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Potential benefits of in-vehicle systems for understanding driver behaviour
A series of small-scale ND studies in Israel
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Abstract

The main objective of the PROLOGUE (PROmoting real Life Observations for Gaining Understanding of road user behaviour in Europe) is to contribute to the reduction of road casualties by exploring, developing, testing and promoting naturalistic observation methodology. This is done by proving the feasibility and usefulness of a large-scale European naturalistic driving observation study.

The Israeli trial, described in this report, is focusing on several aspects of naturalistic studies in order to demonstrate the large potential of naturalistic studies for gaining understanding on road users' behaviour towards the ultimate goal of improving behaviour and consequently reducing injuries and fatalities.

Within the Israeli trial, a number of small-scale naturalistic field trials are conducted. All trials use off-the-shelf in-vehicle technologies which identify and report extreme, pre-defined driving events. The events identified are G-force based and vision-based. The capability of the technologies to provide valid and meaningful information on driving behaviour is explored and discussed.

Several innovative research questions are addressed and discussed within this trial, including: a comparison of events obtained by two totally different technologies installed in the same car, evaluation of proxies to "near-crashes" based on in-vehicle systems that do not contain continuous video information, geographical and spatial analysis of G-force based events of young novice drivers and their parents, a comparison of young drivers' driving behaviour between the period immediately after licensure and 4 years later, and an evaluation of "group" driving characteristics of young drivers belonging to the same social group.

Valuable insights, as well as the overall contribution and potential for future naturalistic studies are explored and discussed.
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Executive Summary

The main objective of the PROLOGUE (PROmoting real Life Observations for Gaining Understanding of road user behaviour in Europe) is to contribute to the reduction of road casualties by exploring, developing, testing and promoting naturalistic observation methodology. This is done by proving the feasibility and usefulness of a large-scale European naturalistic driving observation study.

The Israeli trial, described in this report, is focusing on several aspects of naturalistic studies in order to demonstrate the large potential of naturalistic studies for gaining understanding on road users' behaviour towards the ultimate goal of improving behaviour and consequently reducing injuries and fatalities.

The Israeli field trial is composed of four small-scale naturalistic field trials. Each trial investigates specific research questions through monitoring and modelling specific behaviours. The common thread of all 4 trials is that they all use off-the-shelf in-vehicle-data-recording technologies (IVDR), which identify and report extreme, pre-defined driving events. These events include G-force based events of the vehicle and vision-based out-of-vehicle events. In this study, all events are discrete and no continuous monitoring of behaviour is performed. The potential of analysing naturalistic data based on discrete events is explored, and the tradeoffs between discrete and continuous data collection are discussed.

The four sub-trials are focusing on:

- **IL1**: Integration and comparison of data generated from two different in-vehicle technologies.
- **IL2**: Behavioural, geographical and spatial aspects of driving exposure and driving behaviour of young drivers and their parents.
- **IL3**: Comparison of driving exposure and driving behaviour of young drivers immediately after licensure and 4 years later.
- **IL4**: Modelling driving behaviour of a socially related group of young drivers, and comparison of young drivers belonging to different social sectors and different countries.

The Naturalistic data collected from all trials was used to address several innovative and complex research questions, including: a comparison of events obtained by two totally different technologies installed in the same car, evaluation of proxies to "near-crashes" based on in-vehicle systems that do not contain continuous video information, geographical and spatial analysis of G-force based events of young novice drivers and their parents, a comparison of young drivers' driving behaviour between the period immediately after licensure and 4 years later, and an evaluation of "group" driving characteristics of young drivers belonging to the same social group.

Additionally, several unique comparisons of naturalistic data are addressed. These include: a comparison of naturalistic data to self-reports, a comparison of driving behaviour of young drivers belonging to different social groups and a comparison of young drivers in Israel and in Austria.

In order to conduct the trials and the data analyses required for this trial, several tools were developed, calibrated and implemented. This includes: the development of an application to record and store on-line alerts from in-
vehicle systems, a map-matching tool to associate discrete events with a geographical network system, and integration of data streams emanating from different sources.

The results and insights obtained from this trial constitute a solid contribution to the area of naturalistic data collection, analysis and understanding. Due to the small size of the trials, the nature of the results obtained emphasizes feasibility and potential rather than representative conclusions on behaviour.

In the first trial we demonstrated the capability to integrate two different in-vehicle systems and consequently to provide a comprehensive data set on drivers’ behaviour. The results indicate that the various variables measured by the two systems are complementary, and that when put together they provide a better picture of overall drivers’ behaviour.

In the second trial we explored the potential of in-vehicle systems to document the temporal and spatial aspects of the driving behaviour of novice young drivers. This trial examines the driving exposure and measures of risk of novice drivers during the first year after licensure. Special interest is paid to the differences in driving exposure parameters in the different phases of the Israeli graduated driver licensing (GDL) program. The exposure parameters analyzed include the amount of driving, temporal distribution of driving, risky behaviour and the spatial aspects of driving.

In the third trial we examine driving patterns of young drivers 3-4 years after receiving their driving license. This is accomplished by re-installing in-vehicle systems to the same drivers who participated in a similar study 3-4 years ago. Exposure rates as well as safety levels and safety events are compared. The results indicate that young drivers do not drive safer 3-4 years after they received their driving license. The comparison to the previous study results revealed that whilst driving patterns generally remain similar, their sensation seeking has not changed and in the main, no significant change occurred in the event rates. However, an interesting improvement in driving behaviour has occurred in the cool-off stage and the impact of negative factors, e.g., night-time, is relaxed. It was also found that comparison of naturalistic data and self reports revealed differences between the two methods.

In the fourth trial the reflection of the social environment on the driving behaviour was studied. We examined the driving behaviour of young drivers from a single community and studied their driving patterns in light of their social connections. No correlations of driving pattern among socially related participants were found. However, findings suggest that the outliers of the group may explain some of the general group behaviour and (good) driving norms. In this trial we also compared this group to a group of un-related individuals. A notable difference in the variance of these two groups was found, though in the opposite direction than was expected (the variance in the community group was higher than in the group of individuals). However, there were too many confounding variables in order to reach rigorous and robust conclusions.

The overall contribution and insights of the 4 trials conducted is thoroughly explored and discussed. This includes:

- **Generation of naturalistic data.** The data collected in the various sub-trials reflect naturalistic data corresponding to actual undisturbed behaviour performed by participants using their own private cars. In most
cases, the IVDR systems were non-visible and were assumed to cause minimal or no change to the driver's driving environment.

- **Exposure data.** The various sub-trials created a large data-base of actual driving exposure. This data can be easily analyzed according to a wide range of parameters, such as: characteristics of the driver (i.e. gender, age, level of driving experience), temporal characteristics (i.e. day of the week, time of the day), characteristics of the network (i.e. urban, rural, highway, intersections, roundabouts), and vehicle usage among family members and more. The scope and depth of detail in exposure data obtained by these methods is unique. The possibilities for obtaining representative data through appropriate sampling needs to be explored.

- **Use of (relatively) cheap, off the shelf products, for naturalistic research.** In classical naturalistic studies – continuous, video-based data collection procedures are typically used. These procedures are expensive both in term of cost & data storage requirements as well as data analysis & reduction efforts needed. The technologies used in this trial are relatively cheap, easy to install, user friendly and non-obtrusive, which do not require any interference for data downloading. The trials conducted demonstrate the ease with which naturalistic data collection can be performed in various situations and scenarios.

- **Integration and synchronization of data from two independent IVDR systems.** In IL1 we demonstrated the feasibility of installing, collecting and synchronizing data from two IVDR systems and integrating it into meaningful information. The relations, interactions and complementarities of the two technologies were presented and discussed.

- **Comparisons.** Collecting and storing ND is not enough. Meaningful statements on its content and interpretation need to be derived and validated. In this trial we have demonstrated, through various examples and test-cases, how ND could be compared and analyzed according to diverse measures, such as: comparison to baseline behaviour (in IL3 where the GR system was re-installed in cars of young drivers 4 years after their licensure), distinctive audiences sharing common characteristics (in IL4 young drivers belonging to different communities with different social background), special time periods (in IL2 according to stages in the licensing process), unique relations among participants (in IL4 – young drivers belonging to the same community, living in the same area and know each other) and more.

- **Comparisons to self-reports.** As much as the value of ND becomes apparent and more widely accepted and used – self reports still remain the most popular (and definitely the cheaper) tool for data collection on behaviour. In IL3 we have explored the relations between ND and self reports and estimated the differences, similarities and biases between them. The data obtained, shows very clearly, the bias towards over-estimation of exposure rates as well safety levels – most participants report longer driving times and higher safety levels than what is actually measured by the IVDR. Understanding and evaluating the differences between ND and self-reports has huge practical value.

- **Creation of indications to deal with near-crashes based on non-continuous event-based data.** The possibility to generate good candidates for near-crashes based on non-continuous event based data was explored and demonstrated. In some cases it was even validated.
However, the extent of false-negatives (missed indications) is still unclear. This contribution can be used for analyzing near-crashes based on discrete events, or for data reduction of continuous data.

- **Creation of a map-matching tool.** The tool developed (in IL2) for associating discrete events to road segments was used to analyze aggregate data according to network characteristics. This tool can be further developed and used for multiple purposes such as: analysis of aggregate data, normalization according to specific routes taken, analysis of driving behaviour according to driving purpose and network features and more.

- **Highlighting the importance of clear and uniform terminology and definitions.** The results (in IL1) showed that even seemingly trivial information such as the time, trip start and trip end may be inconsistent when different definitions and measurement methods are used. Furthermore, the variety of sub-trials conducted emphasized the need to generate clear and uniform terminology and definitions.

- **Demonstration of the ability to address complex and original research questions.** In this trial we addressed several innovative research questions. The results obtained were, at least in some cases, surprising. Despite the small samples, these unexpected results generated insights into the importance of collecting ND, as well as to raising questions regarding the ability of the data collected to truly and completely portray driving behaviour.

Finally, the potential of using the insights gained from the current field trials to advance the research-front and conduct large-scale naturalistic studies is discussed.
1 Introduction

1.1 General

The Israeli field trial is aimed at extracting and understanding driving behaviour through the use of data from two types of off-the-shelf in-vehicle-systems (G-force based and vision based systems). The trial is focused on demonstrating the capability to generate reliable and meaningful information based on naturalistic data generated from IVDR systems. The logistical and methodological aspects needed in order to collect, extract and analyse the data are explored and discussed. The main emphasis of the trial is on studying young drivers' behaviour from several aspects.

The trial is divided into 4 chapters and 6 sub-trials:

**IL1** - The first sub-trial is aimed at **studying driving behaviour and style using two different technologies: a G-based event-triggered data recorder and a vision-based driver assistance system.** Within this trial both systems are installed in 10 private vehicles of experienced drivers. The relations and correlations between the data generated by the two technologies, as indicators of drivers' behaviour, are explored. The main aim of this sub-trial is to compare and evaluate the data generated from the two technologies.

**IL2** - The second sub-trial examines the **driving exposure and exposure to risk of novice drivers** in the first year of driving along different phases of Graduated Driving License (GDL) - accompanied driving and independent driving. This trial is based on data from a study conducted earlier (the "First-year study"). In the current study, data analysis is extended to include geographical and spatial aspects of driving and the detailed location of events. Other parameters of exposure, such as: amount of driving, time of driving and risky behaviour is analyzed. The data base includes driving data of 80 young drivers for a period of 9 months after licensure, which includes both the accompanied driving phase and the independent driving phase. The main aim of this sub-trial, apart from the issue under study, is to explore the potential and capabilities of this technology.

**IL3** - The third sub-trial is a **follow-up study of the previous "First-year study",** in which we re-install the IVDR technology in cars of young drivers 3-4 years after they got their license. These are drivers that already drove with the system for 9 months during their first year of driving. The aim of this sub-trial is to explore the potential and capabilities of the technology to monitor evolution of driving patterns over time.

**IL4** - The fourth sub-trial consists of three parts in which various comparisons of driving behaviour among young drivers are made. The major part of this trial, **IL4a**, is the "community model" where participants are young drivers in their first year of driving who live in the same community, thus familiarity among the young drivers and their parents is higher than in previous studies (that are based on individual participation). Furthermore, all participants live in the same geographic environment, thus enabling us to control some environmental variables. Driving behaviour of the group participants is
captured and analyzed. In this sub-trial we also compared this group to a different social group (IL4b), and finally we developed the infrastructure for comparing two groups of young drivers from different countries (IL4c).

1.2 Research questions

The specific research questions of each sub-trial are specified in detail in the sub-trial reports. Generally, the emphasis is on documentation and evaluation of driving performance (according to the measured variables) as a function of experience, network characteristics, drivers' characteristics and feedback from the in-vehicle systems. Hence, all the Israeli sub-trials collect and analyse measures relating to driving exposure (how much, how many, when, where) and driving style (how) as expressed through specific manoeuvres and pre-defined events.

The Israeli trial also addresses the potential of ND to perform and evaluate different types of comparisons: This potential is demonstrated through comparison of the data obtained from two different in-vehicle systems (in IL2), through comparing young novice drivers from different socio-cultural groups (in IL4), comparison between Israeli and Austrian young drivers (in IL4), comparing of driving behaviour of young drivers with different driving experience (in IL3) and comparison of ND to self reports (in IL3).

Some of the research issues addressed in this trial are, to the best of our knowledge, novel and have not been addressed in the scientific literature before. These research issues include:

- A comparison of events obtained by two totally different technologies installed in the same car - vision-based versus G-force based (in IL1).
- Evaluation of proxies to "near-crashes" based on in-vehicle systems that do not contain continuous video information (in IL1).
- Geographical and spatial analysis of G-force based events of young novice drivers and their parents (in IL2).
- A comparison of G-force based events of young drivers between the period immediately after licensure and 4 years afterwards (in IL3).
- Evaluation of "group" driving characteristics of young drivers belonging to the same and different social groups (in IL4).

1.3 Technologies used in the trial

In this section, the technologies and data collection procedures used in the Israeli trial are described. Off-the-shelf event triggered technologies are used in the trial:

A G-force based in-vehicle-system developed by GreenRoad Technologies (GR).
A vision-based headway, forward collision and lane departure warning system developed by MobilEye (ME).

The GreenRoad system is used in all sub-trials, the MobilEye system is used in sub-trial IL1.

1.3.1 The GreenRoad in-vehicle-system

The GreenRoad IVDR system (GR) is a G-force based system which tracks all trips made by the vehicle it is installed in and records the following information:

- Trip start and end time
- Driver identification
- All excessive manoeuvres that have been identified ("events")
- Evaluation of the severity of each event
- Vehicle location (at fixed time intervals)

The overall framework of the system is shown in Figure 1.1. The system incorporates four layers of data collection and analysis: measurement, identification, analysis and reporting.

The first layer in the system is the measurement module, which collects the two-dimensional acceleration and speed of the vehicle at a sampling rate of 40 measurements per second. This raw information is analyzed in two information processing layers. The first is a detection and evaluation layer, which incorporates pattern recognition algorithms to identify and classify over 20 different manoeuvre types in the raw measurements. Examples of these manoeuvres include: lane changes with and without acceleration, sudden brakes, strong accelerations, excessive speed (over 120 km/h) and more. The manoeuvres detected are classified into five major categories – braking, accelerating, turn handling, lane handling and speeding. The quality of performance of the detected manoeuvres is also evaluated. This evaluation is based on parameters of the detailed trajectory of the vehicle during the manoeuvre, such as its duration and smoothness and extent of sudden changes in the vehicle movement, and on the speed it is performed at. The various information elements are transmitted in real-time, continuously throughout the trip, using GPRS wireless networks to an application server, which maintains a database with vehicle-specific and driver-specific trip history. The next layer, which resides in the application server synthesizes the specific manoeuvres that were identified to evaluate an overall driving risk index at the level of the individual trip and of the vehicle overall performance, to characterize and to classify the driver's profile. In the current implementation drivers are classified into three categories (cautious, moderate and aggressive) based on the rate and severity of manoeuvres they generate and on their speed profile.

The final layer is a reporting layer that provides feedback based on the information collected in the database. This may be done both off-line and in real-time. In an off-line application, various reports that summarize and compare information at the level of the driver, vehicle or an entire fleet.
are produced and viewed as printed reports or through a dedicated website. Real-time feedback, which typically includes warnings on aggressive behaviour or on significant deviations from the normal driving patterns compared to a pre-defined baseline of the fleet, can currently be provided in two ways: through a text message sent to the driver or to others (e.g. fleet managers, parents of a young driver) or through an in-vehicle display unit (as demonstrated in Figure 1.2).

![Figure 1.1: Overall framework of the GR IVDR system](image)

All trips performed by the equipped vehicle are monitored and the driver in each trip is identified at the beginning of each trip by using a personal magnetic identification ("dallas") key. In cases where the driver did not identify himself/herself, the trip is recorded with no driver identification.
In the feedback mode, a web-based application provides drivers with reports that summarize and compare information at the level of the driver. An example of a monthly driver report is presented in Figure 1.3 (a). The chart shows the various trips that the driver performed during the month, where each square represents a trip. The X-axis indicates the day of the month and the Y-axis indicates the number of trips performed during each day. Trips are colour-coded according to their classification: green (cautious), yellow (moderate) and red (aggressive). Black triangles correspond to night trips. Detailed information on each trip can be displayed by clicking on the specific trip's square, as presented in Figure 1.3(b). In addition, the report includes statistics of the total hours driven during the month and comparison of the driver’s performance to previous months. Drivers are categorized as green, yellow and red drivers according to the amount and rate of their events where green drivers perform less than 20 manoeuvres per 10 driving hours, yellow drivers perform between 20 and 50 manoeuvres per 10 driving hours, and red drivers perform more than 50 manoeuvres per 10 driving hours.
The GR version used in the current trial is V4.

The cost of the GR system varies according to specific parameters of the implementation and service plan, roughly speaking it ranges approximately between 100-300 US$.
Further information on the technology and examples for its use can be found in the manufacturer's site http://www.greenroad.com/. For previous studies with the system see Toledo et al (2008) and Prato et al (2010).

1.3.2 The MobilEye in-vehicle-system

The MobilEye technology (ME) that is used in the current trial is a vision-based driver assistance system that provides three types of warning alerts:

- headway monitoring and warning (HW)
- forward collision warning (FCW)
- lane departure warning (LDW)

The system includes a single smart camera located on the front windshield inside the vehicle, a processing unit, a display and speakers. The ME processing unit is also interfaced to output signals from the vehicle (vehicle speed sensors, signals and brakes).

The technology is offered as an OEM (Original Equipment Manufacturer) or aftermarket product. Within this trial, we used the aftermarket product also known as the AWS-4000 model/version. This version provides real time alerts only and does not record any data for off-line monitoring or analysis.

The technical specs of the hardware are described in ME's website1. A detailed description of the system, its algorithms and functions can also be found through ME's website2.

As the data is collected via a single camera, advanced algorithms are used to define the region of interest, classify the relevant frames, screen and approve multi-frames and determine the range. A partial demonstration of this process is presented in Figure 1.4, taken from Gat et al. (2004), which shows an example sequence of a truck at various distances. The distance from the horizon line to the bottom of the truck is smaller when the truck is more distant (a) than when it is close (b and c). As the distance to the target vehicle decreases the size of target vehicle in the image increases.

The cost of the system varies according to location and service plans - roughly speaking it is of the order of 1000-1500 US$.

2 http://www.mobileye.com/manufacturer-products/white-papers
Figure 1.4: An example sequence of a truck at various distances.

Following is a description of each warning provided by the MobileEye system.

**Lane Departure Warning (LDW)**

The LDW module detects lane boundaries, finds the road curvature, measures position of the vehicle relative to the lanes, and provides indications of unintentional deviation from the roadway in the form of an audible rumble strip sound. This feature is demonstrated in Figure 1.5. The system can detect the various types of lane markings: solid, dashed, boxed and cat-eyes, and also makes extensive use of vehicle detection in order to provide better lane detection. In the absence of lane markings the system can utilize road edges and curbs. It measures lateral vehicle motion.
to predict the time to lane crossing providing an early warning signal before the vehicle actually crosses the lane. Lane departure warnings are suppressed in cases of intentional lane departures (indicated by activation of turn signal), braking, no lane markings (e.g. within junctions) and inconsistent lane markings (e.g. road construction areas).

Headway monitoring and warning (HW)

The headway monitoring module provides constant measurement of the distance in time to the current position of the vehicles driving ahead in the same lane. The ability to indicate a current in-path vehicle is dependent upon the information from the lane detection module. The headway display provides a visual indication when insufficient distance is being kept to the vehicle ahead, as well as a clear numeric display (in seconds) which provides an accurate cue for driving habits improvement for the driver.

Forward Collision Warning (FCW)

The FCW module continuously computes time-to-contact to the vehicle ahead, based on range and relative velocity measurements. An advanced image processing algorithm determines whether the vehicle ahead is in
a collision path (even in the absence of lane markings) and provides audio
warnings to the driver at predetermined time intervals prior to collision
(e.g. 2.5, 1.6 and 0.7 seconds). The system uses information about driver
actions (e.g. braking) to suppress warnings in situations that are under the
driver’s control.

Further information about the technology and examples for its use can be
found in the manufacturer’s site http://www.mobileye.com/ and in

For previous studies with the system see Gat et al. (2004).

1.4 Main findings from research conducted earlier with the GR
IVDR system

The performance and effectiveness of the GR system was evaluated in
earlier studies (Toledo et al, 2008). Among other things, the connection
between drivers’ scores and events and their safety level and performance
was studied. For this purpose, driving records of manoeuvres and their
severity ratings were used to calculate composite risk indices. Risk indi-
ces are expressed as a linear function of the number and severity of the
manoeuvres for each driver in each time period, normalized by the driving
time in that time period:

$$R_{it} = \frac{N_{it}}{DT_{it}} = \frac{\sum \sum \beta_{j\mu} M_{ij\mu}}{DT_{it}}$$

where $R_{it}$ is the risk index for driver $i$ during time period $t$, $N_{it}$ is the equiva-
 lent number of events for driver $i$ during time period $t$, which is calculated
as a weighted sum of the number of manoeuvres for the driver, $DT_{it}$ is
the driving time for driver \( i \) during time period \( t \), \( M_{ist} \) is the number of manoeuvres of type \( j \) and severity level \( s \) for driver \( i \) during time period \( t \), and \( \beta_{js} \) are weights of the manoeuvres of type \( j \) and severity level \( s \).

Based on pilots conducted with experienced drivers, these indices have been shown to be positively correlated with drivers’ actual crash records and in particular with at-fault crash records (Toledo et al., 2008).

Following this important finding, Or Yarok initiated a study to evaluate the effectiveness of installing an IVDR system in cars of young drivers. For this purpose, cars of 120 families of young drivers were equipped with the IVDR system. Participating families were screened to verify that most or all the trips made by the newly licensed driver would be on the vehicle in which the IVDR was installed, and that this vehicle was also the main vehicle used by the accompanying person. It is important to note that, since participation in the study was on a voluntary basis, the sample is not representative of the Israeli population and is likely to be biased towards self-selection of families with high awareness and willingness to participate.

The data collected during the trial was analysed according to the following phases of the Israeli GDL program and the study design (for more details about the GDL program, see section 1.6):

**Accompanied driving phase**: During the first three months after license, young drivers in Israel must be accompanied by an experienced driver whenever they drive. At this stage the vehicles have already been instrumented but the young drivers and their families do not receive any feedback from the IVDR. Furthermore, only minimal explanation about the purpose and capabilities of the IVDR is given to the families.

**Blind-profiling (solo) phase**: Once the accompanied driving period ends, drivers are allowed to drive without supervision (solo driving) with only a restriction on the number of passengers they can take. At this point drivers still do not receive any feedback from the system. This phase lasted approximately 1 month.

**Feedback phase**: At the end of the blind profiling (about 4 months after license) the young drivers and their families are given access codes to personal web page, which present the information relating to all the trips they have made. Each family can only access the information about trips made in their vehicle. However, in order to put this information in context, they also receive information about the average behaviour of other participants in the experiment. The web pages are continuously updated in real-time with new information as new trips are made. Approximately a month later the in-vehicle real-time feedback unit was turned on.

