Analysis and Modeling of Driving Behavior using In-Vehicle Data Recorder

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1. Abstract

Using IVDR (In Vehicle Data Recorder) that are installed in the vehicle enables continuous measurement and data collection of driver's behavior. The main goal of this research is to develop a drivers' behavior framework defined in safety terms that will identify drivers' behavior characteristics and the risk for car accident involvement. The modeling framework consists of a set of structural equations describing the complicated relationships between the various factors affecting driver behavior and their measurement including IVDR. For this purpose, we conduct an experiment in which we collect data using IVDR and investigate the influence of IVDR installed in a vehicle, on the drivers and safety management of the vehicle fleet organization participating in the experiment. The data collected for this experiment are used as the basis for the model estimation of the driver behavior framework.

The experiment is conducted via a parallel research that was funded by the Ministry of Science and provides the data for this research. The purpose of this experiment is to use the data to identify and model different patterns of driver's behavior. Identifying different behavior patterns allows tailoring treatment programs that fit drivers according to their specific behavior type.

The experiment is carried out in different army units and with one IVDR manufacturer Traffilog, which completed the installations in three air force bases. Traffilog provides data to the safety officer of the army fleet and to the research team. Various technical problems delayed the project but currently we are about to complete the blind phase of the experiment. In this phase, drivers are aware to an instrument installed in their vehicle but does not know the nature and the usage of the IVDR. In the next few weeks we will handle the drivers a questionnaire in which they will be asked about their driving behaviors, attitudes and perceptions towards driving. In this phase, drivers will be exposed to the IVDR and drivers will be given a periodically feedback about their driving.

The research helps identifying the effects of driver characteristics (e.g. age, gender), road and traffic conditions, attitudes and perceptions towards driving on driving behavior. It may be used to identify and classify drivers for purposes of training, monitoring, setting insurance rates and developed policies toward improved road safety. These models will improve our understanding of the characteristics associated with different patterns of
driving behavior, will support the development of methods and tools to modify such behaviors and hopefully contribute to road safety.

This report summarizes the work conducted so far including the development of a theoretical framework of driver behavior and accident risk including the effect of the IVDR as well as many other factors on these variables, literature review, experiment design, surveys and questionnaires, and experiment description and results so far.

2. Introduction

Driver behavior and errors are a major cause of vehicle accidents. Driver behavior is related to the driver's character and socio-economic background. However, it may be influenced through education, training, publicity campaigns and police enforcement. Thus, understanding and influencing driver behavior is a key ingredient for the improvement of road safety. One of the main obstacles in understanding the relations between drivers’ characteristics and their driving behavior is the lack of reliable tools to collect detailed information about individuals, such as the level of skill and driving abilities and to monitor and interpret their driving behavior, as captured for example by acceleration and speed profiles.

In this research we develop general theoretical framing of driver behavior expressing the relations among the different factors of driving behavior. Several sources of data should be used in order to estimate models based on this framework. This research uses newly available In Vehicle Data Recorder (IVDR) data, as well as data about driving styles, characteristics, attitudes and perceptions from traditional self-reported questionnaires. Self-reported data includes two forms of questionnaires: a driving behavior questionnaire in which drivers report about their actions and reactions while driving, and a questionnaire that measures attitudes and perceptions towards driving. The modeling framework integrates IVDR data, self-report questionnaires, operational costs and environmental data to identify relevant driving behaviors that may be related with the risk of accident involvement. IVDRs' various events allow developing indices to evaluate driving behavior during a certain trip or a period of time. The aim of this model is to develop an index expression that will best reflect the risk of accident involvement.

The data that are used to estimate this modeling framework are obtained from an experiment that is conducted for another related research conducted for the Ministry of Science. In this experiment we collect data using IVDR and investigate the influence of
IVDR installed in a vehicle, on the drivers and safety management of the vehicle fleet organization participating in the experiment. These data are used to identify and model different patterns of driver's behavior. Identifying different behavior patterns allows tailoring treatment programs that fit drivers according to their specific behavior type.

