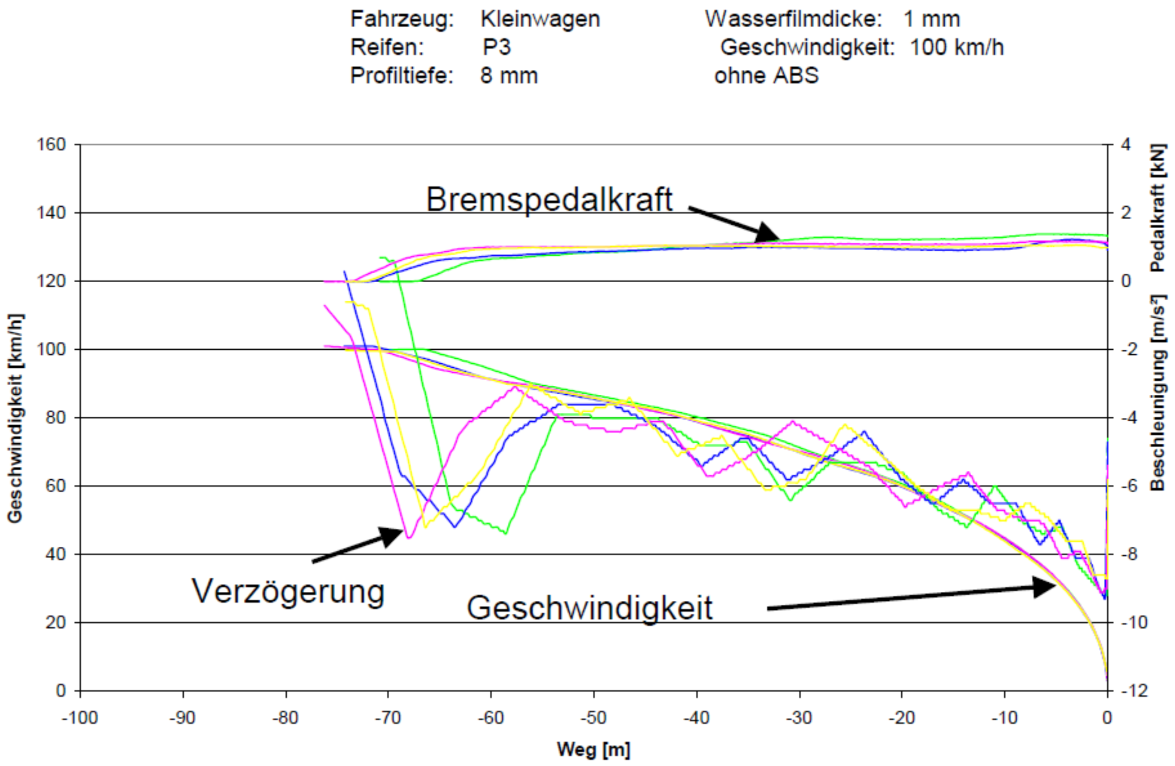

Figure 30: example of measured data during a braking manoeuvre

The average deceleration rates (MFDD) are summarized in Figure 31.

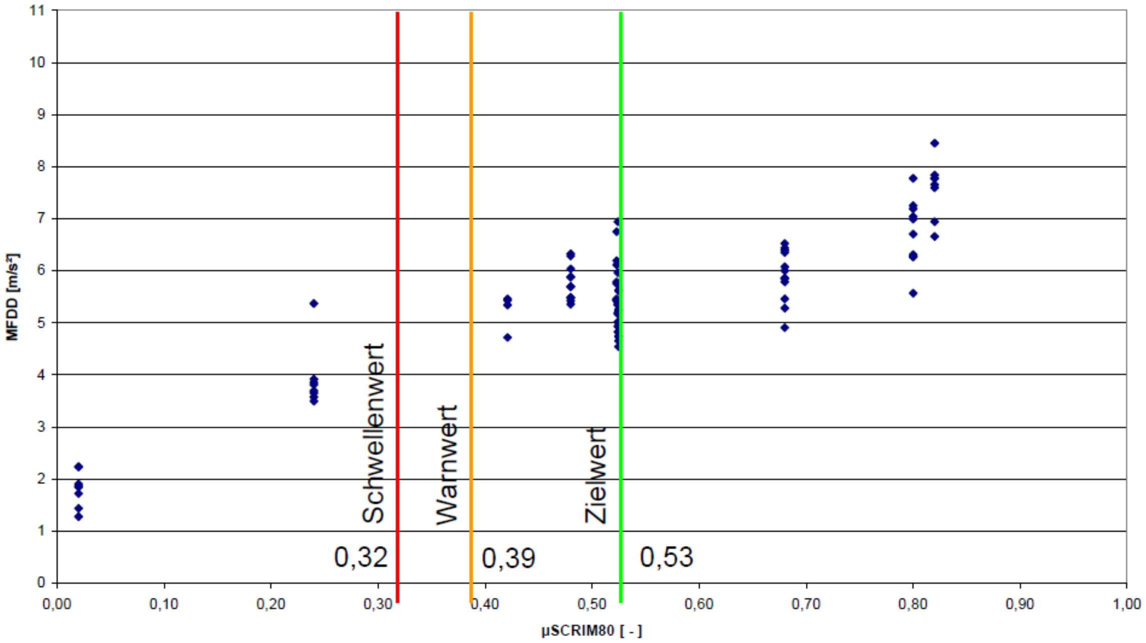

Figure 31: Average deceleration rates (MFDD) as a function of the longitudinal coefficient of friction (μ_{scrim})

This study also confirms that the braking performance is strongly affected by the available longitudinal coefficient of friction. Around the minimum legal coefficient of friction (0.3 on motorways in Germany) the average deceleration rate is 3.5-4 m/s^2.

Table 18 shows the average deceleration rates distinguished for vehicles with and without ABS (for two longitudinal coefficients of friction). When taking cars without ABS into account, the maximum average deceleration rate is in the range of 3-4 m/s^2 (given design speeds of motorways).

V_{85} [km/h]	Aus-gangs- Verzögerung a [m/s²] nach RAS-L (1995)	Mittlere Voll- Verzögerung a [m/s²] nach RAS-L (1995)	Mittlere Vollverzögerung* MFDD [m/s²] ($\mu_{SCRIM60}$ = 0,37)		Mittlere Vollverzögerung* MFDD [m/s²] ($\mu_{SCRIM80}$ = 0,32)	
			ohne ABS	mit ABS	ohne ABS	mit ABS
70	3,15	4,20	4,50	6,00	4,30	5,70
100	2,24	3,35	3,80	6,00	3,70	5,80
130	1,75	2,81	3,30**	5,90	3,20**	5,70

*Mittelwerte **extrapolierter Wert

Table 18: average deceleration rates, for cars with and without ABS for different speeds

6.2.7 Orientation sight distance – Definition and evaluation

Lippold and Krüger carried out test drives in real-life traffic and test runs in a driving simulator and introduced the concept of orientation sight distance (Lippold and Krüger, 2007).

Introduction

Visibility as a road design parameter cannot be definitively specified. To define visibility as a geometric variable, it is necessary to agree initial input parameters for a prescribed model. This includes technical parameters related to automotive engineering and road construction factors, as well as psychological parameters accounting for driver behaviour.

Automotive engineering advancements in recent years have led to continuous improvements in dynamic vehicle behaviour. Modern vehicles have a much higher braking performance than that underlying the currently applicable stopping sight distance according to RAS-L (German design guideline for motorways). Especially the widespread implementation of ABS on vehicles has raised calls for reviewing the dimensional model underlying the current stopping sight distance requirements and calculations.

However, it is not sufficient to assess visibility purely in terms of geometric and technical parameters. The extent to which these parameters account for the driver's perception and reaction is not clear. This situation gave rise to the concept of an orientation visibility which makes the driver the focus of the analysis and attempts to account for driver stress under prevailing visibility conditions.

In an interdisciplinary approach blending transport engineering and traffic psychology, driving behaviour is examined in relation to road design with visibility as a decisive factor [9].

Evaluation methods

The effects of different visibility conditions on driving behaviour were examined using a combination of test drives in real-life traffic and test runs on a driving simulator. Driver stress at steadily decreasing visibility was determined in several series of experiments by examining driving and viewing behaviour, ability to solve secondary problems during driving, as well as measuring reactions to sudden obstacles.

Investigations in real-life traffic took place on a circuit comprising single-carriageway, two lane trunk, main and municipal roads. The 75-km route contained sections with different curvatures, radii and side spaces. To observe changes in driving behaviour as a function of available visibility, a total of 50 crests and bends were selected each restricting the view of the oncoming road and thereby restricting the driver's visibility in increasing measure.

In the first series of experiments, the route was travelled by 20 test drivers. They comprised a homogeneous group of experienced drivers of both genders, each in possession of a driver's license for at least six years, having covered a mileage of at least 60.000 km (in total) and owning a passenger car which is used on a frequent basis.

A second series of experiments was made on the same route after a time interval of about 8 weeks. This experiment series was intended to determine stress on drivers by requesting them to perform a secondary task while driving.

After that, both experiment series were repeated in the driving simulator. Similar to the tests in real vehicles, a screen was mounted in the passenger compartment for the secondary task.

Sixteen people travelled the route in the simulator and under the same instructions as for the real route. To resemble real-life traffic, oncoming vehicles were integrated into the simulated environment at random.

A further experiment series in the simulated environment was intended to measure drivers' response to sudden obstacles. Timely braking before such obstacles was expected to be ensured by the stopping sight distance. However, the underlying model corresponds to hazard braking whereas the orientation visibility is meant to enable the driver to manage such situations without abrupt responses.

The simulator route included standard crests behind which broken down vehicles were parked, or sharp right-hand bends with a radius of 80m. Different crest radii were used to vary the distance at which obstacles became visible to the driver. The route contained a total of 10 crests and subsequent obstacles appearing at visibilities of 70 to 220m. 13 test drivers were instructed to travel the route at 100 km/h.

Results

The results of the real-life tests show that sight distance influences driver behaviour. On straight stretches of road at a freely selectable speed and with clear surroundings, visibilities of less than 200m lead to changes in driver's viewing behaviour and raises driver's stress, causing the driver to concentrate more on the road's vanishing point. At the same time, drivers tend to slow down, either by releasing the accelerator pedal or braking lightly. Visibilities of less than 125m lead to an increase in this behaviour. Drivers concentrate almost exclusively on the road in such situations, most of them tending to apply the brakes. The available visibility is evidently considered critical here.

The analysis of the responses on sudden obstacles gives insight into the braking behaviour in emergency situations. Figure 32 shows the (average) brake pedal force as a function of the available sight distance. It is clear that drivers tend to brake harder with decreasing sight distance.

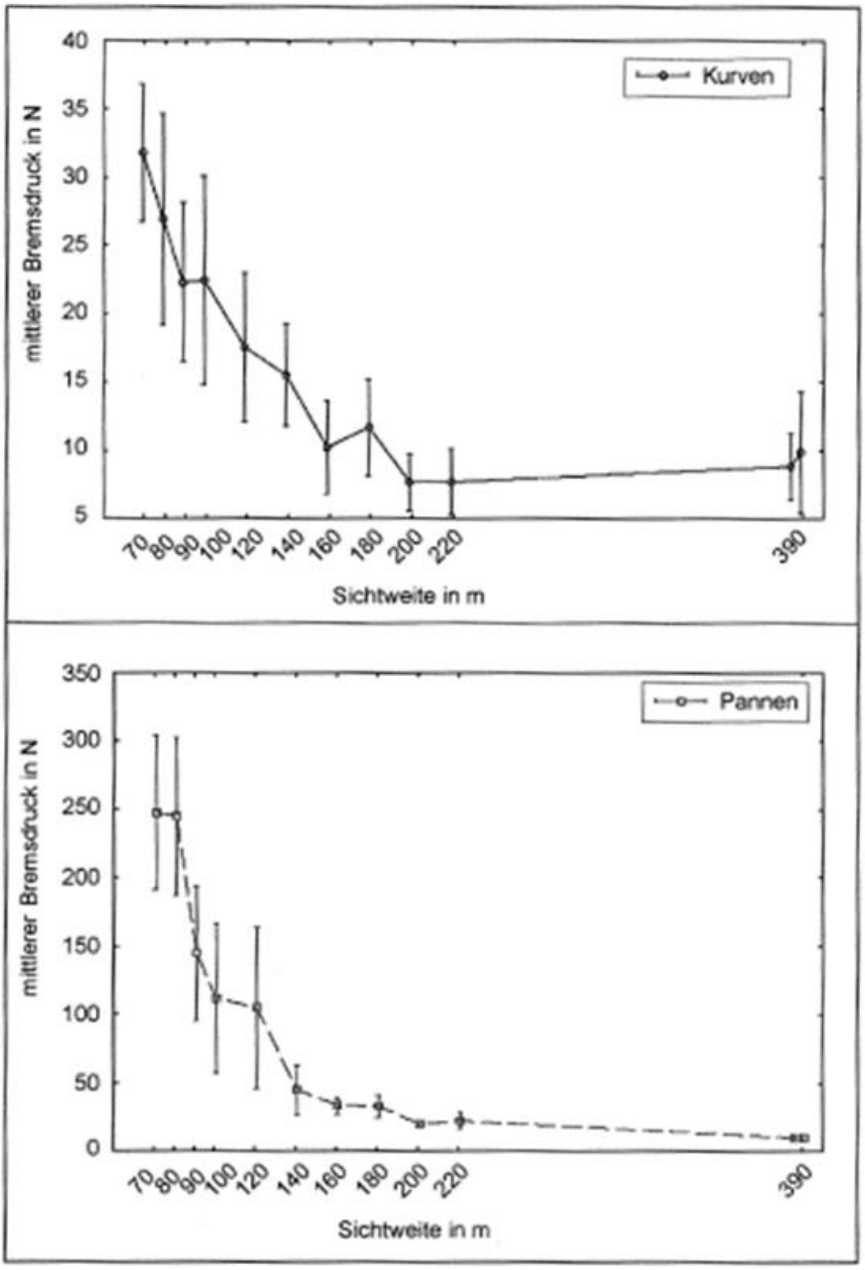

Figure 32: brake pedal pressure as a function of the available sight distance in emergency stop events (top, sharp horizontal curve following crest, down, broken down vehicle parked immediately over crest)

Also the timing of the braking was investigated. This analysis made it clear that drivers tend to postpone their braking manoeuvre until a certain distance to the obstacle at larger sight distances.

Furthermore the deceleration rates during the emergency stops were recorded. Figure 33 shows the decelerations as a function of the available sight distance. The maximum deceleration rates appear for short time periods. At shorter sight distances (smaller than 200m) drivers tend to brake harder.

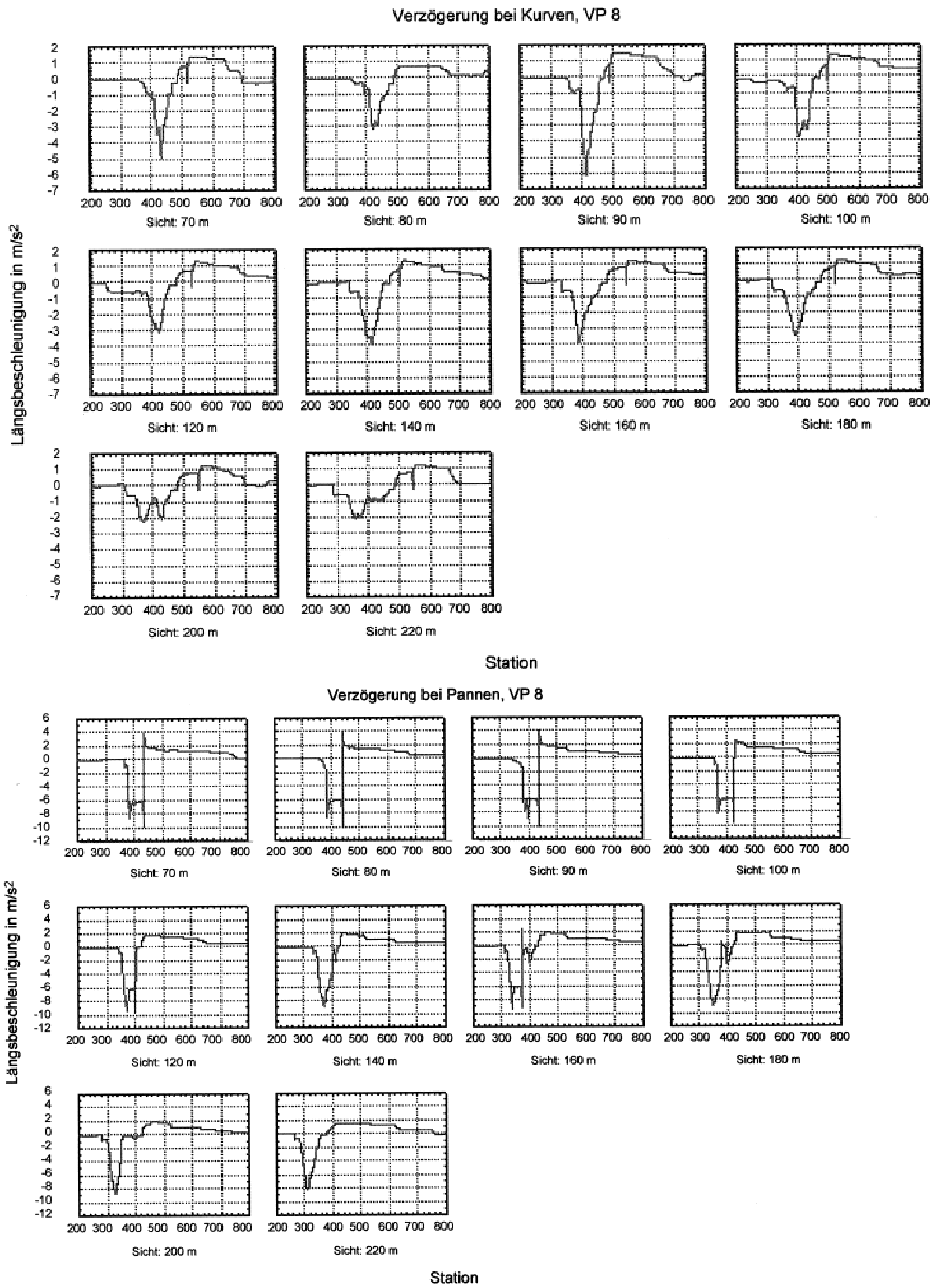

Figure 33: Decelerations rates in emergency stops as a function of the available sight distance (top, sharp horizontal curve following crest, down, broken down vehicle parked immediately over crest)

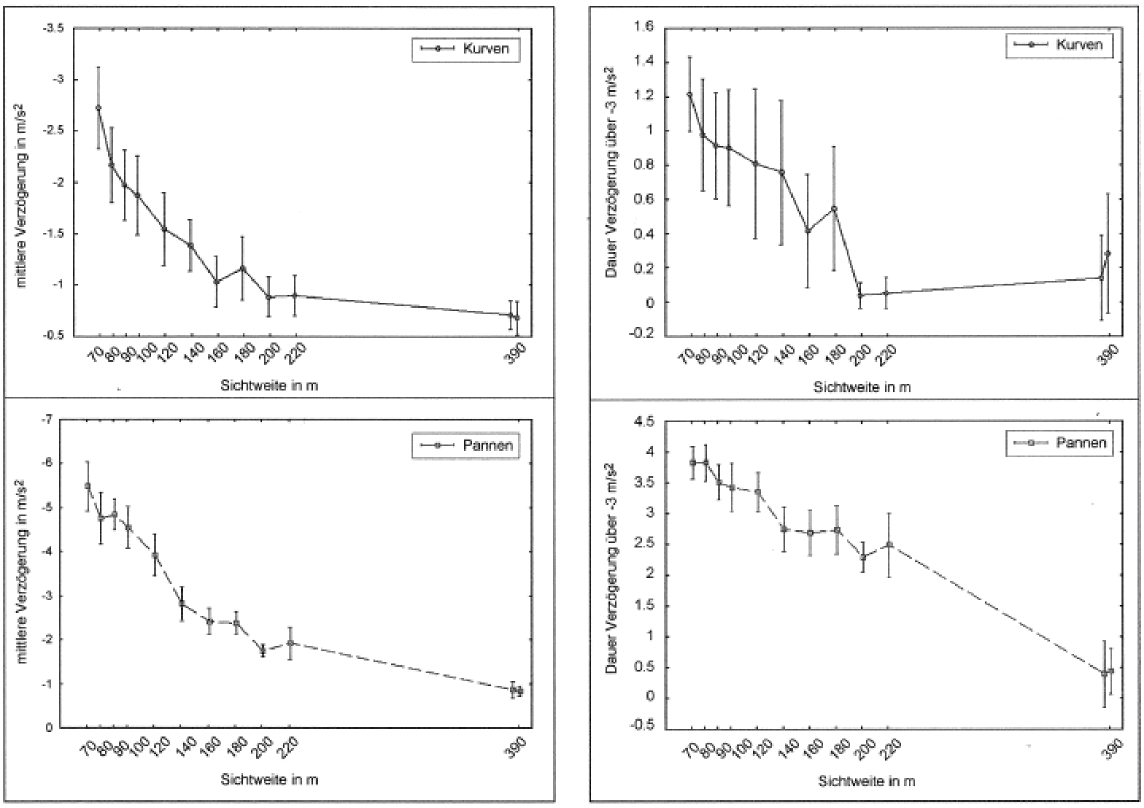

Figure 34: Average deceleration rates (left) and duration of decelerations larger than 3 m/s^2 (right). (top, sharp horizontal curve following crest, down, broken down vehicle parked immediately over crest)

Figure 34 shows the average deceleration rates and duration of deceleration larger than 3 m/s^2. The available sight distance clearly influences the deceleration rates. With a broken down vehicle, the drivers use higher deceleration rates, up to 5.5 m/s^2.