During the trial, drivers were asked to identify themselves using their identification keys. However, there was no mechanism to reward correct identification or punish an incorrect or missing identification. Participants were sent a list of trips with an unidentified driver on a weekly basis. They were then asked to identify the drivers of those trips. This is a cumbersome procedure that the required significant administrative effort and was not always well accepted with the participants.

For each participant the data collection took place over a period of 9-12 months. Overall, the data was collected from September 2005 up to May 2009.

The data collected in this study were used to develop a model that tried to explain the risk taking behaviour of the novice young drivers as cap-
tured by the monthly risk indices during the first year after licensure. Initial results suggest that the risk taking behaviour of young drivers is influenced by gender, sensation seeking tendency, driving behaviour of their parents, amount of supervised driving and level of parental monitoring. For a detailed description of this study and its results, see Lotan and Toledo (2010) and Prato et. al. (2010).

The data from this study, noted hereafter as the "First-year study" was available to the researchers in the PROLOGUE Israeli trial. Thanks to the availability of this data base, various novel and complex research questions could be addressed. These topics are described in detail in IL2, IL3 and IL4.

1.5 Methodology

1.5.1 Participants

All participants in the trial have access to a privately owned or leased car. Hence all data collected is naturalistic in the sense that all trips are performed by the participants following their usual driving routine behaviour without any control or interference regarding trip purpose, route, timing, number of passengers etc.

In general, two major types of drivers participated in the 4 sub-trials; experienced drivers in IL1 and young and experienced drivers in IL2, and young drivers in IL3 and IL4. The recruitment procedures, participants' screening and characteristics of the participants are described in detail in each sub-trial description.

1.5.2 Experimental design

Participant in each of the 4 trials went through at least two types of the following phases along the trial:

- **No-feedback phase** in which no feedback, whatsoever, is provided to participants
- **Feedback phase** in which some feedback is provided to participants

The data collected in the no-feedback phase is purely naturalistic whereas the feedback phase provides some insights into the effects of the intervention. Whenever possible we tried to follow the full experimental design specified in Figure 1.8 below:
According to this design, the data collected in phase I (also called "blind profile phase") is purely naturalistic, the data collected in phase II is (potentially) affected by the intervention, and the data of phase III (also termed "cool-off stage") is partially naturalistic as it might carry some effects of the intervention.

In sub-trial IL3 the full experimental design, as appears in Figure 1.8, was carried out. In IL1 phase I was missing as some of the participants were already familiar with the in-vehicle systems. In IL2 and IL4 phase III was missing.

It should be clarified that even though that all participant experienced at least two of the phases at some order, the analyses refer to the effect of intervention only in some of the trials.

Data
The data used in the trial included new collected data and existing data as follows:

IL1: 10 cars of experienced drivers were equipped with ME and GR systems

IL2: data from the "First-year study" was used

IL3: data from the "First-year study" and new data collected from 31 cars equipped (again) with the GR system of the same drivers who participated in the "First-year study"

IL4: 13 equipped cars with the GR system of young drivers belonging to the same social groups. Comparisons to the data of the "First-year study" were made.

1.5.3 Legal and ethical issues

All participants signed an informed consent form (ICF), and in the case of minors, parents' signature was requested as well. The ICF followed the guidelines set by the 100-Naturalistic driving study (as appears in Deliverable D2.2 of the PROLOGUE) with emphasis on protecting participants' privacy and stating participants' right to stop their participation in the trial and/or erase the data collected at any point in the trial. Furthermore, an
ethical code for OR YAROK, prepared especially for this trial, required that researchers would not have an access to the data collected from the vehicles until the end of the data collection phase. This was required in order to make sure that researchers carry no responsibility whatsoever for the driving behaviour of the participants as long as data is being collected.

1.6 The Israeli licensing system – background information

Since most of the trials included in this report deal with young drivers, a short summary of the Israeli licensing process is described below.

In Israel, young drivers can start taking on-road driving lessons with a professional instructor at the age of 16.5 years. Learners are not allowed to drive outside these lessons. In order to take the on-road driving test, learners must attend at least 28 driving lessons, be at least seventeen years old and pass a theoretical test. Starting in 2000, a (limited) Graduated Driving Licensing (GDL) program was implemented. Following this program two distinctive stages were introduced:

Accompanied driving phase: during the first three months after licensure novice drivers must be accompanied by an experienced driver (at least 24 years old and holds a valid driving license for at least five years), whenever they drive.

Solo driving phase: Once the accompanied driving period ends, the driver is allowed to drive unattended. Up to two years after licensure, the novice drivers are subject to passenger limitations according to which no more than two passengers are allowed) unless an experienced driver is present in the vehicle (provisional license). Two years after licensure and if no traffic violations are registered, the young drivers receive a full license.

1.7 Important comments:

As in all trials in WP3 of PROLOGUE - the emphasis of the trial is on demonstrating feasibility and showing potential of collecting different types of naturalistic data (ND) to answer new and complex research questions, rather than on performing large scale and representative trials and drawing statistically significant results on behaviour.

All the data collected in the trial is automatically collected, reduced and transmitted. For one of the technologies used, this was an inherent feature of the system. For the other, this feature was developed especially for this trial (as described in IL1). This enabled us to perform long duration trials without disturbing participants for data downloads. It also enabled an objective comparison between the technologies.

A very large data set was collected and assembled for all the sub-trials in the Israeli trial. Vast and varied types of analyses of this data set are possible. Due to time and capacity constraints, we focused on limited and topic-specific types of analyses, which naturally, do not
cover the whole possible spectrum of the analysis and insights that could be derived from the data. Topics for further analysis are discussed in the summary of each sub-trial.
2 Integration of G-based and video–based event-triggered information (IL1)

2.1 Introduction

In recent years, advanced driver assistance systems (ADAS) are increasingly being used to enhance and improve road safety. These technologies are mainly aimed at decreasing undesired or unsafe driving behaviours, thus reducing the probability of crash involvement. A large body of literature is devoted to examine the effect of these systems on road safety. For a review of ADAS see, for example, Vlacic et al. (2001). A number of EU-sponsored projects, such as ADASE, EuroFOT, AIDE, COOPERS and others, develop and evaluate various ADAS based on Field Operational Tests, driving simulators and microscopic traffic simulations. The data produced by ADAS sensors can be used not only to assist drivers, but also as measurement tools to collect data on drivers’ behaviour in naturalistic settings.

In the current trial the potential of two such technologies as observational tools for monitoring and documenting driving behaviour is explored. It should be noted that this is not the primary commercial purpose of these systems, which is to mitigate and moderate risky driving behaviour.

Two types of ADAS are used in this work: the GreenRoads (GR) IVDR, which uses kinematic data (acceleration and speed) to detect the occurrence of various manoeuvre events such as hard braking, sharp turning, excessive acceleration, swift lane change, and speeding, and the MobileEye (ME) system, which is a vision based device that provides real-time Forward Collision Warnings (FCW), Lane Departure Warnings (LDW) and Headway warnings (HW). For detailed descriptions of the two systems see section 1.3 of this report.

The purpose of this trial is to evaluate the capabilities and potential of the two technologies for monitoring driving behaviour and to provide an initial understanding of the methods that may be used to analyse the rich data that these systems provide. Specifically, the interest is in the similarities and differences between the data provided by the two technologies. The extent that the data collected by the systems is similar or complementary in understanding driving behaviour and risk is important in the context of determining acceptable levels of data collection, taking into account the costs of additional measurements.

Another research question concerns the ability to integrate different event-triggered data to provide a broader understanding of these events. That means, to study events that occur in time proximity in order to gain deeper knowledge about risky and near crash situations.
2.2 Technologies used

Two off-the-shelf after-market technologies are used in this trial: Green-Road's SafetyCenter (GR) system and Mobileye's AWS-4000 (ME).

It is important to note that while GR systems record the processed data, ME is designed as a warning system only, and does not have built-in capabilities to record, transmit and store data. For this purpose, a solution that will enable creating database of ME records was needed. This application is described next.

The system developed is based on yet another off-the-shelf IVDR system called TrackTec (TT) Dual Purpose Locator (DPL). It was initially developed as a tool to support fleet management services. This system was modified and enhanced to support logging of the ME events, and configured to provide the time-based events. Data is recorded at time points based on two types of triggers:

The time when events identified by ME that are used to alert the driver occur
At regular pre-defined time intervals

The recorded data is transmitted via cellular networks to dedicated servers. A specific hardware connection was developed between ME and TT, allowing the latter to gain access to the internal information channel in ME that send information from the ME video sensor to its display unit. for the purpose of logging.

The TT IVDR itself is installed under the dashboard. It requires 12V electricity supply from the car battery. The installation in the vehicle is done by after-market technicians, and does not require any special certification.

Table 2.1 presents the data items collected by the TT system.

The MobilEye system enables the driver to set the threshold for the HW event in the range from 0 to 2.5 seconds. In this trial, based on some trial-and-error experimentation, the threshold was set to 0.9 second in all vehicles. In addition, there are two built-in constraints on the activation of events:

LDW is activated only if car speed is greater than 55 km/h
HW is activated only if car speed is greater than 30 km/h
Table 2.1: Description of events recorded by the TT system.

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Data fields</th>
</tr>
</thead>
</table>
| Mobileye forward collision warning event (FCW) | Start Speed (kmh)  
End Speed (kmh)  
Duration (Seconds)  
Left Signal (boolean)  
Right Signal (boolean)  
Brakes (boolean)  
High Beam (boolean)  
Foreword collision warning 1 (boolean)  
Foreword collision warning 2 (boolean)  
Start Distance (sec)  
Minimum Distance (sec) |
| Mobileye headway warning event (HW)        | Start Speed (kmh)  
End Speed (kmh)  
Duration (Seconds)  
Left Signal (boolean)  
Right Signal (boolean)  
Brakes (boolean)  
High Beam (boolean)  
Start Distance (sec)  
Minimum Distance (sec) |
| Mobileye lane departure warning event (LDW) | Start Speed (kmh)  
End Speed (kmh)  
Duration (Seconds)  
Left Signal (boolean)  
Right Signal (boolean)  
Brakes (boolean)  
High Beam (boolean)  
Departure to the Right (boolean)  
Departure to the Left (boolean) |

Following guidelines from the FOT Chain Model (Festa, 2008) the system was tested after installation and deployment in order to ensure that the data being collected actually matches the expected/required data. For this purpose, sound feature was programmed in the TT system. It was designed to produce a sound each time the TT system detected and recorded a ME alert. This feature was activated in 4 vehicles. The drivers of these vehicles were asked to identify occasions when the TT sounds and ME alerts were not sounded together. This procedure discovered 2 modes of data failures:

Missing records after actual ME alert messages (under-reporting).

Extra records due to false detection or noisy transmission channel (false records).

These problems were fixed by making changes to the TT recording activation codes and by reducing its sampling rate, thus avoiding duplicate records of the same events.
2.3 Methodology

2.3.1 Participants

Ten drivers participated in the trial (7 males, 3 females). All drivers are Or Yarok employees who drive vehicles provided to them by the organization as part of their compensation plan. They all have at least 15 years of experience, and drive at least 1.5 hours a day. Most of the drivers drive in both urban and interurban roads. The vehicles are used for both work and other purposes. It should be noted that Or Yarok is a road safety organization, and as such all employees are highly aware of safe driving practices. Thus, the sample in this trial is clearly biased and non-representative. Furthermore, all vehicles of the Or Yarok fleet are equipped with the Green-Road IVDR system as part of the organization policy. Therefore, the participants all have prior experience with the GR system. All participants agreed to take part in the trial. No incentive was offered since Or Yarok vehicles are monitored on a regular basis (as part of the fleet safety policy).

In this trial, driver identification was not required. However, in all cases, the OR YAROK employees are the main users of the vehicles.

2.3.2 Intervention/manipulation

The two systems being used are capable of providing feedback to drivers. ME provides real-time alert on the various events it identifies. GR also provides off-line internet-based feedback to the drivers. The following design was implemented with respect to feedback: Initially, all drivers drove with both systems active (with feedback) for 3 months (due to technical difficulties data was collected only for the last 40 days). Then, the feedback (visual and audio) was shut down for one month. The total collection period was thus 70 days.

2.3.3 Data preparation and quality

The resulting database includes the records of the events defined both by the GR and ME (logged by TT) systems for all drivers. Before turning to the analysis of the data, we examined the consistency of the data from the two sources. It was found that even in terms of exposure (trip times and durations) the overlap between the records obtained from the two systems was not complete. The main reasons for this are:

- Differences in the time stamps between the two systems because they use different clocks. GR uses the Windows internal clock, while TT uses GPS time.
- Differences in the definitions and the algorithms used to detect trip starts and trip ends. As a result, TT records many more shorter
trips compared to GR. Overall, TT recorded 3009 trips, compared to only 2132 in GR. Figure 2.1 below presents a histogram (on a logarithmic scale) of trip durations as recorded by the two systems. The figure shows that the number of short trips is significantly higher with TT. At higher travel times there does not seem to be a clear direction to the difference between the two systems.

Figure 2.1: The number of recorded trips as a function of the trip duration

It seems that in some cases, TT divides trips that are recorded as a single trip in GR into multiple trips. A possible explanation may be the difference in the definitions of trips. GR defines trips as the period of time in which the vehicle is moving (from the time it started moving to the time it stopped). No movement for a period of 10 minutes will cause the end of the trip to be recorded. TT uses a different definition based on power switches. The two definitions also include additional filters that aim to screen noise and reduce false, especially very short trips.

Figure 2.2 presents the rate of events over time recorded by the two systems for each vehicle. ME and GR data is represented in black and red dots respectively. Each sub figure represents a vehicle. The X axis represents the time in hours before (negative values) and after (positive values) switching off the feedback (vertical red line). The Y axis represents the rate of events. Note that the scales are different for the two systems, since ME generates events at a much higher rate. In the figure, three vehicle (vehicles 2, 6 and 9) for which ME data was lost for specific periods, can be seen. This is indicated by periods of time in which there are no ME events at all. This was a result of malfunction of the ME system itself. For these trips the TT records exist, but do not show any ME events.
For the purpose of the comparison, there was a need to select comparable trips for which reliable data exists. Trips that did not satisfy the following screening rules were not retained for the comparison:

- Trips during the (known) periods in which ME alerts were not recorded
- Trip with durations of less than 2 minutes or over 300 minutes
- In one of the vehicles, we received extremely high number of forward collision warning events relative to the other vehicles (3010 in comparison to an average of 23). Since a technical problem rather than an actual behaviour is most likely the cause for this, trips on this vehicle were excluded from the analysis of this type of events.

Therefore, the analysis and results will refer to 7-10 vehicles according to data availability.

Table 2.2 below summarizes the raw data as recorded by the systems and the reduced data that was used for the comparison.
Table 2.2: Summary of the raw data and the data used for comparison.

<table>
<thead>
<tr>
<th></th>
<th>Raw data</th>
<th>Analysis data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trips</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenRoad</td>
<td>2132</td>
<td>2128</td>
</tr>
<tr>
<td>Track-tec</td>
<td>3009</td>
<td>2681</td>
</tr>
<tr>
<td><strong>Total Driving Time (hrs)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenRoad</td>
<td>1110.72</td>
<td>1110.67</td>
</tr>
<tr>
<td>Track-tec</td>
<td>1169.47</td>
<td>1141.32</td>
</tr>
<tr>
<td><strong>Mean Trip duration(min)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenRoad</td>
<td>31.26 (sd=27.62)</td>
<td>31.32 (sd=27.62)</td>
</tr>
<tr>
<td>Track-tec</td>
<td>23.32 (sd=32.21)</td>
<td>25.54 (sd=24.35)</td>
</tr>
<tr>
<td><strong>Min Trip time (min)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenRoad</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Track-tec</td>
<td>0.0167</td>
<td>2</td>
</tr>
<tr>
<td><strong>Max Trip time (min)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenRoad</td>
<td>289</td>
<td>289</td>
</tr>
<tr>
<td>Track-tec</td>
<td>1124.18</td>
<td>195</td>
</tr>
<tr>
<td><strong>Events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenRoad</td>
<td>709</td>
<td>707</td>
</tr>
<tr>
<td>ME/Track-tec</td>
<td>20177</td>
<td>16711</td>
</tr>
</tbody>
</table>

After the screening of trips, there was still a need to match trips in the two systems. Due to the differences in the clocks discussed above, only a subset of the trips for which the match in the time stamps was sufficient was created for the purpose of the comparison. The match between trips was defined as sufficient if the time stamps of the two systems were less than 10 minutes apart, and the trip durations did not differ by more than 20%. Using these criteria we obtained a data set with 1,051 paired trips.
2.4 Results

2.4.1 Events counts

Table 2.3 and Figure 2.3 presents the total count of the various event types reported by the ME and GR systems. The event types the Forward collision warning (FCW), lane departure warning (LDW) and headway warning (HW) for ME and turn handling, braking, acceleration, speed and lane changing event for GR.

In the figure, note the different scales for GR and ME events. There are 16,711 ME events in total, among which the most frequent one is the HW. GR reported 707 events, which can be divided into two groups by their frequency: the most frequent are turning, speeding and braking (all together accounts for 96% of the events). Lane changing and accelerating events are relatively rare.

<table>
<thead>
<tr>
<th>vehicle no.</th>
<th>ME EVENTS</th>
<th>GR EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FCW</td>
<td>LDW</td>
</tr>
<tr>
<td></td>
<td>Low speed</td>
<td>High speed</td>
</tr>
<tr>
<td>1</td>
<td>328</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>158</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>211</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>730</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>283</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>223</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>131</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>328</td>
<td>17</td>
</tr>
<tr>
<td>9</td>
<td>155</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2547</td>
<td>203</td>
</tr>
</tbody>
</table>
2.4.2 Events rates

For the events rate, an exploratory data analysis was conducted to evaluate the rate of (assumingly unsafe) events. The rate of events is the ratio between the number of events and driving time. Events rates can be calculated per trip or for each driver (total number of events divided by total driving time). The rates were calculated for each of the GR and ME datasets separately.

Since the true rate (expectation) of driving events is unknown, we use estimations to evaluate it. Two methods were used to estimate the events rate. First is the Poisson regression, which can be implemented over trips data to evaluate the per vehicle events rate as follows:

$$\ln(E(Events_{ij})) = \ln(Duration_{ij}) + \beta_j$$

Where $Events_{ij}$ and $Duration_{ij}$ are the count of events and the duration in minutes of trip $i$ of driver $j$. $\beta_j$ is a vehicle-specific constant.

In addition to the mixed effect Poisson model, we also use the multivariate Poisson-lognormal model. This model is appropriate for panel data, in which observations are grouped by known factors. In our case, trips are grouped by drivers, so the Poisson-lognormal Mixed Effect model was defined using a distribution of driver-specific parameters. In the Mixed Effect model, we assume that $\beta_j \sim N(\beta_p, \sigma_p)$. This means that the driver-specific parameters are drawn from a normal distribution.

Figure 2.4 shows the estimated expected rates of events for each vehicle. The black points and lines represent the Poisson regression fitted values, and their corresponding confidence intervals. The red points represent the estimates obtained from the log-normal Poisson Mixed Effect model.
The two models produce very similar results. Due to the large amount of data (i.e. number of events), especially for the ME events, there is much certainty (narrow confidence intervals) in the rate estimates, and so the Mixed Effect model did not cause substantial changes to the individual rates in the direction of the average across vehicles. For the GR events there is a much smaller number of events, and so the estimation of the Poisson model has less certainty (wider confidence intervals) making the difference between the two models estimates more pronounced. In light of these results we decided to use the Mixed Effect model in what follows.

The estimated events rates by type are presented in the box-plot in Figure 2.5. Once again, it is clear that GR events are much less frequent com-
pared to ME events. The variability among drivers is also interesting as an event that exhibits higher variability across drivers may be more useful when trying to differentiate among drivers. The events with the largest variability are Speed and LDW. Variables with relatively low variability are Turn handling, FCW and Braking.

![Graph showing estimated events rates by type.](image)

**Figure 2.5: Estimated events rates by type.**

### 2.4.3 Comparisons of exposure

High correlations in both trip counts and driving time are observed between the two systems. (0.94, p<0.001 and 0.99, p<0.001 respectively) Figure 2.6 shows the relations between the measurements provided by the two systems. The 45 degrees line represents a perfect match between the measurements.

![Graph showing relation between numbers of trips and driving times measured in the two systems.](image)

**Figure 2.6: Relation between numbers of trips and driving times measured in the two systems.**
2.4.4 Relations among various events

The two systems used in this trial measure different variables. However, it is unclear to what extent the various events are complementary or represent different measurements or manifestations of the same behaviours. To examine that, Table 2.4 presents the Pearson correlations between the various events rates. In all cases the correlations scores are positive. The correlations among ME events is relatively high where the correlation between HW and LDW is also statistically significant (r=0.679, p<0.05). This means that drivers with high events rates on one ME event type are also likely to have a high events rate on the other types. For the GR events, the high correlations between braking and turn handling are also significant (r²=0.696, p<0.05).

![Table 2.4: Correlations among rates of events for the various event types.](attachment:table2.4.png)

The correlations between Mobile-eye and GR's events are especially interesting. There is a high correlation between FCW and Braking and Turning (r²=0.763 and r²=0.833, p<0.05). The correlation between speed events and FCW is not significant but achieved positive scores similar to the correlations between speed and braking (and turn handling). We attribute the lack of significance to the small sample size and not to the actual differences between the devices.

2.4.5 Event indices

2.4.5.1 Two systems separately

We first attempt to derive a single index that captures the events generated by each of the two systems. To this end a principle component analysis (PCA) was carried out over the logarithm of the drivers' events rates. This was done separately for the ME and the GR events. The results are presented in Table 2.5 and Table 2.6, respectively.
Table 2.5: PCA results for ME events.

<table>
<thead>
<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW</td>
<td>0.792</td>
<td>0.609</td>
<td>0.000</td>
</tr>
<tr>
<td>LDW</td>
<td>0.922</td>
<td>-0.212</td>
<td>-0.323</td>
</tr>
<tr>
<td>HW</td>
<td>0.901</td>
<td>-0.319</td>
<td>0.294</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>2.290</td>
<td>0.518</td>
<td>0.193</td>
</tr>
<tr>
<td>Proportion of the variance</td>
<td>0.763</td>
<td>0.173</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Table 2.6: PCA results for GR events.

<table>
<thead>
<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brake</td>
<td>0.788</td>
<td>-0.586</td>
<td>0.190</td>
</tr>
<tr>
<td>Speed</td>
<td>0.637</td>
<td>0.758</td>
<td>0.140</td>
</tr>
<tr>
<td>Turn</td>
<td>0.969</td>
<td>0.000</td>
<td>-0.246</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>1.965</td>
<td>0.919</td>
<td>0.116</td>
</tr>
<tr>
<td>Proportion of the variance</td>
<td>0.655</td>
<td>0.306</td>
<td>0.039</td>
</tr>
</tbody>
</table>

The first ME principle component explains 76% of the total variance. It has a high correlation (loading scores) with all ME events, especially with LDW and HW. Additional components are much less useful. The first GR principle component explains 66% of the variance, and is fairly associated with all variables and especially with the Turn handling events. In this case the second component explains 31% of the variance. It represents the remaining unexplained variance in braking and speed behaviour. Based on these results we use the first component in each case to represent an overall index for the events recorded by the system.

The indices calculated for each driver are ranked (for each system separately) from the highest rate of events (presumably expressing risky behaviour) to the lowest one. Figure 2.7 shows the ranking for each driver with the two systems. The spearman correlation between the scores was equal to 0.4 (p=0.29). The agreement between the two indices is not strong, and given the small sample not statistically significant. However, a positive trend is evident in the figure.
In this subsection, we use all the event types generated by both systems jointly to identify latent factors that may represent underlying driving behaviours. An exploratory factor analysis was undertaken by implementing PCA as the axis selection procedure and "Varimax" as the rotation procedure. We received 6 dimensions of which the first two, that had eigenvalues larger than a unit, accounts together for 82% of the variance.