The experiment is carried out in different army units and with one IVDR manufacturer, Traffilog, which completed the installations in three air force bases. Traffilog provides data to the safety officer of the army fleet and to the research team. Various technical problems delayed the project and Traffilog along with the army fleet are working to solve these problems in order to successfully conclude the experiment.

Currently we are about to complete the blind phase of the experiment. In this phase, drivers are aware to an instrument installed in their vehicle but does not know the nature and the usage of the IVDR. In the next few weeks we will handle the drivers a questionnaire in which they will be asked about their driving behaviors, attitudes and perceptions towards driving. In this phase, drivers will be exposed to the IVDR and drivers will be given a periodically feedback about their driving.

This report summarizes the work conducted so far including the development of a theoretical framework of driver behavior and accident risk including the effect of the IVDR as well as many other factors on these variables, literature review, experiment design, surveys and questionnaires conducted and experiment description and results so far.

3. Literature review

Most studies that evaluate driving behavior focus on drivers’ self-estimation, perceptions and attitudes. These studies are often based on responses to self-reporting questionnaires, in which drivers are asked to evaluate their own driving behavior, attitudes and perceptions towards driving, such as risk taking and law-obedience, as well as report their past safety record (e.g. accidents, police citations). This method has several important advantages. Most importantly, it can be used to collect a large amount of data in a relatively short time and low cost. As a result, this approach has been used extensively for a wide range of applications, including studies of aggressive driving (Parker et al., 1998; Lajunen et al., 1998; Chliaoutakis et al., 2002; Ulleberg & Rundmo, 2002; Iversen, 2004; Maxwell et al., 2005), relations between alcohol and drugs use and driving behavior (Shinar, 1995; Sechehtman et al., 1999; Caetano & Clark, 2000; Begg &
Several methods for self-report questionnaires were developed over the years and are described below.

### 3.1 Self-Report: Driver Behavior

One class of questionnaires is those in which the drivers are asked to describe his/her actual behavior while driving or actions and reactions related to driving behavior.

Reason et al. (1990) developed a survey instrument to distinguish between different forms of aberrant behavior on the road. The Driver Behavior Questionnaire (DBQ) was originally established to make the distinction between errors and violation which were assumed to have different psychological origins. Three main factors were identified (Reason et al., 1990):

- **Violations** which include speeding, running through red traffic lights and tailgating. These behaviors were found to be associated more with males and young drivers.

- **Errors** included all those occasions in which a planned sequence failed to achieve its intended outcome. Errors include failing to notice road signs, failing to notice other road users, missing turns, etc. This group was not associated with any demographic group.

- **Lapses** involved problems that occurred due to lack of attention or failures of memory. The group was associated mainly with women and elderly drivers. Lapses are typically relatively harmless.

DBQ was replicated in many countries among different populations including the UK (Parker et al., 1995), Western Australia (Blockley and Hartley, 1995), Sweden (Aberg and Rimmo, 1998), Great Britain, Finland and the Netherlands (Lajunen et al., 1999), New Zealand (Sullman et al., 2002), Greece (Kontogiannis et al., 2002), China (Xie and Parker, 2002) and Turkey (Sumer et al., 2000; Ozkan & Lajunen, 2005).

Gulian et al. (1988, 1989) defined driver stress scale using the Driver Behavior Inventory (DBI). “Trait” (personal nature) driver stress was measured using a variation of the Driving Behavior Inventory. According to the DBI method, drivers are influenced not
only by stress related to driving but also by general stress at home or work environments. They therefore propose the use of the term “driver stress” rather than “driving stress”. The Gulian et al DBI assessment consists on 16 items for evaluating driver stress. The method was found to be valid, robust and reliable measure of trait driver stress in several studies (Glendon et al, 1993, Hennessy & Wiesenthal, 1997; Matthews et al, 1999 Wickens & Wiesenthal 2005).