Conclusions

On roads outside municipal limits, a visibility of at least 200m is needed to provide drivers with sufficient response and decision-making time. Lower visibility distances increase driver stress and uncertainty. Based on the investigation's results the following orientation visibility distances are recommended at the following speeds:

- 100-120 km/h: 220-250m
- 80-100 km/h: 180-220m

These values are conservative, accounting for intra- and inter-individual differences among all the drivers in the pool.

6.2.8 Summary literature review results

Table 19 contains the deceleration rates found in the literature review; these are deceleration rates that represent the recommended values for use in the guidelines. In the third column background information is given on the principles of the studies.

Nr. study	*Authors*	*Recommended Deceleration rate*	*Background*
1	Layton and Dixon	3.4 m/s^2	• Literature review. • Value refers to the AASHTO Green Book • Comfortable deceleration rate
2	Kassaagi, Brissart and Popieul	No conclusion on deceleration rates	• Trials on open roads and simulator study
3	Van der Sluis	3.5 m/s^2	• Deceleration rates measured on test tracks (closed sections of motorways) • Value refers to a car on wet surface, no ABS, low friction coefficient. • Average deceleration rate in emergency stops
4	Greibe	3.7 m/s^2	• Decelerations rates measured on test tracks • Value is recommended for the Danish guideline • Value is based on worst case scenario: wet road (1mm water layer), low friction coefficient, low braking capabilities, ABS, worst performing driver
5	Fambro et al	3.5 m/s^2	• Trials on open road, simulating emergency situations (expected and surprise) • Value refers to a comfortable (average) deceleration rate (approx. 95 percentile)
6	Von Loeben	3.5-4 m/s^2	• Decelerations rates measured on test tracks • Range of deceleration rates refers to a car without ABS on a wet road surface and a low friction coefficient (0.3-0.4)
7	Lippold and Krüger	3.3 m/s^2	• Decelerations measured on open road and in driving simulator • Conclusions on minimum (orientation) sight distance, not on maximum deceleration rates • Value refers to the calculated average deceleration rate from a braking distance of 250m (120 km/h, BRT 2.5s)

Table 19: summary deceleration rates from literature review

7 Conclusions and recommendations

The driving experiment has attempted to evaluate driver behaviour in emergency braking situations in real-traffic conditions. Despite the 400 hours of collected driving data, real emergency manoeuvres (i.e. hard braking to avoid hitting an obstacle) according to the stopping sight definition were not recorded: in most cases a vehicle in front determined the braking behaviour of the participant.

Nevertheless, the results of the experiment have provided data on the deceleration rates and behaviour of events in which drivers had to slow down significantly (in most cases because of congestion).

Deceleration distributions of the 37 participants of the experiment show that deceleration rates larger than 4 m/s^2 seldom occur. In situations which require immediate response and a significant decrease of speed (at least 40 km/h), a typical maximum deceleration rate of 3-4 m/s^2 was found. Only in situations with short times-to-collisions were short peaks of higher deceleration rates up to 6 m/s^2 and higher noted. A value of 3-4 m/s^2 can be interpreted as a comfortable deceleration rate.

The distribution of deceleration rates of drivers participating from different countries is reasonably stable; the differences in the distributions per country are small. One has to bear in mind that the number of participants from Germany and Belgium are very small and conclusions cannot really be drawn from the results.

The results of the driving experiment are in line with the findings of the literature review. Literature on braking trials on test tracks (maximum braking performance) and other studies on driving behaviour in emergency brake situations, confirm that a deceleration rate of 3-4 m/s^2 is a reasonable value for average deceleration rates from a traffic safety perspective:

- Cars without ABS, which are still present on EU member states motorways, are not capable of decelerating faster in worst case situations (wet road surface, low tyre tread depth, etc.)
- Driver work load and stress increases significantly with limited sight distances associated with higher deceleration rates.

The literature review underlines the risk of increasing the deceleration rate in the stopping sight distance definitions, because of the increased braking capabilities of modern cars; this will influence traffic safety in a negative way.

Deceleration rates between 3 and 4 m/s^2, which are incorporated in all the studied design guidelines of EU Member States, still seem to be appropriate values.

8 Acknowledgement

The research presented in this deliverable was carried out as part of the CEDR Transnational Road Research Programme Call 2013. The funding for the research was provided by the national road administrations of The Netherlands, Germany, UK and Ireland.

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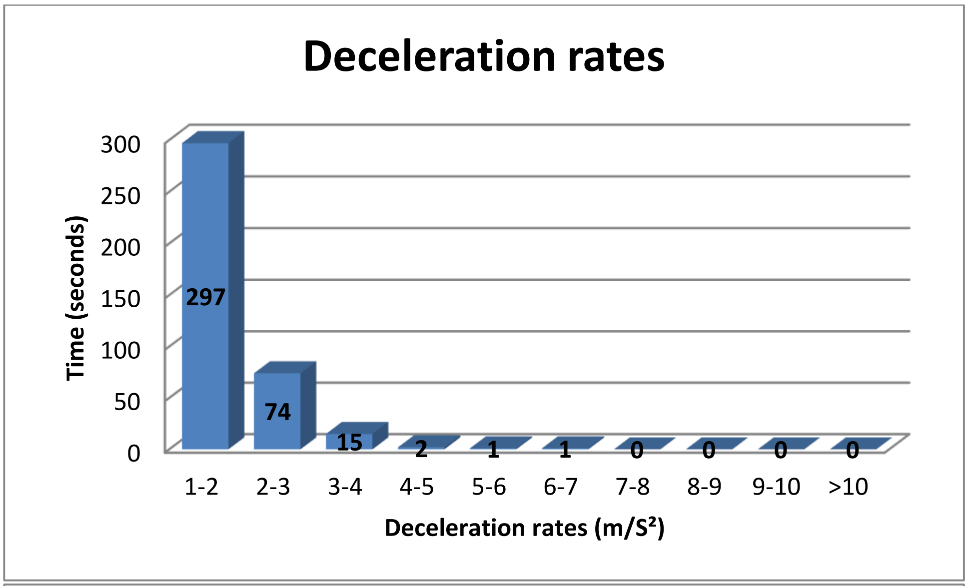
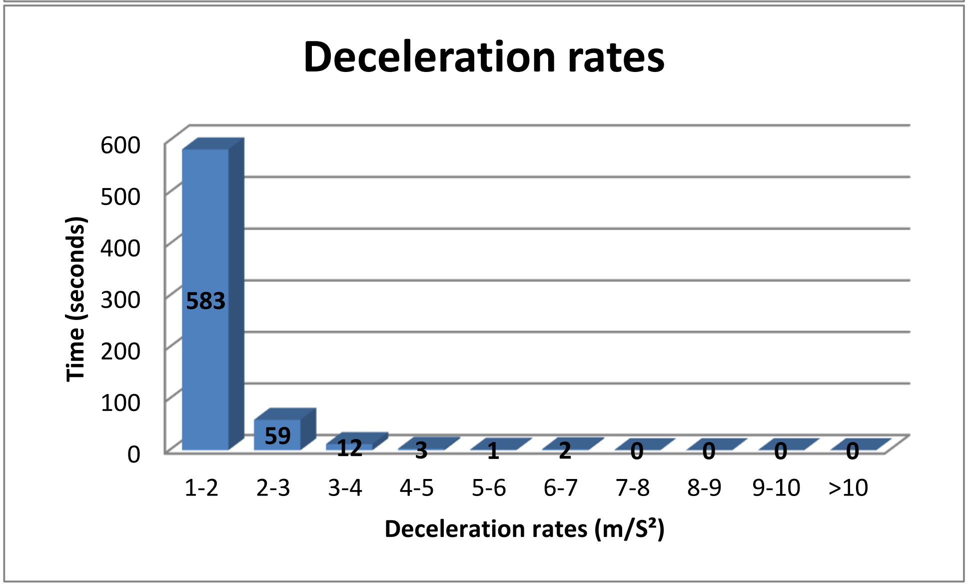
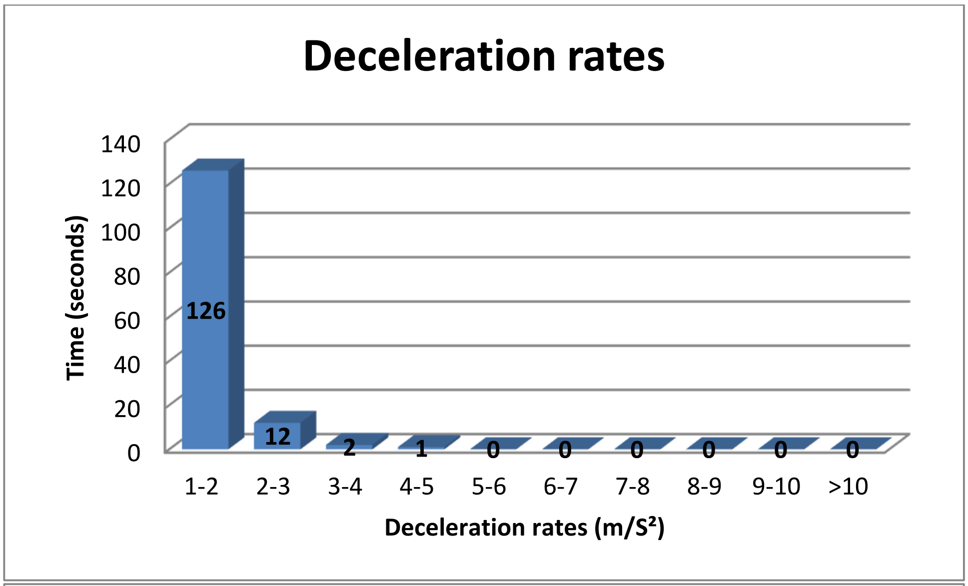
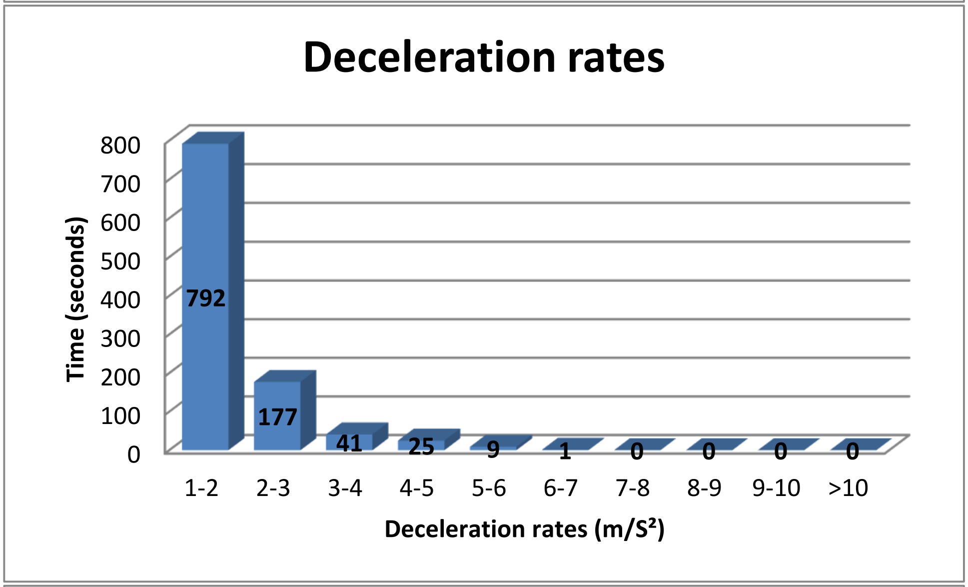
Appendix A: Distribution of individual deceleration rates

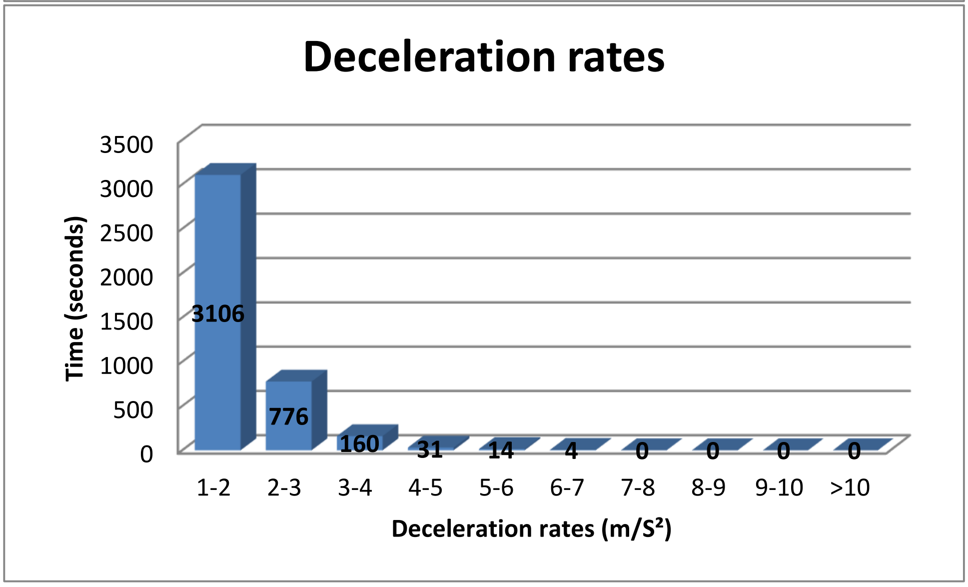
A1: The Netherlands

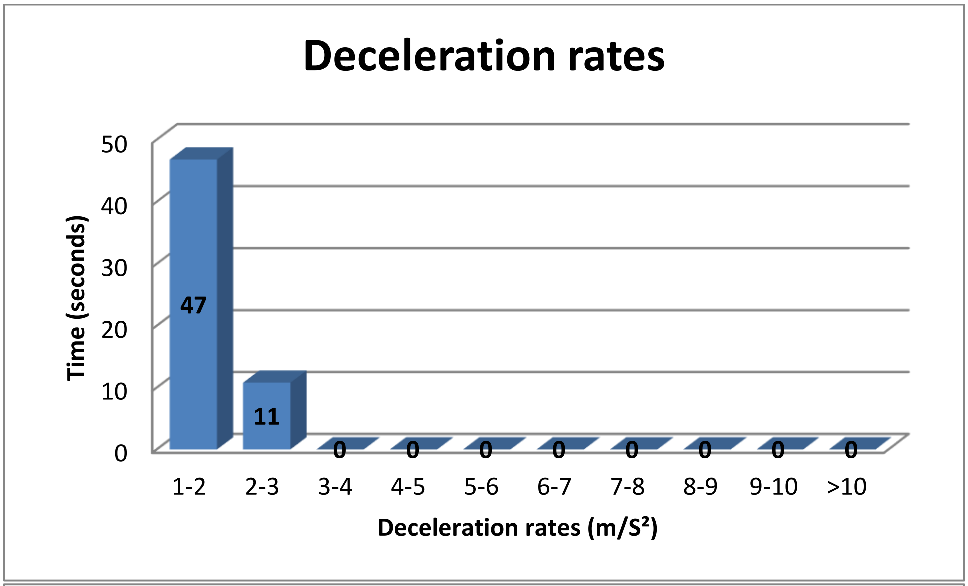


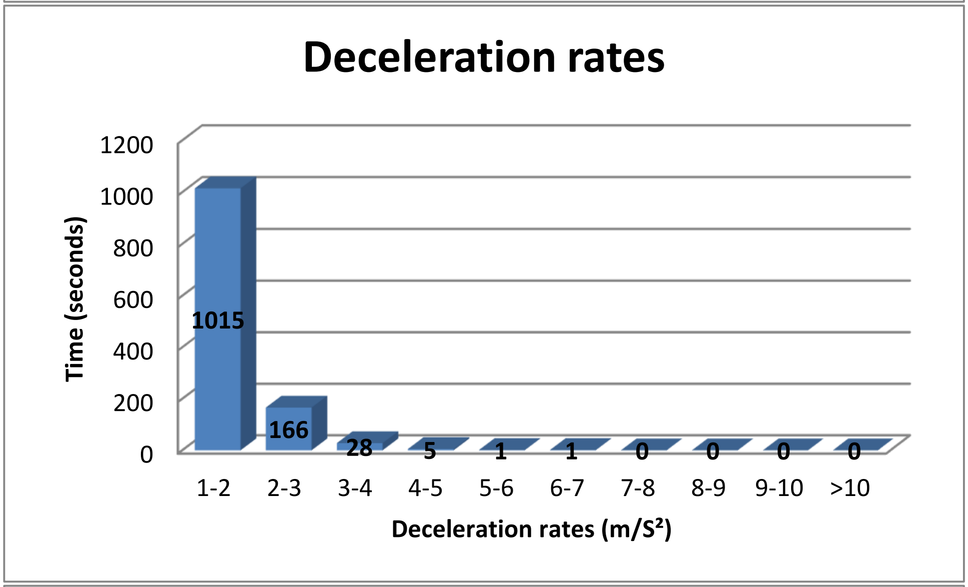


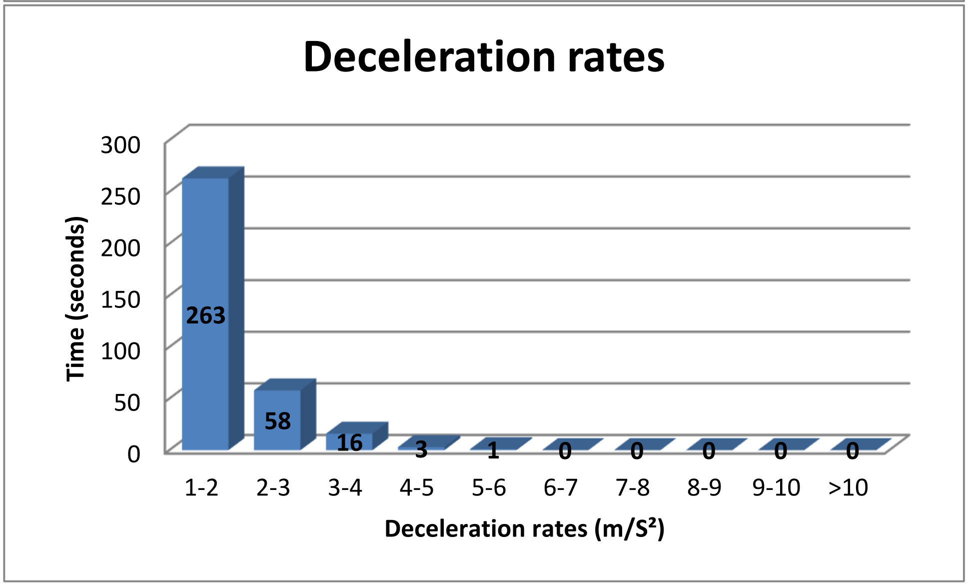

Deceleration rates
Time (seconds)
140
120
100
80
60
40
20
0
126
12
2
1
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

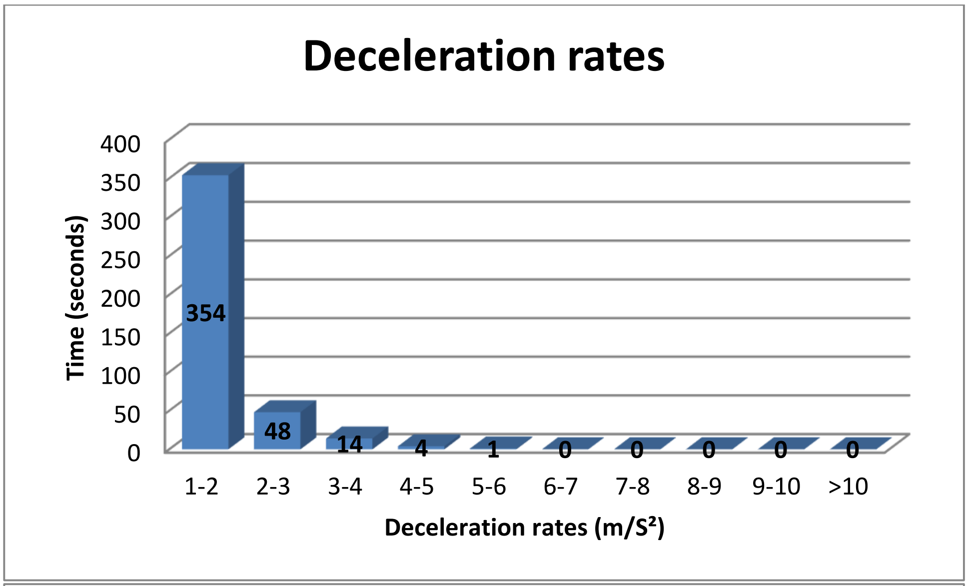

Deceleration rates
Time (seconds)
800
700
600
500
400
300
200
100
0
792
177
41
25
9
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

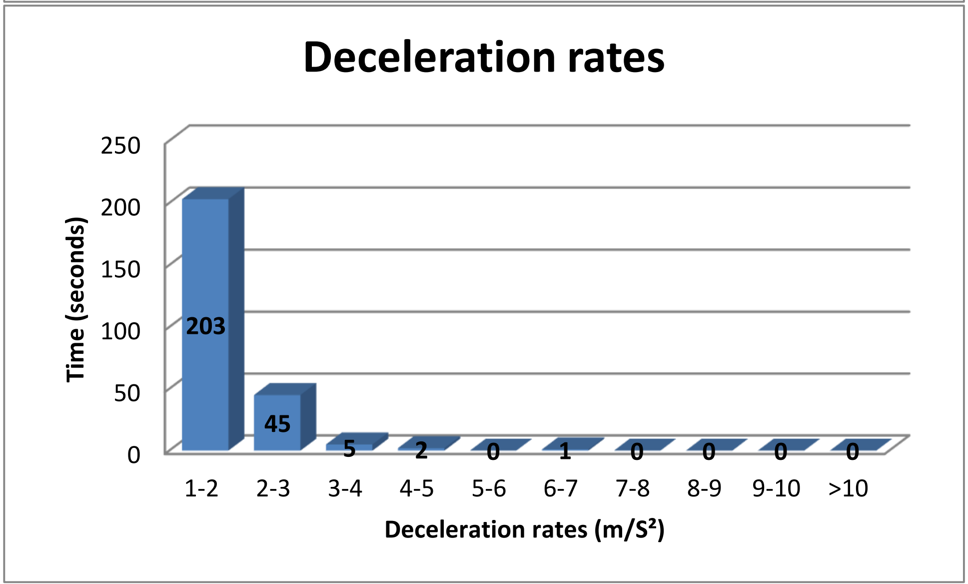

Deceleration rates
Time (seconds)
3500
3000
2500
2000
1500
1000
500
0
3106
776
160
31
14
4
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