Table 2.7 presents the loadings of the variables to the two factors (rotated). Bold entries represent variables assigned to the corresponding factor. The first factor represents FCW, Braking and Turnings. High rates of braking and turning can indicate a high exposure to urban driving where many intersection and traffic signs exist. Most FCW events occur at low speeds, which may reinforce the assumption that the first principle component be related to urban driving. The second component includes LDW, HW and Speed. The speed event is more likely to occur on highways as it is defined as speed exceeding a high threshold (120km/h in our case). LDW and HW are also more relevant in inter-urban areas. Therefore, the second component may represent Inter-urban driving.
Table 2.7: PCA results for all event types jointly.

<table>
<thead>
<tr>
<th>Event</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCW</td>
<td>0.84</td>
<td>0.47</td>
</tr>
<tr>
<td>LDW</td>
<td>0.11</td>
<td>0.92</td>
</tr>
<tr>
<td>HW</td>
<td>0.07</td>
<td>0.90</td>
</tr>
<tr>
<td>Brake</td>
<td>0.94</td>
<td>-0.08</td>
</tr>
<tr>
<td>Speeding</td>
<td>0.25</td>
<td>0.70</td>
</tr>
<tr>
<td>Turn</td>
<td>0.90</td>
<td>0.26</td>
</tr>
<tr>
<td>Proportion of the variance</td>
<td>0.42</td>
<td>0.41</td>
</tr>
</tbody>
</table>

2.4.6 Trip level analysis

The analyses presented above are conducted at the level of the driver. They may be useful to characterize or classify types of drivers or behaviours. But, deeper understanding of the road scene also necessitates investigating behaviour at the more detailed level of trips or events. In this section we examine the temporal connection among events recorded by the two systems. A basic condition for such analysis is having an exact match between GR and ME records with regard to start and end time as well as trip duration. Therefore, we used the 1051 trips for which a match between GR records and ME exists, as described earlier.

First, we look for trips during which both systems identified events. Table 2.8 presents the distribution of trips according to systems' reports of events. ME reported events in 789 of the trips compared to only 173 trips in which GR events were reported. 238 trips are totally event-free and the rest 813 trips had at least 1 event. Only 149 trips events were recorded by both systems.

<table>
<thead>
<tr>
<th>Event Reported</th>
<th>ME Event Recorded</th>
<th>No events recorded</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR</td>
<td>149</td>
<td>24</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>640</td>
<td>238</td>
<td>878</td>
</tr>
<tr>
<td>Total</td>
<td>789</td>
<td>262</td>
<td>1051</td>
</tr>
</tbody>
</table>

Table 2.9 presents a more detailed breakdown of ME and GR events that occur in the same trip. Note that the number of pairs of events in trips is larger than the number of trips due to trips in which multiple events were recorded. We do not observe a specific type of ME event that occurs more frequently with GR events. For GR events, Braking and Turn han-
dling events are paired with ME events more frequently compared to other event types.

Table 2.9: Count of trips in which event occur together.

<table>
<thead>
<tr>
<th></th>
<th>ME</th>
<th>HW</th>
<th>LDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerating</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Braking</td>
<td>67</td>
<td>59</td>
<td>85</td>
</tr>
<tr>
<td>Lane Handling</td>
<td>9</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Speed</td>
<td>25</td>
<td>27</td>
<td>46</td>
</tr>
<tr>
<td>Turn</td>
<td>55</td>
<td>51</td>
<td>64</td>
</tr>
</tbody>
</table>

The results presented above did not consider the timing of the events within the trips. We present one example that demonstrates the potential use of this information.

This example includes a FCW event reported by ME followed immediately by a braking event reported by GR, as shown in Table 2.10.

Table 2.10: Sequence of events in a single trip

<table>
<thead>
<tr>
<th>System</th>
<th>DriverID</th>
<th>EventTime</th>
<th>EventType</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME</td>
<td>127</td>
<td>05/30/2010 11:35:36</td>
<td>FCW</td>
<td>&gt;50</td>
</tr>
<tr>
<td>GR</td>
<td>127</td>
<td>05/30/2010 11:35:40</td>
<td>Braking</td>
<td>NA</td>
</tr>
</tbody>
</table>

The specific vehicle was equipped also with in-vehicle camera, providing visual documentation of the events. Figure 2.8 and Figure 2.9 show the pictures taken at the time the two events were recorded. Figure 2.8 shows the time the FCW was generated. The vehicle is close to the vehicle in front of it. The small picture in the upper left corner of the figure shows the indication of the ME and GR in-vehicle displays. The ME display is coloured red to indicate the alert and shows the time to collision value of 0.5. The GR display is blank, as no event has been detected yet. Figure 2.9 shows the situation at the time the GR event is recorded, which is its end time. After braking the distance between the two vehicles has increased, the ME display does not show the warning anymore, but the GR display has turned on to indicate the braking event that was recorded.
2.4.7 Near Crashes

Typically near crashes are identified based on continuous data monitoring and reduction. This involves huge processing effort for data viewing, analysis and verification. Currently, large effort is devoted for developing procedures to automate this process, however results are limited and manual data processing still dominates this area. In this trial we try to use the events recorded by the IVDR systems, especially the most severe ones, as proxies to near crash situations. To demonstrate this potential, we
use the GR events. GR events are classified into severity levels based on the extent of the accelerations applied in the manoeuvre and its duration. We use the events at the highest severity level as potential proxies for near crashes. Out of the of 707 GR events in the data only 7 events were classified at the highest severity level. Of these, 5 were braking events and 2 turn handling events.

Table 2.11 presents the details of these events. In this very limited sample, the speed is not necessarily correlated with severity. Events 1, 3 and 4 are recorded at relatively low speeds. Interestingly, 4 out of the 7 events (events 3-6) occurred during two controlled test-drives, in which professional drivers were asked to deliberately drive aggressively in order to simulate risky driving. Hence, indeed, these events can be considered as good proxies for near-crashes and deserve further analysis.

An interview with driver 8101 revealed that event 1 happened when the driver applied harsh braking to avoid collision with a pedestrian entering the vehicle’s path. Hence this event as well indeed corresponds to a near-crash situation. Interestingly, there were no ME events recorded in the proximity of any of these 7 GR events.

Following the example presented in this section, we were able to detect 5 good proxies for near crashes out of 7 candidates based on severe GR events. However, the question of how many other candidates exist in the data remains unknown.

The possibility to use the harshest events recorded by the IVDRs as proxies to near misses, and the optimal definitions of these events, could be an interesting and useful direction for future research.

<table>
<thead>
<tr>
<th>Event</th>
<th>Driver ID</th>
<th>Trip ID</th>
<th>Type</th>
<th>Date and Time</th>
<th>Speed [Km/H]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8101</td>
<td>8228550</td>
<td>Braking</td>
<td>16/5/2010 1:37</td>
<td>39</td>
</tr>
<tr>
<td>2</td>
<td>8101</td>
<td>8321341</td>
<td>Braking</td>
<td>6/6/2010 8:05</td>
<td>61</td>
</tr>
<tr>
<td>3</td>
<td>296</td>
<td>8367154</td>
<td>turn</td>
<td>16/6/2010 17:20</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>296</td>
<td>8367154</td>
<td>turn</td>
<td>16/6/2010 17:20</td>
<td>46</td>
</tr>
<tr>
<td>5</td>
<td>127</td>
<td>8292421</td>
<td>Braking</td>
<td>30/5/2010 11:39</td>
<td>NA</td>
</tr>
<tr>
<td>6</td>
<td>127</td>
<td>8292421</td>
<td>Braking</td>
<td>30/5/2010 11:40</td>
<td>NA</td>
</tr>
<tr>
<td>7</td>
<td>127</td>
<td>8426725</td>
<td>Braking</td>
<td>30/6/2010 12:48</td>
<td>51</td>
</tr>
</tbody>
</table>

2.5 Discussion

This field trial had two main objectives: The first was to demonstrate the ability to extract reliable ND behaviour from IVDR systems and to assess to what extent behaviour could be learned based on this kind of technology. The second was to explore the complementarities of two different systems and to point out the type of measurements that are important in order to gain an understanding of the underlying behaviours.
The results presented here must be regarded very cautiously because the sample is small and cannot be considered representative enough to suggest any valid conclusion regarding driving behaviour. Thus, the discussion relates mainly to methodological and data handling issues rather than to interpretation of the findings with regard to behavioural aspects.

In the trial two different off-the-shelf IVDR systems were used in order to demonstrate the ability to collect ND and use it to evaluate driving behaviour.

Unlike most ND studies that are conducted using continuous data, mainly through video in vehicle cameras, the systems used in this trial do not involve analysis of video data (except for the measurement of distances in ME). While this limits the range of data that may be collected, the decision to avoid video data also offers several advantages:

Relatively low cost of the systems, especially when compared to other technologies using video cameras. The cost includes the equipment, the data logging, the storage and outputs/data.

Quick and relatively easy installation procedures.

Since most of the systems discussed are commercial having been on the market for a few years, much of the relevant knowledge is already implemented in it. That means that the systems definitions and algorithms are highly trustworthy. This is exemplified in their ability to screen "noises" and so on.

The use of off-the-shelf systems offers not only direct cost savings, but also assists and simplifies the processes of transferring and hosting the data, quality assurance (at least at basic levels), maintenance and support and so on.

A major effort that took place in this trial was the creation of a system to log ME events through another system (TT). The main importance of this step is in providing the capability for two different systems to communicate, i.e., connect in a way that relevant information from one system is transmitted to the other, recognized and integrated into the original database, thus creating a richer, more elaborated data set. The amount of work devoted to integrating the data sets of ME/TT and GR at a later stage and the problems of matching data sets that were generated by different sources emphasize the huge advantage of using analysis-ready unified data sets.

In the trial itself, the results show a big difference in the number of events recorded by the two systems. This brings about the issue of setting the thresholds used to define events that should be recorded. These definitions need to be clearly defined and open, as it is possible that the conclusions derived from studies that use the event data would depend on these definitions and thresholds.

The analysis presented here demonstrates our ability to extract both meaningful and rich ND information at two main levels: the driver level and the trip level. At the driver level we used the types of events defined by the manufacturers to characterize driving patterns and tendencies. At the trip level we showed a way to potentially construct proxies for near crashes
and to certain extent reconstruct specific situations, such as a forward collision alert and the drivers' response to it.

The various events the two systems record, and the driving indices generated using these events suggest that the measurements are complementary, at least to some extent. The PCA analysis, although limited in terms of sample size, suggests that various events indicate on underlying factors that are not specifically related to the measurements of each system separately.

Beyond the driver indices, we examined events that were recorded together during the same trip and in time proximity. This type of analysis provides a screening tool that may help focus analytical efforts on interesting driving situations as well as provide insight regarding evolvement of driver action in certain situations. Further development of this type of tools may result in powerful automatic tools for data reduction even in cases that video or other continuous data is analyzed. Event sequences may be used instead of, or in addition to simple triggers for detailed analysis.

Another potential direction is to use the most severe events recorded in the data as proxies to near-crash situations. In the present case we used the definitions of severe events implemented by the manufacturers. But, we were still able to identify a small number of extreme events, and qualitatively indicate, at least in some of the cases, that they in fact represent near-crash situations.

On the other hand, using the system's "closed" definitions may limit our analytical capabilities. One example is the categorization described above regarding turning and braking. Another example is that we found that the proportions of FCW in low speed and high speed are not balanced: there is a high proportion of the low speed FCW and a minor amount of the high speed. In light of the fact this trial was conducted with highly safety-oriented drivers, who are not suspected to have many risky behaviours, the amount of low speed events suggests that these events, as opposed to high speed events, do not reflect real hazards or potential conflicts.

2.5.1 Methodological and data handling issues

From a methodological point of view, the two main challenges we faced were finding a solution to log ME data accurately and the integration of the two data sets (ME and GR) into a coherent one. Problems and inconsistencies can arise even in measuring seemingly trivial information, such as the time or the start and end of a trip. This experience has highlighted the importance of using clear and (to the extent possible) uniform definitions for measurements.

2.5.2 Potential for up-scaling

The potential for scaling is very high because of the various properties of the IVDRs used:

They are easy and cheap to install and suitable for mass installation
The infrastructure for installation, namely technicians and installation facilities, already exist, are easily spread over geographic areas, and easy to train and maintain.

The amount and potential value of the data collected is relatively large when combining the main functions of all systems, even without the use of video data.

2.5.3 Challenges

The systems are in many cases received as "black box" where the algorithms used, definitions of measurements and events, and threshold values are not explicitly known or sometimes hard wired into the equipment, and so cannot be changed.

As noted above, when working with different sources of data that are based on different sensors, it is imperative to set the same definitions for all sources. In the current case, examples for this problem were the use of different clocks and the definitions of the trip start and end time.

There is a trade-off between large amount of data that might be mostly not worth working with and small amounts of data, relying on triggers or predefined events, but that may lead to loss of information. For example, lowering thresholds for ME warnings may result in much larger numbers of events and a richer data set that could compensate for the discreteness of data. But, this may also cause many false alarms and irrelevant data to be collected. Automatic tools to screen and find meaningful data, such as defining temporal and spatial threshold to identify near-crash situations, may be very useful as a reduction tool.
3 Spatial analysis of novice drivers driving behaviour (IL2)

3.1 Introduction

The main objective of the second sub-trial is to explore the potential of IVDR systems to document the temporal and spatial aspects of the driving behaviour of novice young drivers. This study examines the driving exposure and measures of risk of novice drivers during the first year after licensure. Special interest is paid to the differences in driving exposure parameters in the different phases of the Israeli graduated driver licensing (GDL) program. The exposure parameters analyzed include the amount of driving, temporal distribution of driving, risky behaviour and the spatial aspects of driving.

This sub-trial is based on data from the "First-year study" (see section 1.4), in the current study data analysis is extended by including geographical and spatial aspects of driving and detailed location of events. These data are analyzed using a map-matching process (see Appendix).

3.2 Technology used

The driving behaviour data were collected using the GR system which was installed in the vehicles of the families participating in the study. A complete description of the system is described in section 1.3.1.

A distinctive aspect of this trial is an addition of the spatial exposure element to the overall framework of the IVDR system as shown in Figure 3.1. The data logged by the GR system includes GPS location measurements at a 2 minute time resolution. This data is post processed by a map-matching utility to identify the road sections the measurement were located on, and to aggregate these to a complete description of a travel route from origin to destination. This new element provides spatial driving characteristics and spatial statistics of road safety events using a map-matching process. The technical aspects of the map-matching process are described in detail in the Appendix.
3.3 Methodology

3.3.1 Sample and participants

Participants' characteristics and recruitment procedures are described in detail in section 1.5. As this study aims to examine the behaviour of novice young drivers over time and to draw conclusions on reliable data, the study sample contains young drivers who drove the equipped vehicle for a minimum of 5 months during the experiment.

The original "First-year study" dataset was also "cleaned" to exclude missing data. The resulting sample used in the analysis that follows included 87 young drivers, 53 male and 34 female. The average age of these drivers when they received their driving licenses was 17 years and 4 months, with the youngest being 17 years old and the oldest 18 and 8 months.

3.3.2 Geographical location of the trial
The participants could drive throughout the state of Israel. Their home loca-
tions were mostly in the Central part of Israel. Figure 3.2 and Figure 3.3 show the home locations of all the participants, and a zoom in on the Tel Aviv Metropolitan area where most homes were located, respectively. Figure 3.4 shows a map of Israel with the locations of the points where measurements were obtained.
3.4 Data handling

The dataset extracted from the database for this study was organized in four information tables at various levels of aggregation:

1. Trip
2. Driver
4. Safety events
5. Location (GPS) records

These tables are used by the map-matching tool (described in detail in the Appendix) to produce the following GIS layers that are used as the core sample dataset for this study:

*Exposure layer* – provides information on each road segment contained in a trip route such as traverse time, segment type and classification (e.g. urban or non-urban, ramp, highway), length and so on.
Events layer - provide location of safety events on a specific segment contained in a specific trip route.

The outputs of the map-matching tool are illustrated in Figure 3.5. Each route is presented by the set of network segments it consists of. Each segment corresponds to a row in the exposure table, where the following parameters are indicated:

A unique identification number for the current segment on the exposure table

segment identification number

the trip identification number, in which the segment was included

The travel direction, were, 1 is the segment direction defined in the GIS map, and -1 is the opposite direction

The exit time from the segment

The average speed on the segment

The length of the segment

The two points on the segment (defined by a percentage of the segment length) where the trip started and ended. For example, the exposure table for the trip illustrated in Figure 3.5 indicates that in this trip the driver travelled on segment 19 from its beginning up to point located at 23% of its length (i.e. because this is the end point of the trip).
exposure layer

<table>
<thead>
<tr>
<th>Uid</th>
<th>TripID</th>
<th>Segment</th>
<th>TravDir</th>
<th>Exit Time</th>
<th>Speed</th>
<th>Length</th>
<th>From%</th>
<th>To%</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>1691971</td>
<td>223000</td>
<td>1</td>
<td>21/12/2007 13:02</td>
<td>49</td>
<td>290</td>
<td>0</td>
<td>100</td>
<td>17</td>
</tr>
<tr>
<td>18</td>
<td>1691971</td>
<td>223000</td>
<td>1</td>
<td>21/12/2007 13:02</td>
<td>49</td>
<td>75</td>
<td>0</td>
<td>100</td>
<td>18</td>
</tr>
<tr>
<td>19</td>
<td>1691971</td>
<td>128229</td>
<td>1</td>
<td>21/12/2007 13:02</td>
<td>49</td>
<td>76</td>
<td>0</td>
<td>23</td>
<td>19</td>
</tr>
</tbody>
</table>

Event layer

<table>
<thead>
<tr>
<th>Uid</th>
<th>EventType</th>
<th>RunDist</th>
<th>EventDate</th>
<th>TravDir</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>-</td>
<td>23</td>
<td>13:02 11/12/2007</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>7</td>
<td>98</td>
<td>13:27 11/12/2007</td>
<td>1-</td>
</tr>
</tbody>
</table>

Figure 3.5: Illustration of the map-matching tool outputs.

The event table includes a row for each event that occurred during the trip. The information in this table indicates the following:

- The unique identification number of the segment within the exposure table, that allows matching the events to the trip and segment they occurred on.
- Event type code
- The point on the segment where the event occurred, defined by a percentage of the segment length from its beginning
- The event time
- The travel direction

For the purposes of the analysis of the trips, the following summary statistics on the trip and additional information about the driver were derived for each trip:

- Driver identification number, the family it belongs to and the vehicle used for the trip
- Driver type: novice drivers, parents, others (siblings)
- Driver gender
- GDL phase (for the novice drivers): accompanied, solo with and without feedback provision
- The day of the week for the trip
- Time of the day of the trip
- Trip time duration and distance travelled

It should be noted here that a significant number of trips were excluded from the resulting dataset. Most of those trips were dropped due to missing identification of drivers. There have also been dropped observations in the map matching process and geographic analysis. To a large extent these are a by-product of the relatively low time resolution (2 minutes) of the GPS location records. This means that in many cases, a route could not be identified reliably. This happened when:

- Less than 3 GPS locations records were available for the trip. With the available GPS location measurements, this implies that routes
were not identified for most short trips with durations under 4 minutes. This number will be smaller if the time resolution of GPS location measurements would be higher.

Failure of the map matching algorithm to identify the segment a specific GPS observation belongs to. This may be due to an error in the GPS measurement and/or errors in the GIS map. This problem is also expected to greatly diminish if the time resolution of GPS measurements would be higher.

In addition, in some cases events were recorded without their GPS location. These events were excluded from the spatial analysis only. It should be noted that it would be also possible to interpolate the position of the vehicle at the time of the event from the time series of GPS locations. However, the accuracy of this would be greatly improved if the GPS measurements time resolution would be higher (i.e. smaller time gap between measurements).

The summary trips’ statistics are given in Figure 3.6.

```plaintext
<table>
<thead>
<tr>
<th>180000 performed trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>76804 trips with GPS data</td>
</tr>
<tr>
<td>21919 filtered trips:</td>
</tr>
<tr>
<td>14482 trips with &lt;3 GPS points;</td>
</tr>
<tr>
<td>4406 trips performed on one segment;</td>
</tr>
<tr>
<td>95 trips with time gap &gt;6 min.;</td>
</tr>
<tr>
<td>194 trips with undefined short path;</td>
</tr>
<tr>
<td>2740 trips - exceptions.</td>
</tr>
<tr>
<td>56885 map-matching trips</td>
</tr>
<tr>
<td>31315 filtered trips:</td>
</tr>
<tr>
<td>23444 trips with missing driver ID;</td>
</tr>
<tr>
<td>2379 trips with missing location of safety event;</td>
</tr>
<tr>
<td>4492 trips with speed filtering;</td>
</tr>
<tr>
<td>25570 trips used for spatial analysis</td>
</tr>
</tbody>
</table>
```

Figure 3.6: Trips’ statistics.

The geographic analysis presented here is based to a large extent on a classification of the road segments as urban or non-urban and into four functional categories. This classification is built into the definition of the GIS network. The functional categories are defined as follows:

**Class 1:** Freeway segments that provide largely uninterrupted travel between and through metropolitan areas. They are designed for high speeds and support large traffic volumes.

**Class 2:** Arterial segments that support large traffic volumes at high speeds. This class also includes freeways with some at-grade intersections.

**Class 3:** Collector segments that provide moderate speeds and volumes. The roads commonly connect between arterial segments and collect traffic from local roads.
Class 4: Local segments that include streets and roads that have the lowest speed limits and carry low traffic volumes. Unpaved roads are also included in this category.

It should be noted that this classification is the one used in the Israeli GIS maps. Different road classes and definitions may be used in other countries.

3.5 Data analysis

The research questions illustrated in this study involve the analysis of the temporal and spatial characteristics of trips young novice drivers undertake, in order to better understand their exposure and risk behaviour:

The analysis includes the following aspects:

- Total travelled distance and travel time, and its distribution according to the road classes
- Comparison of the spatial distribution, in terms of exposure to different road-types by the novice drivers and their parents.
- Comparison of temporal trip characteristic (i.e. distribution over the hours of the day and the days of the week) of the novice drivers in different GDL phases and of their parents.
- Comparison of the generation of safety events by the novice drivers in different GDL phases and their parents in terms of their spatial distribution by road classes.

3.6 Results

3.6.1 Temporal analysis

In this section, the temporal driving characteristics of novice drivers in the various GDL phases are presented in comparison with that of their parents. The average travel statistics for these drivers are presented in Table 3.1.

<table>
<thead>
<tr>
<th>Driver type</th>
<th>Weekly travel time (hr/week/driver)</th>
<th>Weekly number of trips (trips/week/driver)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice drivers, accompanied phase</td>
<td>1.75 (1.90)</td>
<td>3.56 (2.76)</td>
</tr>
<tr>
<td>Novice drivers, solo phase</td>
<td>3.70 (3.25)</td>
<td>10.46 (6.86)</td>
</tr>
<tr>
<td>Parents</td>
<td>4.16 (3.73)</td>
<td>10.51 (7.37)</td>
</tr>
</tbody>
</table>

Numbers in cells represent means and the numbers in brackets are the SDs.
Figure 3.7 shows the distribution of the driving time of novice drivers during the days of the week in the accompanied and solo phases in comparison with the driving time distribution of their parents. There is a significant difference between the driving exposure of the novice drivers and their parents. Driving times of novice drivers split almost evenly among weekdays and increase on the weekends (Friday and Saturday in Israel): weekend driving rates are 33.2% and 32.5%, respectively for accompanied and solo phases. This increase may be associated with easier access of the young drivers to vehicles during the weekend. In contrast, the driving rates of parents are significantly higher on weekdays and are lower on weekends (20.7% of the driving time).

Figure 3.8 presents the distributions of driving times over the day for the young drivers in the accompanied and solo periods and their parents. The results show a significant difference in the exposure of the young drivers between two phases. Novice drivers shift their driving in the solo phase to later hours in the evening and night-time compared to the accompanied phase. The peak driving hours in the accompanied phase are 5–9PM (44.7%). On weekdays these hours are the ones immediately after the end of the working day. In the solo phase, the peak hours are 7–11PM (33.9%). These hours are typically when the family vehicle becomes more available to young drivers. At the same time, novice drivers drive significantly more during the night after they enter the solo phase. While in the accompanied phase only 3.7% of the driving time is between midnight and 6AM, in the solo phase 16.2% of the driving is during these night hours. In contrast, the driving activity of parents takes place mostly in the daytime. The peak driving hours for parents are 7–8AM (16.4%) and 4–7PM (26.1%), which is typically the beginning and the end of the working day. Only 5.8% of the driving time is between midnight and 6AM.
Figure 3.7: Distribution of driving time over the week.
Figure 3.8: Distribution of driving time over the day.
3.6.2 Spatial analysis

This section presents the spatial analysis of the trips for which routes were identified. This dataset includes 25,569 trips that include 1,830,574 road segments. They total in 9,271 hours of travel time and 271,414 km of distance travelled. To put these numbers in context, Table 3.2 presents the total roads’ length in the various road classes that were defined above, as they exist in the Israeli GIS database.