French et al. (1993) developed the Driving Style Questionnaire (DSQ), which is composed of six independent dimensions of driving style. West and French (1993) also studied driving style and found a link between self report of speeding behavior and accident risk. Hoedemaeker and Brookhuis (1998) used the DSQ method to assess driver behavior in response to new technologies. They assessed adaptive cruise control regarding behavioral adaptation and driver acceptance, using different driving styles with respect to speed and focus. In their study they found that self-reported differences in driving style are good predictors of the participants’ actual driving style as displayed in a driving simulator. Drivers who scored high on the factor speed of the driving style questionnaire drove faster than participants that scored low.

Hennessy & Wiesenthal in several studies defined different questionnaires as a mean of identifying driver behavior. The driving Vengeance Questionnaire (DVQ; Hennessy & Wiesenthal, 2001; Wiesenthal et al., 2000) was developed to evaluate vengeful driving reactions. Items represented common driving situations in which participants might be irritated or unjustly treated by another driver. Respondents were asked to choose among four options that correspond with decreasing levels of aggression. The DVQ was found to be a reliable measure of vengeful driving attitudes and to predict the likelihood of mild driver aggression and violence (Hennessy & Wiesenthal, 2001; Wiesenthal et al., 2000).

Hennessy & Wiesenthal also developed two questionnaires to evaluate levels of driver aggression. The first one, Self-Report Driver Aggression Questionnaire (Hennessy & Wiesenthal, 1997, 1999, 2001) in which they tried to evaluate the likelihood of engaging in mild aggressive behaviors while driving. The five aggressive items were horn honking, tailgating, yelling, using hand gestures and fleshing high beams. Respondents rated on a 6 point scale indicating how frequently they committed a certain behavior while driving. Hennessy (2000) found that self-reported driver aggression scores correlated highly with actual acts of mild aggression occurring during high congestion conditions (Hennessy & Wiesenthal, 2005).
The second one, Self-Report Violent Driving Questionnaire (Hennessy & Wiesenthal, 2001) was designed to evaluate the frequency at which drivers conduct violent actions such as physical roadside confrontation, chasing other vehicles, throwing objects, etc. The questionnaire was composed of seven items indicating the frequency of being involved in these behaviors.

Recently, in Israel, a method for evaluating drivers' behavior was developed by Taubman Ben-Ari et al. (2004). The Multidimensional Driving Style Inventory (MDSI) is a self-report 44-item scale, assessing four broad domains of driving styles: (1) Reckless and careless driving style (2) Anxious driving style (3) Angry and hostile driving style and (4) Patient and careful driving style. The researchers investigated the usefulness and the validity of this multidimensional measure in self-report driving style. A factor analysis was conducted to confirm the hypothesis. Eight factors were developed making more fine distinctions within each of the domains. The method was implemented later in a study that examined associations between parents and their adult children driving style. A significant correspondence was found for most of the MDSI factors (Taubman et. al., 2005).

3.2 **Self-Report: Attitude and Perception**

There have been many attempts to use drivers' attitudes and perceptions towards driving as predictors of drivers' behavior. The approach assumes that it is possible to identify certain attitudes associated with behaviors and that attitudes are causally related to behavior. Most studies found a rather low correlation between the two (Forward, 1997). However, this result only led to increased efforts to establish a stronger relation between the two.

Theory of Reasoned Action (TRA) was developed by Fishbein and Ajzen (1975) in which they found that drivers differ from each other by their readiness to commit traffic law violation. The theory states that the intention to commit a certain behavior can be predicted by a person beliefs and attitudes towards that behavior. It was extended later to the Theory of Planned Behavior (TPB) (Ajzen, 1985). TPB predicts behaviors based on intentions and attitudes towards an act and perceived behavioral control. Intentions refer to a willingness to try and it considers the strongest predictor of a chosen behavior. Attitudes refer to individual evaluation of performing a certain behavior while perceived
behavioral control refers to people beliefs about approving or disapproving a certain behavior (Aberg, 1997).