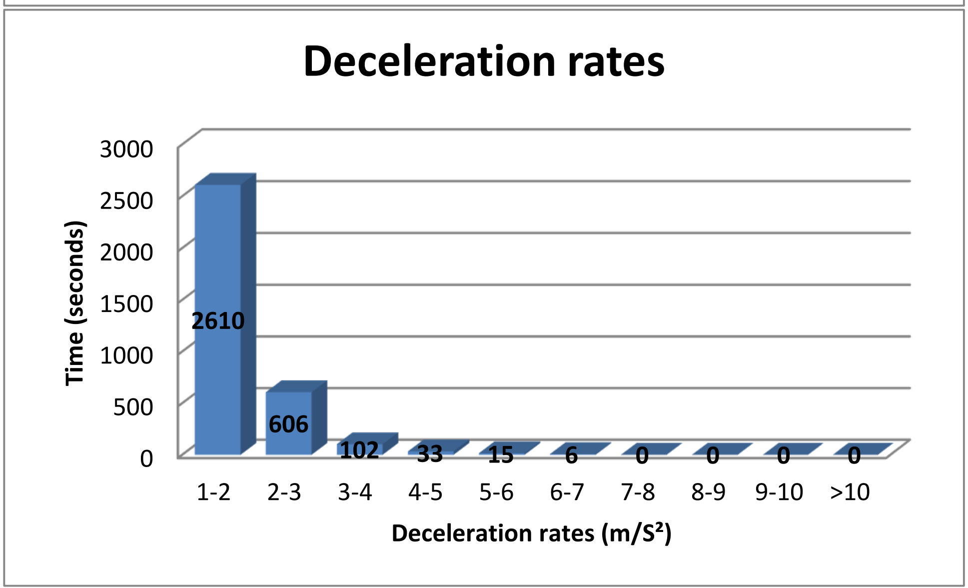

Deceleration rates
Time (seconds)
50
40
30
20
10
0
47
11
0
0
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

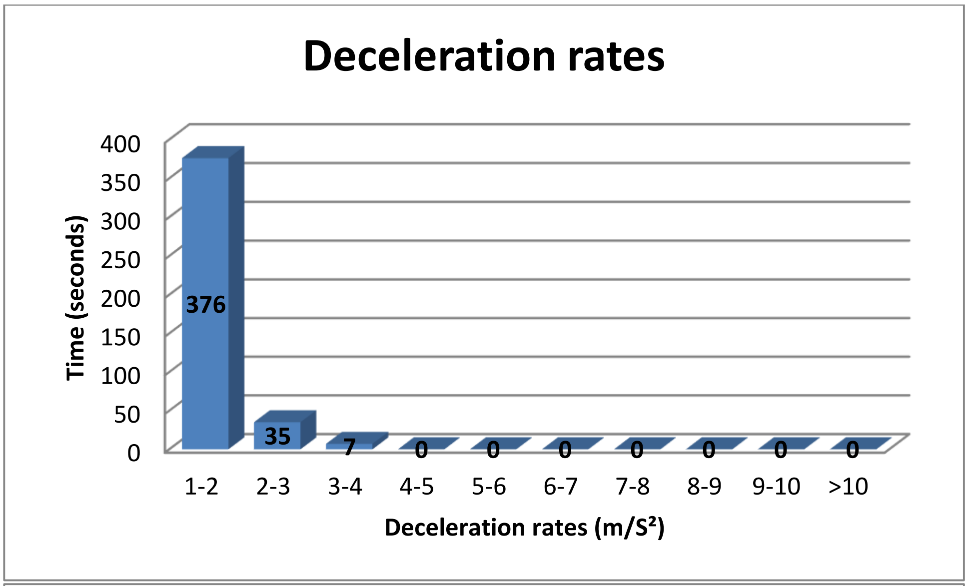

Deceleration rates
Time (seconds)
1200
1000
800
600
400
200
0
1015
166
28
5
1
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

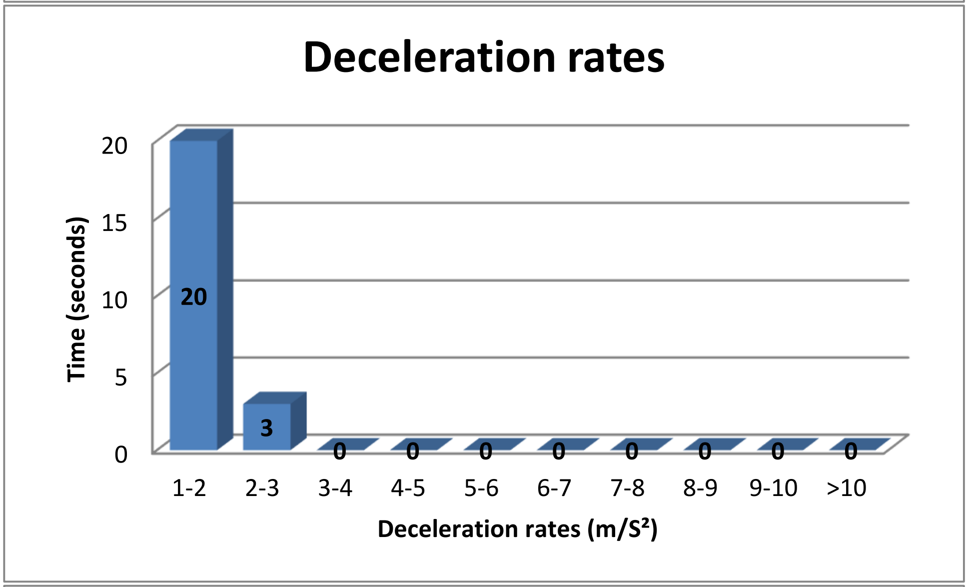

Deceleration rates
Time (seconds)
300
250
200
150
100
50
0
263
58
16
3
1
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

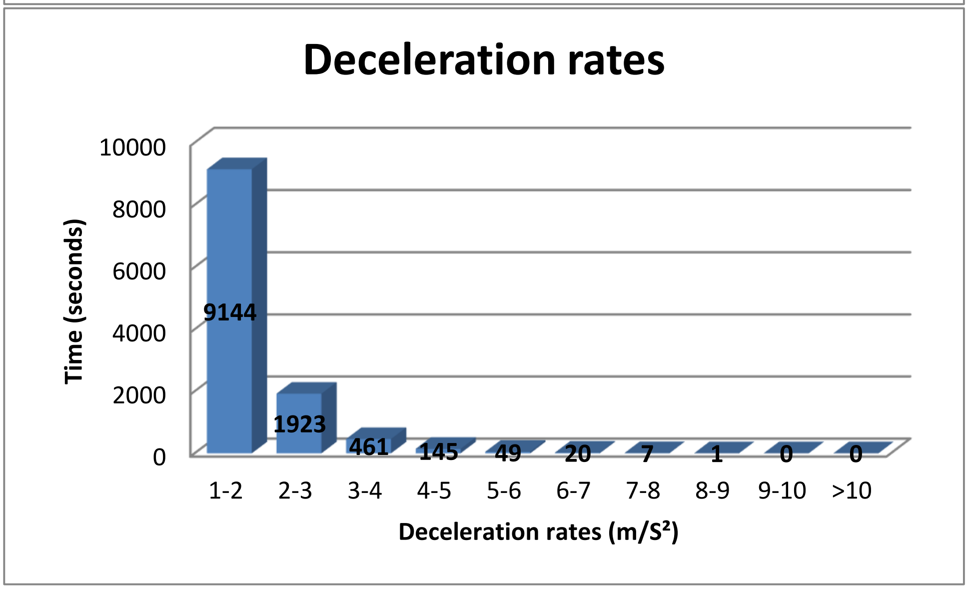

Deceleration rates
Time (seconds)
400
350
300
250
200
150
100
50
0
354
48
14
4
1
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

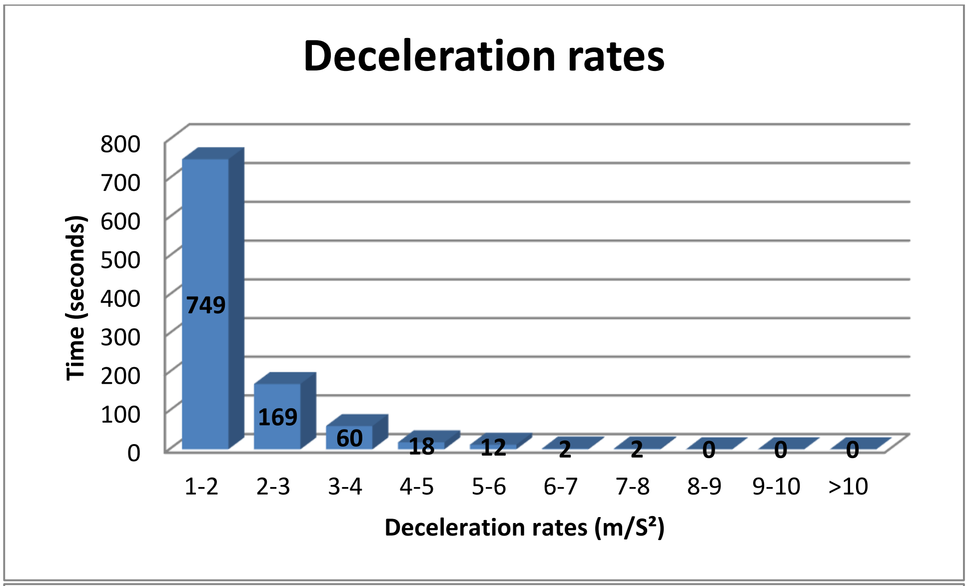

Deceleration rates
Time (seconds)
250
200
150
100
50
0
203
45
5
2
0
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

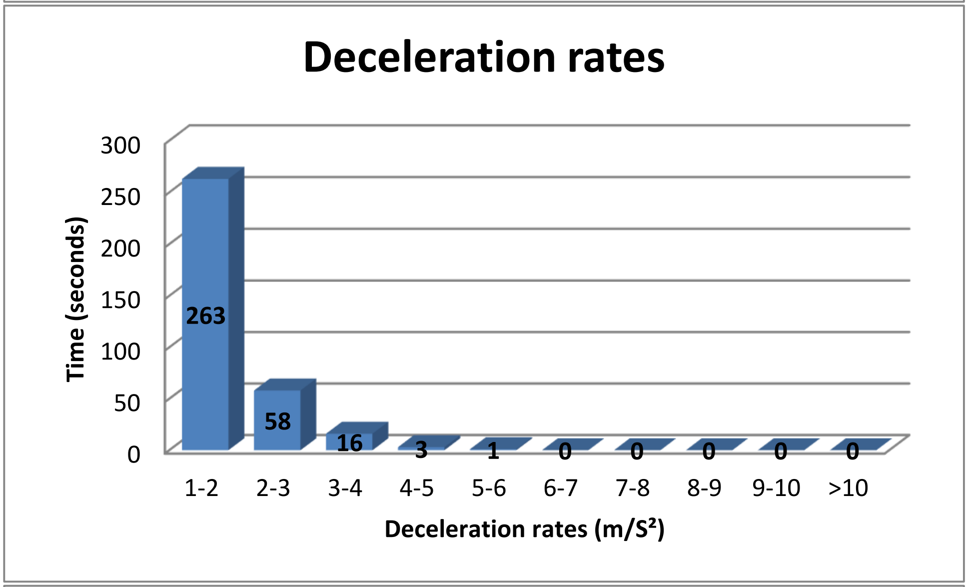

Deceleration rates
Time (seconds)
3000
2500
2000
1500
1000
500
0
2610
606
102
33
15
6
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

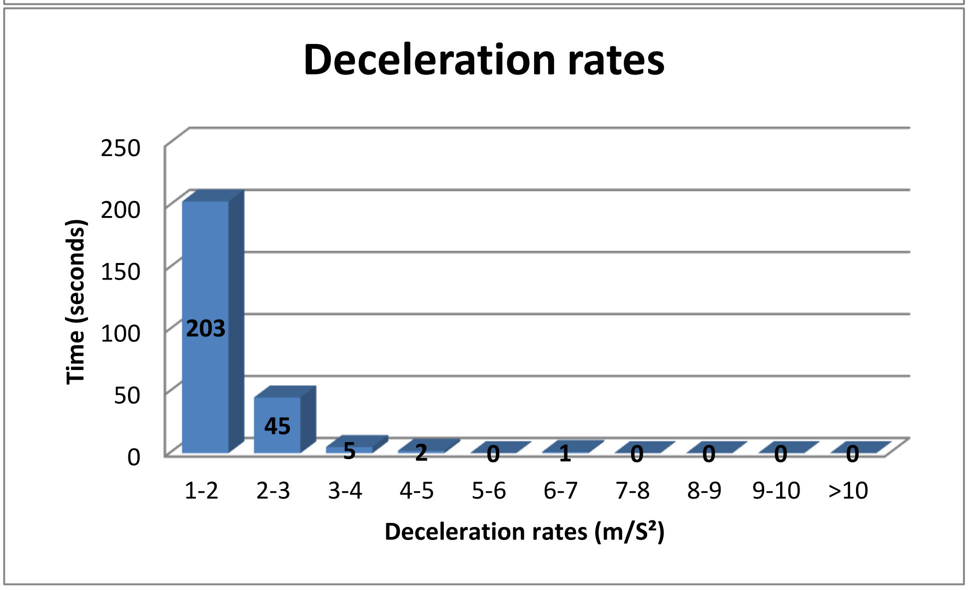

Deceleration rates
Time (seconds)
400
350
300
250
200
150
100
50
0
376
35
7
0
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

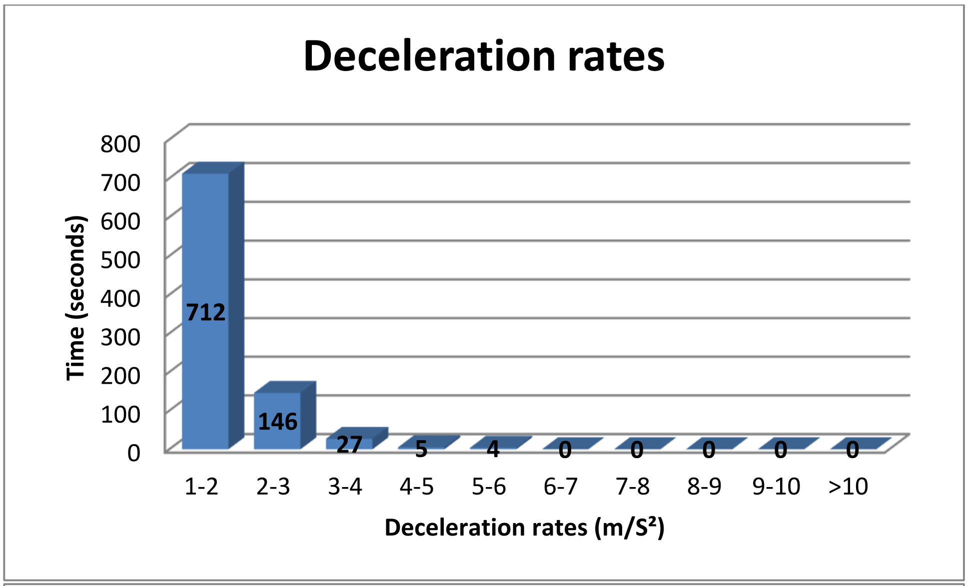

Deceleration rates
Time (seconds)
20
15
10
5
0
20
3
0
0
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

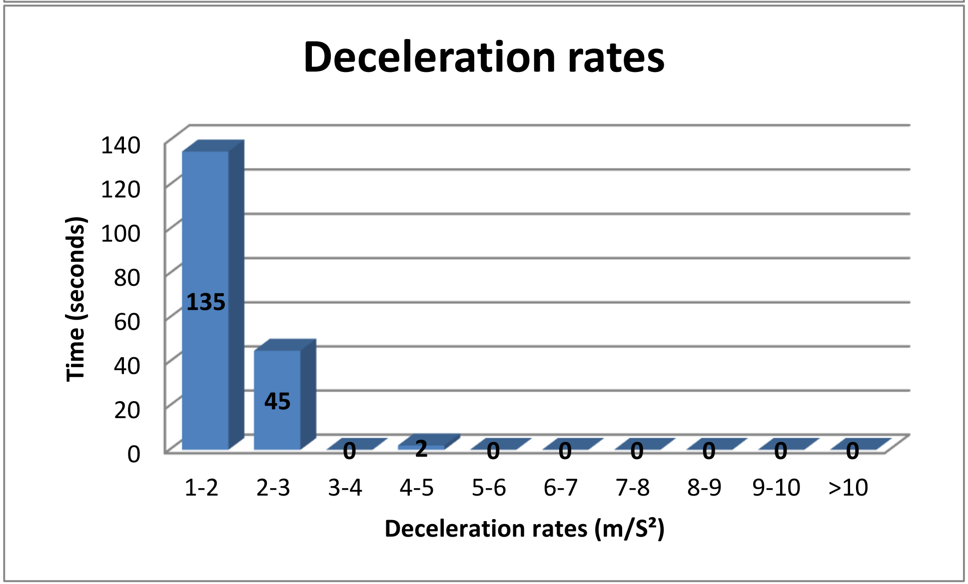

Deceleration rates
Time (seconds)
10000
8000
6000
4000
2000
0
9144
1923
461
145
49
20
7
1
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

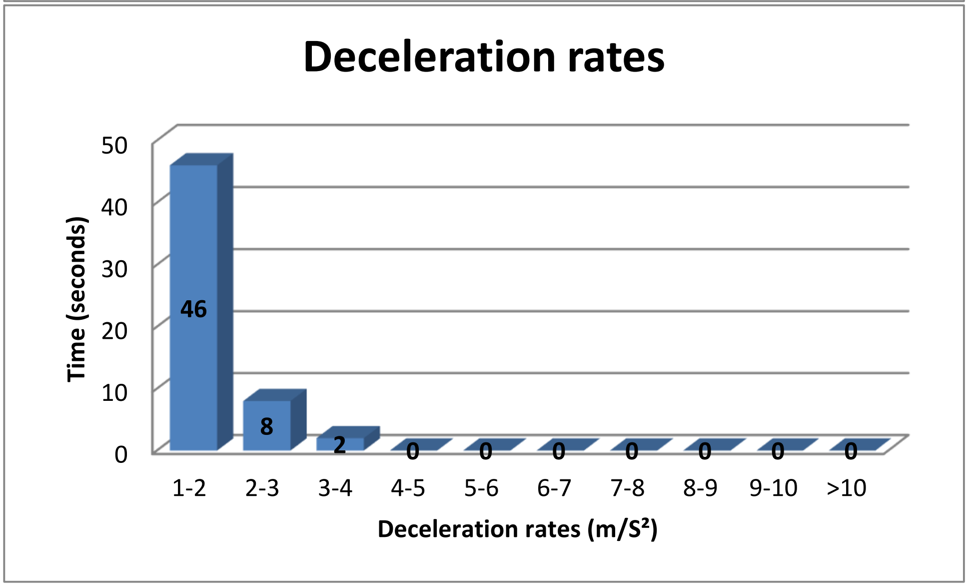

Deceleration rates
Time (seconds)
0
100
200
300
400
500
600
700
800
749
169
60
18
12
2
2
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