Table 3.2: Total length of roads by class in Israel.

<table>
<thead>
<tr>
<th>Road class</th>
<th>Length (km)</th>
<th>Non-urban</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>637 (1.1%)</td>
<td>113 (0.2%)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11,416 (20.1%)</td>
<td>2,602 (4.6%)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1,984 (3.5%)</td>
<td>9,276 (16.3%)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6,610 (11.6%)</td>
<td>24,243 (42.6%)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20,647 (36.3%)</td>
<td>36,234 (63.7%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3 summarizes the travelled distance and the driving time of novice drivers on the various road types. The statistics presented in this table indicate that novice drivers drive mostly in urban areas. This is more pronounced in the travel times compared to the travelled distance, maybe because the speeds on urban roads are generally lower. In terms of road types, the largest proportion of driving time and distances overall is on arterial roads (class 2). In urban areas the largest proportion of travel is on collector roads (class 3).

Table 3.3: Travelled distance and driving time of novice drivers on different road types.

<table>
<thead>
<tr>
<th>Road class</th>
<th>Driving time (hr)</th>
<th>Travelled distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-Urban</td>
<td>Urban</td>
</tr>
<tr>
<td>1</td>
<td>155 (6.1%)</td>
<td>73 (2.9%)</td>
</tr>
<tr>
<td>2</td>
<td>470 (18.6%)</td>
<td>485 (19.2%)</td>
</tr>
<tr>
<td>3</td>
<td>33 (1.3%)</td>
<td>815 (32.2%)</td>
</tr>
<tr>
<td>4</td>
<td>15 (0.6%)</td>
<td>485 (19.2%)</td>
</tr>
<tr>
<td>Sum</td>
<td>672 (26.6%)</td>
<td>1859 (73.4%)</td>
</tr>
</tbody>
</table>

The results reported in Table 3.3 may be misleading. As shown in Table 3.2, the stock of road length is not distributed equally among the various classes in Israel (as expressed in the GIS database). Thus, if drivers were choosing ran-
domly among road segments, a distribution similar to that of the distance travelled that would be similar to that of the road lengths would be expected. To overcome this bias, Table 3.4 presents the travelled distance proportions for novice drivers and their parents normalized by the total road length in each class. The presented statistics demonstrate that after accounting for the road length stock drivers utilize non-urban roads more compared to urban ones. However, compared to their parents, novice drivers utilize urban streets more compared to non-urban roads.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Normalized exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Novice drivers</td>
</tr>
<tr>
<td>Non-urban</td>
<td>1.3</td>
</tr>
<tr>
<td>Urban</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Table 3.4: Normalized travelled distance proportions.

Important limitations of the results should be mentioned here. First, as noted earlier, given the time resolution of the measurements, the map matching process tends to drop short trips. Considering that the home location for most of the participants in the experiment is in urban and suburban areas this likely leads to underestimation of the proportion of travel on urban roads. Furthermore, the home locations of the participants in the experiment do not form a representative sample of the population, but biased towards urban and suburban locations and towards locations in the Central part of the country. This again is likely to bias the results towards the types or roads and environments that these drivers are more likely to encounter close to their home locations. These difficulties may be overcome, at least partially, by increasing the time resolution of the GPS location records, by considering the types of roads drivers are exposed to in the areas close to their home locations and by using representative samples in terms of geographic home locations.

A valid comparison of the utilization of the various road types can be made between the novice young drivers and their parents, who share the same home locations and road environment. Figure 3.9 presents a detailed comparison of the novice drivers and their parents. The presented diagrams demonstrate that parents drive more on non-urban roads compared to their novice drivers. They also drive more of their travel on highways (class 1) compared to their children, while the novice drivers use more collector roads (class 3) and local streets (class 4).
It was shown above, that novice drivers spend substantial driving time during the weekend. Figure 3.10 looks at the geographical distribution of weekend driving. The figure shows the distribution of distance travelled among the different road classes and driving environment during the weekend in the accompanied and solo phases.

The presented comparison shows that on weekends novice drivers drive mostly on non-urban highways (class 1) and arterials (class 2) in both the accompanied and solo phases. Among urban roads, the largest proportion of travel occurs on collector road (class 3) and arterials (class 2).

Figure 3.10: Distribution of distance travelled on various road types by novice drivers on weekend in accompanied and solo phases.

### 3.6.3 Spatial distribution of safety events

This section presents the spatial distribution of safety events observed during the study. The driving safety characteristics of the novice young drivers are compared to those of their parents. The statistics used as in-
icicators on the unit of risk are the number of safety events (split into five types: speeding, acceleration, braking, turn handling and lane handling) per 1000 km of travel distance on each road type.

Figure 3.11 presents the spatial distribution among road types of all safety events for the novice drivers and their parents. The figure demonstrates that novice drivers generate a much higher rate of events than their parents. In non-urban areas, the young drivers generate 60 events per 1000 km, while their parents generate only 35 events per 1000 km. In urban areas, the difference between the rates of events is maintained, but the absolute numbers are higher for both the young drivers and their parents: 157 events per 1000 km for the young drivers, and 101 events per 1000 km for the parents. The figure also clearly demonstrates the relation between the road design and function, as captured by the road class, and safety. Both for the young parents and their parents, and for urban and non-urban road, the rate of events increase for roads that are lower in the classification hierarchy.

Figure 3.11: Spatial distribution of all safety events.

Figure 3.12 to 3.16 show the rate of events per 1000 km travelled for the various types of events (speeding, acceleration, braking, turn handling and lane handling, respectively). Speeding events occur mainly on highway and arterial road (classes 1 and 2). This is expected, especially given the way speeding events are defined. A speeding event is recorded when the speed exceeds 120 km/hr (the maximum speed limit is Israel is 90 km/hr, except 3 highways with speed limits up to 110 km/hr). In principle, a finer and more useful definition would define speeding in relations to the speed limit on each specific road segment. A layer of speed limits is available within the Israel GIS database. However, its reliability is considered questionable.

The comparison of speeding events by the young drivers and their parents reveals that overall the parents generate a higher rate of speeding events. However, the locations where the two groups generate events differ substantially. The vast majority of speeding events the parents generate (25.3 events per 1000 km) are where they can be expected – on non-urban highways that are designed for high speeds. In contrast, the novice
young drivers generate higher numbers of speeding events on other road classes – mostly non-urban arterials and urban highways that are not designed or function as high-speed roads (8.7 and 9.3 events per 1000 km on non-urban and urban highways for the young drivers, compared to 4.6 for parents on urban arterials, 13.6 events per 1000 km on non-urban arterials for novice drivers compared to 7.0 for the parents). This may reflect a difficulty of the young drivers to correctly assess and perceive the level of risk they are facing on these roads.

Most acceleration and braking events are observed on urban roads. There is also a significant difference in the rates of these events for novice drivers and their parents. The novice drivers generate more braking events on all road classes both in urban and non-urban environments and more acceleration events on almost all road classes. For example, on local urban streets (class 4) the number of acceleration and braking events generated by novice drivers is almost 2 times higher than that of their parents: 9.86 and 5.02 acceleration events per 1000 km, and 41.8 and 19.9 braking events per 1000 km, respectively. On urban collector segments (class 3) novice drivers generate 110.7 braking events per 1000 km, while their parents generate 52.7 events per 1000 km. The number of acceleration and braking events on highway segments (class 1) is relatively very small. This may be a result of the uninterrupted flow on these highways which implies constant speeds.
There is little difference between the novice drivers and their parents in the rates of turn handling and lane handling events. These events occur mostly in urban area, especially on collector segments (class 3). This may be related to the geometric design of these segments, which may involve frequent turns and curves that are not as common in highway and arterial segments.
3.7 Discussion

This part of the Israeli trial aimed to explore the potential of IVDR system integrated with a map-matching process to document driving behaviour of novice young drivers, and in particular their geographical-spatial and temporal characteristics. The main work in this part was the development of a map matching tool that enables us to link the exposure and driving behaviour records obtained by the IVDR with the geographic properties of the road segments that are available in the GIS database.

To demonstrate the capabilities and potential of this tool, we presented some results on the distribution of driving exposure and safety events, recorded by the IVDR, to the various road classes within urban and non-urban environments of novice young drivers and their parents. The results reported focused mainly on the spatial exposure of novice drivers in the different GDL phases. The reported results clearly demonstrate the huge potential of the spatial and temporal study of IVDR data to improve our understanding of driving exposure and risk. Many further analyses...
could be pursued in this direction, for example, in relations to the spatial extent of travel and generation of safety events (e.g. relative to the home location or to the trip origin), and exploiting additional characteristics of the road segments, beyond the type classification, such as speed limits, measured traffic volumes and so on. Another use of this data set would be to study the potential for detection of infrastructure issues and failures through identification of locations with massive number of events generated by different drivers.

The trial also revealed some difficulties with the linkage of IVDR data and GIS databases. The 2 minutes time resolution of GPS location records that was available in the data causes difficulties for the map matching algorithm to identify the travel routes for short trips and for trips with missing observations. It seems that a better balance needs to be struck between the higher accuracy obtained by a higher resolution of GPS records, and the computational and communication demands that such a higher resolution brings about. It seems to us that a time resolution in the order of 30 seconds would be a useful compromise. An additional difficulty, common to all trials with this IVDR, is driver identification. In a significant number of trips, the drivers were not identified, which leads to biases in summary statistics (although analyses at the level of individual trips are not affected). The solution to this problem in this case was to send the participants a list of unidentified trips in order to solicit the information from them. However, this is a cumbersome and time-consuming effort, not to mention that it suffers from inherent problems with self-reports (see section 4.1.1); thus to some extent this undermines the naturalistic nature of the study. Other technology-based remedies to this issue are needed. Finally, we note that the results obtained in studies similar to these, have strong dependency on the properties of the GIS databases being used. In the case of road classifications, for example, the road classification definitions may not be uniform across maps and different GIS databases may have different levels of detail in including specific road types (e.g. not including unpaved roads), which may lead to underrepresentation of the trips that use the relevant road types.
4 Experienced young drivers - a follow-up study (IL3)

4.1 Introduction

Naturalistic driving studies or naturalistic data (ND) imply unobtrusive recording of the behaviour of drivers driving their own cars under ordinary traffic conditions. This is normally achieved by means of advanced recording equipment that is mostly concealed from the driver’s view. It is known as a very useful tool for understanding driver behaviour, and enables studies of behaviour that cannot be studied with any reasonable validity by other methods (PROLOGUE D3.1, 2009). ND makes it possible to acquire knowledge about safety-related and other driving behaviour in real traffic. Similar to the other Israeli field trials, this part of the study used the GR IVDR system, described in detail in Toledo et al. (2008) and in the Introduction (section 1.3.1).

This research is partially based on data from the "First-year study" as described earlier in section 1.4. The current research is in many ways an improved and a follow-up study in which the IVDR systems were re-installed in cars of these young drivers 3-4 years after they obtained their driving licenses. The data obtained through the IVDR system were compared to self-reported data and to the data collected in the previous study, which was conducted immediately after the young drivers received their driving licenses.

Several interesting research questions arise from such comparisons and will be the focus of this study:

How do young drivers drive 2-4 years after licensure compared to how they drove immediately after licensure? This question will be addressed by using the following parameters and analyses:

- perceived and actual safety levels per trip and in general
- events rate
- the impact of feedback
- qualitative analysis: experience with IVDR, relationship with parents then, now, and in a time perspective

What is the relationship between naturalistic data and self-report data?

- comparison of variables (ND vs. perceived) of exposure and safety level
- can the two approaches be used in a complementary manner?

To the best of our knowledge, this is the first time that a follow-up study with naturalistic data is conducted in this context. Therefore, the study and its results cannot be compared to other studies. Typically, although the definition of a "young driver" in Israel includes new drivers in the ages of 17-24, the main attention in the safety literature is given to young drivers in the ages of 17-18. As is shown in Figure 4.1 they are involved in car crashes more than any other age group. This trend has remained unchanged over the last decade (Lotan and Toledo, 2007). In this trial, the
behaviour of young drivers in their twenties is compared to their behaviour in the ages of 17-18 and immediately after licensure, based on IVDR data.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Total</th>
<th>Serious injury crashes</th>
<th>Fatal crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 18</td>
<td>1.6</td>
<td>13.0</td>
<td>7.9</td>
</tr>
<tr>
<td>24–19</td>
<td>1.7</td>
<td>6.8</td>
<td>1.3</td>
</tr>
<tr>
<td>34–25</td>
<td>1.3</td>
<td>5.5</td>
<td>1.2</td>
</tr>
<tr>
<td>44–35</td>
<td>1.2</td>
<td>5.3</td>
<td>1.1</td>
</tr>
<tr>
<td>54–46</td>
<td>1.1</td>
<td>5.2</td>
<td>1.1</td>
</tr>
<tr>
<td>64–56</td>
<td>1.1</td>
<td>4.7</td>
<td>1.1</td>
</tr>
<tr>
<td>65+</td>
<td>1.3</td>
<td>6.4</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.1: Car crash rates by age group in Israel in 2009 (source: RSA, 2010).

With regard to the relationship between ND and self-report data, this issue has been given some attention in the literature (for more details about self-reported data see the following background section). The self-reported traffic data serve, in many cases, as substitute to ND, although the best way may be to use these two approaches in a complementary manner. The cost associates with ND data are significantly higher compared to self-reports. Although the ND approach has several obvious advantages as a research method there are some possible limitations. For example, the report from the 100-car study (Neale et al., 2006) indicates that drivers behave normally despite being aware that their behaviour is being recorded, but the possibility of observer effects on behaviour cannot be ruled out entirely (see Backer-Grøndahl et al, 2009, D1.1). Thus, it is important to understand what is the relationship between the measurements of driving behaviour derived by naturalistic studies and the measurements derived from self-reports. In addition, the integration of the two sources of data may increase the validity and reliability of estimated variables since information is gathered from different sources and the data items collected may be complementary.

More specifically, in this research, we have used IVDR as an alternative to traditional self reported driving questionnaires. We compare our findings where possible with those obtained from self reports in order to evaluate the potential benefits of using IVDR and self-reports to collect such driving behaviour data.

In line with the PROLOGUE goals (D1.1), the potential for expansion to large scale will also be addressed.

## 4.1.1 Background: self-reported traffic data

Self reports are very popular tools employed in driver safety research (see Wåhlberg, 2009). Self-reported data has many well recognized advantages, such as its ease of use and the ability to collect large data sets relatively cheaply. Even though self-reported data suffers from well known
limitations regarding its validity as an indicator of actual behaviour (Saberg and Backer-Grendahl, 2010; Wåhlberg, 2009), many studies use it even as a sole source of data. The drawbacks tend not to be acknowledged and it is generally assumed that the self reported data is unbiased and that its error is random. However, the majority of the studies which addressed this issue have found that the validity and reliability of self-report traffic data is fairly low at the individual level and that it has low agreement with other sources of data (Wåhlberg, 2009).

There are two main failures affecting the validity and reliability of self-reported data. The first is memory failures – people suffer from strong forgetting and may also “remember” things that never happened. The impact of memory failures increases with the passage of time. In addition, uncertainty about details often occurs (e.g., remember the dates of incidents incorrectly), causing confusion in the self-reported data. The second is cognitive/social distortions - people tend to report what they think others would opt to hear and will make them look "good"(Wåhlberg, 2009; Wåhlberg et al, 2010).

The most common self-reported variables used in safety research are traffic crashes and level of driver exposure.

4.1.2 Traffic crashes

The self reported crashes are commonly compared, where possible, to official records (e.g. maintained by state authorities or insurance companies). Generally, it should be noted that the absence of a proven source for road crashes (Hauer and Hakkert, 1988) is problematic when performing comparisons.

Self-reported traffic crashes are especially subject to memory failures since subjects are most often asked to recall the crashes they had over a long period up to several years. Wåhlberg (2009) reviews several studies and conclude that people actually do forget they have had vehicle crashes, even fairly severe ones, while others report crashes that have never occurred. Both under-reporting and over-reporting of crashes at the individual level have been established. For example, McGuire (1976) found that drunk drivers clearly tend to underreport crashes while McGwin et al. (1998) found that drivers self-reported crashes that could not be found in official registers. Boufous et al. (2010) reported that 85% of road crashes recorded in the police records during the year prior to the survey were also self-reported by young drivers. However, such high agreement was not found in other cases, and may depend on characteristics of the population and the information being collected. McGwin et al. (1998), for example, found that among drivers above 60 years old only about two-third of the crashes recorded in police data for a period of the last five years, were self-reported.

The accuracy of self-reported near-crashes, which are much more common, is even more doubtful than that of self-reported crashes. For example, Chapman and Underwood (2000) found that 80% of near-crashes were forgotten after two weeks.
4.1.3 Driving Exposure

The level of driving exposure is well known in the safety literature as an important variable which has a strong impact on the risk of being involved in a road crash (Evans, 1991). Similar to self-reported road crashes, also this self-reported variable suffers from low level of accuracy compared to other driving exposure measures and therefore seems to be not very reliable (Wåhlberg, 2009).

Huebner et al. (2006) found low correspondence with over 30% differences between self-reported and recorded travel distances obtained from a CarChip (an electronic device installed in the car). Chipman (1982) reported better results, a correlation of 0.86. In both studies the period of interest was one week (the week prior to the date the self-reporting was carried out). The subjects in Huebner et al. (2006) were older drivers (N=20) with an average of 50 years of driving experience and they both under and overestimated their amount of driving. Blanchard at al. (2010) reported on a study undertaken using a similar method with older drivers (N=61) and found similar results. Although self-reports of travel distances were not systematically different from the distances recorded by the CarChips, participants tended to either under or overestimate how far they had driven over a week. Leaf et al. (2008) reported that among young drivers (N=118) obtaining trip-by-trip details provided the most reliable, credible, and informative estimates of the amount of teen driving. Retrospective questionnaires (asking about individual trips of the previous week without forewarning) provide comparable estimates, but overall week mileage estimates were 20–30% lower than with trip-by-trip listings, except among teens whose overall estimates were very low. White (1976) reported that high distances travelled by vehicles (not drivers) have been underestimated in self-reports whilst low distances travelled tended to be overestimated. In contrast, Staplin et al. (2008) reported the opposite relationship.

Lotan and Toledo (2007) found large differences between the IVDR measurements and similar statistics obtained through self-reports. The study involved young drivers during two periods: the accompanied period within the GDL program and the solo driving period that follows. Participants were asked to report about the amount of accompanied driving they undertook in terms of driving hours and number of trips and in terms of the amount of day and night driving. The differences between the self reports and IVDR data are very large and statistically significant in all cases. The driving times young drivers and their parents report are higher by 140%-300% compared to the IVDR data. Drivers seem to be a little better at estimating the numbers of trips (overestimate by 20%-100%) and the average lengths of trips (overestimate by 33%-45%). The correlation between the total driving times that were measured by the IVDR and those obtained from the self reports for the drivers who completed these reports (N=16) was only 0.53.

In summary, it seems that the usefulness and reliability of self-reported driving exposure still needs further investigation. The review of self-reported traffic data indicates that the reliability of self-reported data decreases with the passage of time between the occurrence of the events reported and the time of the reporting and with the frequency of the reported events (Wåhlberg, 2009). However, the recommendations that stem from these results may not be easy to implement. For example, crashes, especially severe ones, are rare events and therefore the time period reported should be long enough to gather data at the individual
level. In addition, more emphasis should be put on the way the items and terms in the self-report are phrased: e.g. what is the definition of terms such as "slight crash", a "near crash" and so on. The differences in the accuracy of self-reported data may also be associated with age: as suggested by Boufous et al. (2010) self-reports may be very useful tools for estimating variables especially among young drivers. However, Lotan and Toledo (2007) reported that significant biases are present in self reports of young drivers.

To conclude, all self reported variables should be compared where possible to other measures in order to achieve more accurate estimates.

4.2 Methodology

Participants in this trial drove their own cars or their family cars on their regular trips. The vehicles were all equipped with GR IVDR systems. The main body of data that was collected by the IVDR concerns various aspects of their driving behaviour in different traffic conditions. All trips done in the equipped vehicles were monitored. Drivers were asked to identify themselves using a magnetic key. The family members of the participants also received magnetic keys and were asked to identify themselves when driving the equipped vehicle, but their identification was voluntary.

4.2.1 Participants

The participants were recruited from the participants’ pool of the "First-year study" that was conducted 3-4 years ago. Those who agreed to participate were again screened for car availability and sufficient driving experience. The response was quick and mostly positive, with most of the participants indicating that they were willing to participate in the trial. The participants also received a small compensation for participating.

Eventually, 32 young drivers participated in this study, after signing an informed consent form. 21 of the participants (66%) were males and 11 (34%) were females. Their average age at the time the study started was 20.5 ± 0.5 years. The majority of subjects (75%) were in their regular military service during most of the time in which the study took place (a national mandatory military service exists in Israel for young people at the age of 18 for 2-3 years at least). Therefore, their use of the family car was assumed from the beginning to be not too intensive. Generally, their travel in the car was during their off-duty time. On average, subjects got their driving license 40.0 ± 6.6 months prior to the installation of the IVDR systems. Three out of the 32 subjects reported that they were involved as drivers in injury road crashes in the time since they obtained their licenses, and reported it was not their fault. 50% of the participants did not drive the same car they used in the previous study due to replacement. However, one of the screening criteria for the current study was that their current car belonged to the same vehicle group as the one used in the earlier study. This car replacement rate is consistent with the average age of passenger cars in Israel, which is 6.7 years.
As these drivers all participated in the previous study with GR IVDR sys-
tem, they are all familiar with the technology, the feedback structure, and
the terminology associated with it.

4.2.2 Data collection period

The overall study period was 8 months. The experimental design followed
the 3 stages structure described in section 1.5 above, where the first stage
("no feedback") started immediately after the installation and lasted about
2.5 months. As noted earlier, in this stage, the IVDR was installed in the
vehicle, but the participants did not receive any feedback from it. Accord-
ing to the relevant literature mentioned above and since the subjects were
familiar with the system it was assumed that the presence of the IVDR
would not cause changes in subjects' driving behaviour. In the feedback
stage that followed, participants received feedback via the web-reports
and the in-vehicle display. This stage lasted about 3.5 months. Finally, a
two month cool-off stage was used in which the participants continued to
drive with the IVDR but did not receive any feedback.

4.2.3 Self-reported data

A self-reported questionnaire was developed for this study. The question-
naire was internet-based. Participants received an email referring them to
the questionnaire website and asking them to respond to it.