TRA had been applied to number of driver behaviors and found to be significantly predictive of driver behavior (Parker et. al, 1992; Yagil, 1998; Gordon and Hunt, 1998). Researchers where mostly dealing with intentions to commit behaviors such as speeding or driving and drinking. Extensive review and examples of TPB may be found in Ajzen (2006).

3.3 Limitations of Self-Reporting

Despite its common practical use, several researchers raised doubts concerning the reliability of self reports for measuring drivers’ behavior since various biases may be introduced. For example, Maycock et al. (1991) show that the number of self-reported traffic accidents may be lower than the actual number by as much as 30%. For near accidents and driving violations, the non-reporting rate was even higher. This under-reporting is not easily corrected since other databases that contain car accident information, such as those maintained by the police, hospitals and insurance companies also suffer from significant under-reporting (Hauer & Hakkert, 1988). Arthur et al. (2001) also assessed the correlation between archival and self-reported crashes and moving violations. They found low correlation between the two. The paper also lists several other studies that found significant under-reporting of accidents and moving violations. Biased reporting also appears in other types of questions. Most drivers, and especially males, tend to overestimate their driving skills (McKenna et al., 1991). Significant biases were observed when drivers were asked to indicate how often they committed a certain behavior, with higher bias occurring with undesirable behaviors compared to desirable ones (Linderman & Verkasalo, 1995). Lajunen and Summala (2003) found that this social desirability bias in self-reported driver behavior depends on the questionnaire design and on the survey procedures.

3.4 In Vehicle Data Recorder

These limitations of self-reporting as a basis for the study of driving behavior clearly indicate the need for other more reliable sources of information that can complement the
self-reports. One such class of tools that has recently been developed is the In Vehicle Data Recorders (IVDR). IVDRs are installed in the vehicle and provide detailed information about its position, speed, vertical and horizontal acceleration and maneuvers performed.

The first application of vehicle data recorders was the Event Data Recorder (EDR). An EDR is similar to the “black box” used in aircraft. It records data when events, such as crashes, occur and stores the information in the unit. This information is later used to investigate and analyze the circumstances leading to the crash. The first experiments with EDRs were conducted by the NHTSA (National Highway Traffic Safety Administration – in the US) in the 1970’s. Today EDRs are widely installed and used by vehicle manufactures, insurance companies, law enforcement agencies and researchers. A comprehensive review of EDR research, use and history can be found in NHTSA (2005). While these tools are useful for the study of the crash event itself, the data they store is limited to a period of a few seconds prior to the event and they are not sufficient for a more general study of driver behavior.

More recently, the use of recorders has been expanded to the study of driver behavior in non-crash situations as well. IVDR were first introduced in the trucking industry over twenty years ago. The equipment was originally intended for fleet management tasks, such as routing and tracking. Since then several other functionalities have been added to these devices including some oriented at monitoring and improvement of driver behavior and safety. In this context IVDRs were used as part of Behavioral-Based Safety (BBS) schemes, which apply a set of methods demonstrated to improve safety performance by engaging workers in the improvement process, teaching them to identify critical safety behaviors, perform observations to gather data, provide feedback to encourage improvement, and use gathered data to target system factors for positive change (Krause et al., 1999). Krause et al. (1999) concluded that BBS has significant potential to improve truck safety, especially if new technologies such as IVDR are utilized. Several studies showed positive impact on safety when weekly safety performance reports were provided to supervisors and fleet managers as part of a BBS implementation (Grindle et al., 2000; Sulzer-Azaroff & Austin, 2000).

Studies that evaluated the impact of feedback to drivers about their driving behavior on safety generally found significant safety improvements. For example, Wouters and Bos (1997) conducted an experiment with 840 vehicles, 270 of which were fitted with IVDR.
They found a 20% reduction in car crashes for drivers that were confronted with the data recorded by the IVDR. The success of IVDR can be partly attributed to the use of an objective technology-based system. Using focus groups, Roetting et al. (2003) found that drivers had positive attitudes towards feedback about their driving and in particular when it is provided by a new technology. On the other hand, Heinzmann & Schade (2003) who investigated whether the presence of Driving Data Storage Units in the cars of young male drivers had preventative effect by leading to more discipline and careful driving, showed that the installation of the unit alone had no significant effects on behavior or accident occurrence.