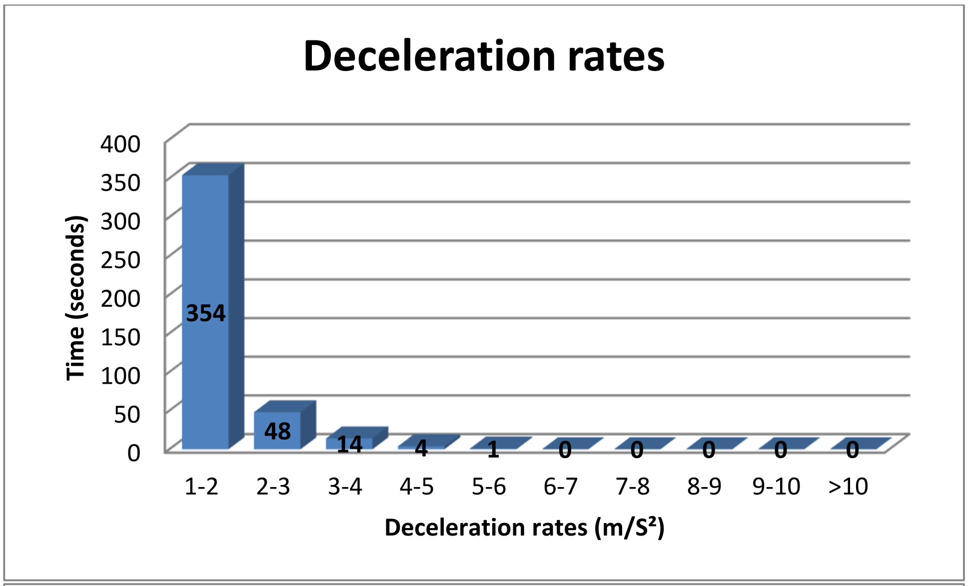

Deceleration rates
Time (seconds)
0
50
100
150
200
250
300
263
58
16
3
1
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
0
50
100
150
200
250
203
45
5
2
0
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
800
700
600
500
400
300
200
100
0
712
146
27
5
4
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
140
120
100
80
60
40
20
0
135
45
0
2
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
50
40
30
20
10
0
46
8
2
0
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
400
350
300
250
200
150
100
50
0
354
48
14
4
1
0
0
0
0
0
1-2
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4-5
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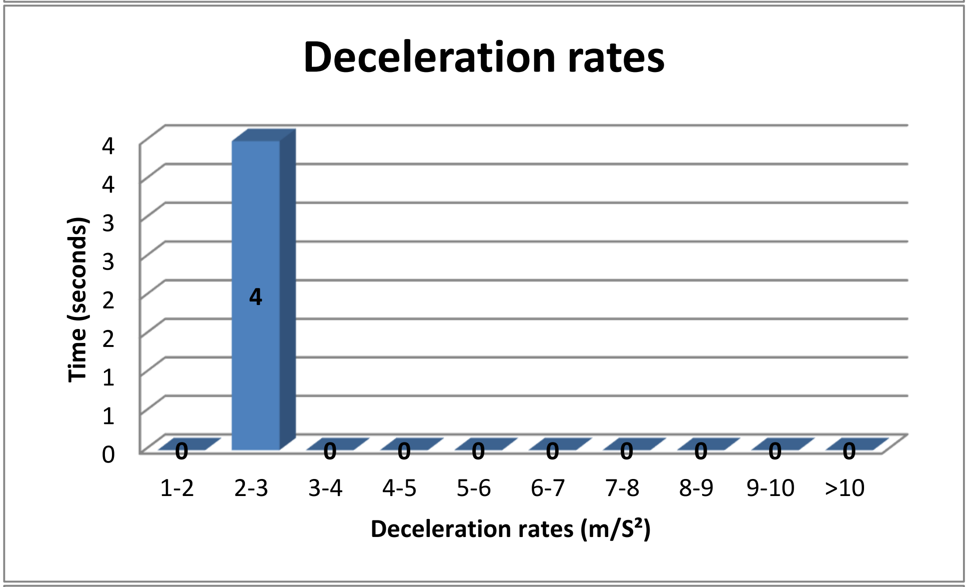
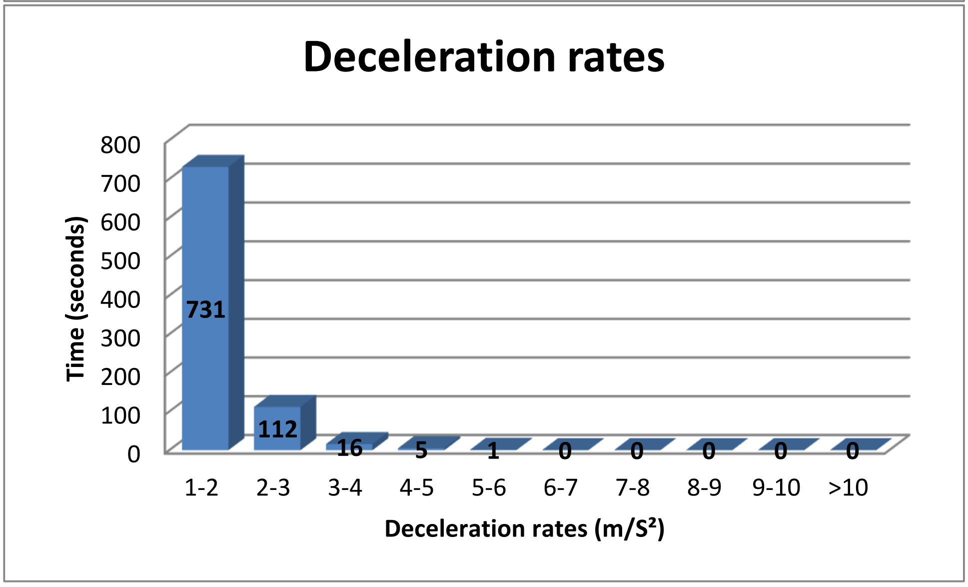
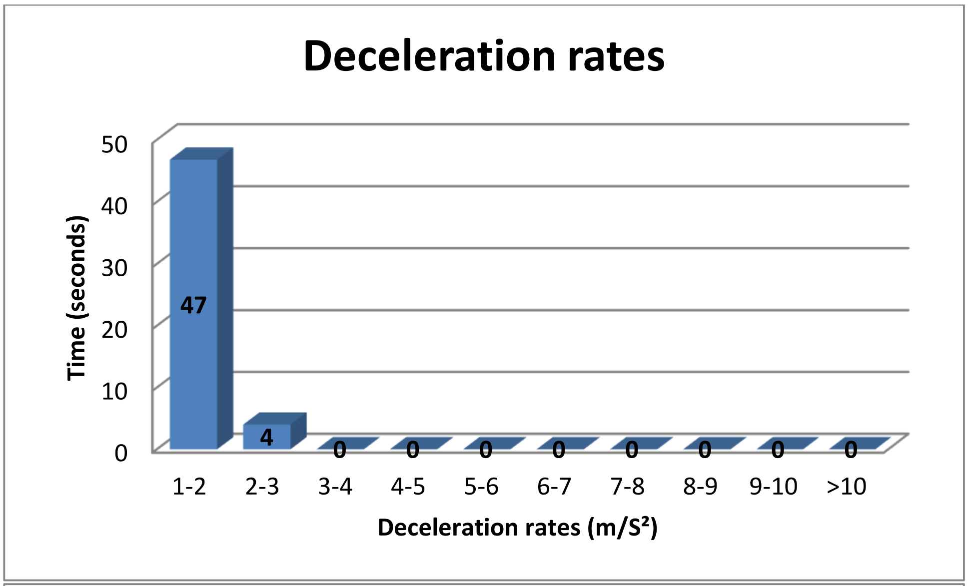
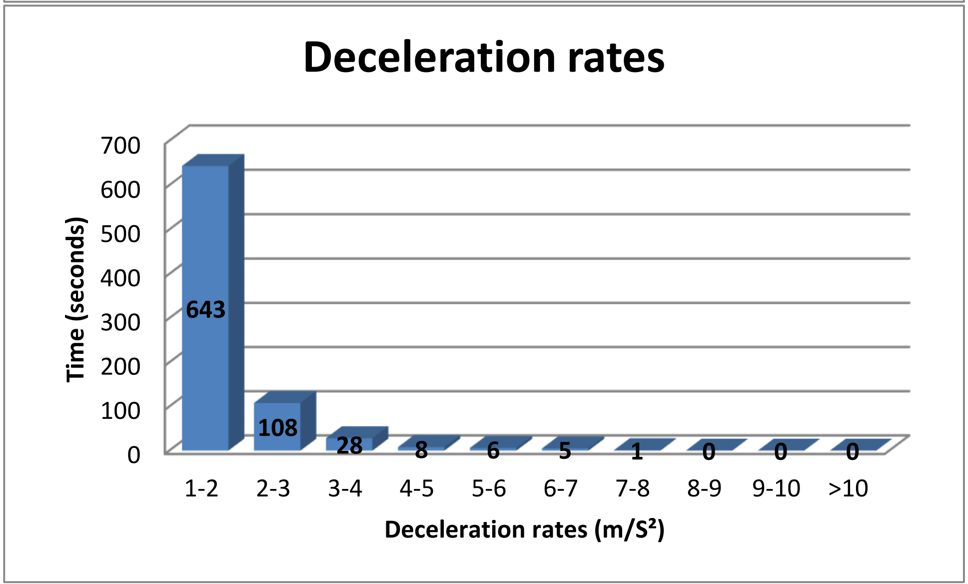
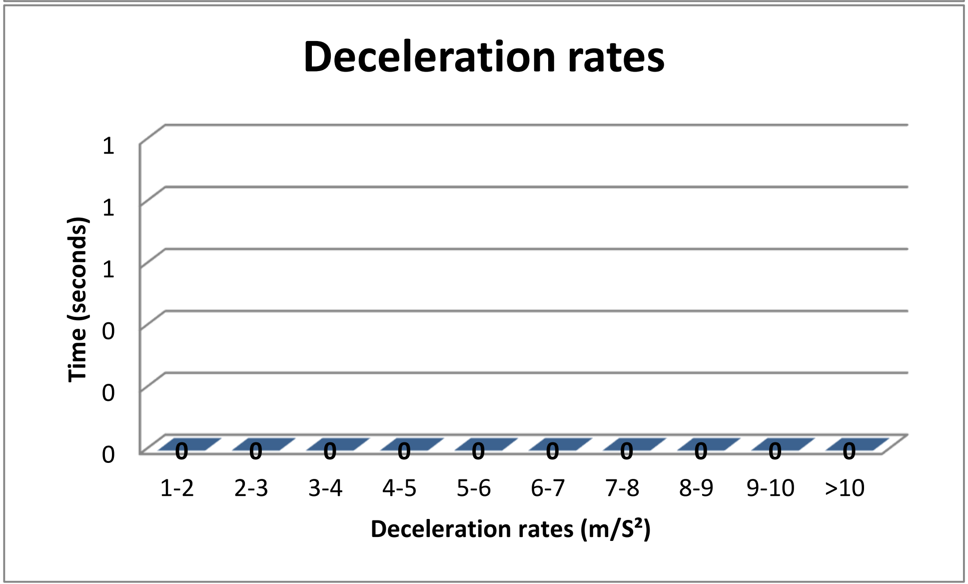
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

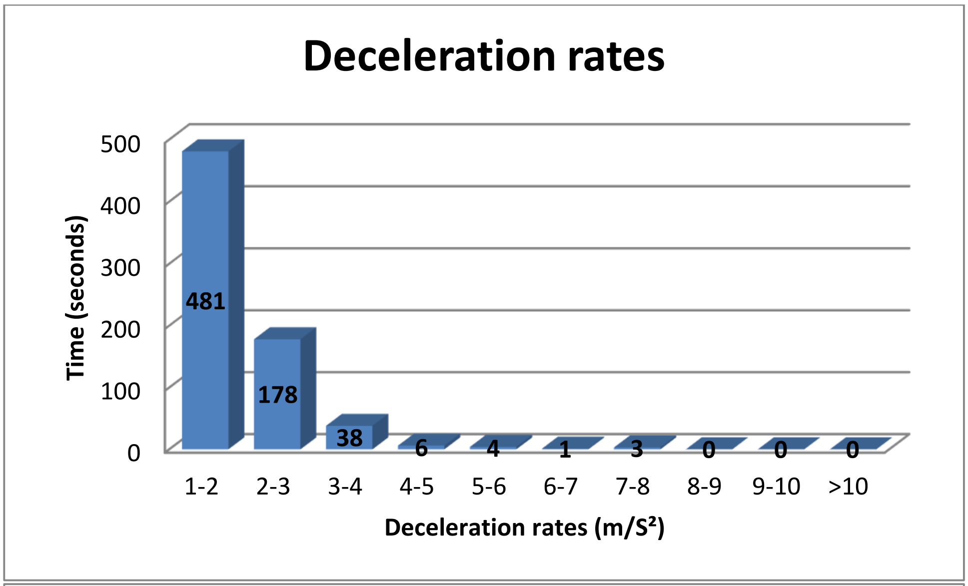

Deceleration rates
Time (seconds)
4
4
3
3
2
2
1
1
0
0
4
0
0
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

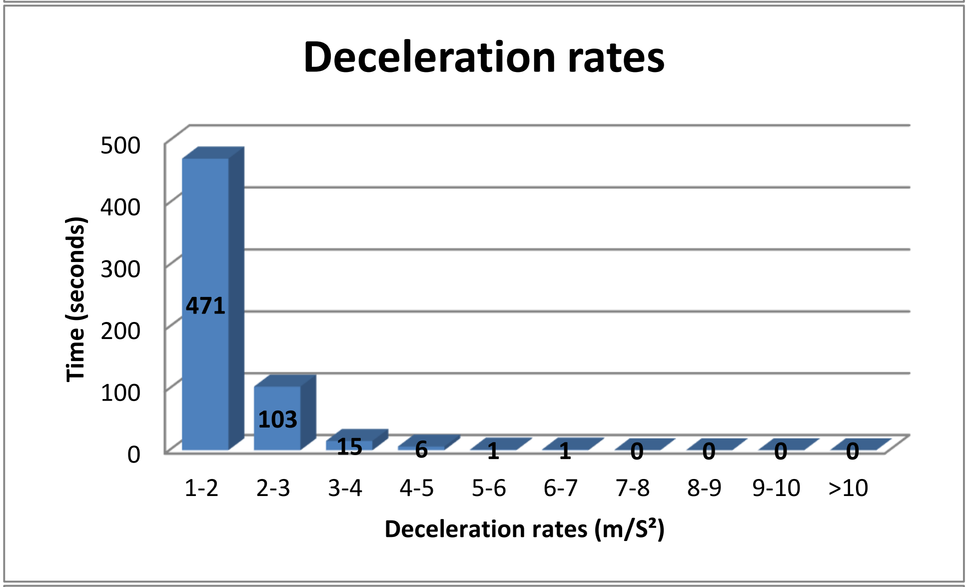

Deceleration rates
Time (seconds)
800
700
600
500
400
300
200
100
0
731
112
16
5
1
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

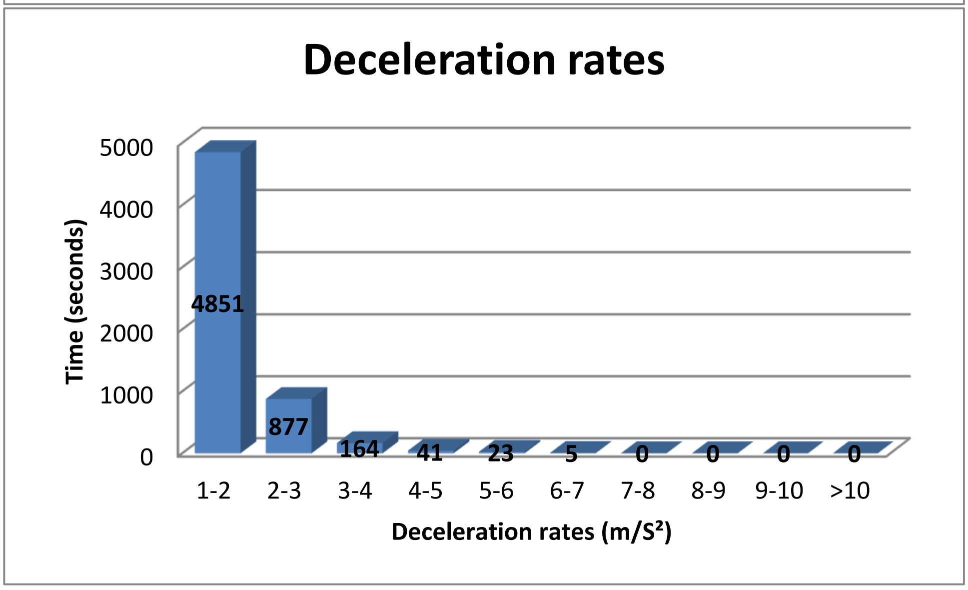

Deceleration rates
Time (seconds)
50
40
30
20
10
0
47
4
0 0 0 0 0 0 0 0
1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 >10
Deceleration rates (m/S²)

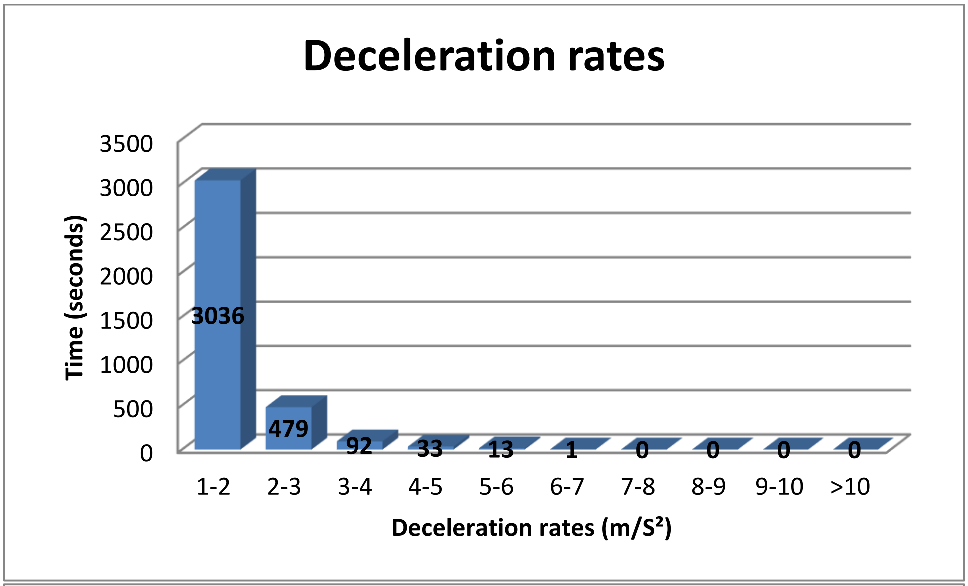

Deceleration rates
Time (seconds)
700
600
500
400
300
200
100
0
643
108
28
8 6 5 1 0 0 0
1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 >10
Deceleration rates (m/S²)

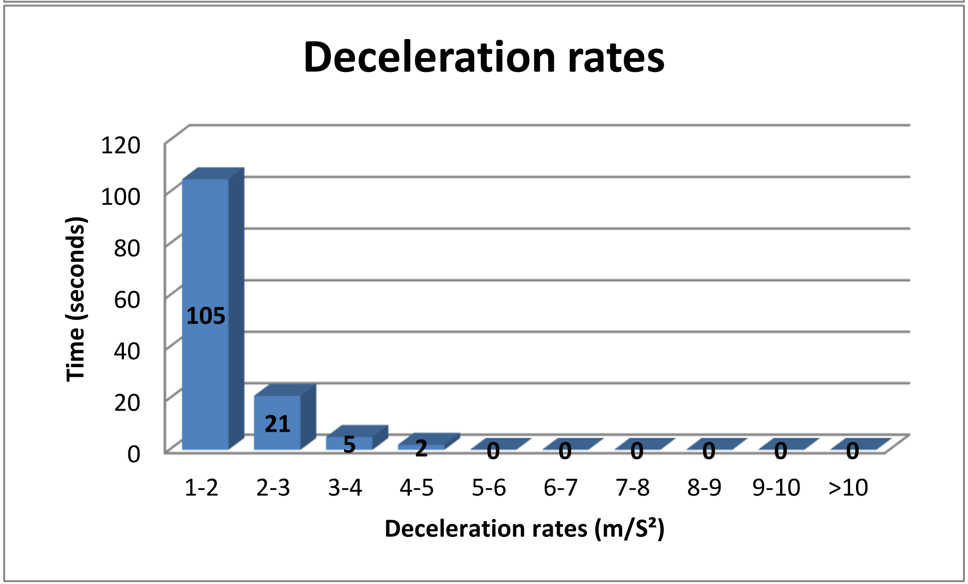

Deceleration rates
Time (seconds)
1
1
1
0
0
0
0 0 0 0 0 0 0 0 0 0
1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10 >10
Deceleration rates (m/S²)

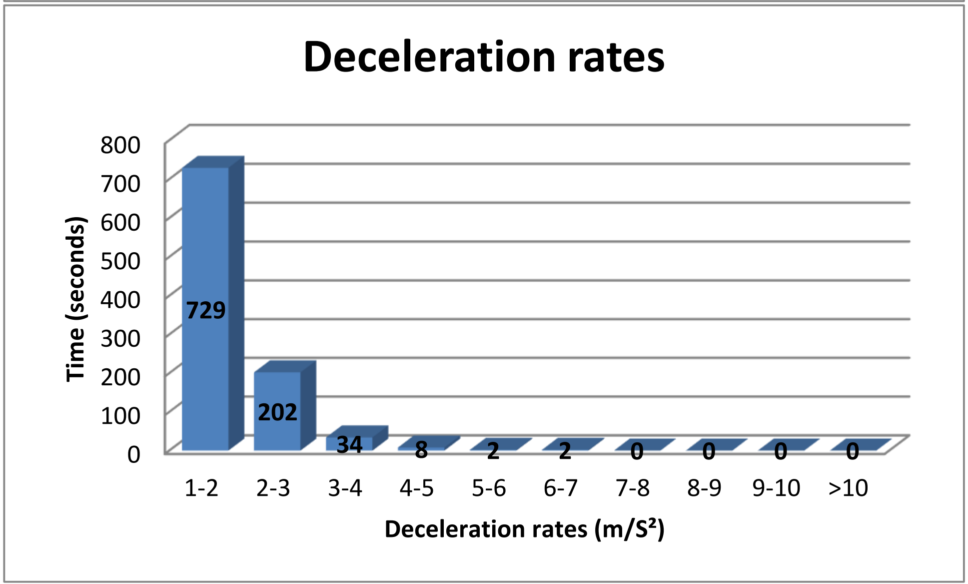

Deceleration rates
Time (seconds)
500
400
300
200
100
0
481
178
38
6
4
1
3
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
500
400
300
200
100
0
471
103
15
6
1
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

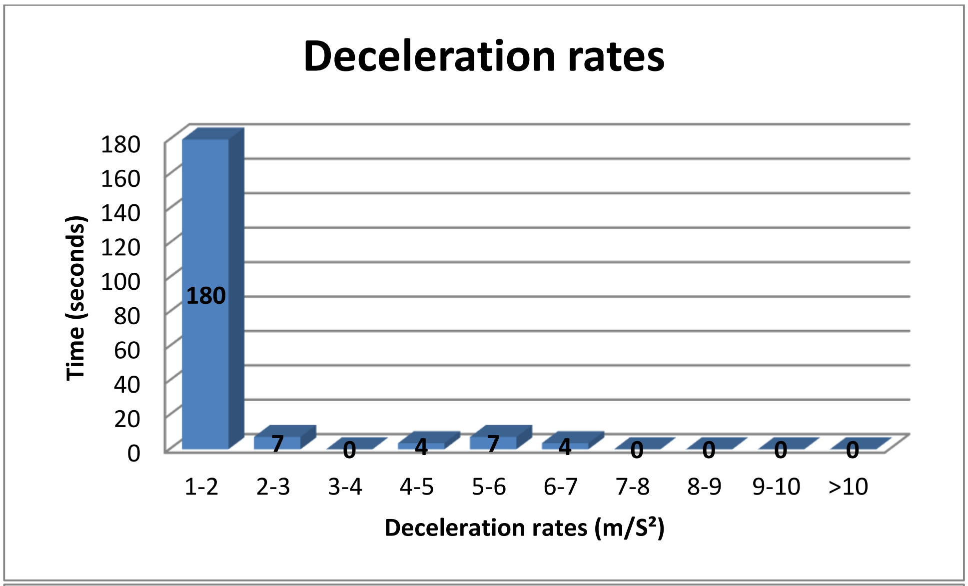

Deceleration rates
Time (seconds)
5000
4000
3000
2000
1000
0
4851
877
164
41
23
5
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