The questionnaire consisted of two main parts. The first part was a self-
reported trip diary for a short recall period of 48 hours. The self report was
done for the periods they did not receive feedback; that is, only in the first
and third stages of the study. The dates on which the questionnaires were
distributed were selected randomly. Each participant was asked to fill 2-3
consecutive trip diaries in each stage; that is, a total of approximately 5
diaries were obtained from each participant. The 48 hour period for report-
ing was used in order to reduce memory failures. The trip diaries format is
shown in Figure 4.2. The information requested for each trip included the
date and start and end time of the trip, the trip purpose, the number of
passengers, risky events that occurred during the trip and the overall per-
ceived level of risk involved in the trip. Trip purposes were selected from a
menu that included Work, Education, Leisure, Errands and Other. Some of
these variables are comparable to the IVDR data (e.g., driving exposure)
while others are not available from the IVDR (e.g., trip purpose). The risky
events that occurred during the trips and the overall risk level were defined
similarly to the IVDR definitions, which the participants were familiar with.
Thus, risk events were categorized as Braking, Acceleration, Turn han-
dling, Lane handling and Speeding. The overall trip safety was Red (ag-
gressive behaviour), Yellow (moderate) or Green (cautious).
The second part of the questionnaire included questions on driving behaviour. It included 30 items in various domains:

- Perceived level of safety: in general and compared to others
- Perceived comparison of current driving behaviour to that as a novice driver (about three years ago)
- Changes in driving behaviour in the last eight months
- Opinions regarding the effect of various feedback tools: technology-based and human feedback on driving, real-time in-car display feedback and internet-based feedback, positive and negative feedback.
- Perceived contribution of the IVDR to their driving in time perspective
- Open questions

Participants were also asked about their socio-economic characteristics and completed a sensation seeking questionnaire in the area of Thrill and Adventure Seeking (TAS). This scale was also completed in the "First-year study". The TAS scale includes 10 items in a format of a forced choice. It is derived from the TAS part of the well established form V sensation seeking questionnaire (See Zuckerman, 1994, and the references there). TAS is established in the literature as the sensation seeking aspect which is strongly related to risky driving behaviour (See Jonah, 1997; Rimmo and Aberg, 1999; Jonah et al., 2001). In the "First-year study", TAS was found to be one of the factors affecting young driver's risk indices (Prato et al., 2010). Consequently, the aim in this trial was to investigate the changes in this variable over time among the young drivers and to evaluate its impact on their driving behaviour at the current stage.

Finally, personal interviews were carried out with participants in order to clarify open questions, to gain more details about the relationship with parents in light of having the IVDR installed in the car, and about difficulties associate with providing self-reported data.
As noted above, the method and the data compiled in this study are similar to the earlier "First-year study" conducted immediately after licensure.

4.3 Results

4.3.1 Summary statistics

More than 37,000 trips were monitored in the IVDR equipped vehicles. In 40% of the trips the driver was identified. It is important to note here that only the young drivers were required to identify themselves when driving. Overall, 6,474 trips in the study period (17.5%) were associated with the 32 participants. These trips are used in the analysis that follows.

Table 4.1 presents general statistics of the trips the participants undertook in the two studies. The mean trip duration is 22.1 min. (SD = 20.9 min.). As novice drivers (in the previous study), the participants undertook 1.55 trips per day, but only 1.02 trips per day as more experienced drivers (in the current study). This may be explained, as noted above, by the limitations imposed by their military service.

<table>
<thead>
<tr>
<th></th>
<th>Novice drivers</th>
<th>3-4 Years experience drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accompanied</td>
<td>Solo No feedback</td>
</tr>
<tr>
<td>No. of trips</td>
<td>1,267</td>
<td>2,313</td>
</tr>
<tr>
<td>Total duration of trips (hrs)</td>
<td>499.1</td>
<td>799.4</td>
</tr>
<tr>
<td>Trip duration Average (min)</td>
<td>23.6</td>
<td>20.7</td>
</tr>
<tr>
<td>SD (min)</td>
<td>21.5</td>
<td>18.5</td>
</tr>
</tbody>
</table>

4.3.2 Thrill and Adventure Seeking (TAS)

29 participants completed the TAS scale both as novice and experienced drivers. The average scores were somewhat lower in the later period of time. The average TAS score as novice drivers was 5.93 ± 3.76. As more experienced drivers the average score was 5.76 ± 3.05. Higher scores indicates a higher level of TAS. However, the difference between the results in the two studies is not statistically significant. Among the participants, 55% had lower TAS scores as experienced drivers, 14% had exactly the same scores, and 31% scored higher as experienced drivers. The correlation between participants’ scores in the two periods is 0.67. More in-
Interestingly changes in TAS are found with respect to gender. Whilst the average score of male participants was found to decrease from 6.62 to 5.90 \((N=21)\), the average score of female participants was found to increase from 4.13 to 5.38 \((N=8)\). These changes are again not statistically significant. It should be noted that even with this trend, female participants scored lower than male participants in both studies.

These results are only partly consistent with similar ones reported in the literature. Zuckerman et al. (1978) reported on a significant decline in TAS with age and especially between age groups 16-19 and 20-29. They found that the average score of TAS in the age group 16-19 was 7.4 for male and 5.6 for female compared to 6.6 for male and 4.4 for female in the age group 20-29. Another study by Johan et al. (2001) reported that high and low sensation seekers (not specifically TAS seekers) did not significantly differ on age (the average age of the sample investigated in this study was 25 years, S.D.=6.3 years).

### 4.3.3 Comparison of exposure

The exposure of the drivers to driving in the two studies was compared in terms of temporal distributions of the trips (only for corresponding phases of solo driving with and without feedback). Figure 4.3 and Figure 4.4 present the temporal distribution of trips in the two studies with respect to time of the day and the days of the week.

Overall, the exposure patterns are somewhat similar, but some differences may be observed. In terms of the time of day, the young experienced drivers undertake a smaller part of their driving in the evening and night times (from 18:00 to 06:00) and more during the day (from 06:00 to 18:00). This may be a result of the changes in their daily activities as they have shifted from being senior high school students to military servicepersons or employed individuals. With respect to the days of the week, the young experienced drivers now drive more on weekends (which include Friday and Saturday in Israel) and on Sundays compared to when they were novice drivers. This again is consistent with expectations given the changes in their main activities and schedules.
4.3.4 Comparison of events rates

As in the other Israeli trials, the events rate is the basic measure used here to represent driving behaviour. Again, it is the ratio between the safety events and total driving time. The analyses presented hereafter are based on a more progressive calculation of a logarithmic model to indicate the estimated rate of events as described in detail in section 2.4.2 (IL1). For convenience, in this section this measure is called an "events rate".

The average events rates for the various stages of the studies are presented in logarithmic scale in Figure 4.5. The width of each box is pro-
portional to the number of trips in the specific stage as presented in Table 4.1.

![Figure 4.5: Events rates by study stages.](image)

Events rates seem to be similar in the stages with and without feedback in both studies. The accompanied driving stage is clearly characterized by the lowest events rate, which seems plausible and in line with the impact of this stage on safety (See Lotan and Toledo, 2007). This effect is prominent enough to be detected by the statistical analysis even with the relatively small sample size used in our study. A Tukey post-hoc test ($\alpha=0.05$) did reveal that the events rate in the accompanied driving stage is different from the other two stages in "First-year study". A small decline in events rates is also observed in the passage from the no feedback to the feedback period within the solo driving. However, this effect was not statistically significant.

No significant difference was found between the events rates that were found in the current study and those found in the former one (excluding the accompanied phase of course).

In the current study of the more experienced drivers, the events rates in the stage with feedback are only slightly lower than those in the period without feedback. These differences are also not statistically significant. However, the events rates in the final cool-off stage are lower. This difference is statistically significant at the $\alpha=0.05$ confidence level. This is an unexpected result that needs to be further investigated.

### 4.3.5 Temporal effects on events rates

Figure 4.6 and Figure 4.7 present the events rates as a function of the time of day and day of the week for both studies. The results show that higher events rates are observed in the night-time, from midnight to 6:00 and during the weekend. These results are consistent with novice drivers' safety literature, which
repeatedly reports increased involvement in crashes during weekends and at night-time (See for example, Lotan and Grimberg, 2008; Åkerstedt and Kecklund, 2001; Doherty et al., 1998).

Figure 4.6: Events rates by the time of day for the young drivers.
Figure 4.7: Events rates by the day of the week for the young drivers.

Figure 4.8 presents the comparison of events rate by daytime (on the left), by weekday (on the middle) and by feedback provision (on the right) in the two studies. The information is presented only for drivers with trips in all combinations. This figure provides more insights on the temporal effects that cannot be obtained from the previous figures. Whilst the effect of night-time on events rate is prominent in both studies, it seems that more experienced drivers tend to have more intensive decrease in the events rate during this problematic daytime period. Not trivial is the effect of weekend where the events rate for more experienced drivers is higher than it was 3-4 years ago. It is interesting to note that even though we received two contradicting temporal effects, still there was no significant change in the average events rate of the two periods as presented in Figure 4.5. The effect of feedback is also notable as its provision causes lessen events rate.

As shown in Figure 4.5 a significant and unexpected decrease in events rate has been noticed for more experienced drivers in the cool-off stage. In an attempt to understand this effect we have focused on the impact of the two important factors, study stage and weekend on events rate. The following interaction plot presented depicts the mean over events rate for a subset of 21 drivers with observations at each of the combinations (to create balanced data). As can be seen in Figure 4.9, the passage of time has a noticeable effect in situations where the events frequency is relatively high (as in the weekend), and that driving with IVDR may trigger improvement in driving behaviour. Once again the effect of the cool-off stage is prominent.
4.3.6 Comparison of IVDR data and self-reported data

The self-reported data compiled for specific days in the no feedback stages of the current trial (i.e. the blind profile and the cool-off stages) were compared to the data collected by the IVDR for the same days. In this part of the study, trips that were self-reported were matched with trips recorded by the IVDR. The matching was based on the trip date and time that the driver reported. As mentioned earlier, the drivers were not identified in all the trips, even those undertaken by the young drivers. However since each trip is identified by IVDR also at the car level it was feasible to attribute specific unidentified trips via the self-report information regarding the trip date and time which the driver reported.

In the first no-feedback stage (the blind profile) 16 participants self-reported on trips. However, the trips reported by 4 participants could not be matched to any trip in the IVDR data. The other 16 participants stated they did not drive at all on the specific dates covered by the self-reports.

109 trips have been self reported by these 16 participants, however only 48 of the trips (44%) could be matched. The other trips could not be matched due to missing self-reported data, e.g., time, date, driver identification, etc.

In summary the comparison of IVDR data and self-reported data is based on 48 matched trips by 12 young drivers.

In the last stage (cool-off stage) 25 participants self reported on trips. However, the trips reported by 8 participants could not be matched to any trip in the IVDR data. The other 7 participants stated they did not drive at all in the specific dates covered by the self-reports.

194 trips have been self reported by these 25 participants, however only 106 of the trips (55%) could be matched. The other trips could not be matched due to missing self-reported data, e.g., time, date, driver identification, etc.
In summary the comparison of IVDR data and self reported data is based on a total of 106 trips by 17 young drivers. The comparison of IVDR data and self-reports was undertaken with respect to the driving exposure and trip safety evaluation.

**Driving exposure**

In the first no-feedback stage (the blind profile) the total duration of the matched trips was 1487 minutes according to the IVDR data and 1742 minutes in the self-reports. This results in an average trip duration of 31.6 ± 39.1 minutes for the IVDR and 36.9 ± 45.3 minutes for the self-reports. The correlation between the total driving times was 0.96 at the level of individual participants; 4 subjects (33%) under-estimated their travel time while 8 (67%) over-estimated it.

In the last stage (cool-off stage) the total trip time was 2746 minutes in the IVDR records and 2795 minutes in the self-reports. This results in average trip duration of 26.8 ± 21.6 minutes in the IVDR data and 27.3 ± 16.0 minutes in the self-reported data. The correlation between the total driving times at the individual level was 0.90 at the level of individual participants; 6 subjects (35%) under-estimated their travel time while 11 (65%) over-estimated it.

**Trip level risk evaluation**

We compared the trip risk evaluation scores provided by GR IVDR to those perceived by the participants. To re-iterate, the risk level of each trip is categorized as High (red), Moderate (yellow) or Low (green).

In the initial no feedback stage, the IVDR risk classification were higher (indicating higher level of risk) than the self-reports in 47% of the trips. The categories were equal in 45% of the trips. Only in 8% of the trips the risk category recorded by the IVDR was lower than the self-reported one.

In the cool-off stage risk level reported by the IVDR was higher than the self-reported one in 30% of the cases, the two were equal in 70% of the cases. There were no cases in which the IVDR reported lower risks.

**Overall risk evaluation: perceived vs. IVDR**

We then compared the overall risk evaluation scores (RES) of the young drivers as provided by GR IVDR and in the self-reports. To conduct statistical comparisons, we converted the original ordinal scale to an interval one ranging from 0 to 1. For the categorization of drivers, values up to 0.2 are categorized as low-risk drivers (green), 0.2≤RES<0.5 indicate intermediate driving (yellow), and values over 0.5 indicate aggressive driving (red). Accordingly, on the aggregate level, in the no-feedback stage, the average RES obtained from IVDR data is 0.465 compared to 0.185 obtained from the self-reports. In the cool-off stage the average RES obtained from IVDR data is 0.270 compared to 0.035 obtained from the self-reported data. Subjects significantly perceived themselves as safer drivers compared to the IVDR estimates. The comparison of the perceived RES of each subject to the RES calculated from the IVDR data in the cool-off stage is shown in Figure 4.10. In the figure, the bars for each subject are
colour coded by their self-reported risk levels (green for low, yellow for intermediate and red for high risk). The figure indicates that 6 out of the 14 subjects perceived themselves in general as safer drivers than they really are according to the IVDR data (e.g. subjects with RES of 0.85-0.9 are above the red line are certainly "red" but perceived themselves as "yellow"), 7 classified themselves similarly to the IVDR and only one self-reported higher risk level compared to the IVDR.

Figure 4.10: Driving safety levels measured by the IVDR and self-reported.

4.3.7 The impact of trip purpose and presence of passengers on trip safety

One of the potential advantages of using different sources of data is the ability to obtain complementary information, which is often not available from a single source. In this section we used variables that are available only from the self-reports, the trip purpose and the number of passengers in this case, and used them to explain the trip safety indices obtained by IVDR. Our focus was on trip purpose for recreation and on the presence of passengers in the car since these two factors are established as causes for more risky driving behaviour among young drivers (Doherty et al, 1998; Chen et al, 2000; Williams, 2003).

The data used here includes the 154 trips (48 in the no feedback stage and 106 in the cool-off stage) that were matched between the IVDR and self-reported data. 35 (23%) of them were classified by IVDR as "red", 25 (16%) as "yellow" and 94 (61%) as "green". In the data, the distribution was as follows: 40 (26%) of trips were for recreation purpose and in 80 (52%) of the trips passengers were present in the car.
Figure 4.11 and Figure 4.12 show the distribution of trip safety indices by the trip purpose and by the presence of passengers respectively. Figure 4.11 indicates that the impact of recreation purpose on trip safety cannot be considered valuable as a similar share (approximately one-quarter) of the trips at each safety level are for recreation.

Interestingly and not trivial is the impact of presence of passengers in the young-experienced driver’s car on trip safety which is shown in Figure 4.12. As can be seen in 60% of the trips which were classified “green” there were passengers in the car whilst in 30% of the trips which were classified “red” there were passengers in the car.

These results clearly suggest that the presence of passengers in the car has a positive impact on trip safety. This is somehow unexpected as the common literature reports that among novice drivers, driving with passengers is more risky (Williams, 2003; Doherty et al, 1998; Preusser et
al., 1998). However, there is also some evidence that driving with passengers, especially among relatively older-young drivers (19-24 years old) that the presence of passenger in the cars may positively affect the risk level and depends on social interactions between drivers and passengers (Doherty et al., 1998; Engström et al., 2008).

4.3.8 Qualitative analysis

The majority of the subjects reported a good and fruitful experience with IVDR technology, and that it made them more aware of their driving behaviour. According to their responses, this impact was much more intensive in the period immediately after licensure. But, most of them believe that the current experience with IVDR also helped improve their driving. 30 out of 32 subjects (94%) would recommend or highly recommend to others to install IVDR immediately after licensure. The two who did not recommend it said that the IVDR only added to their confusion and caused more conflicts with their parents. 26 out of 32 subjects (81%) would recommend or highly recommend to others to install IVDR also 3-4 years after licensure. Those who did not recommend mostly said that the benefit from the IVDR at this period may not justify the installation as they did not often use the system feedback.

With respect to the desired intervention and feedback, 16 out of 32 subjects (50%) think that the technology-based feedback would be best. 11 (34%) prefer professional in person feedback and 5 (16%) prefer to receive a feedback from an adult family member. Regarding the IVDR feedback, 20 out of 32 subjects (62.5%) stated that both the real-time in-vehicle display feedback and the internet-based feedback are important, 11 (34%) stated that the real time feedback is more important and only one stated that the internet feedback is preferred. No difference was found in the effect of positive and negative feedbacks.

4.4 Discussion

This trial presents an attempt to analyze and compare, based on naturalistic data, the driving behaviour of young drivers with 3-4 years of experience with the behaviour of the same individuals immediately after licensure. The comparison uses data collected by IVDR and by self-reports.

The various results reported in this part of the Israeli trial demonstrate the usefulness of naturalistic data collection against or in conjunction with other sources of data such as self-reports. The comparison with self-reported driving exposure data revealed that substantial differences may be observed between the two even if drivers are asked to recall their trips for only a short time period. This comparison highlighted not only the deficiencies of self-reports, but also difficulties that arise with naturalistic data collection, and in particular with obtaining complete and correct driver identification. For a future large-scale data collection effort, different options to obtain reliable driver identification should be evaluated.

The results obtained in this trial should be considered as exemplifying the potential of what may be done with naturalistic data. When considering the results themselves, it is important to take into account that the
analyses are based on a small sample of 32 subjects, which are by no means representative of young drivers. The sample is likely to be biased towards individuals and families that have a high awareness and positive attitudes towards traffic safety. In addition, the status of the participant – a large fraction of them in military service – impacts on their exposure patterns in a way that may be unique to their situation.

The results indicate that young drivers do not drive safer 3-4 years after they received their driving license. The comparison to the previous study results revealed that whilst driving patterns generally remain similar, their sensation seeking has not changed and in the main, no significant change occurred in the event rates. However, an interesting improvement in driving behaviour has occurred in the cool-off stage and the impact of negative factors, e.g., night-time, is relaxed.

This may indicate that young-experienced drivers may improve their safety level while driving with IVDR.

It is also worth to note that, as generally opposed to the known literature about novice drivers, neither "night" nor "recreation" effects were found among young-experienced drivers. In addition, the presence of passengers in the car was found to positively affect safety. However, these unexpected results can not be generalized and should be treated with caution due to the limitation of the study sample as discussed earlier. These results should be further investigated in future studies using similar methodology. In addition, our results suggest that there is no significant impact of feedback on driving behaviour of young experienced drivers.

Young-experienced drivers clearly perceived themselves as regular safer drivers than they are according to IVDR data. However, they are accurate in their driving exposure reports. Subjects reported a good experience with IVDR but interestingly opt to receive not only technology-oriented feedback. This may indicate that other sources of feedback and interventions should be considered to improve safety.

As discussed earlier, the results should be considered with respect to the sample characteristic. However, the data collection methodology and the way the data were analysed are more robust. IVDR technology is a valuable tool to understand driving patterns and behaviour. The detailed analysis of events provides insights on safety issues, especially as the relationship between safety related events and crashes is well established in the safety literature (for example, "Heinrich's triangle" as described in Backer-Grøndahl et al., 2009). Together with other sources of data, such as self-reported data, the information gathered is more valid, reliable and provides a more complete picture of driving behaviour. Most of the results of this trial are based on a combination of IVDR and self-reported data, and demonstrate the strength of analyses that use these two approaches in a complementary manner.
5 Group comparisons of young drivers (IL4)

5.1 Introduction

Adolescence and young people driving style is commonly characterized by risky driving behaviour (Bina et al., 2006) and hence leads to increased involvement in road crashes. Various studies have shown that adolescents' behaviour and risky driving behaviour in particular, is widely influenced by their family (e.g., Taubman - Ben-Ari et al., 2005; Clark and Lohéac, 2007) and peers' behaviour (e.g., Prinstein et al., 2001; Maxwell, 2002).

Taubman - Ben-Ari et al. (2005) found significant associations between parents and off-springs' driving styles. They found that both parents' anxious, reckless and careful driving styles were reflected in their off-spring's driving styles. In addition, Engels and Bogt (2001) have shown that engaging in risky behaviour is related to both quantity and quality of peer relations in adolescents' social groups. Different studies found that risky health behaviours such as alcohol use (Clark and Lohéac, 2007), cigarette smoking (Alexander et al., 2001), and drug use (Bauman and Ennett, 1996) were strongly influenced by social peers.

Another aspect of the influence of social peers on teenagers' behaviour and teenage driving behaviour in particular, relates to the presence of passengers in the vehicle whilst driven by a young driver. The effect of teenage passengers on young driver crash risk is well known from analyses of crash statistics. Williams and Ferguson (2002) studied the factors contributing to increased crash risk of young, novice drivers. Results of this study showed that one of the most influential factors on young drivers' crash risk was driving with passengers from the peer group. Similar results were found in an earlier study conducted by Chen et al. (2000). Relative risk analysis in this study revealed that the risk of death for young drivers increased with the number of young passengers (aged 20 to 29) up to 2.7 times higher with the presence of two or more passengers in comparison to driving without passengers.

An explanation to these findings can be found in Simons-Morton et al's. (2005) studies. They found that the presence of teenage passengers, especially male passengers, was associated with risky driving behaviour among teenage drivers.

In summary, research has shown that there is a significant influence of peers on the behaviour of young people and on risky behaviour in particular. However, to the best of our knowledge, the influence of the social group to which drivers belong on direct naturalistic measures of driving behaviour of young drivers has not been addressed in the scientific literature.

In the current trial, a "community model" was used to test driving behaviour among young drivers who belong to the same social group and know each other (IL4a). We also compared this group to a different social group (IL4b), and finally we developed the infrastructure for comparing two different groups from different countries (IL4c). In this chapter, the three types of comparisons are described and discussed.
5.2 Research objectives

The main goal of this trial was to examine whether similar social environment and familiarity among drivers, create and encourage similar driving patterns. Similarities are evaluated with respect to driving exposure and risky behaviour as expressed by the events rate of the GR technology.

In the first part, IL4a, we examined the effect of social relations (social connectedness) on driving behaviour. A second-order objective was to explore the effect of feedback intervention within a close group.

The second part, IL4b, examined differences between two groups of Israeli young drivers, regarding exposure patterns as manifested through driving frequencies, trips duration, and day/night time trips ratio. Additionally, the two groups were compared according to the distribution of their extreme driving events, as measured by the GR technology.

In the third part, IL4c, we created the infrastructure for comparing driving behaviour of Israeli and Austrian young drivers using the GR technology for the Israeli drivers and the pdrive technology for the Austrian drivers.

5.3 IL4a: The community Model - The effect of social connections on driving patterns

In this sub-trial we examined the connection between social relation among young drivers who belong to a close homogeneous community and driving patterns, as reflected in driving exposure and in events rate of the GR technology.

The community that was selected for this trial was an Arab local council (rural community) in the north district of Israel, called Kfar Yasif ("Joseph’s Village"). This community has a population of 8800 inhabitants, with a population density of 2755 people/km². The majority of the population are Christians (56%), 41% are Muslims and the remainder are Druze.

The roads infrastructure in Kfar Yasif is only moderately developed. There are no traffic lights at intersections and paved sidewalks are partially built as can be seen in Figure 5.1, presenting the main road of the village.
Participants in the community group live and/or study in Kfar Yasif. All of them are spending most of their time in the village and therefore the majority of their trips are within the boundaries of the village.

5.3.1 Methodology

5.3.1.1 Recruitment Procedure

The goal of this trial was to examine driving patterns among socially connected groups of young drivers. Therefore, the basic requirement was to include only young drivers who know each other and engage in similar everyday activities. Because of these requirements, the recruitment procedure took a long time, since several communities that the trial team approached did not show the collective willingness to take part in the trial. The families that were eventually recruited were directly contacted through a contact person who had already worked with Or-Yarok in the past and lived in the community.

The local contact person organized the first meeting between the young drivers (the participants) and the trial team on January 14th 2010. This meeting had two main purposes: the first was to introduce the young drivers to the trial’s guidelines and procedures and to the obligations and the benefits accompanying the participation in the trial. As an incentive for participation and cooperation, each young participant received 400 NIS (about 100 US$) at the end of the trial period. The second purpose of the meeting was to ask the young drivers whether they would want their parents to see the feedback on their driving. The decision whether to use a collective feedback (where every member of the family can access all other members’ driving feedback) or personal feedback (where only the driver can access his/her driving feedback) was defined as a “group” decision, meaning that all participants had to agree on it and respect it.
In the meeting, the participants showed great willingness to participate in the trial and were interested in the trial process and potential results. They unanimously agreed that they would not want their parents to have access to their driving feedback. Therefore, it was decided that the driving feedback would be personal. Participants could choose to share their driving records with other members of the family or friends.