While these studies clearly indicate that IVDR technology can have a significant impact on road safety, there is only limited understanding of what data should be collected and how they should be interpreted and analyzed. For example, it is not yet clear how second-by-second speed and acceleration profiles translate to accident risk. As IVDR data becomes more accessible, the importance of their correct interpretation is increasing. Some attempts in this direction have been initiated recently. The Drive Atlanta study (Georgia Tech, 2002) focuses on the collection of IVDR data from 1100 equipped vehicles. The data is downloaded weekly and includes trip level information, such as the distance traveled, trip duration and route choice as well as second-by-second speed and acceleration. The experiment is on-going and results have not yet been published. TripSense (TripSense, 2005) is a similar program conducted in Minnesota. At the trip level the data collected includes the start and end time of trips, distance driven, and trip duration. Driver behavior data includes speeds at 10 seconds intervals and the numbers of aggressive braking events and aggressive acceleration events. Aggressive braking and acceleration are defined, rather arbitrarily, as exceeding 7 mph per second. The experiment is conducted in conjunction with an insurance company, which allows drivers to view their own driving reports on a dedicated web page and compare themselves to other drivers.

Recently in Israel, Or Yarok conducted a research study including 33 participants whose vehicles were equipped with IVDR Systems. During the first phase of the experiment drivers did not get any feedback from the IVDR, while in the second phase drivers got an access to a personal web-page that summarized information recorded by the IVDR. The results showed significant correlation between drivers' historic crash records and the
IVDR measurements. In addition, the results showed that the initial exposure to the system had significant positive impact on drivers' behavior (Toledo & Lotan, 2006).

3.5 **Driver Behavior Models**

There are several types of driving behavior models in the literature. One type of models is designed to evaluate the impact of various safety devices vehicle systems such as automatic collision avoidance. For this purpose detailed drivers' actions are detected and modeled, usually using driving simulators. Miyazaki et al. (2001) focused on the detection of the driver's intended action, in which the driver's steering, acceleration, and braking patterns are modeled as a set of hidden Markov models (HMMs). Other models aim to predict accident risk. These models often concentrate on one aspect of driving behavior as a proxy for risk taking. For example, driver's choice of travel speed (Gaudry & Vernier, 1999, Verhoef & Rouwendal, 2004) or driver's gap acceptance (Poulus, Shiftan & Shmueli-Lazar, 2005, Spek et al., 2005).

Gaudry & Vernier (1999) used three equation groups for their estimation structure: the first two explain accident frequency and severity with discrete choice logit-type models. Verhoef & Rouwendal (2004) develop a behavioral model on traffic congestion. According to this model, drivers optimize their speeds by trading off time costs, expected accident costs and fuel costs. Since the presence of other drivers affects the latter two cost components and hence the Nash equilibrium speed, a ‘behavioral’ speed-flow relationship results for which external congestion costs include expected accident costs and fuel costs, in addition to the time costs considered in the conventional model. The speed equations, explaining both the mean and the variance of speeds, also consist of non linear flexible-form models.

IVDR provides much richer information on drivers' behavior that has not been available earlier. To the best of our knowledge driving behavior models that exploit this information have not yet been reported in the literature.

In summary, IVDR technology, which monitors driving behavior by recording vehicles' positions, speed and acceleration, can have a significant positive impact on road safety. However, in order to realize this potential, further research is required regarding the proper analysis, interpretation and presentation of the data, about the connection
between the information the system records and the risk of accidents, and the potential to use these data to improve modeling of driving behavior.
4. Methodology

In this research we develop models of driving behavior that will help identifying extreme behaviors that may be related with the risk of involvement in car accidents using information on drivers’ behavior collected by IVDR. These behavioral models will help to identify the relations between observed driving behaviors and drivers’ characteristics and perceptions towards driving.