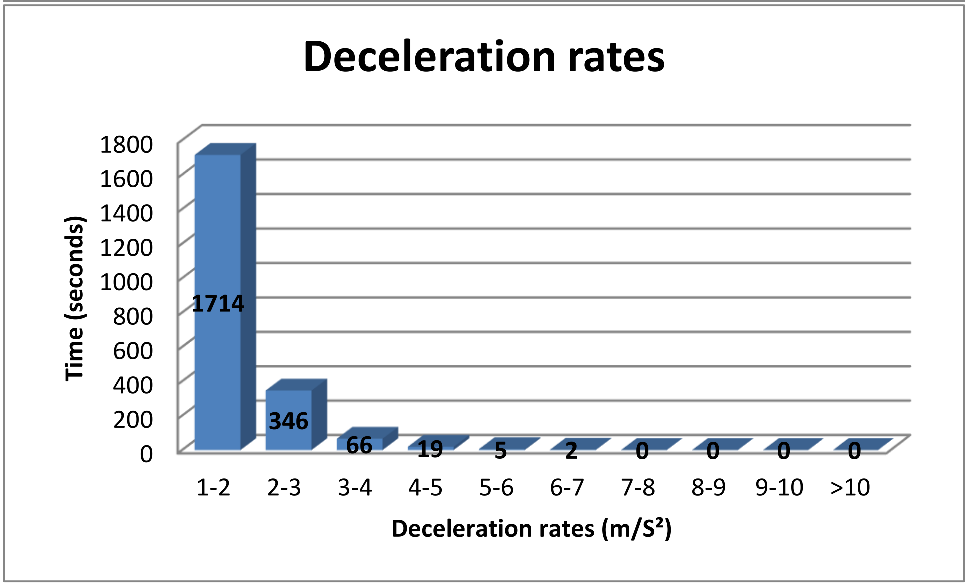

Deceleration rates
3500
3000
2500
2000
1500
1000
500
0
Time (seconds)
3036
479
92
33
13
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
120
100
80
60
40
20
0
Time (seconds)
105
21
5
2
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

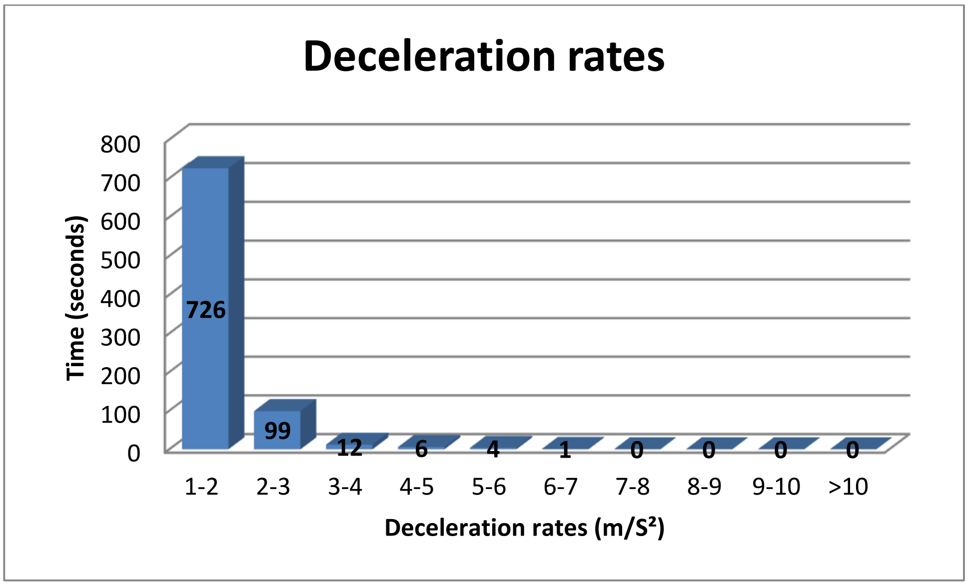

Deceleration rates
800
700
600
500
400
300
200
100
0
Time (seconds)
729
202
34
8
2
2
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

A2: Belgium

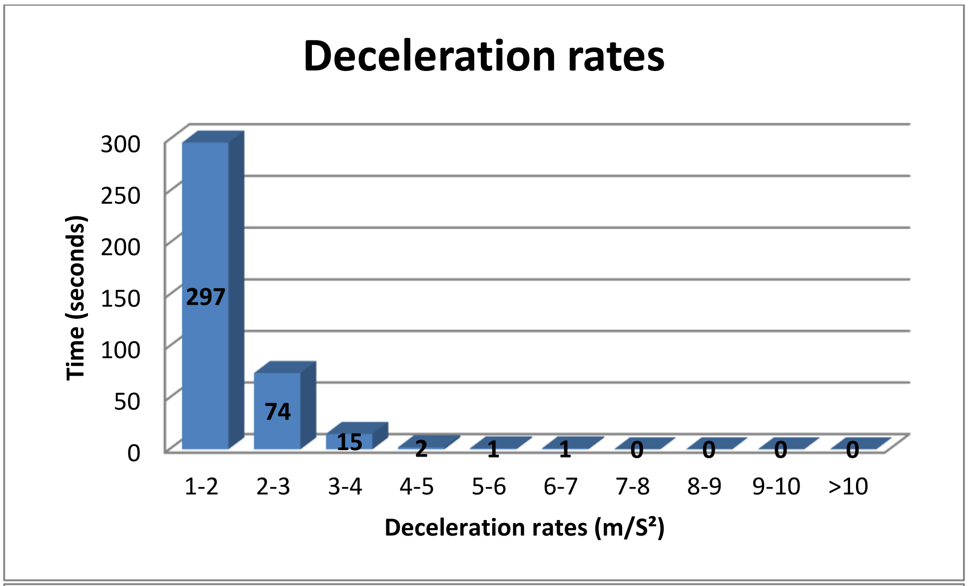

Deceleration rates
Time (seconds)
180
160
140
120
100
80
60
40
20
0
180
7
0
4
7
4
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

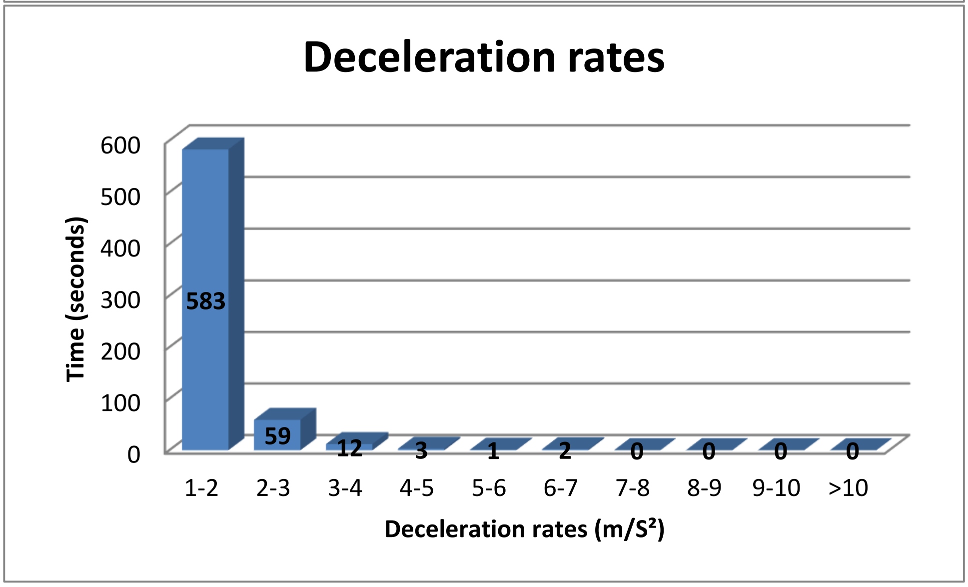

Deceleration rates
Time (seconds)
1800
1600
1400
1200
1000
800
600
400
200
0
1714
346
66
19
5
2
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

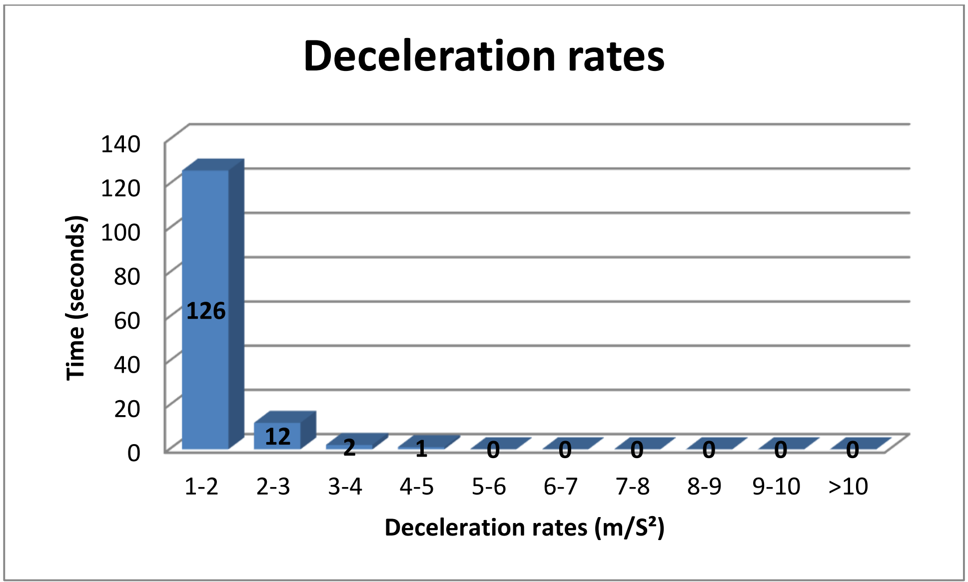
A3: Germany

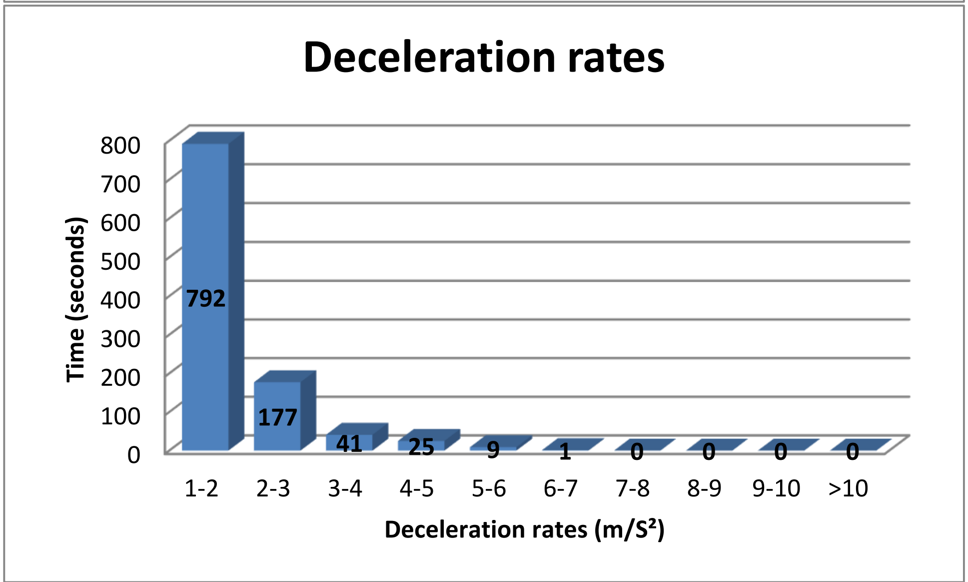

Deceleration rates
Time (seconds)
800
700
600
500
400
300
200
100
0
726
99
12
6
4
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

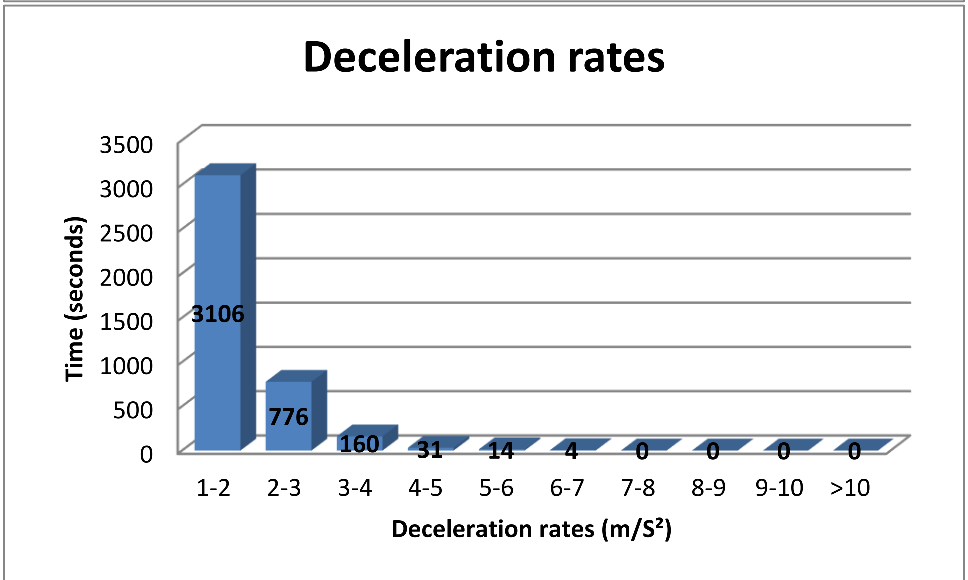
A4: UK


Deceleration rates
Time (seconds)
300
250
200
150
100
50
0
297
74
15
2
1
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
600
500
400
300
200
100
0
583
59
12
3
1
2
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
140
120
100
80
60
40
20
0
126
12
2
1
0
0
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
800
700
600
500
400
300
200
100
0
792
177
41
25
9
1
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)


Deceleration rates
Time (seconds)
3500
3000
2500
2000
1500
1000
500
0
3106
776
160
31
14
4
0
0
0
0
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Deceleration rates (m/S²)

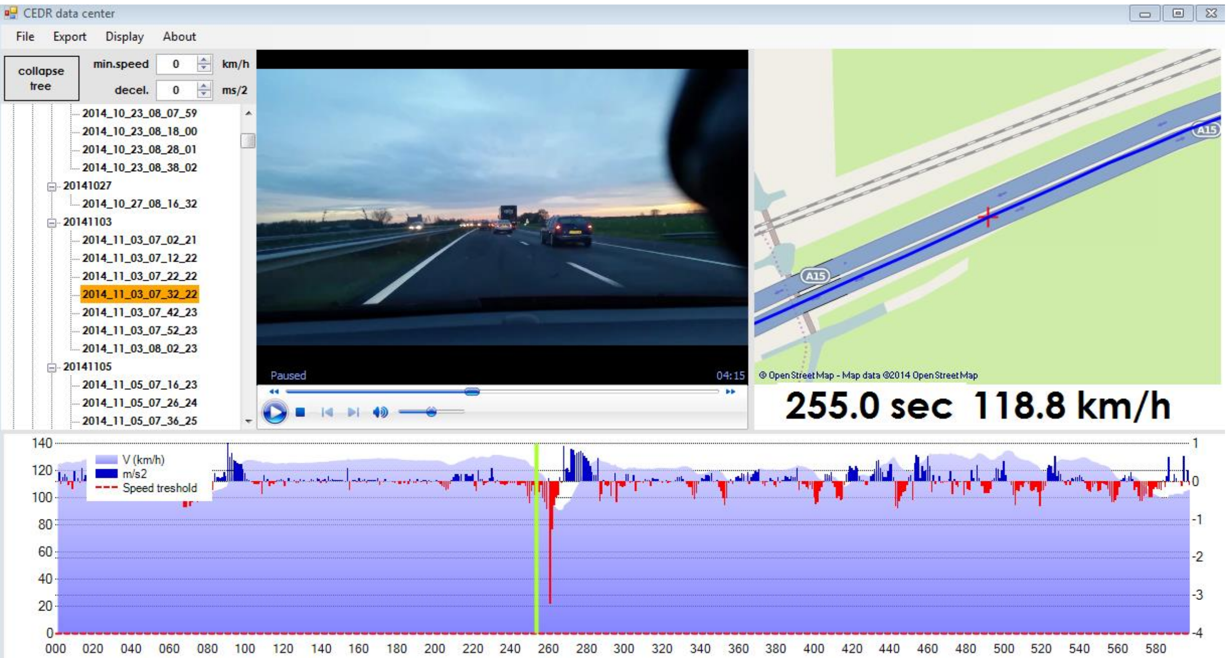
Appendix B: Selection of emergency braking manoeuvres

B1: Introduction

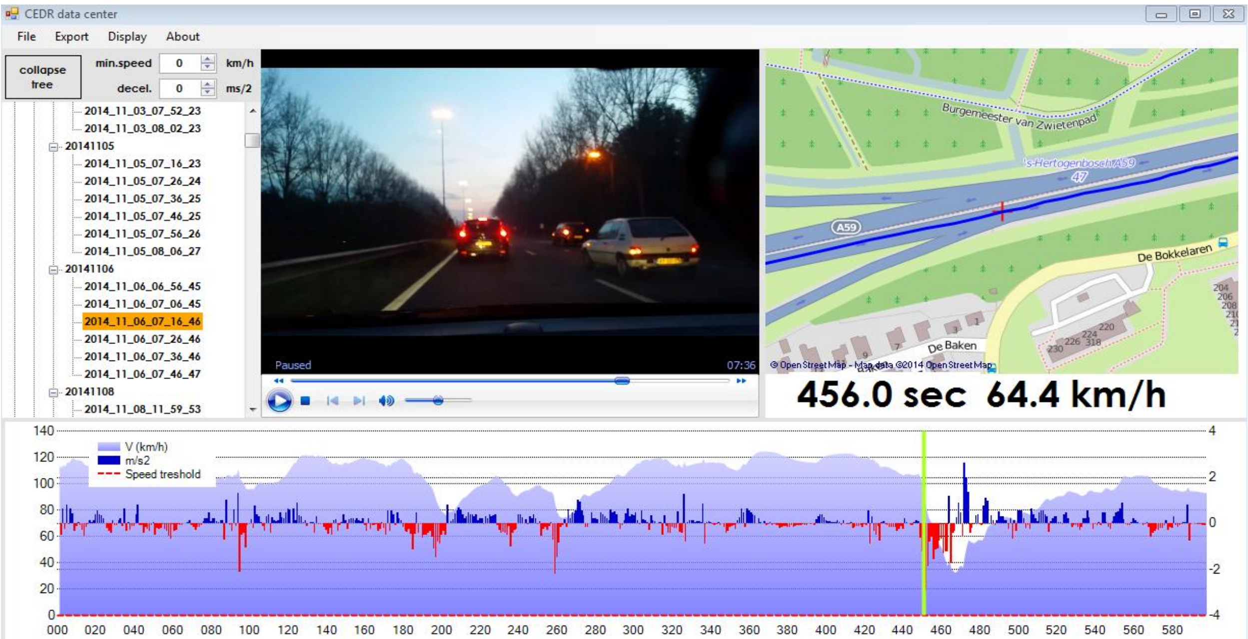
Braking manoeuvres on motorways
Speed drop of at least 40 km/h
Deceleration rates over 3 m/s^2