During the following two weeks the trial team met with the parents of the young drivers. The parents’ meeting took place at each of the parents' private residence. During these meetings, the parents were informed of the trial procedure and their off-springs’ involvement in the trial. All parents expressed their consent to participate in the trial. They were informed that their children decided that the system's feedback would be personal and that they needed to respect this decision. At the end of this meeting, the parents signed an informed consent form.

5.3.1.2 Participants

The sample in this trial consists of 13 novice young drivers, who live in the same community – Kfar Yasif. Two participants were later excluded from the sample because they failed to identify themselves at the beginning of each trip, as had been requested. Therefore, effectively the data analysis in this trial was conducted 11 participants.

All participants (7 males and 4 females) know each other and most of them attend the same class at senior year of high school. The range of ages within the group was from 17 to 19 years with the exception of one 20-years old subject (Av.=18.09; SD=0.78). Some of the participants are related (cousins).

All participants, with one exception, were at the beginning of the trial in the "solo" phase of their first year of driving (Av.=3.7 months experience; SD=2.21). One participant had obtained his license 31 months before beginning the trial.

5.3.1.3 Technology and data collection procedure

The technology used in this trial was an In-vehicle system developed by GreenRoad Technology as described in the introduction section 1.3.1.

5.3.1.4 Questionnaires

Prior to systems' installation, participants were asked to fill out a web based background questionnaire. This questionnaire included socio-demographic data (sex, age, driving experience, family size, household size, number of vehicles in the family etc). They were also asked about the number of drivers who use the vehicle in which the system was installed, and availability of this vehicle to the young driver.

In addition, during the research period, participants were personally interviewed regarding the social and familial relations between them. In these interviews, participants were asked who their best friends were among the group members, with whom did they ride, and who rode with them.

5.3.1.5 Experimental Design and Procedure
Following the recruitment process described in section 5.3.1.1, 13 in-vehicle systems of GreenRoad Technology were installed on February 14th 2010. Every member of the families participating in the trial, who were to drive the vehicle, received a personal magnetic identification key, but only the young drivers were required to identify themselves.

As described in the introduction (section 1.5.2), the experimental design included two main stages:

**Blind-profiling stage:** This stage lasted about ten weeks immediately after the in-vehicle system installation. This stage was intended to measure the driver’s baseline behaviour and therefore in this stage drivers did not receive feedback whatsoever. It is therefore expected that the installation had minimal effect on drivers’ behaviour during this period.

**Feedback stage:** At the end of the blind-profiling stage, the young drivers were invited to a meeting in which they learned about the feedback that the In-vehicle system provides. During this meeting they received access codes to a web site that shows their own data, and the real-time display feedback in their vehicles was also activated. This stage lasted three months.

All the trips performed by the installed vehicles during these two periods (February 14th to July 28th) were monitored (whether identified by a specific driver or not). In order to avoid loss of trips of the young drivers, all drivers received a list of unidentified trips once per week from which they were asked to mark their own trips, if there were any.

### 5.3.2 Results

The overall data collected in this trial included 12,142 trips which resulted in over 3580 driving hours. A total of 6,916 GR events were documented.

#### 5.3.2.1 Summary statistics

Table 5.1 presents descriptive statistics of the data collected for trips that were conducted and identified by the 11 young drivers that participated in the trial. The details in the table show large variance among participants in driving exposure and in events rates. It seems that the most common events performed by the young drivers were braking and turning. For most participants (except for participant no. 7), the majority of their events were either braking or turning.

Table 5.1 also presents summary statistics for the distribution of trips conducted by the young drivers and for trips conducted by other family members driving the equipped vehicles.

Results, presented in the table, showed large range of trip frequencies (ranging from 34 to 618 trips in 5.5 months) and time travelled (15 to 235 hours in 5.5 months). However, when looking at the average trip duration, it seems that the range is narrowed (15 to 27 minutes per trip). It also shows that young drivers performed about a quarter of all the recorded trips and had a similar events rate to the rate of other family members. The trip mean duration of the young drivers is moderately higher than mean duration of other drivers, and it appears that the young drivers...
perform fewer speeding events and more accelerating and lane change events in comparison to other drivers.
Table 5.1: Descriptive statistics of 11 young drivers' trips and of trips of other drivers in their vehicles.

<table>
<thead>
<tr>
<th>Driver No.</th>
<th>Gender</th>
<th>Total no. of trips</th>
<th>Total driving time (hr:min)</th>
<th>Trips mean duration (min)</th>
<th>Total no. of events</th>
<th>Events rate (per minute)*</th>
<th>No. of red events**</th>
<th>No. of events by type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Braking</td>
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<tr>
<td>1</td>
<td>Male</td>
<td>431</td>
<td>149:21</td>
<td>20.79</td>
<td>252</td>
<td>0.028</td>
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<td>130</td>
</tr>
<tr>
<td>2</td>
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<td>298</td>
<td>134:34</td>
<td>27.10</td>
<td>138</td>
<td>0.017</td>
<td>6</td>
<td>43</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>131</td>
<td>55:47</td>
<td>25.56</td>
<td>140</td>
<td>0.042</td>
<td>4</td>
<td>46</td>
</tr>
<tr>
<td>4</td>
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<td>209</td>
<td>51:16</td>
<td>14.72</td>
<td>165</td>
<td>0.054</td>
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<td>37</td>
</tr>
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<td>23.43</td>
<td>20</td>
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<td>0</td>
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</tr>
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<td>0.015</td>
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<td>35</td>
</tr>
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<td>61:58</td>
<td>15.18</td>
<td>198</td>
<td>0.053</td>
<td>23</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>Male</td>
<td>235</td>
<td>84:8</td>
<td>21.48</td>
<td>306</td>
<td>0.061</td>
<td>13</td>
<td>77</td>
</tr>
<tr>
<td>9</td>
<td>Female</td>
<td>578</td>
<td>159:46</td>
<td>16.58</td>
<td>281</td>
<td>0.029</td>
<td>7</td>
<td>123</td>
</tr>
<tr>
<td>10</td>
<td>Male</td>
<td>618</td>
<td>235:53</td>
<td>22.90</td>
<td>330</td>
<td>0.023</td>
<td>13</td>
<td>57</td>
</tr>
<tr>
<td>11</td>
<td>Female</td>
<td>40</td>
<td>15:19</td>
<td>22.98</td>
<td>4</td>
<td>0.004</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total for young drivers</td>
<td></td>
<td>3,030 (25%)</td>
<td>1,023:31 (29%)</td>
<td>20.76</td>
<td>1,891 (27%)</td>
<td>0.031</td>
<td>81 (35%)</td>
<td>571 (26%)</td>
</tr>
<tr>
<td>Total for other drivers</td>
<td></td>
<td>9,112 (75%)</td>
<td>2,562:45 (71%)</td>
<td>16.89</td>
<td>5,025 (73%)</td>
<td>0.033</td>
<td>152 (65%)</td>
<td>1,657 (74%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>12,142 (100%)</td>
<td>3,586:16 (100%)</td>
<td>6,916 (100%)</td>
<td>0.031</td>
<td>233 (100%)</td>
<td>2,228 (100%)</td>
<td>212 (100%)</td>
</tr>
</tbody>
</table>

* Events rate = number of events / trips duration (in minutes)
** red events refer to GR's terminology of aggressive events (see section 1.3.1)
5.3.2.2 Exposure measures

Driving exposure can be measured in two ways – by number of trips and by total driving time. These two measures can often produce different results when exploring different driving distributions (such as days of the week, day/night trips and so on). Table 5.1 presents large variance between participants in both measures - number of trips and total driving time.

Exposure analysis according to the day of the week reveals a different picture when examining the data according to these two measures. Figure 5.2 presents total number of trips performed by all young drivers across 7 days of the week. The figure shows minor differences between different days with a slight increase from Friday to Monday. Figure 5.3 presents the same data but distributed according to total driving time (in hours). This figure reveals a clearer picture that is consistent with previous studies (Prato et al., 2009), in which young drivers drive more during weekends (mostly on Saturday and Sunday) than on other days of the week.

Figure 5.2: Total no. of trips of young drivers by day of the week
Another exposure measure refers to the difference between day and night driving. In Figure 5.4, day trips were defined as trips performed between 6 AM and 10 PM and night trips were between 10 PM and 6 AM. The figure shows that young drivers in this trial drove much more during the day than at night-time. Analysing day and night exposure using total trips driven resulted in similar findings.
5.3.2.3 Events rate

One of the most informative factors regarding the drivers' behaviour is the measure of "events rate", which was described in previous sections of this report (see, for example, section 2.4.2). Average events rate of a group of drivers, can be computed in two different ways. In the first way, the sum of events (of all drivers) is divided by the sum of trips duration. This way, the average is weighted so that events rate of a driver with higher trips duration will influence the total average more than the events rate of a driver with low trips duration. The second option to calculate average events rate is by computing the mean value of the drivers' events rate averages. In this case, all drivers have an equal influence on the total average.

In the current trial, the general events rate (calculated as weighted average – sum of events divided by sum of trips duration) of young drivers (0.031) was relatively similar and even lower than other drivers' events rate (0.033). Figure 5.5 presents a scatter plot of the events rates of young and other drivers (all the trips in the young driver's vehicle that were not identify as the young driver's trips) for each of the 11 equipped vehicles. Each dot in the figure represents a combination of the average events rate of a young driver (x-axis) and the average events rate of other drivers in their family (y axis).

As the figure shows, in most cases events rates of young drivers are positively correlated with the ones of other drivers, with three extreme exceptions (marked with a circle in the figure). In one exception, the events rate of the young driver was much higher compared to the events rate of the other drivers in the same vehicle, and in the other two exceptions, the opposite phenomenon occurred.
Figure 5.5: Events rates of young and other drivers in their family.

The young drivers' events rate was also analysed according to the day of the week and time of the day. Figure 5.6 presents average events rate for each day of the week. According to this analysis, the lowest events rate was found during weekend (Saturday and Sunday) and the highest was found on Wednesday. Nevertheless, no significant differences were found between different days.

Comparing Figure 5.3 (Total driving time by day of the week) and Figure 5.6 (Events rate by day of the week) shows the opposite effect of mid-week and weekends. As participants drove more hours per weekday, their events rate was lowered.
A comparison of day trips' and night trips' events rates for each participant is presented in Figure 5.7. According to the figure, it seems that driving behaviour of young drivers is more "aggressive" or eventful while driving by night. The majority of participants had, on average, much higher events rates while driving at night.

Although participants drive more during the day (as shown in Figure 5.4), their night trips involve more events. This implies that there is no correlation between night time exposure and the night time events rate score. An extreme example of this phenomenon is driver no. 7. This young driver hardly drives at night but when he does, his driving is aggressive. In contrast, driver no. 10 has relatively high night time driving rate, but his events rate is relatively low at night.

![Figure 5.7: Events rate of young drivers by day and by night.](image)

5.3.2.4 Social connections among young drivers

Beyond learning about general similarities in driving patterns within the original group we were interested to see if these patterns could be explained by the inter-relations of the group members. In particular, we wanted to see if we could cluster subgroups and characterize driving within and between subgroups. As described in section 5.3.4, participants specified their friends among the group (who will be referred to as "type A" relations). In addition, the social relations interview included questions about driving peers. Participants specified with whom they ride regularly ("type B" relations), and which participants are riding with them regularly ("type C" relations). The social connections network including all three relation types is presented in Figure 5.8, where nodes correspond to participants and there is a directed link from node i to node j if participant i specified a relation with participant j.
As presented in Figure 5.8, drawing a network based on these relations reveals a very highly connected network among four participants: 2, 3, 7 and 10. This group has 12 A-type relations (complete mutual coverage), 7 B-type relations and 9 C-type relations. A second, weaker sub-group contains participants 1 and 4 with 2 A-type relations, 1 B-type and 1 C-type. The rest of the participants (5, 6, 8, 9 and 11) are quite isolated, with participants 5 and 8 having only 1 relation, and the rest having mostly out-going relations (meaning that they relate to other participants, but other participants do not relate to them).
Table 5.2 summarizes the number of people (among the participants) that each participant mentioned in answer to each of the three questions: "Who are your best friends among the group?"; "Who do you ride with regularly?"; and "Who rides with you regularly?".
Table 5.2: Total count of friends and riding mates.

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Who are your friends? (&quot;type A&quot;)*</th>
<th>Who do you ride with? (&quot;type B&quot;)*</th>
<th>Who rides with you? (&quot;type C&quot;)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
<td>0</td>
</tr>
<tr>
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<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Each column in the table details the total number of people that each participant mentioned.

Looking at the total events rates and specific events rates of the groups mentioned, does not reveal a clear classification or connection among sub-group members. Clustering analysis according to participants' events rate, as presented in Figure 5.9 resulted in two main groups: first group – participants 3, 4, 7, 8 (dots); and second group – participants 1, 2, 5, 6, 9, 10, 11 (red squares). Clearly, this clustering divides participants according to high and low events rates. This distribution does not coincide with the social and driving inter-relations among participants as presented in the social network (see Figure 5.8).
A particular interesting view-point that might shed some light on group driving behaviour can be gained by looking at the outliers. There are two clear outliers to this group:

- Participant number 10 – with a total of 16 relations (definitely very "popular"), with a very impressive driving record of a total of 618 trips and 235 hours driven (by far – the largest exposure of the group), and with a very good events rate record of 0.023 and no speeding events.
- Participant number 8 – with only 1 relation and with an events rate of 0.061, the worst of the group.

Having the most "popular" member of the group exhibit good driving behaviour and the least popular - poor driving behaviour, might point to the direction of the group norms regarding driving and could contribute to understanding the overall good driving behaviour of the group.

### 5.3.2.5 The effect of feedback on driving behaviour

As described in section 5.3.1.5, the experimental design was composed of two stages: blind-profile stage and feedback stage. As expected, weighted average events rates of all young drivers during the blind-profile period (0.0326) were higher than the weighted average events rate during the feedback period (0.0296). This difference is not statistically significant, probably due to the small sample size.
However, a detailed examination of average events rate of each of the 11 young drivers, as presented in Figure 5.10, reveals an interesting picture. It seems that the effect of feedback on the participants’ driving behaviour was not consistent among drivers. The analysis as presented in Figure 5.10, shows no meaningful effect of feedback in terms of reduction in events rate, and even the opposite — in most cases average events rate is higher during the feedback period in comparison to the blind profile period. Two extreme observations of participants 7 & 8 contribute to the overall difference.

The inconsistency between weighted average events rates of all drivers, that indicated a positive effect of feedback on drivers’ events rate, and the individual events rate, as presented in Figure 5.10, may be attributed to the Simpson's Paradox (Malinas and Bigelow, 2004). According to this paradox, a trend present in different groups (or individuals) can be reversed when the groups are combined. Another explanation for this inconsistency could have its origins in the small sample-size.

![Figure 5.10: Events rate of young drivers by experimental stages.](image)

### 5.3.3 Summary of IL4a

Influence of peers on adolescents’ engagement in various risky behaviours was well established in earlier research. Studies of road safety showed a meaningful effect of young passengers’ presence on road crashes involvement of teen drivers.

The purpose of the current trial was to explore ways to observe naturalistically the effect of peers driving behaviour on subjects’ driving, amongst a group of novice young drivers. The trial design examined latent/indirect influences of socially related young drivers, in order to see if similar social environment and familiarity among drivers create and lead to similar driving patterns. In other words - do young drivers belonging to the same social environment present the same driving behaviours as reflected both in exposure measures (driving frequencies and their temporal distributions) and in driving patterns.

A second-order objective was to explore the effect of feedback intervention within a close group.
The group that was selected for this trial consisted of 11 young males and females in their first year of driving, all from Kfar-Yassif, a rural Arab community in the north district of Israel. Driving behaviour was studied through GR IVDR system.

**Exposure**

Results showed a large range of trip frequencies and time travelled. This is not surprising since driving exposure may be influenced more from vehicle accessibility than from social norms.

In accordance with previous findings (Prato et al., 2009), results revealed a higher driving exposure during the weekend in comparison to mid-week days. On the other hand, we found significantly higher proportion of young drivers’ trips during daytime in comparison to night time. However, the sample is too small and unrepresentative to draw valid conclusions.

Compared to other drivers, driving the same vehicle, the young drivers performed about a quarter of all the recorded trips. The mean duration of the young drivers’ trips was found to be moderately higher then mean duration of other drivers.

**Events Rate**

Driving behaviour of drivers in this trial was examined by using events rate. Generally, we found relatively low events rates among the young drivers (Weighted Av. = 0.031), indicating that these young drivers demonstrate moderate behaviour on the road. Nevertheless, two potential reasons can cast suspicion on these findings. Firstly, the fact that the participants know that their trips are monitored could positively influence their driving behaviour. Secondly, because only the young drivers (and not other members of their family) were asked to identify themselves during every trip, about three quarters of the trips were not identified. Maybe the young drivers failed to identify themselves while deliberately driving in an unsafe manner so that these trips will not be associated with them. Therefore it can be assumed that the findings do not necessarily present an accurate picture of their actual everyday driving behaviour.

A comparison of day and night trips’ events rates shows that in general, driving behaviour is more aggressive (eventful) while driving at night. This finding is in line with previous knowledge about young drivers’ behaviour (i.e., Prato et al., 2009), but did not correlate with night time exposure. The higher events rate at night can be due to more difficult driving conditions during the night and lack of experience in night time conditions.

In comparison with other family members, for most young participants, we found compatibility between their events rate and other drivers’ average events rate. This implies that the young drivers performed similarly to other family members using the same vehicle.

In order to explore further the "community effect" on driving patterns, we analyzed not only the in-vehicle recorded data, but also subjective social relations self-reports. We wished to see if social inter-relations are reflected in driving patterns – that is, if subgroups are characterized differently with regard to events rate. Due to the small number of participants it was hard to divide the group into subgroups but still one "distinctive" subgroup was found. We found no compatibility between events rates and social connections among participants. A potential explanation to this inconsistency, could be related to the fact that the overall group events rate is relatively low and hence it is difficult to differentiate among individuals and sub-groups in a significant way.
Even though we could not find such a relationship between social connectedness and driving style, it seems that the outliers may explain some of the general group behaviours. Two clear outliers to this group were found in terms of numbers of social connections as well as events rate: one has many inter-relations within the group and a very good (low) events rate record while the other has the fewest connections and the poorest events rate (high). Having the most “popular” member of the group exhibit good driving behaviour and the least popular - poor driving behaviour, might point to the direction of the group norms regarding driving and could contribute to understanding the overall good driving behaviour of the group.

**Effect of feedback**

Although the main purpose of this trial was to examine community effect on naturalistic driving, we also compared naturalistic driving with intervention phase where driving feedback was given to the drivers. The expectation was that feedback will positively affect events rate so that drivers will perform better after being exposed to feedback on their driving.

Looking on the general events rate shows, as expected, that during the feedback phase the group received lower average events rates compared to the previous, no-feedback phase. This may indicate a positive, calming effect of the feedback on driving behaviour. However, the score distribution among drivers revealed a different picture. It seems that among individual drivers, the effect of feedback on driving behaviour tends to be minor and even negative in terms of reduction in events rate. This phenomenon may be attributed to the Simpson’s Paradox as noted in the results section (see section 5.3.2.5). Another explanation for this inconsistency could simply be the small sample size.

**Social connections**

This trial aimed at studying the effect of belonging to a social group on driving patterns. This effect could be studied when comparing driving performance of individuals (as in the next sub section of this trial – see section 5.4) or when compared to other groups. We also presented ways to explore social relations within a group and to analyze these interrelations in accordance to events rate.

Based on the experimental design presented in the current trial, it can be concluded that self reports are essential tool to this kind of study. Social relations interview conducted in this trial added valuable explanatory information and enable us to create a social network of the relations within the group.

One conspicuous limitation that was raised in the current trial was driver identification problem. Since only the young drivers were asked to identify themselves at every trip, whilst other members of their family that drove the same vehicle usually did not identify themselves, over two thirds of the trips were not identified by any driver. This experimental design made it impossible to verify that young drivers are indeed identifying at every trip. Two possible solutions can be acquired in future study in order to overcome this problem. The first solution is to ask all members of the family that are using the installed vehicle to identify themselves at every trip. This solution requires driver cooperation and past experience indicate that this solution is only partial. Another solution that does not require any effort from the drivers is installing a still camera inside the vehicle which photographs the driver once at the beginning of the trip. This way, it will be possible to fully and correctly identify all trips.


5.4 IL4b: Comparison between two groups of Israeli young drivers

Young drivers in Israel (till the age of 24 years) constitute about fifteen percent of all drivers. Nevertheless, during the last few years, young drivers were involved in about one third of all fatal road crashes. This problem of young drivers' involvement in car crashes, more than any other age group, is a worldwide problem. Earlier studies have shown that the risk of crash involvement declines with increased driving experience, but the more newly licensed teenagers drive, the more their exposure to risk increases (Prato et al., 2009).

The main reasons for young drivers' high involvement in road crashes include: driver's age, gender, lack of driving experience, peer pressure and high exposure to risky driving conditions. Young drivers in Israel tend to perform traffic offences that involve risk taking behaviours. For example, speeding was recorded as a factor involved in 33% of all fatal crashes involving young drivers, compared with only 7% among the drivers who are over 24 years old (Israel National Road Safety Authority, 2010).

Several studies conducted by Or-Yarok based on data collected by the Israeli Central Bureau of Statistics, examined involvement of Israeli young drivers in car crashes as a function of the months of driving experience, during the first two years after licensure. Figure 5.11 presents young drivers' involvement in car crashes for the years 2008 and 2009. The graph shows that the involvement of young drivers in car crashes whilst they are in the accompanied driving period is very low. However, once they enter the solo driving period (in the fourth month), crash rates increase dramatically. These rates then gradually decrease as drivers gain more driving experience.

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**Figure 5.11: Israeli young drivers (of all sectors) - involvement in road crashes during the first two years of driving.**

The Israeli population consists of a majority of Jews and several minorities including the Arab sector as the largest minority. Even though Israeli Arabs constitute about
Data collected by the Israeli Central Bureau of Statistics, shows that the high rate of road crash involvement of Israeli Arabs can also be found among young drivers (Israel National Road Safety Authority, 2010). Data processing conducted by the Israeli Central Bureau of Statistics for Or-Yarok, revealed meaningful differences between Jewish and Arab young drivers in road crash involvement, during the first months of driving. The results of this analysis are presented in Figure 5.12 for Israeli Jews and in Figure 5.13 for Israeli Arabs.

As can be seen, both Jewish and Arab young drivers tend to have high involvement in road crashes during first months after starting the solo driving phase, where they are starting to drive without an accompanying adult. The difference between the two groups is expressed in subsequent months where Jewish young drivers exhibit consistent decrease in its crash-involvement, whereas the Arab young drivers group presents a non-uniform, somewhat chaotic, involvement in road crashes throughout these months, sometimes even higher compared to what is considered the critical post-accompanied period.

Figure 5.12: Israeli Jews young drivers’ involvement in road crashes during the first months of driving.

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3 Road crash figures relate to the average for 2007 to 2009
The current trial aims at comparing two groups of Israeli young drivers that differ mostly in their cultural and ethnical background. The first group, referred to as "Group A", consists of 11 young drivers from the "community model" trial, described in section 5. The participants in this group were mostly Christian Arabs, and live in a village called Kfar Yasif (for more details, see section 5.3.1.2). The second group, referred to as "Group B", consists of 11 young drivers that were selected from an earlier study conducted in Israel, known as the "First year study" (for more details, see section 1.4). Group B drivers are Jews who live in several different villages in the west district of Israel (the area known as the north of the Sharon district).

The two groups in the current trial were of young Israeli drivers. Both groups include drivers at their first year of driving (after the accompanied driving phase), who live in rural neighbourhoods, but in different geographical areas. In spite of the similarities in the groups' milieu, there are two significant differences between these groups: cultural difference as expressed by their religion, and social difference as all the participants in group A live in one community and hence know each other, whereas drivers in group B are scattered in different communities and for the best of our knowledge do not know each other. Figure 5.14 presents the location of Kfar Yasif (Group A) and Group B participants' residences.

The current trial examines differences between these two groups of Israeli young drivers, regarding exposure patterns as manifested through driving frequencies, trips duration, and day/night time trips ratio. Additionally, the two groups are compared according to the distribution of their extreme driving events, as measured by the GR technology.
5.4.1 Methodology

Participants

Group A consisted of 11 young drivers who participated in the community model trial. Details regarding this group can be reviewed in section 5.3.1.2. The data used in the current trial included only the feedback period that started about ten weeks after the beginning of the community model trial. Therefore, for our purposes, the participants'
age was 18.28 on average (SD=0.78). One participant had received his driving licence 33 months before the trial began, and the other ten participants had a driving experience of 5.93 months on average (SD=2.21).

The sample used for Group B consists of 11 participants who live in 7 different Jewish Villages in the area of north Sharon. Four of the 11 participants made no recorded trips during the feedback period of the earlier study ("First-year study") and therefore were excluded from the analysis.

The remaining 7 participants in Group B were 2 males and 5 females, aged 17 to 20 years at the time of data collection (Av.=18.40; SD=1.62). All participants were at their first year of driving unattended (Av.=5.24 months experience; SD=1.93).

All participants in the current trial went through a similar experimental procedure including a blind-profile stage and a feedback stage as detailed in section 5.3.1.5, however there was a difference between the groups in the feedback specification: In the earlier "First-year study" (Group B), the feedback was family-based, meaning that all members of the family driving the same car could see feedbacks of other members. In contrast, the feedback in Group A was personal, i.e., the feedback was available only to the young drivers and not to other members of the family.

**Technology and data collection procedure**

The technology used for both groups was the In-vehicle system of GR as described in section 1.3.1 above. The data that was used for the current trial were as follows:

Group A – data of three months of driving with feedback (see details on experimental periods in section 5.3.1.5).

Group B – data of up to three months of driving with feedback, starting four months after licensure (during solo period). Some participants drove less than three months with feedback.

Due to technical reasons and because of differences in driving experience between the groups, the comparison between the groups included data from three months of driving during feedback stage only.

**Dependent Measures**

The dependent measures that were analyzed were as follows:

Events rates composed of the number of events recorded divided by trips duration.

Exposure measure statistics, such as the time travelled by the driver and their temporal distributions (e.g., time of day, day of week).

**5.4.2 Results**

**Summary statistics**

Table 5.3 presents descriptive statistics of the data collected for seven young drivers from group B. In addition, the table includes a summary of the data collected for group A and group B young drivers. Because of the different samples sizes between the two groups, the summary rows in the table present averages per driver. The ratio analysis presented in the table emphasizes the differences between the groups.

It should be noted that the data of Group A that is used in the following analysis include three month of data collection during the feedback period only. Therefore, the
data presented as follow will not be compatible to the data presented in the community model results section (section 5.3.2).
Table 5.3: summary statistics of drivers' trips from group B young and summary data for groups A & B.

<table>
<thead>
<tr>
<th>Driver No.</th>
<th>Gender</th>
<th>No. of trips</th>
<th>Trips duration (hr:min)</th>
<th>Trips mean duration (min)</th>
<th>Total no. of events</th>
<th>Events rate*</th>
<th>No. of red events**</th>
<th>No. of events by type</th>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td>Braking</td>
</tr>
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<td>76</td>
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<td>17.41</td>
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<td>0</td>
<td>1</td>
</tr>
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<td>21.26</td>
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<td>0.008</td>
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<tr>
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<td>Female</td>
<td>76</td>
<td>22:3</td>
<td>17.41</td>
<td>5</td>
<td>0.004</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><strong>Average per driver for Group B(7 participants)</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>133</td>
<td>43:00</td>
<td>20.52***</td>
<td>76</td>
<td>0.029***</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td><strong>Average per driver for Group A(11 participants)</strong></td>
<td></td>
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<td></td>
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</tr>
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<td></td>
<td></td>
<td>161</td>
<td>55:57</td>
<td>20.76***</td>
<td>100</td>
<td>0.030***</td>
<td>3</td>
<td>32</td>
</tr>
<tr>
<td><strong>Ratio (B/A)</strong></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>0.83</td>
<td>0.77</td>
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<td>0.76</td>
<td>0.97</td>
<td>0.92</td>
<td>0.48</td>
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</tbody>
</table>

* Events rate = number of events / trips duration  
** red events refer to GR's terminology of aggressive events (see section 1.3.1)  
*** Weighted average
In general, data shows that on average, young drivers in Group A conducted more trips than young drivers in Group B and accordingly more events, during similar periods (three months). On the other hand, the trip mean duration, "red events" ratio and events rate are quite similar in both groups (ratio between groups is close to 1). These findings indicate that the two groups differ in driving exposure, but are nearly similar in driving behaviour.

**Exposure measures**

As previously mentioned descriptive statistics analysis showed that young drivers in group A performed more trips and more driving hours, than young drivers in group B. The difference in driving exposure between the two groups is clearly shown in Figure 5.15. The two graphs presented in this figure emphasize the significant exposure difference between the groups. It also reveals minor differences in the distribution of exposure along week days. It seems that the group A drivers, drive more during the weekend (Friday to Sunday), while group B drivers drive less during the weekend and more on Tuesday, Thursday and Friday.

![Figure 5.15: Young drivers' driving exposure by group and day of the week.](image)

Another comparison between the groups driving exposure is presented in Figure 5.16 – driving exposure by daytime and by night-time. This analysis shows similar driving distribution between day and night – in both groups, young drivers tend to drive more during daytime than at night.
Events rate

Average events rate (number of events recorded divided by trips duration) of a group of drivers, can be computed in two different ways. In the first way, the sum of events (of all drivers) is divided by the sum of trips duration. This way, the average is weighted so that events rate of a driver with higher trips duration will influence the total average more than the events rate of a driver with low trips duration. The second option to calculate average events rate is by computing the mean value of the drivers' events rate averages. In this case, all drivers have an equal influence on the total average.

As presented in section 5.3.2.5, weighted average of events rate can reveal a different picture than the detailed averages of the participants, phenomenon known as "the Simpson's Paradox" (Malinas and Bigelow, 2004). This phenomenon appears also in the current analysis of the comparison between two groups of Israeli young drivers. Although it seems, according to Table 5.3 that Group A and Group B produce similar average events rates as a group, a distribution analysis, as presented in Figure 5.17 describes a meaningful difference between the groups. The figure shows differences in terms of group's events rate median (group A has much higher events rate median than group B) and in terms of events rate variance (events rate variance is larger in group A compared to group B).
5.4.3 Summary of IL4b

The current trial compared two groups of Israeli young drivers that differ in two major factors - cultural and ethnical background (Jewish vs. Christian Arab young drivers), and social relations (community relations vs. individuals). The aim of this trial was to examine the feasibility of comparing these two groups and suggesting optional analysis or comparison. Having several confounding variables makes it difficult to draw valid conclusions from the results. These confounding variables are:

First, the two groups were small, the trials were conducted with different GR system versions and the experimental design was not similar, therefore the results of this trial cannot be generalized to the general population.

In addition, the groups selected for the current comparison do not constitute a representative sample of the Jewish nor the Arab populations in Israel. Group A consists of a majority of Christian Arabs, while the Israeli Arab population is mostly Muslims. In order to create a similar driving environment conditions in both groups, the participants selected for group B consisted of young drivers who lived in Jewish rural communities. Therefore group B participants also were not representative of the Israeli Jewish population.

Despite the limitations mentioned, the difference in events rate between the groups that was found was consistent with previous studies that have shown cultural differences between young Israeli drivers effect their driving patterns and behaviour. Results showed higher events rate in group A compared to group B, indicating that drivers in group A have a tendency for more risky behaviour while driving. On the other hand, events rate variance among group A's drivers was much higher than in group B.

Another possible explanation for the higher events rate in group A can be related to the difference in experimental design. The data used in both groups was obtained during the feedback period, namely, participants could see feedback on their driving on a web based system. Nevertheless, feedback type was different between the groups – drivers in group A received a personal feedback (where only the driver can access his/her driv-
ing feedback), while drivers in group B received a collective feedback (where every member of the family can access all other members' driving feedback). Since parents of drivers in group B could see their children's feedback (and in group A the parents could not see their children's feedback), it could affect the young drivers' driving behaviour. It can be assumed that young drivers in group B were more cautious in their driving since they were aware that their parents could see their driving feedback. Further research should be devoted to evaluate the effect of personal feedback as opposed to other kinds of feedbacks.

Results also revealed meaningful differences between the two groups in terms of driving exposure. It was been shown that drivers in group A had higher driving exposure in term of number of trips and driving duration, than drivers in group B, during a similar period of time. One possible explanation for this difference could be the number of vehicles per family in the different cultures. While Jewish families usually own one or two vehicles, Arab families in the current trial own on average three vehicles per family. The number of vehicles in the family can affect the availability of vehicles to the young drivers of the family.

5.5 IL4c: Comparison between Israeli and Austrian young drivers

It is well known that countries differ in terms of the number of road crashes and of drivers' involvement in road crashes. These differences are, in part, due to cultural differences among countries. These cultural differences can be expressed by different risk perception (Hayakawa et al., 2000), differences in self assessment of driving skills (Lajunen, 1998; Özkan, 2006a), and different driving style (Özkan et al., 2006b).

Özkan et al. (2006b) used the Manchester Driver Behaviour Questionnaire (DBQ) in order to evaluate reported driving behaviour among drivers from six different countries. The authors found significant differences in self reporting driving behaviour and aggressive driving between the tested countries. For example, it was found that Greek drivers tend to become annoyed by other road users and act in a hostile manner towards them much more frequently than drivers from other nationalities. On the other hand, British, Dutch, and Finnish drivers had the lowest scores on aggressive violations scale.

In the current trial, we planned to compare data on driving behaviour of Austrian and Israeli young drivers. The Israeli and the Austrian field trials have several aspects in common: both trials involved young drivers at their first year of driving, unattended; in both trials an in-vehicle system was installed in the participant's vehicle; and both trials use a G-based event data recorder technology. Therefore, a comparison between the two trials should be feasible and interesting.

Israel and Austria differ in various aspects such as their respective areas size, population size, population density and factors related to road safety (for detailed information see Table 5.4).
Table 5.4: Israel-Austria young drivers’ general factors comparison.

<table>
<thead>
<tr>
<th></th>
<th>Israel*</th>
<th>Austria**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area size (km²)</td>
<td>22,072</td>
<td>83,870</td>
</tr>
<tr>
<td>Population size</td>
<td>7,587,000</td>
<td>8,355,260</td>
</tr>
<tr>
<td>Population density (people/km²)</td>
<td>345</td>
<td>99</td>
</tr>
<tr>
<td>Level of motorization</td>
<td>346</td>
<td>633</td>
</tr>
<tr>
<td>Number of road crash deaths (2007)</td>
<td>382</td>
<td>691</td>
</tr>
<tr>
<td>Road crash deaths per million inhabitants (2007)</td>
<td>50</td>
<td>83</td>
</tr>
</tbody>
</table>

* Source: The Israeli Central Bureau of Statistics

Additional background information on the differences between the two countries — in terms of driving behaviours can be found in the Social Attitudes towards Road Traffic Risk in Europe survey (SARTRE) conducted in 2003 by the European Highway Safety Research Institutes Corporation (the Israeli part was completed in 2005 by Or Yarok, see Lotan and Levanon [2007]).

Results of the SARTRE 3 survey revealed several differences between Israeli and Austrian drivers’ responses. It was found, for example, that 22% of Israeli respondents admit that they drive faster than other drivers, in comparison to 13% of the Austrian respondents. In addition, 15% of Israeli respondents report that they often do not give right-of-way to pedestrians in crosswalks, in comparison to 8% of the Austrian respondents.

To the best of our knowledge, no other comparison was conducted between Israeli and Austrian drivers. The novelty of the current comparison is its potential to compare actual driving behaviour of young drivers in the two countries, using naturalistic methods for data collection.

The following sections describe the preparations made in order to execute the comparison between Israeli and Austrian young drivers’ driving behaviour. Unfortunately, due to technical problems in data collection from the Austrian pdrive system, too little data was collected and hence it was impossible to perform the data comparisons. Nevertheless, massive efforts to create the infrastructure for the comparisons were made, both in terms of creating a comparable experimental design and in terms of calibrating the two technologies. These efforts are described below.

5.5.1 Research objective

The current trial was designed to examine differences between Israeli and Austrian young drivers, regarding exposure patterns - driving frequencies, trips duration, and day/night time trips ratio. Additionally, the two groups are compared according to the distribution of their extreme driving events, as measured by two different in-vehicle-systems.
5.5.2 Methodology

Technology and data collection procedure

The comparison between the Israeli and Austrian trials was mainly a comparison of the same population (young drivers, starting their solo driving) from different cultures, using two different technologies. These technologies have common basis – both technologies are In-vehicle systems that rely on G-forces in order to locate driving events made by the driver and were calibrated to be as similar as possible.

In Israel: The Israeli technology for this trial was an In-vehicle system developed by GR Technology as described in section 1.3.1.

In Austria: The Austrian technology for the current trial was the pdrive system. For this trial, the system was used as an IVDR, i.e. a G-force-based video event data recorder. The core of the system is a data recording system, which can be easily installed in all kinds of vehicles and records the most important vehicles and driver data during a trip. This system is also used in the Dutch field trial of the PROLOGUE (Task 3.4).

Whilst driving, all important data of the vehicle and the driver are recorded. Therefore, a GPS-antenna, two video cameras and a G-force sensor register all movements of the vehicle and the driver in an objective way, which is not subjected to intentional distortions.

Additional to the driving speed, longitudinal forces (acceleration, deceleration) and lateral forces (steering manoeuvres) are measured. Furthermore, the system captures date, time, video (traffic situation in front of the vehicle, the present driver with passengers) and audio data simultaneously and stores all data on a commercial compact flash card.

For this trial, the system collected data in two ways:

1. Permanent data recording: From the beginning to the end of a trip, GPS position and time, speed as well as lateral and longitudinal forces were recorded. Therefore, it was possible to also calculate the trip length in terms of mileage and time.

2. Event triggered recording: When certain, pre-defined thresholds were exceeded, an additional data and video file was generated, 15 seconds before and after the actual event has happened.

To ensure comparability between the Israeli and Austrian data and collection methods, it has to be assured that the same types of events are collected. Therefore, the Austrian system had to be calibrated towards the Israeli system, i.e. the respective G-force thresholds applied in the GreenRoad system. This process is described in the next section.

Israel-Austria systems calibration

As a preparation to data analysis and comparison between the two countries’ databases, two pilot test-trials were conducted, in order to synchronize between the systems. In these test-trials, both systems (the Israeli GR system and the Austrian pdrive system) were installed in the same vehicle.

The calibration process was realized by two test drives, using one vehicle installed with the two systems, one carried out in December 2009 and the other in June 2010 where
several events and risky manoeuvres were carried out under safe circumstances, i.e. a professional driver performed manoeuvres on a closed track near Tel Aviv, Israel.

As the vehicle was equipped with the Israeli GR system, a feedback display was already mounted on the dashboard providing feedback regarding the carried out driving manoeuvres on three risk levels: green (cautious), yellow (moderate) and red (aggressive). Each colour corresponds to a pre-defined safety level and is represented with a coloured LED on the vehicle's dashboard: as presented in Figure 5.18.

![Figure 5.18: LED feedback, Green Road system.](image)

In order to calibrate the pdrive system with the GreenRoad system, one camera of the Austrian pdrive system was pointing towards the LED feedback of the Israeli system, as shown in Figure 5.19.

![Figure 5.19: pdrive recording LED feedback](image)

A first step to ensure comparability of captured data of both systems was synchronizing the system's clock. It turned out that there is a time-stamps difference of about 37 sec-
onds. After eliminating this time lag, the captured data of both systems could be perfectly synchronized.

The main challenge of the calibration process was to identify precise thresholds of the given Green Road classification of driving manoeuvres. In order to isolate single events and identifying respective thresholds, a lot of post-processing work was carried out.

TTI received the protocol of the test drives by Or Yarok, containing all the data regarding time, event type, safety level and speed. After the time synchronization of both data files, every single event was analysed and described in terms of measured values. Thus, a step-by-step approach to isolate thresholds of different manoeuvres and safety levels was carried out.

Table 5.5 summarizes the occurrence of events during the two calibration test drives. The numbers shown in the table provide the distribution of the realized manoeuvres. For manoeuvres with a high number of occurrences at different safety levels, it was possible to identify the G-force based thresholds between safety level "0" (green=safe) and safety level "2" (yellow=moderately safe) of manoeuvres "Braking", "Turning" and "Braking while exiting turn".

However, it was neither possible to identify valid thresholds for all other manoeuvre types nor to further distinguish between safety level "2" and "3" (red=unsafe) between the three identified manoeuvre types by all means.

### Table 5.5: Occurrence of events by safety levels as summarized for both calibration test drives

<table>
<thead>
<tr>
<th>Event type</th>
<th>Safety level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Braking</td>
<td>82</td>
</tr>
<tr>
<td>Accelerating</td>
<td>73</td>
</tr>
<tr>
<td>Braking into turn</td>
<td>4</td>
</tr>
<tr>
<td>Accelerate into turn</td>
<td>10</td>
</tr>
<tr>
<td>Accelerate while in turn</td>
<td>2</td>
</tr>
<tr>
<td>Sudden brake in turn</td>
<td>3</td>
</tr>
<tr>
<td>Turning</td>
<td>63</td>
</tr>
<tr>
<td>Braking while in turn</td>
<td>1</td>
</tr>
<tr>
<td>Accelerate while exiting turn</td>
<td>3</td>
</tr>
<tr>
<td>Braking while exiting turn</td>
<td>9</td>
</tr>
<tr>
<td>Lane change</td>
<td>0</td>
</tr>
<tr>
<td>Bypass</td>
<td>0</td>
</tr>
<tr>
<td>Lane Handling</td>
<td>0</td>
</tr>
</tbody>
</table>

Due to this lack of a sufficient number of identified events and a biased exposure of comparable Austrian novice drivers (caused by holidays) it was decided not to carry out the actual comparison between Israeli and Austrian data as invalid results could be expected. Both the Israeli and the Austrian team recognize that additional effort to synchronize the two systems and more data can result in very interesting results. This will hopefully be conducted in the future.
5.6 Discussion

The importance of the social context and its influence on driving is already well-established in safety research. When it comes to young drivers, the social factors play a major role. In the three sub-trials described in this chapter we demonstrated ways to investigate the relations between social context and driving with respect to young drivers. This was done in two ways – the first by looking at driving behaviour within a certain group that comes from the same environment and examining the social connections that may explain the driving behaviour of the group as a whole; and the second way by looking for the socio-cultural differences between different groups (or different social environments) and how they are reflected in driving measures.

We found that social factors (whether there are connections within a group or socio-demographic background) can be expressed by naturalistic driving measures.

It is recommended that this kind of studies will be complemented by self-report tools in order to provide information that cannot be achieved solely by technology.
6 Summary and Discussion

The summary and insights from the individual sub-trials were presented earlier in this report. In this section we briefly mention and discuss the major themes and insights that arose from the overall Israeli field trial.

6.1 Overall contribution

*Generation of naturalistic data.* The data collected in the various sub-trials reflect naturalistic data corresponding to actual undisturbed behaviour performed by participants using their own private cars. In most cases, the IVDR systems were non-visible and were assumed to cause minimal or no change to the driver's driving environment.

*Exposure data.* The various sub-trials created a large data-base of actual driving exposure. This data can be easily analyzed according to a wide range of parameters, such as: characteristics of the driver (i.e. gender, age, level of driving experience), temporal characteristics (i.e. day of the week, time of the day), characteristics of the network (i.e. urban, rural, highway, intersections, roundabouts), and vehicle usage among family members and more. The scope and depth of detail in exposure data obtained by these methods is unique. The possibilities for obtaining representative data through appropriate sampling needs to be explored.

*Use of (relatively) cheap, off the shelf products, for naturalistic research.* In classical naturalistic studies – continuous, video-based data collection procedures are typically used. These procedures are expensive both in term of cost & data storage requirements as well as data analysis & reduction efforts needed. The technologies used in this trial are relatively cheap, easy to install, user friendly and non-obtrusive, which do not require any interference for data downloading. The trials conducted demonstrate the ease with which naturalistic data collection can be performed in various situations and scenarios.

*Integration and synchronization of data from two independent IVDR systems.* In IL1 we demonstrated the feasibility of installing, collecting and synchronizing data from two IVDR systems and integrating it into meaningful information. The relations, interactions and complementarities of the two technologies were presented and discussed.

*Comparisons.* Collecting and storing ND is not enough. Meaningful statements on its content and interpretation need to be derived and validated. In this trial we have demonstrated, through various examples and test-cases, how ND could be compared and analyzed according to diverse measures, such as: comparison to baseline behaviour (in IL3 where the GR system was re-installed in cars of young drivers 4 years after their licensure), distinctive audiences sharing common characteristics (in IL4 young drivers belonging to different communities with different social background), special time periods (in IL2 according to stages in the licensing process), unique relations among participants (in IL4 – young drivers belonging to the same community, living in the same area and know each other) and more.

*Comparisons to self-reports.* As much as the value of ND becomes apparent and more widely accepted and used – self reports still remain the most popular (and definitely the cheaper) tool for data collection on behaviour. In IL3 we have ex-
explored the relations between ND and self reports and estimated the differences, similarities and biases between them. The data obtained, shows very clearly, the bias towards over-estimation of exposure rates as well safety levels — most participants report longer driving times and higher safety levels than what is actually measured by the IVDR. Understanding and evaluating the differences between ND and self-reports has huge practical value.

**Creation of indications to deal with near-crashes based on non-continuous event-based data.** The possibility to generate good candidates for near-crashes based on non-continuous event based data was explored and demonstrated. In some cases it was even validated. However, the extent of false-negatives (missed indications) is still unclear. This contribution can be used for analyzing near-crashes based on discrete events, or for data reduction of continuous data.

**Creation of a map-matching tool.** The tool developed (in IL2) for associating discrete events to road segments was used to analyze aggregate data according to network characteristics. This tool can be further developed and used for multiple purposes such as: analysis of aggregate data, normalization according to specific routes taken, analysis of driving behaviour according to driving purpose and network features and more.

**Highlighting the importance of clear and uniform terminology and definitions.** The results (in IL1) showed that even seemingly trivial information such as the time, trip start and trip end may be inconsistent when different definitions and measurement methods are used. Furthermore, the variety of sub-trials conducted emphasized the need to generate clear and uniform terminology and definitions.

**Demonstration of the ability to address complex and original research questions.** In this trial we addressed several innovative research questions. The results obtained were, at least in some cases, surprising. Despite the small samples, these unexpected results generated insights into the importance of collecting ND, as well as to raising questions regarding the ability of the data collected to truly and completely portray driving behaviour.

### 6.2 Limitations

**Small and non-representative samples.** It is quite clear that due to time, budget and logistical constraints the samples presented in this trial are neither big enough nor representative of the population they come from. However, the experience gained provided clear understanding on how to conduct a larger-scale trial.

**Driver identification.** One of the major limitations in all sub-trials was the procedure used for drivers’ identification. This procedure was based on manual identification, performed by the driver, at the beginning of each trip. However this turned out to be cumbersome and not reliable enough, resulting in a fair amount of unidentified trips (up to 30%) hence causing data loss, and necessitating verbal or e-mail communication with participants to recover "lost" trips. Furthermore, even when trips were identified there was no way to guarantee that they were correctly identified. In future studies it is highly recommended to improve the identification procedure by fully automating it and including a visual (possibly still) drivers’ identification.

**Creating valid baselines for comparisons given different technologies, different versions of the same technology, different target audiences.** In order to ad-
dress some of the complex research questions that were posed and to perform valid comparisons, there was a necessity to control for external variables and noise. In many cases, this was not feasible, or could not be done with complete certainty. In IL3, for example, the novel research question regarding young driver behaviour immediately after licensure and four years later, assumed that (occasional) different car ownership and a different version of the technology were controlled for. This was verified with the participants and with GreenRoad, however, other circumstantial factors, such as the fact that most participants were in active army service, could also affect behaviour.