B2: The Netherlands

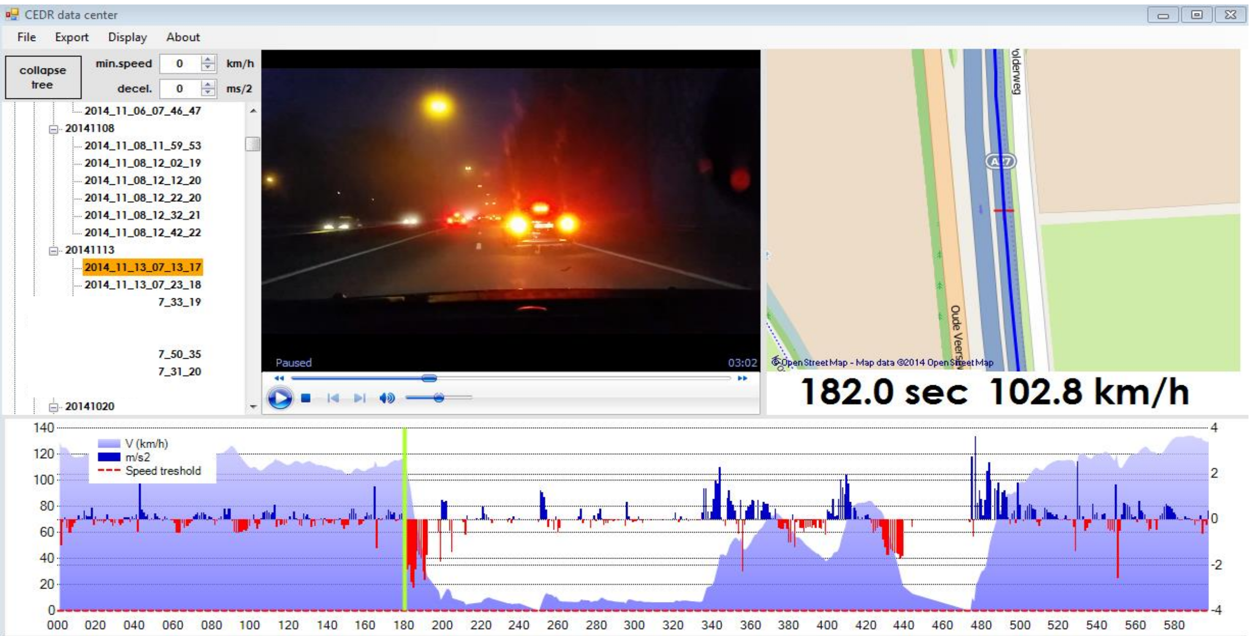
Participant 1



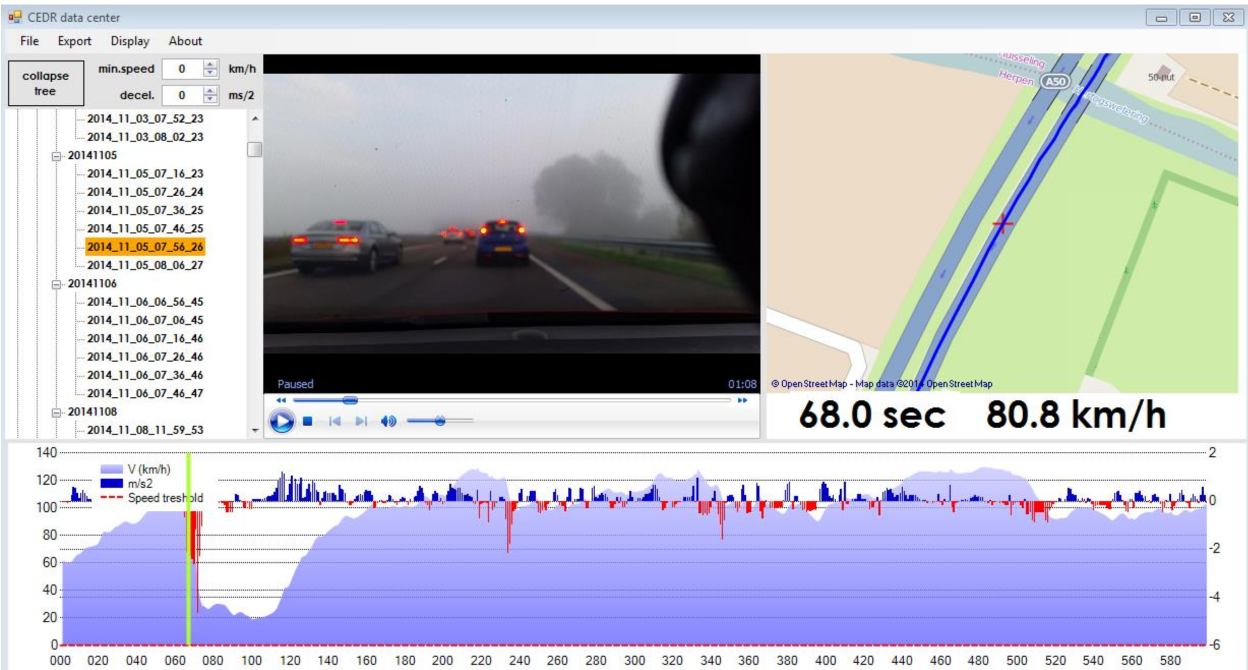
Date and time	2014_11_03_07_32_22
Location	A15, straight road section
Start speed	130 km/h
End speed	90 km/h
Speed drop	40 km/h
Maximum deceleration	3.2 m/s^2
Duration of the braking	20s
Conditions	Sunrise, dim, dry
Road surface	Dry
Description	Calm traffic situation with truck on the right hand lane. Car overtakes truck with a low speed, needing the participant to brake.



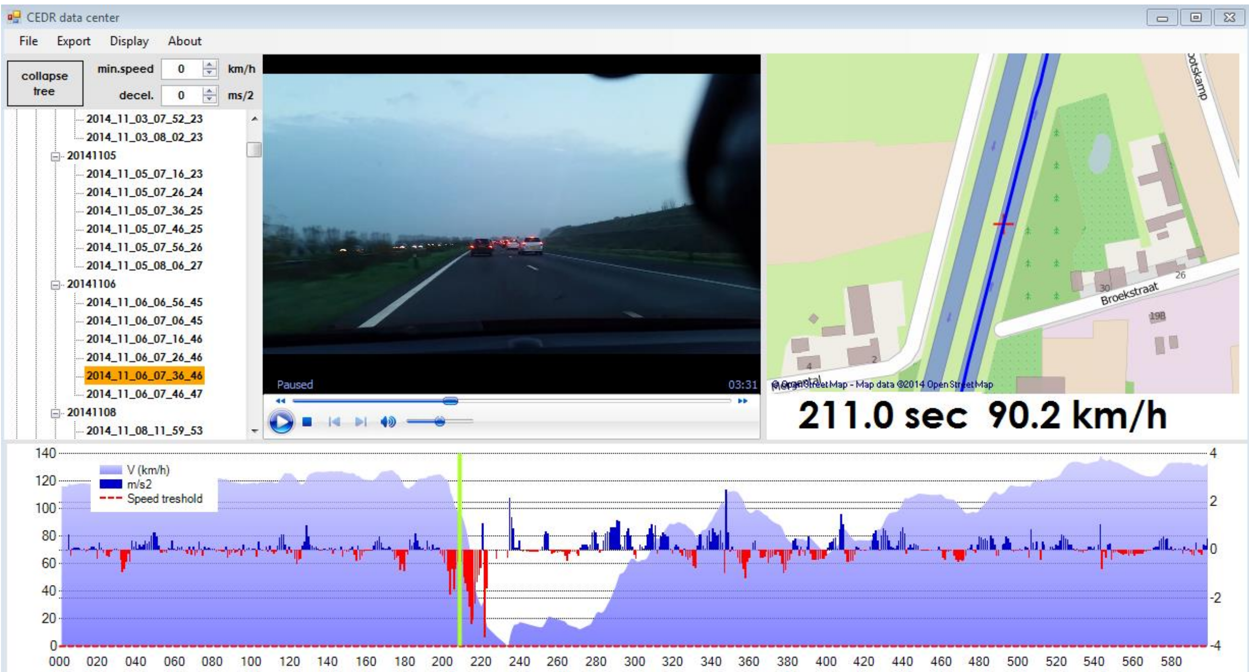
Date and time	2014_11_06_07_16_46
Location	A59, straight road section
Start speed	105 km/h
End speed	38 km/h
Speed drop	67 km/h
Maximum deceleration	3 m/s^2
Duration of the braking	20s
Conditions	Dim, dry
Road surface	Dry
Description	Congested traffic situation near urban area (‘s-Hertogenbosch). Entrance ramp on the right hand side. During the braking manoeuvre a vehicle is merging from the entrance ramp on the mainline carriageway. Merging traffic is the cause for the braking.



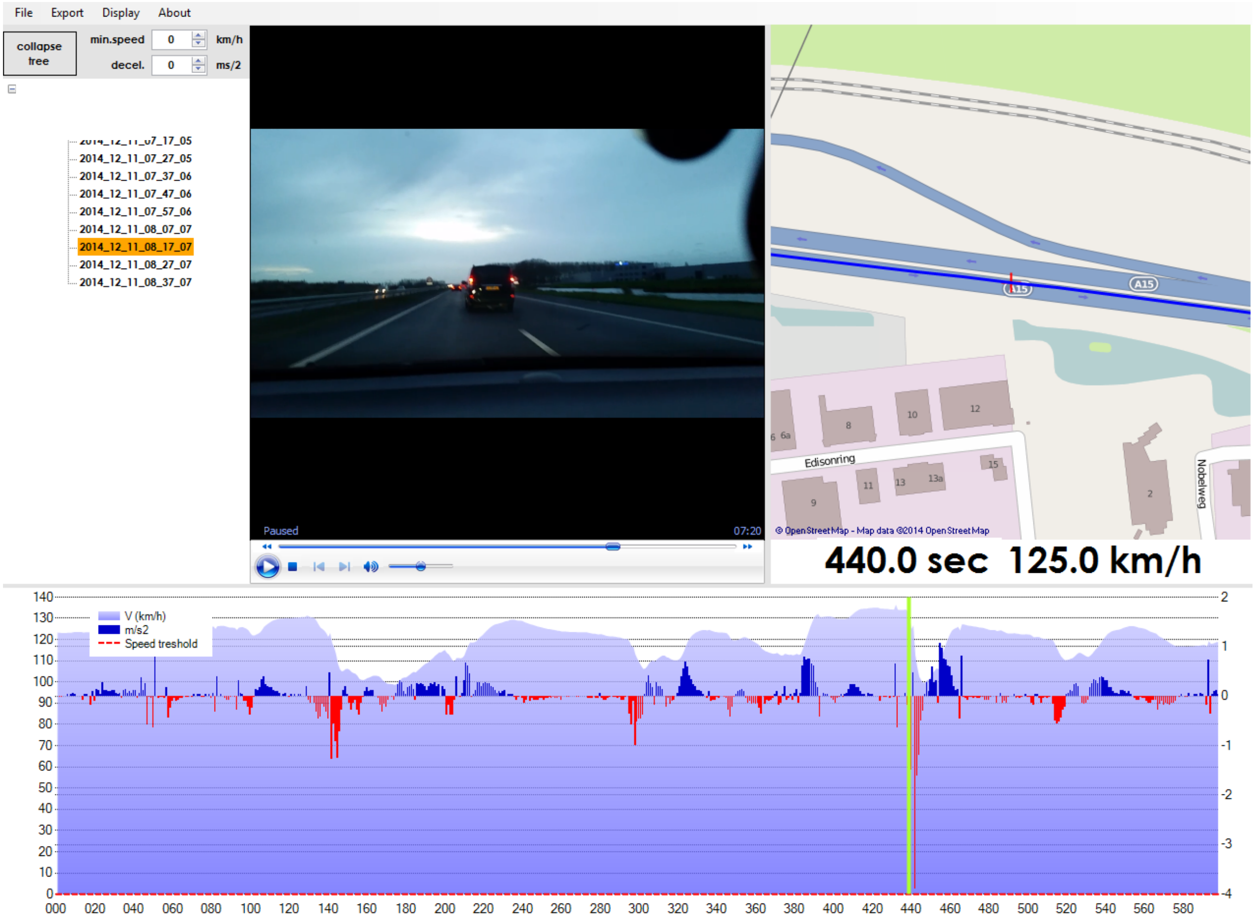
Date and time	2014_11_13_07_13_17
Location	A27, wide curve
Start speed	120 km/h
End speed	20 km/h
Speed drop	100 km/h
Maximum deceleration	3 m/s^2
Duration of the braking	10s
Conditions	Dark, foggy, dry
Road surface	Moist
Description	Dense traffic, view of traffic influenced (slightly) by fog. Queue ahead; cars in front of the participant are already braking, causing a shockwave.



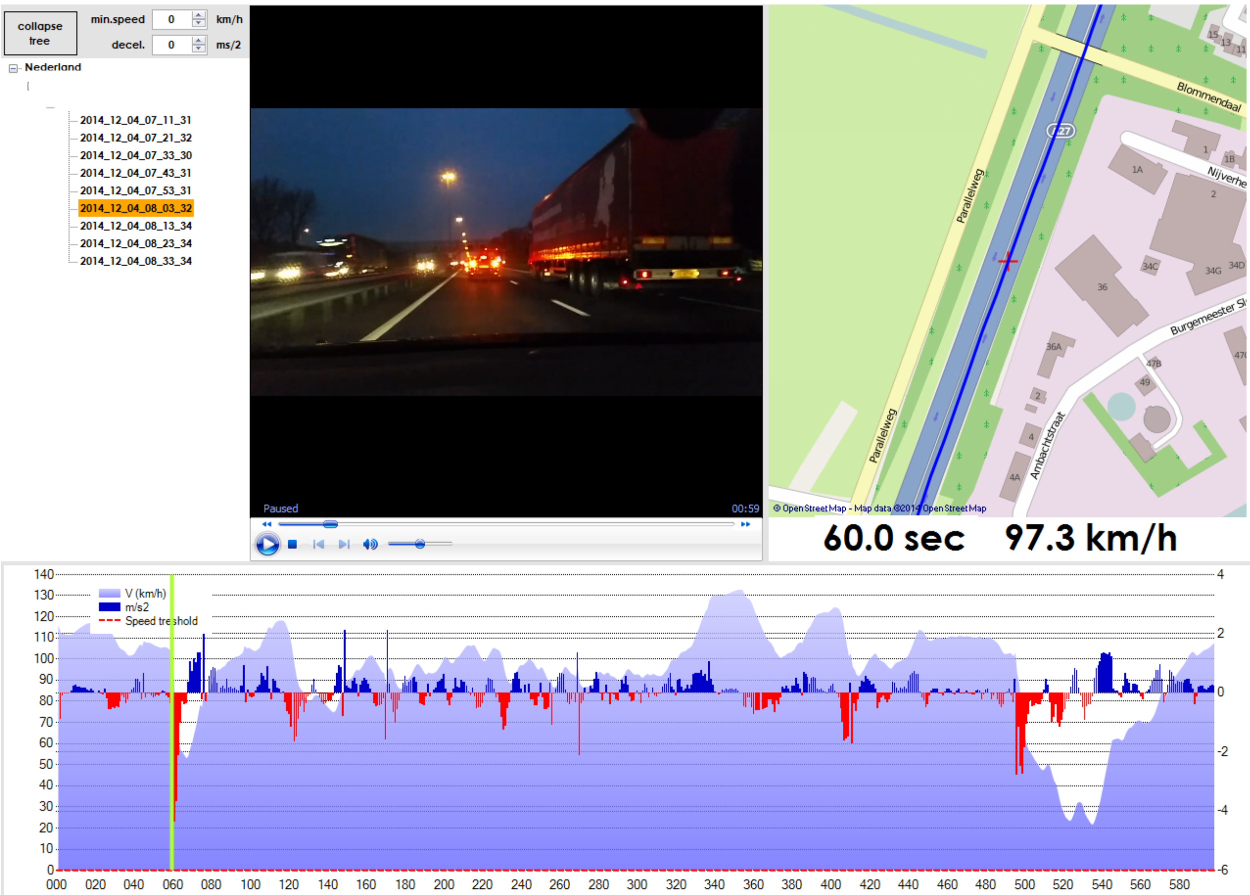
Date and time	2014_11_05_07_56_26
Location	A50, straight road section
Start speed	120 km/h
End speed	30 km/h
Speed drop	90 km/h
Maximum deceleration	5 m/s^2
Duration of the braking	10s
Conditions	Daylight, foggy, dry
Road surface	Dry
Description	Dense traffic. No entrance ramp. A shockwave causes the braking manoeuvre of the participant.



Date and time	2014_11_06_07_36_46
Location	A27?
Start speed	120 km/h
End speed	0 km/h
Speed drop	120 km/h
Maximum deceleration	4 m/s^2
Duration of the braking	30s
Conditions	Daylight, dim, dry
Road surface	Dry
Description	Dense traffic situation. Downstream braking resulting in a shockwave. Participant comes to a complete standstill. Congestion ahead.



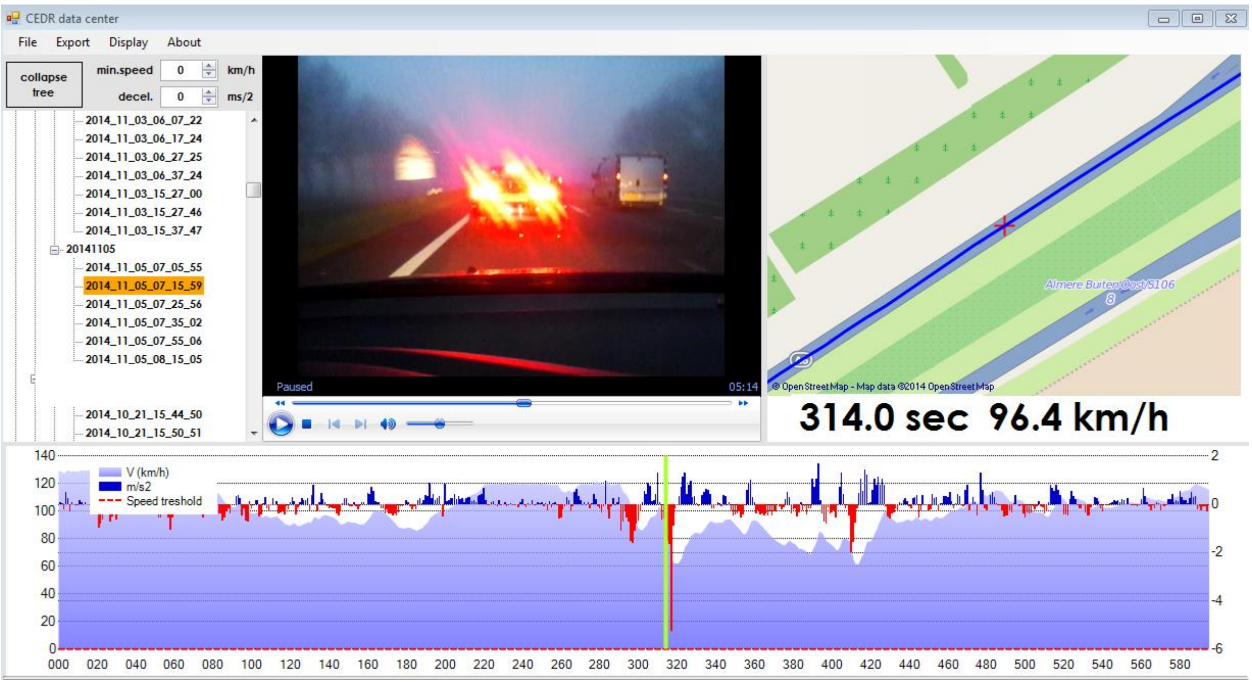
Date and time	2014_12_11_08_17_07
Location	A15 Rotterdam – Nijmegen, straight road section
Start speed	135 km/h
End speed	100 km/h
Speed drop	35 km/h
Maximum deceleration	4 m/s^2
Duration of the braking	10s
Conditions	Dim, cloudy, dry
Road surface	Moist
Description	Calm traffic situation, no congestion. Participant has to brake because a vehicle in front overtakes a truck with a low speed.



Date and time	2014_12_04_08_03-32
Location	A27 - Breda – Almere, straight road section
Start speed	110 km/h
End speed	55 km/h
Speed drop	55 km/h
Maximum deceleration	4 m/s2
Duration of the braking	10s
Conditions	Dark, cloudy, dry
Road surface	Dry
Description	Heavy traffic, cars overtaking trucks. Shockwave: car in front brakes suddenly.

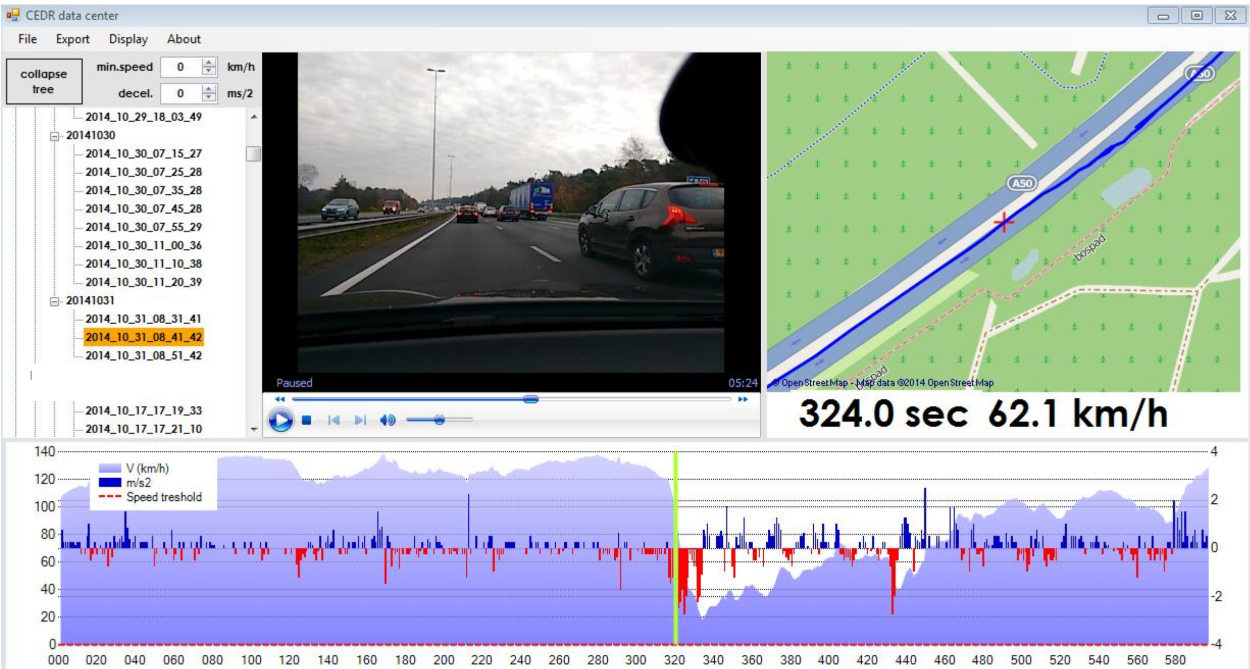
Locatie:

Participant 2



Date and time	2014_11_05_07_15_59
Location	A6, straight road section
Start speed	100 km/h
End speed	60 km/h
Speed drop	40 km/h
Maximum deceleration	5 m/s^2
Duration of the braking	5s
Conditions	Dim, drizzle/foggy
Road surface	Moist/wet
Description	Dense traffic situation. A shockwave caused by a merging vehicle from an entrance ramp, requires the participant to brake (hard). No braking manoeuvre to a complete standstill. Only braking on the left hand lane.

Participant 3

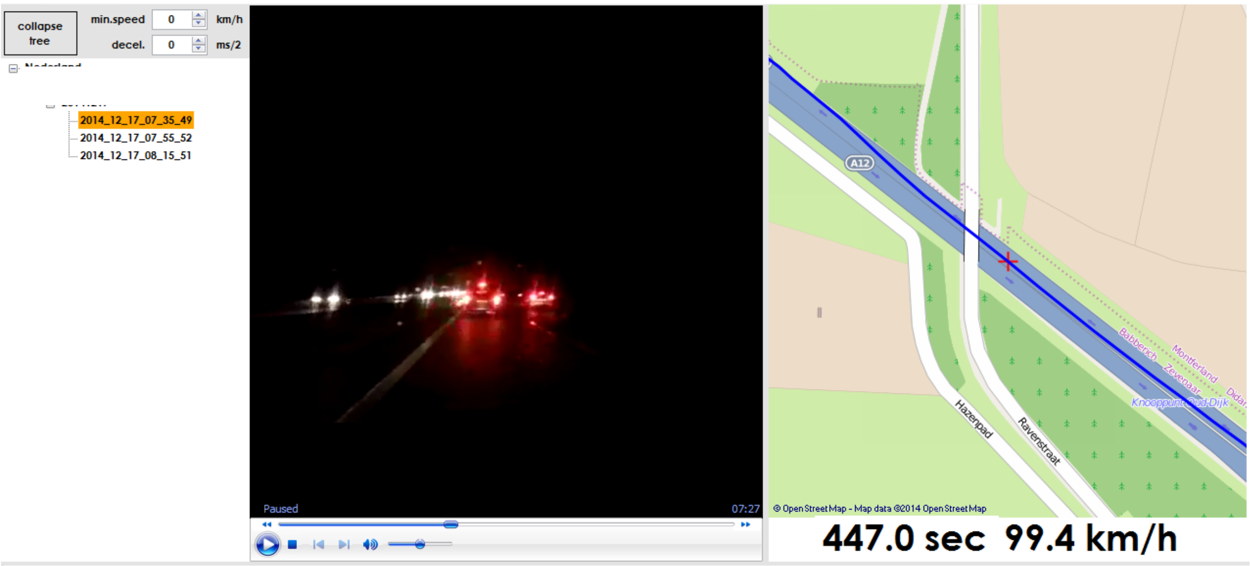


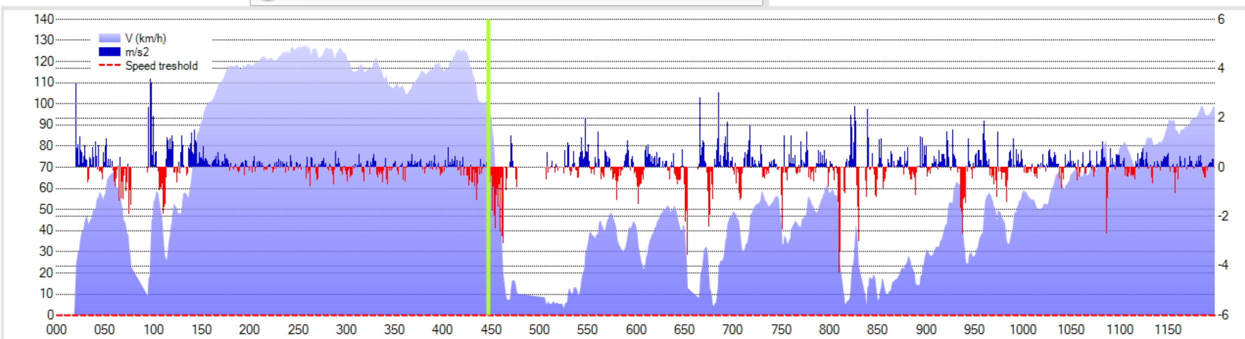
Date and time	2014_10_31_08_41_42
Location	A50 straight road section
Start speed	120 km/h
End speed	40 km/h
Speed drop	80 km/h
Maximum deceleration	3 m/s^2
Duration of the braking	10s
Conditions	Daylight, dry
Road surface	Dry
Description	Dense traffic situation. Slow moving traffic ahead (interchange with diverge)

Participant 4

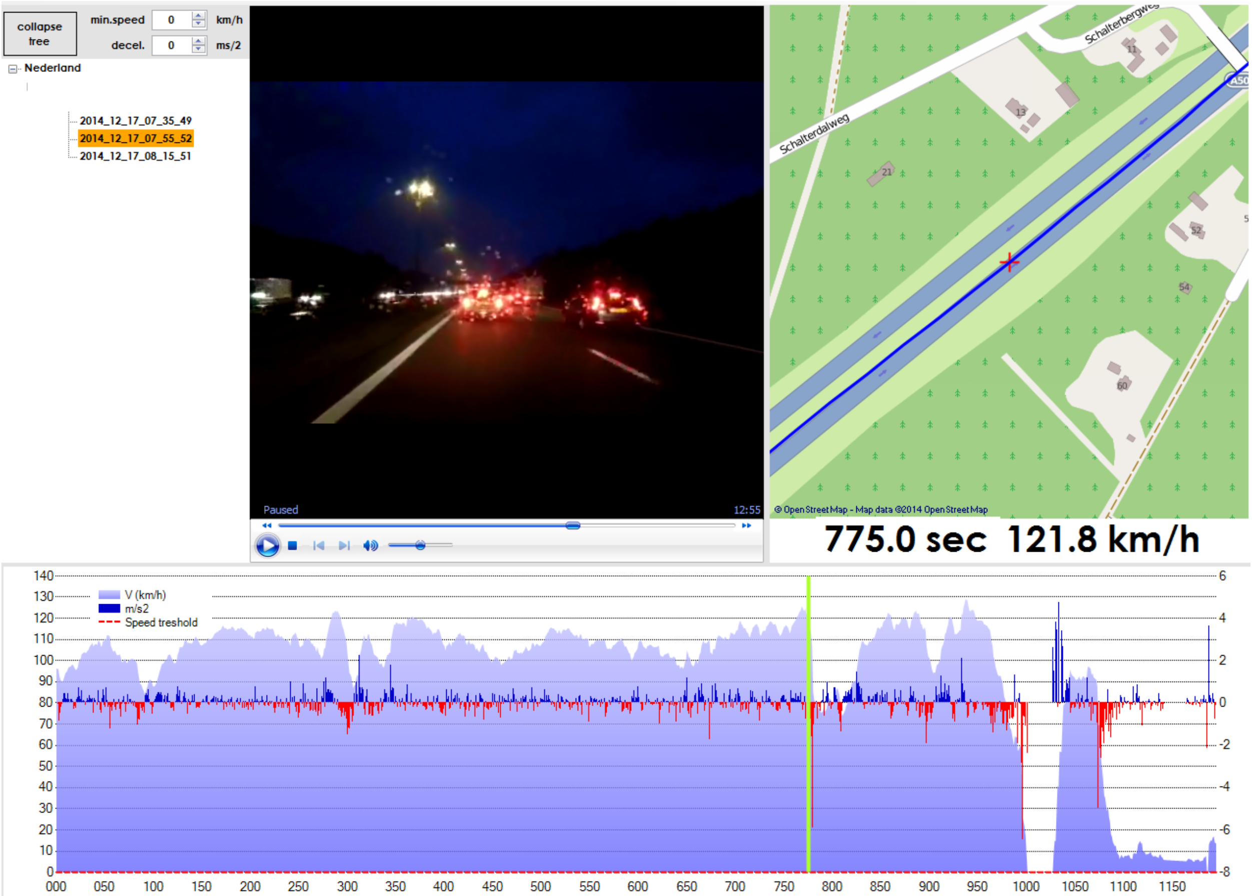
Date and time	2014_11_04_18_18_20
Location	A59, wide horizontal curve
Start speed	120 km/h
End speed	65 km/h
Speed drop	55 km/h
Maximum deceleration	3 m/s^2
Duration of the braking	10s
Conditions	Dark, dry
Road surface	Dry
Description	Congestion ahead. First braking manoeuvre to 60 km/h, followed by a second braking manoeuvre to speeds below 10 km/h.

Participant 6





Date and time	2014_12_17_07_35_49
Location	A12 Oberhausen – Arnhem, straight road section
Start speed	125 km/h
End speed	10 km/h
Speed drop	115 km/h
Maximum deceleration	3 m/s2
Duration of the braking	20s
Conditions	Dark, rainy
Road surface	Wet
Description	Dense traffic situation with congestion ahead, caused by large flow on entrance ramp. Reduced maximum speed (70 km/h) is shown on dynamic traffic signs above the road. Traffic in both lanes is braking severely.



Date and time	2014_12_17_07_55_52
Location	A50, Arnhem – Apeldoorn, straight road section
Start speed	125 km/h
End speed	80 km/h (0 km/h)
Speed drop	45 km/h (125 km/h)
Maximum deceleration	6 m/s^2
Duration of the braking	10s (20s)
Conditions	Dark, rainy
Road surface	Wet
Description	This trip contains three severe braking sections. In the first braking manoeuvre the participant has to decelerate to a speed of 80 km/h. The dynamic traffic signs show a maximum speed of 90 km/h. In the second situation, a broken down vehicle causes a complete standstill of the participant. Further downstream the participant can accelerate again, but a queue makes the third braking manoeuvre necessary.

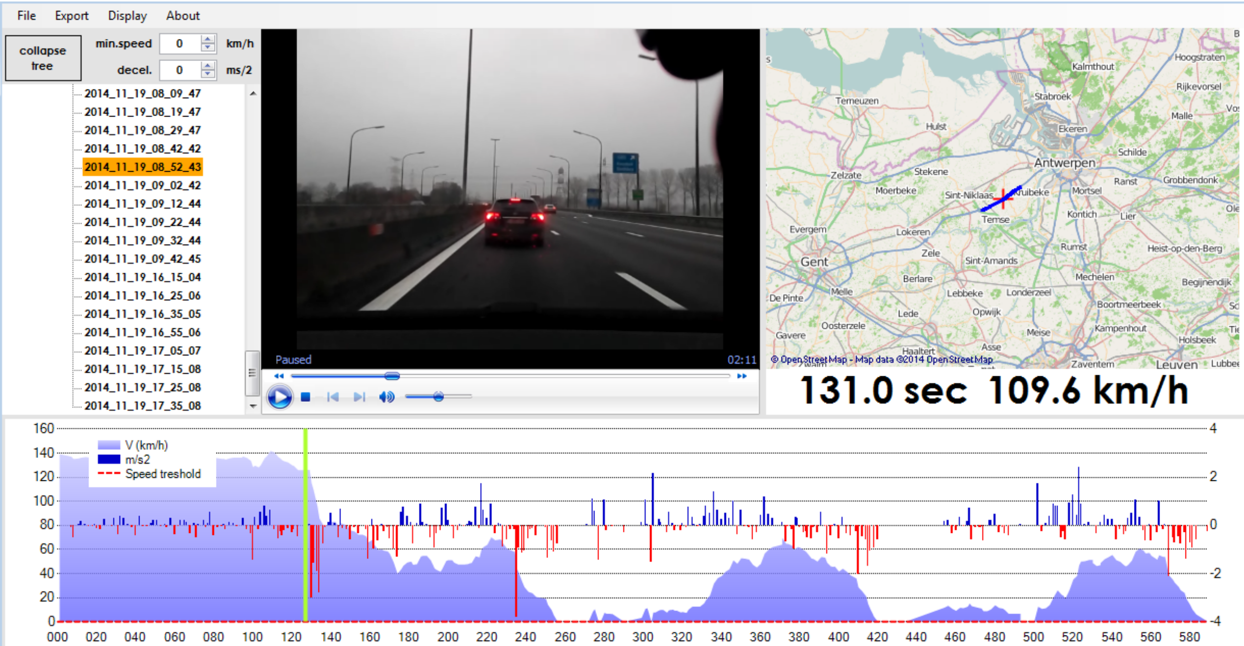
Participant 7

Date and time	2014_12_04_15_50_36
Location	A2, Utrecht – Maastricht, wide horizontal curve
Start speed	135 km/h
End speed	20 km/h
Speed drop	115 km/h
Maximum deceleration	3 m/s^2
Duration of the braking	20s
Conditions	Cloudy, dry
Road surface	Dry
Description	Heavy traffic conditions. Vehicles on the left hand lane have to merge with traffic on the middle lane (because of a lane drop). There is a stationary vehicle on the pavement marking; as a result, braking manoeuvres occur.

Date and time	2014_12_02_16_04_11
Location	A76 – Geleen – Aachen, straight road section
Start speed	135 km/h
End speed	80 km/h
Speed drop	55 km/h
Maximum deceleration	5 m/s^2
Duration of the braking	10s
Conditions	Cloudy, dry
Road surface	Dry
Description	Merging traffic at left lane drop. Participant is accelerating to overtake the truck changing to the left. Participant has to brake for braking cars in front.

B3: Belgium

Participant 1



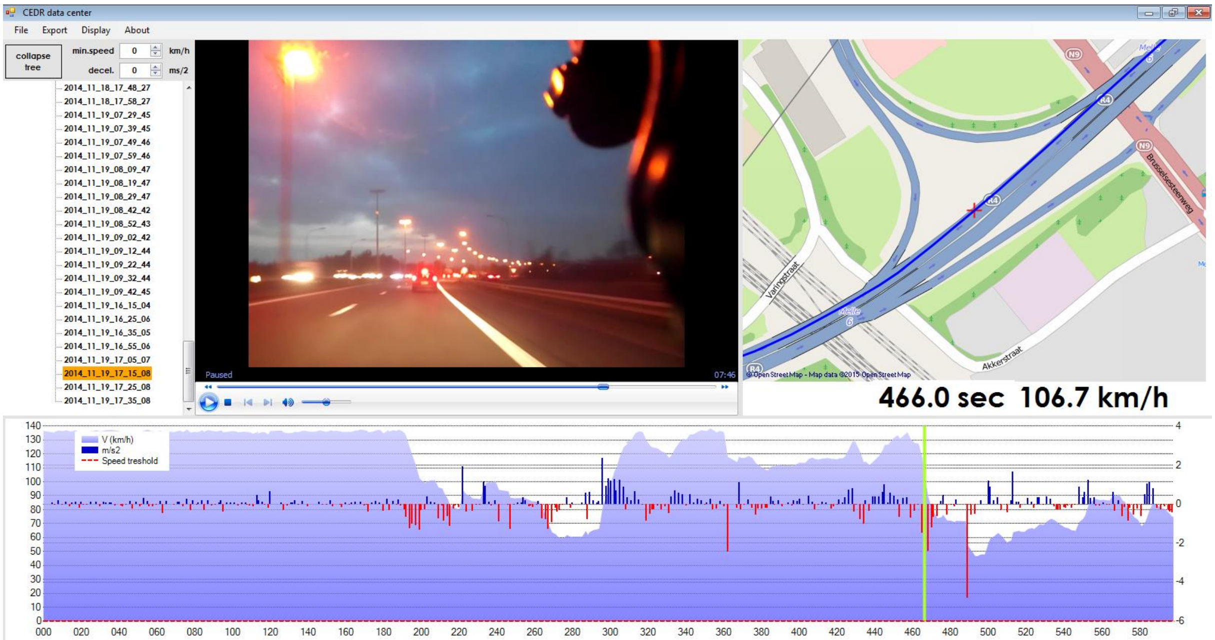
Date and time	2014_11_19_08_52_43
Location	E17 Gent – Antwerpen, straight road section
Start speed	125 km/h (60 km/h)
End speed	80 km/h (0 km/h)
Speed drop	45 km/h (60 km/h)
Maximum deceleration	3 m/s^2 (4 m/s^2)
Duration of the braking	8s
Conditions	Cloudy, dry
Road surface	Dry
Description	Participant has to brake for the vehicle in front After a section with speeds between 40 and 60 km/h, participant has to brake hard for the second time for a stationary queue.

Date and time	2014_11_19_09_32_44
Location	E313, Antwerpen – Luik
Start speed	120 km/h
End speed	85 km/h
Speed drop	35 km/h
Maximum deceleration	3,5 m/s^2
Duration of the braking	10s
Conditions	Cloudy, dry
Road surface	Dry
Description	There is a broken down camper van on the hard shoulder. A car on the right lane changes lane, needing the participant to brake firmly.

Participant 2

**** Speeds and deceleration rates have to be multiplied by 3.6 ****

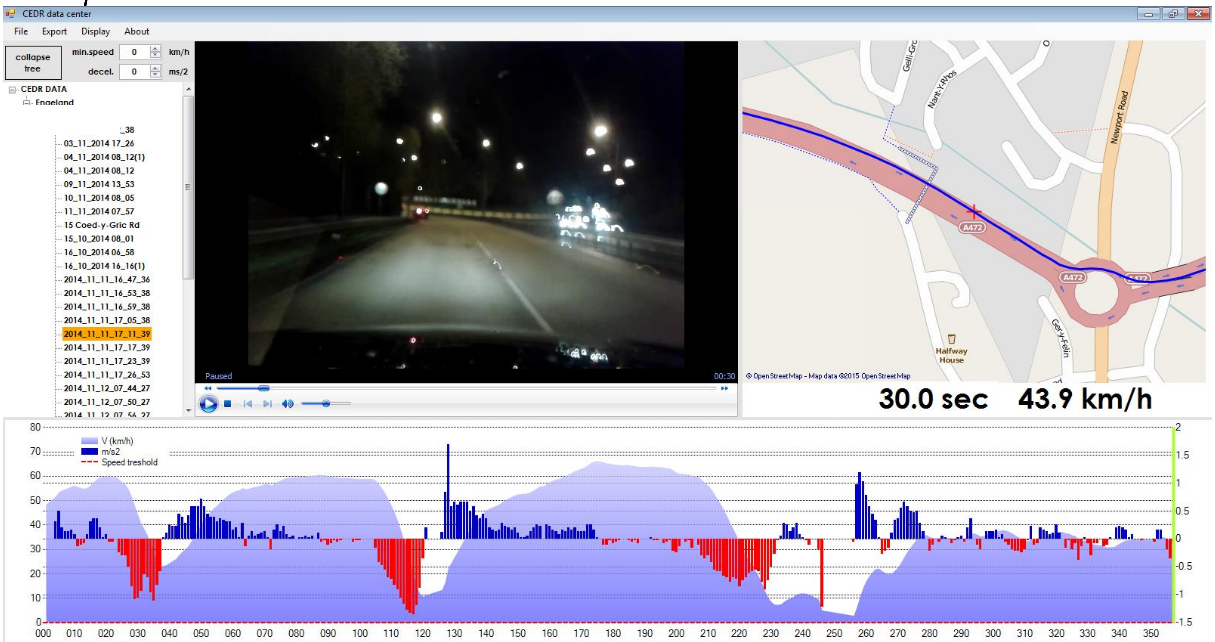
Date and time	1418279795
Location	E17, Antwerpen – Gent, straight road section
Start speed	125 km/h
End speed	45 km/h
Speed drop	80 km/h
Maximum deceleration	5 m/s^2
Duration of the braking	15s
Conditions	Dark, lighting
Road surface	Dry
Description	An entrance ramp with a large traffic volume causes congestion. Participant has to brake firmly and eventually comes to a standstill.



Date and time	2014_11_19_17_15_08
Location	R4
Start speed	130 km/h
End speed	50 km/h
Speed drop	80 km/h
Maximum deceleration	5 m/s^2
Duration of the braking	20s
Conditions	Dry, cloudy, sunset
Road surface	Dry
Description	An entrance ramp causes congestion. Participant has to brake firmly in the queue for a short moment.

B3: UK

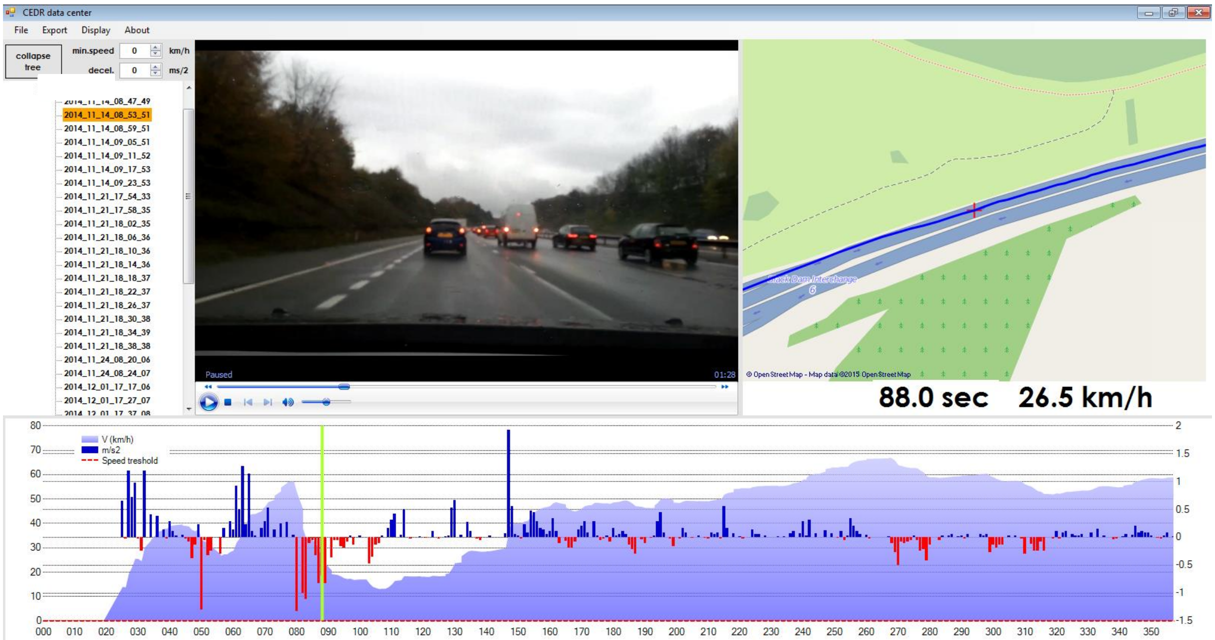
Participant 2



In miles/h instead of km/h

Date and time	2014_11_11_17_11_39
Location	A472
Start speed	95 km/h
End speed	35 km/h
Speed drop	60 km/h
Maximum deceleration	1.5 m/s^2
Duration of the braking	15s
Conditions	Dry, dark
Road surface	Dry
Description	Participant has to brake for a roundabout at the end of the motorway.