**Inflexibility and incomplete knowledge due to the use of off-the-shelf systems.** In order to fully understand, evaluate and analyse the data, very often a clear and concise definition of events, threshold values and the algorithms used is needed. When using off-the-shelf systems that may be proprietary, and hence not always feasible.

**Drivers' distraction and inattention could not be addressed.** The behavioural indicators identified by the technologies used and the trial could be related, directly or indirectly, to distraction and inattention. However, due to lack of continuous (visual) records of both the inside and outside views of the vehicle, this could not be verified. In future studies – such analysis can provide important insights to factors leading to and factors influenced from distraction and inattention.

### 6.3 Future research and potential

Several "small-scale" trials were carried out within the Israeli field trial. All of them addressed important and even critical issues regarding driving behaviour. We tried to address the potential of ND research to shed light and explain behaviour towards the ultimate goal of understanding drivers' behaviour and in particular unsafe behaviours that could lead to crashes. A major guiding theme in all trials was to explore the potential of the data collected to reveal the "true" story on the road. In order to substantially improve this understanding, the following directions for future research are recommended;

**Larger and more representative samples.** It is quite evident that due to the small scale nature of the trials, no valid conclusions could be drawn. Hence, at least for some cases, it is worth repeating the trials with larger and more representative samples. These cases and samples should be chosen based on a very detailed consideration and evaluation of their potential to significantly improve the state-of-the-art.

**Addition of continuous video data recording.** An inherent and important characteristic of all the sub-trials described in this report is the fact that the data was collected through (relatively) cheap, over-the-counter, discrete-event monitoring type of technologies, with no continuous video data collection. When planning for future research, addition of continuous data (both inside and outside the vehicle) could further be used to verify the validity of the discrete indicators and to complete the picture towards obtaining the full story. However, the necessity for the use of continuous video data should be evaluated and its extent should be as minimal as possible.

**Automatic mechanism for driver identification.** The procedure for drivers' identification should be fully automatic and verified such that it will not require drivers' active initiation and will be highly reliable.
**Fuel consumption and its relation to driving.** In order to address issues related to environmental implications of driving behaviour, and to establish the relations between safe driving and environmental-friendly and economic driving, fuel consumption as well as other environmental related data should be collected in conjunction with the driving data.

**Integrated systems.** Although we demonstrated (in IL1) that two independent in-vehicle systems could be integrated – it is highly recommended to use systems that are inherently integrated and coordinated.

**Integrating data from different sources.** Although an integrated system is preferred – it would still be necessary to be able and integrate data from various sources, including external type of data.

**More elaborate and validated indicators for crashes and near crashes.** In IL1 we have demonstrated the potential of generating indicators (or triggers) for near-crashes. This should be further developed and researched.

**Potential indicators for distraction and inattention.** It is highly recommended to address issues and indicators related to distraction and inattention in future trials through inclusion of continuous video data collection.

**Extensive analysis of the spatial characteristics of the ND.** It is well known that driving behaviour is highly influenced from the road characteristics. The tool developed in IL2 for map-matching can be further improved to be able and address elaborate spatial behaviour characteristics of ND.
References


Lotan T. and Levanon V. (2007). *Drivers in Israel compared to drivers in Europe: selected results of international comparisons based on SARTRE 3 project*. Or Yarok report, Hod HaSharon (in Hebrew)


Appendix: Data Map-Matching

Abstract

Map-matching is the process of aligning a sequence of observed user positions with the road network on a digital map. It is a fundamental pre-processing step for many applications, specifically in our case, obtaining spatial statistics of road safety events. Most existing map-matching approaches only deal with high sampling rate (typically one point every 10–30 seconds) GPS data, and become less effective for low sampling rate points (e.g., one point every 2 minutes on average) as the uncertainty in data increases. In this appendix, we outline the global map-matching algorithm used in the proposed study for obtaining low sampling rate GPS trajectories. The algorithm considers (1) the spatial geometric and topological structures of the road network and (2) the temporal/speed/heading constraints of the trajectories.

1. Introduction

A Naturalistic driving study was conducted to provide an unprecedented level of detail concerning driving pattern characteristics and factors associated with critical incidents, near crashes and crashes. To monitor driving patterns and behaviour, vehicles involved in the study were instrumented with IVDR obtaining longitudinal and lateral kinematical information. The IVDR measures acceleration, speed and position. The IVDR events are split into two types: (1) location event at a fixed rate of 2 minutes, (2) safety events as they occur. The IVDR safety events are categorized into five categories: acceleration, braking, speeding, lane handling and turn handling.

Analysis of the data obtained using the IVDR has two main goals:

Comparison of driving exposure and exposure to risk between novice drivers and their parents and between novice drivers before and after feedback;

Comparison of the spatial exposure between novice drivers and their parents.

In order to achieve these goals, the observed GPS positions should be aligned with the road network on a given digital map. This process is called map-matching. In the presented field trial, the map-matching technique is challenging due to the low sampling rate of data, on the one hand and positional errors of the GPS trajectory and the digital map, on the other hand.

Most existing map-matching approaches employ local or incremental algorithms that transfer current or neighbouring positions into vector road segments on a map. The result of the approach considering only current positions is greatly affected by measurement errors. Local approaches are considered computationally efficient, though their performance is sensitive to the decrease of sampling frequency. Alternatively, the global algorithm aligns an entire trajectory with the road network. Generally speaking, a global approach achieves better accuracy at a higher computational cost.

Available off-the-shelf commercial software packages, such as ESRI network analyst, TransCad, etc., were examined closely and found to be unsuitable to cope with the requirements of the trial exposure analysis. Therefore, it was decided to develop a new generic software tool that would fulfil the requirements and could deal with different digital maps (e.g., from different providers) and different IVDR technologies.

The developed map-matching algorithm relies on the relevant road network and the data provided from IVDR (position, speed, heading and timestamp) and operates under...
temporal and speed constraints of the GPS trajectories. This makes it less vulnerable to a decrease of sampling rate.

The remainder of Appendix is organized as follows. Section 2 outlines a brief review of the existing map-matching approaches. The developed algorithm is described in Section 3. Evaluation results are discussed in Section 4. Finally, Section 5 presents concluding remarks.

2. Literature review

Nodes, vertices, links and segments should be defined clearly before the literature review. Nodes and links are relatively well known. For example, an intersection is a node. A link is a section of road between two intersections. Figure 1 illustrates nodes as circles, and links as lines. When the real road network is digitized, a curve is described with a set of several straight lines. Vertices are points which separate these straight lines. Each straight line is a segment. The matching of a GPS sampling point $P_i$ is performed by finding all lines that have a perpendicular distance “$d_i$” not exceeding a certain threshold (Figure A-1b).

![Figure A-1. (a) The composition of road network; (b) Line based matching](image)

The existing map-matching algorithms can be generally classified into three classes: local/incremental methods (Greenfeld, 2002, Chawathe, 2007), global methods (Lou et al., 2009, Alt et al., 2003, Brakatsoulas et al., 2005), and statistical methods (Hummel and Tischler 2005, Pink and Hummel 2008).

The local/incremental methods are fast and perform well when sampling frequency is very high (e.g. 2-5 seconds). They rely on geometric similarity measures, such as distance and orientation similarity to evaluate the candidate edges (Chawathe, 2007). The incremental principle is well presented by Greenfeld (2002), where the matching process starts with high-confidence segments and continues with low-confidence ones. Since the incremental methods rely on local information, by exploiting small portion of trajectory for geometric and topologic relationships, they are only suitable for data at high sampling rates. However when the sampling rate decreases substantially, there is no adjacency in GPS points and local interrelated rules are no longer valid, which cause accuracy degradation (Chawathe, 2007).

Global methods aim to match the entire trajectory with the road network. The Fréchet distance or its variants are most common (Alt et al., 2003, Brakatsoulas et al., 2005). Global methods are intended to minimize the Fréchet distance between the trajectory and the matched road segments. Recently, Lou et al. (2009) presented a global method that outperformed Fréchet distance based methods. Firstly, their method handles one or more corresponding segment candidates for each GPS point. Then, a graph of candidates is formed and, finally, the path with highest likelihood is found over
this graph. The total probabilistic score relies on two probability measures: a distance between GPS point and their candidates and the shortest path length. The presented method is suitable for real data with low sampling rate and significantly outperforms local algorithms. Nevertheless, it does not exploit the benefits of the orientation information to achieve better solutions.

Statistical models are particularly effective to handle GPS measurement errors and can be combined with the global methods. For instance, a map-matching procedure extended by a Kalman filter was presented by Hummel and Tischler (2005). Later Pink and Hummel (2008) proposed another algorithm based on a Bayesian classifier.

3. Algorithm principles

In this section, the developed map-matching algorithm is described in detail. Major steps are depicted in Figure 2.

The developed map matching algorithm has two main characteristics: (1) Each GPS sampling point may have more than one corresponding candidate edge. This contributes to the robustness and correctness of the algorithm. (2) A major assumption made is that travellers tend to choose the shortest path between two consecutive GPS sampling points. This assumption may fail when the sampling rates decrease substantially. At sampling rate less than 2 minutes, it is a well established assumption. Obviously, the solution obtained from concatenating shortest paths between consecutive sampling points might differ substantially from the shortest path solved between the starting and ending points of the GPS trajectory.

3.1. Selection of candidates

The horizontal displacement of GPS points from their true location on road segments is contributed by:

- the GPS point positioning with an estimated average accuracy of ±10 meters at 95% significant level;
- IVDR latency in data recording;
- the representation of physical roads with several lanes by one centre line and the positional errors of the digitized road centre lines.

Based on our experience with training sets, we estimate the displacement to be under 50 meters at the 99% significance level.

For every GPS point, the corresponding network edge is searched using 3 perpendicular distance thresholds \([r_1 \ r_2 \ r_3]\), ordered from smaller to larger radii. At each distance threshold, the travel direction represented by heading is tested to be in threshold range
δ from the edge travelling azimuth. If at the current distance threshold no candidates are found, a search is performed with a larger distance. The topological edges of the network corresponding to GPS sampling points are obtained by comparing the travel direction (e.g. AZ) of link and measured heading (e.g. H) of the GPS point. We identify the following cases of the network edge searching:

In the case of a missing GPS heading and a one-way segment, the edge in travelling direction is chosen;

In the case of a missing GPS heading and a two-way segment, both edges are chosen;

In the case of an available heading and a one-way segment, the edge corresponding to the constraint H-δ<AZ<H+δ is chosen. If there is no suitable edge, the GPS point (or the GPS trajectory) is rejected.

In the case of an available heading and a two-way segment, the edges in both directions corresponding to the constraint H-δ<AZ<H+δ are chosen.

Figure 3 depicts an example of the candidate selection on a directed network. N2–N1 is a one-directional segment and N2–N3 is a two-directional segment. Both segments are in the range of the perpendicular distance threshold. Edge N2→N3 is considered a candidate, while N1→N2 is not, since its direction is out of the GPS heading range.

A GPS sampling point is tagged to have a missing heading value, either due to missing value in the data record or due to an unreliable heading value, which may occur when very slow speed is measured at the GPS point. When the heading value is missing, all candidate edges in the distance range are considered. In the example in the figure, a missing heading would result in 3 edge candidates of point p; N2→N3, N3→N2 and N1→N2.

To filter invalid edges from the candidate graph, a localized temporal analysis is performed. Figure A-4 presents an example of temporal analysis filtering for the trip having 3 sampling points. The heading of point p_2 is out of the threshold range meaning that edge N2→N5 is not a possible candidate. So, the only viable candidate is edge N2→N3. The shortest path solution is N1→N2→N3→N4→N5→N6.

The average speed over the path between edge pairs is estimated based on the path travel time and its distance. Thus, speeds over edges N2→N3→N4→N5 are estimated using the travel time and the distance between p_2 and p_3. Then, the estimated speeds are compared to the speed constraints corresponding to the road class of the concerned segments.
3.2. Speed estimation

To illustrate the speed estimation procedure, we use an example of a trip between two GPS points depicted in Figure 5.

To calculate segment traverse time ($TT_{\text{Time}}$), all types of the GPS sampling points, either location events or safety events, can be used. The $TT_{\text{Time}}$ is calculated using a linear interpolation. For instance, $TT_{\text{Time}}$ for node N2 is calculated as follows:

$$TT_{N2} = T_p + (T_p - T_{p-1}) \cdot \frac{L_{p-1}}{L_{p-1} + L_p + L_{p+1}}$$

(1)

where $T_p$ is a timestamp for GPS point $p$, $L_i$ is the length of route part $i$ (full or partial segments).

The speed for each segment of the route is calculated as follows:

$$S_{\text{segment}} = \frac{TT_{\text{end}} - TT_{\text{start}}}{L_{\text{segment}}}$$

(2)

where $S_i$ is the speed on segment $i$, $TT_{\text{end}}$ and $TT_{\text{start}}$ are the traverse times at the segment end and at the segment start, respectively.

3.3. The shortest path computation

The candidate graph is generally represented by a combinatorial sequence of network edges. To define the shortest path for this graph, we use Dijkstra's algorithm (Cormen et al., 2001), though, computationally efficient alternatives may be used as well (Hart et al., 1968, Fu et al., 2006). The set of the edge candidates with the lowest travel cost is declared as the shortest path and chosen as the desired route solution. Figure 6 presents the general graph of candidates, where $C_j$ is candidate edge $j$ for GPS point $P_r$. A GPS point may have only one candidate (e.g., $P_3$ in Figure A-6).
In practice, the trajectory can include too many points. Consequently, the candidate graph can have a huge number of path combinations. In this case, the candidate graph should be divided into several partial candidate graphs. For example, the route containing 10 points with 3 candidates for each point produces the graph of candidates with $3^{10} \approx 60K$ possible path combinations. While, splitting the route into two groups will give only $3^5 \cdot 2 \approx 500$ path combinations.

An example of the graph splitting is given in Figure A-7. As illustrated in the figure, each partial candidate graph is constructed from a “sliding window” subset of the trajectory, with a window size of $w$. The shortest route is calculated for each window in turn. In order to have inter-related route solutions, there is an overlap of $q$ GPS points between consecutive windows. After finding the shortest path for the first window, the GPS points of this window have only correct candidates. Then the algorithm slides to the second window, where the point $P_{w-q}$ has only one candidate according to the previous window solution.

### 3.4. Dataset and output description

The presented field trial was performed on the existing Israeli road network. The network consists of about 195,000 nodes and 242,000 segments, contributing to about
420,000 edges. Additional information of turn restrictions was not considered in the data analysis.

The GPS sample data included the observations of the novice young drivers and their family members for the period immediately after licensure. This period has two phases: the accompanied driving phase and the independent (solo) driving phase.

As an output, the following GIS layers are created, which are used as the core sample dataset for this trial:

**Exposure layer** – provides information on each road segment contained in a trip route such as traverse time, segment type (e.g. urban or non-urban, and road class), length and so on.

**Events layer** - provides location of safety events on a specific segment contained in a specific trip route.

The contents of the exposure and event layer are given in Tables A-1 and A-2, respectively:

Table A-1. Exposure layer content

<table>
<thead>
<tr>
<th>Field name</th>
<th>Field description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uid</td>
<td>a unique identification number to join the event table</td>
</tr>
<tr>
<td>TripID</td>
<td>the trip identification number of the GPS trajectory, in which the segment was included</td>
</tr>
<tr>
<td>SegmentID</td>
<td>segment identification number</td>
</tr>
<tr>
<td>TravDir</td>
<td>the travel direction, were, 1 is the segment direction defined in the GIS map, and -1 is the opposite direction</td>
</tr>
<tr>
<td>Exit Time</td>
<td>the exit time from the segment</td>
</tr>
<tr>
<td>Speed</td>
<td>the average speed on the segment, [km/h]</td>
</tr>
<tr>
<td>Length</td>
<td>the segment length, [m]</td>
</tr>
<tr>
<td>From %</td>
<td>the segment point (defined by a percentage of the segment length) where the trip started. If a path consists of N segments, then for N-2 inner segments this value is equal 0%.</td>
</tr>
<tr>
<td>To %</td>
<td>the segment point (defined by a percentage of the segment length) where the trip ended. If a path consists of N segments, then for N-2 inner segments this value is equal 100%.</td>
</tr>
</tbody>
</table>

Table A-2. Event layer content

<table>
<thead>
<tr>
<th>Field name</th>
<th>Field description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uid</td>
<td>a unique identification number to join the exposure table</td>
</tr>
<tr>
<td>EventType</td>
<td>event type code</td>
</tr>
<tr>
<td>RunDist</td>
<td>the point on the segment where the event occurred, defined by a percentage of the segment length from its beginning</td>
</tr>
<tr>
<td>EventDate</td>
<td>the event time</td>
</tr>
<tr>
<td>TravDir</td>
<td>the travel direction</td>
</tr>
</tbody>
</table>
4. Results

Based on the positional accuracy of GPS points and the experience gained from the training sets, the set of distance thresholds is defined as [25 35 50]. The minimum speed, considering a heading value to be reliable, is set to 5 km/h. The azimuth range δ is set to ±80 degrees. The sliding window size “w” is taken as 7 GPS points and the overlap region was set to 3 GPS points.

Table 3 presents summary statistics of the filtered trips performed. The total number of trips is about 79,000. 27.8% of the trips are filtered out. About 86% of the filtered trips are rejected due to corrupted GPS trajectories, which can’t be considered to be reliable (e.g. trips with less than 3 different GPS locations), or due to location of GPS trajectories in only one geographical segment. Also, about 13% of the filtered trips are rejected due to exception cases that are not handled by the algorithm. Another ~1% of the refused trips cannot be solved due to lack of the network information. The road network incompleteness is the result of temporal inconsistency between the road network, created from digital maps published in 2008, and GPS trajectories, which were collected over a period of 4 years (from 2005 to 2009).

<table>
<thead>
<tr>
<th>Trips’ category</th>
<th>Number of trips</th>
<th>Percentage from all trips [%]</th>
<th>Percentage from filtered trips [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total trips performed</td>
<td>78804</td>
<td>100.0</td>
<td>-</td>
</tr>
<tr>
<td>Total valid trips for analysis</td>
<td>56885</td>
<td>72.2</td>
<td>-</td>
</tr>
<tr>
<td>Total filtered trips</td>
<td>21919</td>
<td>27.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Trips with less than 3 different GPS locations</td>
<td>14482</td>
<td>18.4</td>
<td>66.1</td>
</tr>
<tr>
<td>Trips with the route containing only one segment</td>
<td>4405</td>
<td>5.6</td>
<td>20.1</td>
</tr>
<tr>
<td>Trips with time gap more than 6 minutes</td>
<td>95</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Trips for which the shortest path was not found</td>
<td>194</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Exceptions</td>
<td>2740</td>
<td>3.5</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Due to limitations of the hardware resources, the GPS trajectory data are split to 7 small sets. Figures A-8 to A-10 present trip characteristics and processing statistics for one of these sets, which are quite representative for other ones.

Statistics presented in Figure A-8 demonstrate that about 45% of GPS points have more than one candidate (even under the comparatively strict distance and azimuth thresholds), indicating the importance of considering more than one candidate per GPS point. Figure 9 shows the percentage comparison of the combinations’ number solved per window over the candidate graph. The presented statistics demonstrate the importance of the step-by-step search for the shortest path that provides computational cost reducing without significant loss of accuracy. Figure 10 presents the maximum sampling interval statistics. About 99% of trips have a maximum time interval of 4 minutes. According to the cumulative distribution, we set a threshold of 6 minutes for maximum sampling interval, so trips are disregarded beyond that threshold. In these cases, we suspect malfunctioning of the IVDR.
A small set of 40 representative GPS trajectories was chosen for the implemented algorithm evaluation. 37 trips were solved correctly, 2 trips had a problem only at the start or at the end point of trip, though the rest of the trajectory matching was correct. Four cases of the correctly solved GPS trajectories are presented in Figure A-11.

Figure A-12 presents additional sample cases. In Figure A-12a, the GPS trajectory has the point with timestamp 14:53:18, with missing heading information and located on a two way segment. In this case, both segment’s directions are considered as candidates, and eventually the trip is solved correctly. Figure A-12b illustrates a case of a large time gap between timestamps 10:21:14 and 10:31:08. Obviously, the IVDR malfunctions on this trip. This trip cannot be solved correctly and is rejected. A case of an incomplete network is shown in Figure A-12c. This trip is also rejected by the algorithm, since using a large distance threshold, (for instance, 100m as in Lou et al., 2009), leads to a wrong solution. Figure A-12d demonstrates a case for which the correct candidate selection failed for the search radius of 25m and successful for the search radius of 50m.
Figure A-10. Maximum time interval statistics
Figure A-11. Representative cases of correctly solved GPS trajectories
Figure A-12. Demonstrative cases: (a) missing heading, (b) large time gap, (c) incomplete road network, (e) search at larger radius.
5. Conclusions

We presented a heuristic map-matching algorithm, which is a part of the broader PRO-LOGUE research. The developed algorithm provides spatial exposure of driving and detailed location of events, which are substantial for achieving some goals of the naturalistic study. It can be considered as state of the art due to its success rate and robustness in dealing with low sampling rate GPS trajectories. The algorithm can be used as well in other trials and studies.

The main findings and suggestions for improving the algorithm and its framework are outlined as follows:

We used Dijkstra's algorithm for the shortest path computation, which is not always the optimal choice in the sense of computational efficiency. Other efficient alternatives, such as bidirectional search, can be used to reduce overall computational cost.

The temporal analysis filtering can be enhanced. To increase the algorithm robustness against errors, only incorrect sampling points should be excluded, instead of rejecting the whole GPS trajectory.

In order to improve the matching quality, the algorithm performance can be further evaluated based on a larger set of ground truth (i.e. the “true” path of the moving object). This may be obtained from the data characterised by high sampling rate (e.g. 5-10s).

The current score function is applied only to the cost of edges. Better results may be achieved by incorporating in the score function a factor of the calculated travel time deviation from the reference travel time. The reference travel time over the day might be available from traffic data providers.

In a further study, it is suggested:

- to compare the developed heuristic algorithm with other state of the art algorithms;
- to enhance the algorithm functionality, such as extracting of spatial characteristics of the network to combine with the dynamic event locations.

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<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAS</td>
<td>Advanced Driver Assistance Systems</td>
</tr>
<tr>
<td>Av.</td>
<td>Average</td>
</tr>
<tr>
<td>CBS</td>
<td>Central Bureau of Statistics</td>
</tr>
<tr>
<td>DBQ</td>
<td>Driver Behaviour Questionnaire</td>
</tr>
<tr>
<td>DPL</td>
<td>Dual Purpose Locator</td>
</tr>
<tr>
<td>FCW</td>
<td>Forward Collision Warning</td>
</tr>
<tr>
<td>FOT</td>
<td>Field Operational Test</td>
</tr>
<tr>
<td>FT</td>
<td>Field Trial</td>
</tr>
<tr>
<td>GDL</td>
<td>Graduated Driving License</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GR</td>
<td>GreenRoad</td>
</tr>
<tr>
<td>HR</td>
<td>Hour</td>
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<td>HW</td>
<td>Headway Warning</td>
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<tr>
<td>ICF</td>
<td>Informed Consent Form</td>
</tr>
<tr>
<td>IL</td>
<td>Israeli field trial ($IL1$ to $IL4$ stand for different Israeli sub-trials)</td>
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<tr>
<td>IVDR</td>
<td>In Vehicle Data Recorder</td>
</tr>
<tr>
<td>LDW</td>
<td>Lane Departure Warning</td>
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<tr>
<td>ME</td>
<td>MobileEye</td>
</tr>
<tr>
<td>Min.</td>
<td>Minutes</td>
</tr>
<tr>
<td>N.A.</td>
<td>Not available</td>
</tr>
<tr>
<td>ND</td>
<td>Naturalistic data</td>
</tr>
<tr>
<td>PCA</td>
<td>Principle Component Analysis</td>
</tr>
<tr>
<td>RES</td>
<td>Risk Evaluation Score</td>
</tr>
<tr>
<td>RSA</td>
<td>(Israeli) Road Safety Authority</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>TAS</td>
<td>Thrill and Adventure Seeking</td>
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<tr>
<td>TT</td>
<td>TrackTec</td>
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<td>TTime</td>
<td>traverse time</td>
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