Participant 3

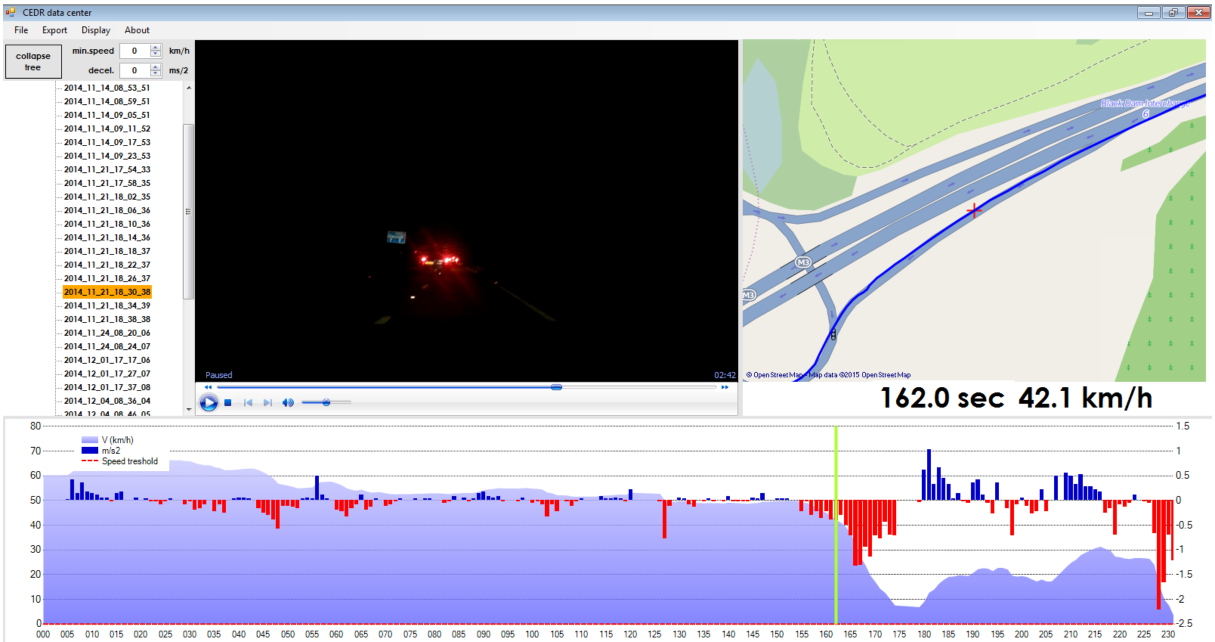


In miles/h instead of km/h

Date and time	2014_11_14_08_53_51
Location	M3
Start speed	95 km/h
End speed	30 km/h
Speed drop	65 km/h
Maximum deceleration	2.5 m/s^2
Duration of the braking	15s
Conditions	Rain, daylight
Road surface	Wet
Description	Queue on the mainline carriageway of the M3. Queue is positioned downstream of an entrance.

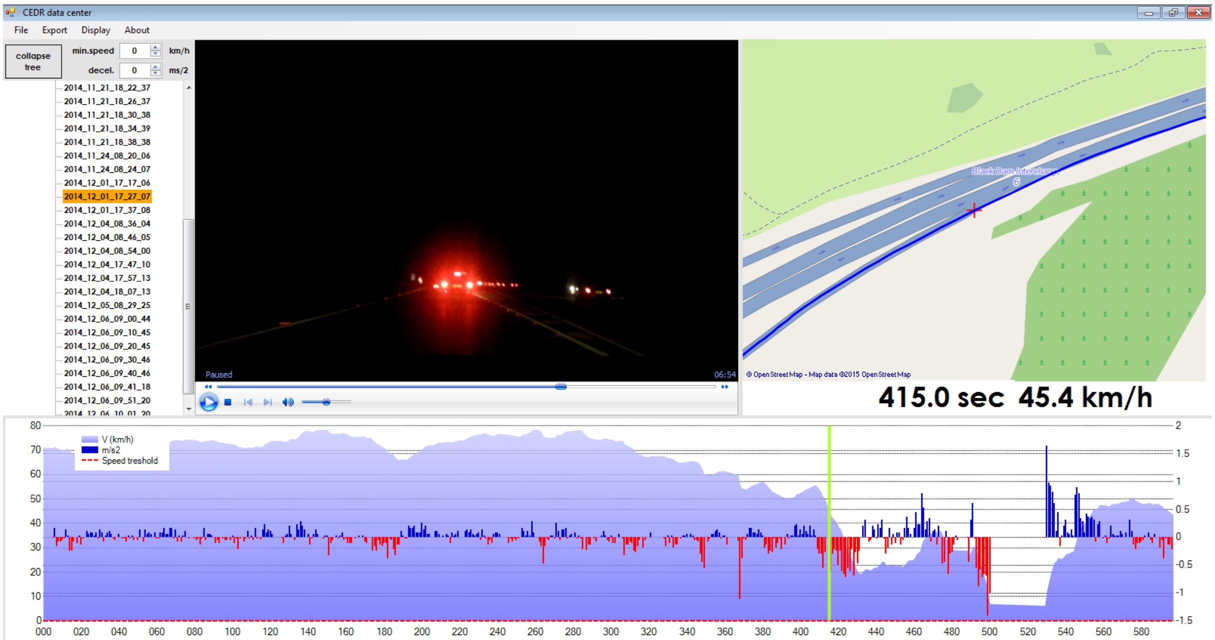
In miles/h instead of km/h

Date and time	2014_11_14_09_11_52
Location	M3
Start speed	70 km/h
End speed	5 km/h
Speed drop	65 km/h
Maximum deceleration	3.0 m/s^2
Duration of the braking	15s
Conditions	Rain, daylight
Road surface	Wet
Description	Deceleration on an exit ramp of the M3. Participant has to brake for a queue waiting for traffic lights.



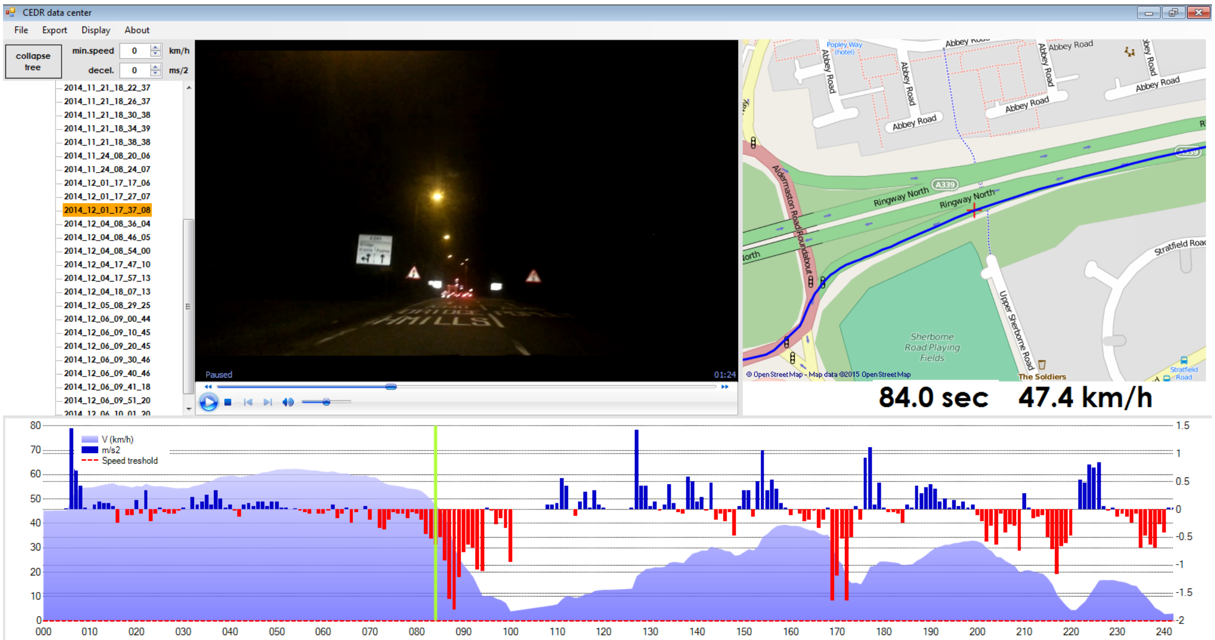
In miles/h instead of km/h

Date and time	2014_11_21_18_30_38
Location	M3
Start speed	80 km/h
End speed	10 km/h
Speed drop	70 km/h
Maximum deceleration	2.5 m/s^2
Duration of the braking	15s
Conditions	Dry, dark
Road surface	Dry
Description	Deceleration on an exit ramp of the M3. Participant has to brake for a queue waiting for traffic lights.



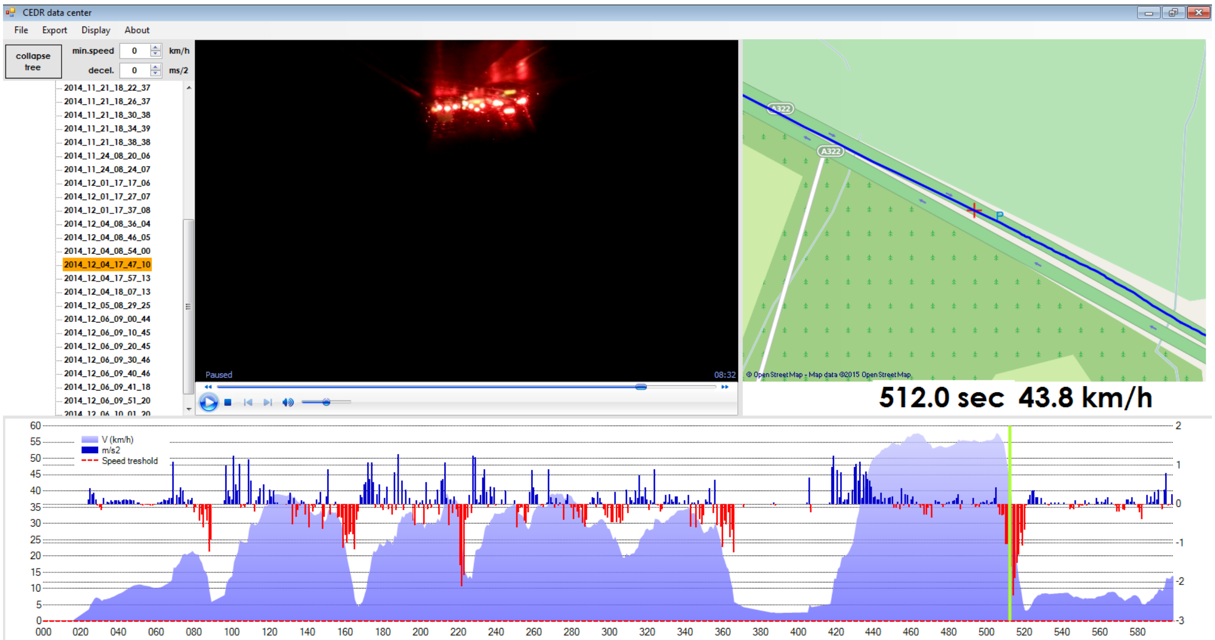
In miles/h instead of km/h

Date and time	M3
Location	2014_12_01_17_27_07
Start speed	95 km/h
End speed	35 km/h
Speed drop	60 km/h
Maximum deceleration	1 m/s^2
Duration of the braking	15s
Conditions	Dry, dark
Road surface	Dry
Description	Deceleration on an exit ramp of the M3. Participant has to brake for a queue waiting for traffic lights.



In miles/h instead of km/h

Date and time	2014_12_01_17_37_08
Location	A339
Start speed	90 km/h
End speed	5 km/h
Speed drop	85 km/h
Maximum deceleration	3 m/s^2
Duration of the braking	15s
Conditions	Dry, dark (lighting)
Road surface	Dry
Description	Deceleration on an exit ramp of the A339. Participant has to brake for a queue waiting for traffic lights.



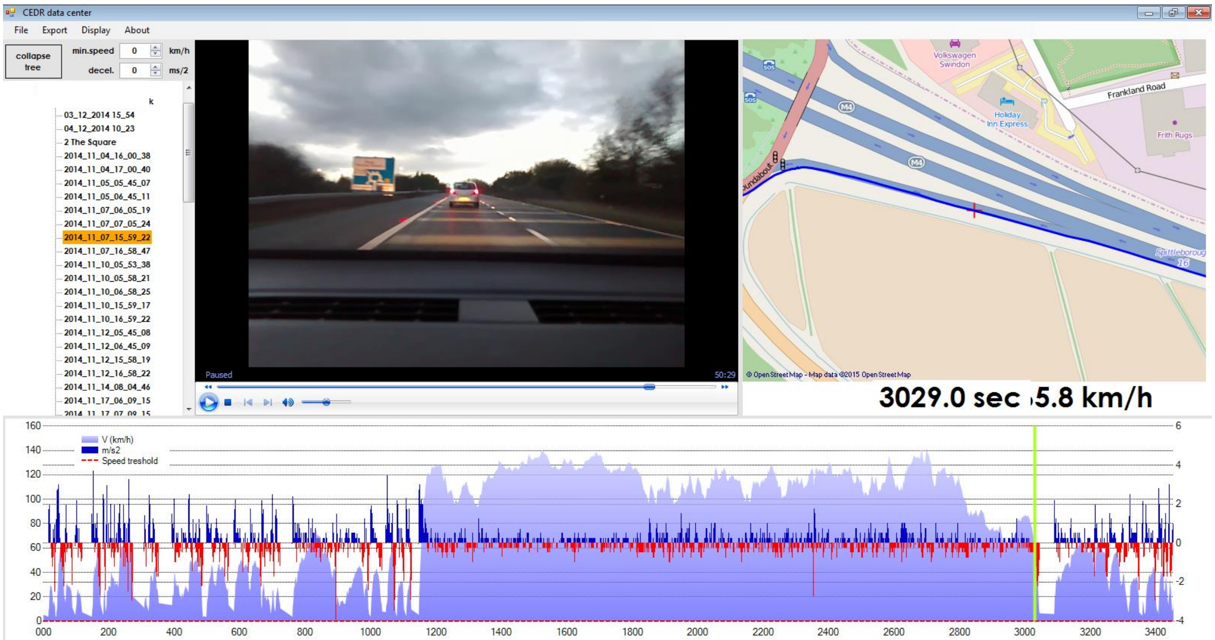
In miles/h instead of km/h

Date and time	2014_12_04_17_47_10
Location	A322
Start speed	90 km/h
End speed	5 km/h
Speed drop	85 km/h
Maximum deceleration	4 m/s^2
Duration of the braking	10s
Conditions	Wet, dark
Road surface	Wet
Description	Participant has to slow down for a queue on the mainline carriageway

Participant 4

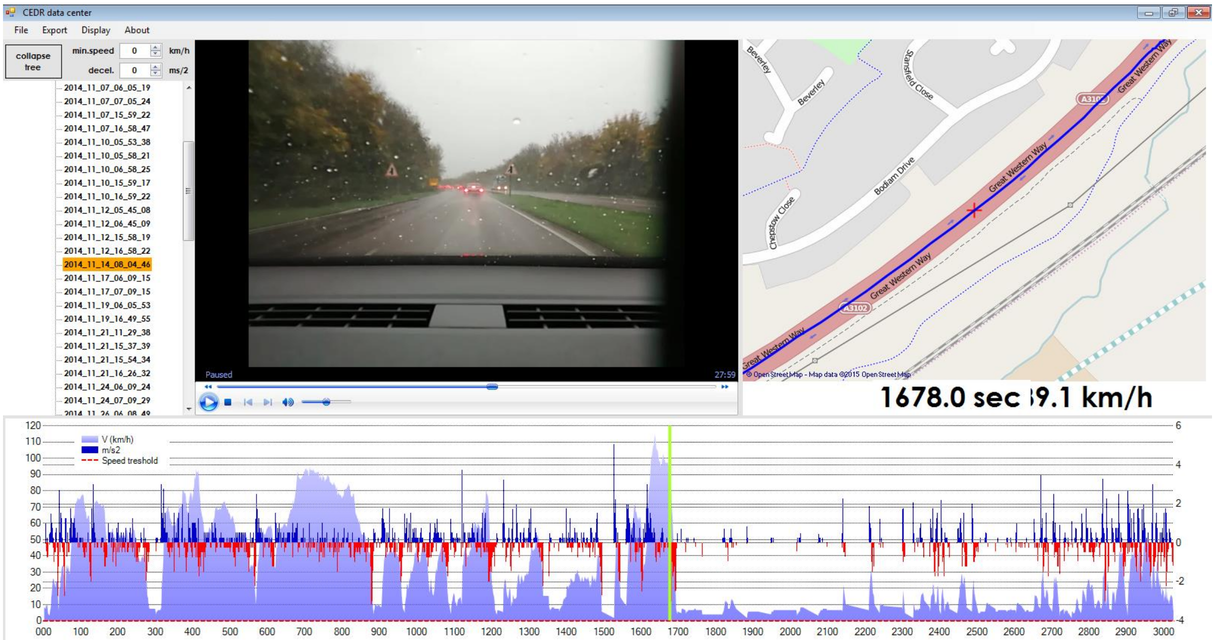
Date and time	2014_12_03_08_19_46
Location	A3290
Start speed	110 km/h
End speed	10 km/h
Speed drop	100 km/h
Maximum deceleration	4 m/s^2
Duration of the braking	20s
Conditions	Dry, daylight
Road surface	Dry
Description	Participant has to slow down for a queue on the mainline carriageway

Participant 5

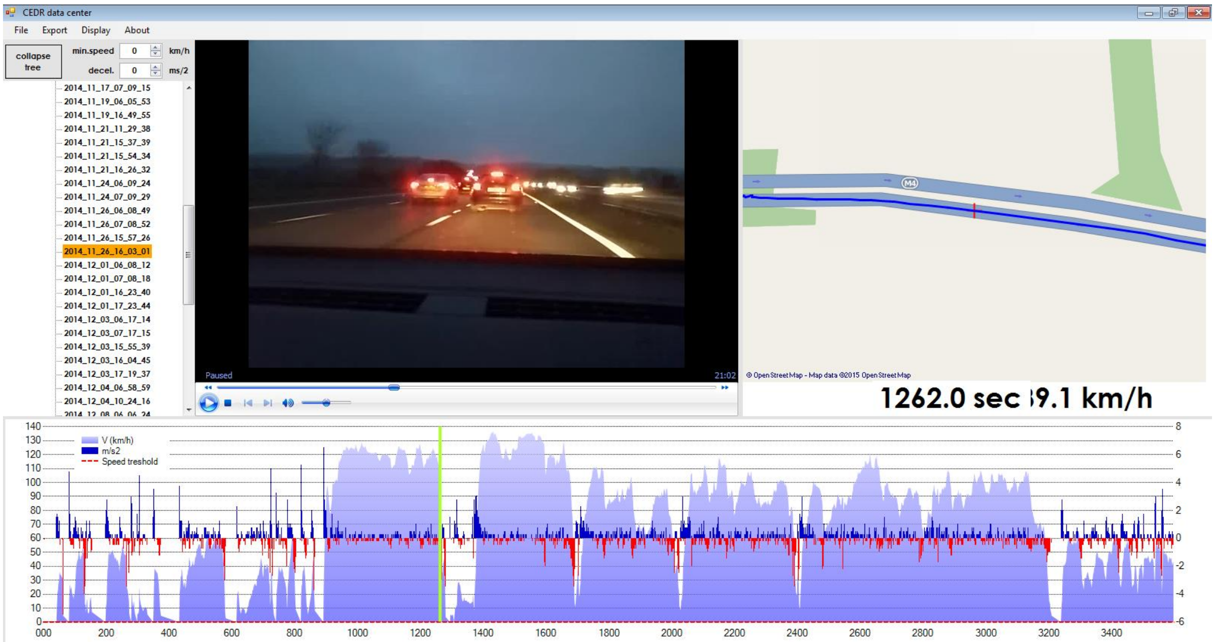


Date and time	2014_11_07_15_59_22
Location	M4
Start speed	80 km/h
End speed	5 km/h
Speed drop	75 km/h
Maximum deceleration	2 m/s^2
Duration of the braking	10s
Conditions	Dry, daylight (sunset)
Road surface	Wet
Description	Deceleration on an exit ramp of the M4. Participant has to brake for a queue waiting for traffic lights.

Date and time	2014_11_12_15_58_19
Location	M4
Start speed	100 km/h
End speed	0 km/h
Speed drop	100 km/h
Maximum deceleration	2 m/s^2
Duration of the braking	20s
Conditions	Dry, daylight (sunset)
Road surface	Dry
Description	Shockwave on the M4. Participant has to slow down to a standstill and can accelerate again to 100 km/h.



Date and time	2014_11_14_08_04_46
Location	A3102
Start speed	110 km/h
End speed	5 km/h
Speed drop	105 km/h
Maximum deceleration	3.5 m/s^2
Duration of the braking	15s
Conditions	Rain, daylight
Road surface	Wet
Description	Participant has to slow down for a queue on the mainline carriageway



Date and time	2014_11_26_16_03_01
Location	M4
Start speed	120 (100) km/h
End speed	0 (0) km/h
Speed drop	120 (100) km/h
Maximum deceleration	3.5 (2) m/s^2
Duration of the braking	15 (10) s
Conditions	Dry, sunset
Road surface	Dry
Description	Participant has to slow down for a queue on the mainline carriageway. Hard braking.