Our research is based mainly on IVDR data recorded continuously in the vehicle providing data on vehicle speed, acceleration, deceleration and GPS readings along with supplementery data such as questionnaires, drivers’ history data, environmental data, operational cost and maintenance.

General theoretical framework of driver behavior is developed, including available measuring tools, which express the relations among the different factors of driving behavior. In order to estimate models based on this framework we are collecting IVDR data, as well as data about driving styles, characteristics, attitudes and perceptions from traditional self-reported questionnaires. Two forms of questionnaires are used in the study: a driving behavior questionnaire in which drivers are asked about their actions and reactions while driving, and another questionnaire that measures attitudes and perceptions towards driving (a sample of the questionnaire, used in the experiment, is given at the end of the report). The model integrates IVDR data, self-report questionnaires and operational and environmental data to identify relevant driving behaviors that may be related with the risk of accident involvement. The specific models that will be derived from this framework will be specified using econometrics tools as systems of structural and measurement equations. Estimation of the system equations parameters will utilize the maximum likelihood approach.

Once the sub-models described above have been estimated, the driving behavior model can be used to examine related questions, such as the impact of socio-economic characteristics and the potential of providing feedback from the IVDR to drivers to change their behavior.
4.1 Conceptual framework

Figure 1 introduces the modeling framework describing the connections among the various factors affecting driving behaviors.

Figure 1: Model framework

In this figure, elliptic shapes represent latent variables, which are unobserved or cannot be measured. For example, drivers' characteristics, perceptions and attitudes cannot be measured directly and therefore have to be estimated indirectly using indicators. Note that IVDR data are detailed indicators of driving behavior that have not been available previously. Rectangular shapes represent measured variables. Wide arrows indicate cause and affect relations. For example, weather conditions affect drivers' behavior and their
risk for accident involvement. Dashed arrows represent measurement equations for unobserved variables using indicators. Accident risk and operational costs are both affected by drivers' actual behavior and by environmental conditions. For example, with similar driving behavior the risk of accident involvement may be higher when driving through a rain storm compared to a sunny day. Drivers' actual behavior is affected by the drivers' characteristics, attitudes and perceptions and by the environmental conditions. It is indicated on by IVDR measurements and/or driving behavior self-reports.

The IVDR data and other supplementary data collected in the experiment are used as indicators to measure drivers' behavior and risk for accident involvement. Four important classes of data are shown in the figure:

1. **IVDR data**, which describes drivers’ detailed actions (e.g. speed, acceleration, braking and maneuvers)

2. **Self-responses to questionnaires**:
   - Driving behavior.
   - Attitudes and perceptions.
   - Accident involvement and violations.

3. **Environment conditions**, such as road traffic and weather conditions.

4. **Driver history records**, which may include accident reports, insurance and traffic violations records.

The accident risk depends on the drivers’ behavior influenced by its' own characteristics among other factors. The driver's acceptable level of risk (D) is a result of the driver actions and the environmental conditions. Driver behavior is monitored and recorded by the IVDR. The IVDR data are being processed using statistical tools to identify drivers’ behavioral patterns that will allow us to define different patterns of behavior, which may lead to elevated risk for vehicle accident involvement.

### 5. The Model

The overall model, as described in the framework shown in Figure 1, can be mathematically formulated as a set of structural equations that describe the connections between drivers' perceptions and attitudes, behavior and performance indicators, such as
the risk of accident involvement and operational costs. Sections A to D below describe the different elements that will be estimated within the overall model (the letters A to D refers to figure 1).

5.1 **Section A – Self-Report – Driving Behavior**
We use a self-reported driving behavior questionnaire, which includes about 40 questions in which drivers are asked about their driving style and behavior. We will perform factor analysis to group response variables with high correlation into factors that represent a single type of driving behavior, such as, careful, angry, high-speed, risky and aggressive driving. This model is given by:

\[ Y_1 = f_1(F_1) \]

\[ Y_1 \] – Responses to the driving style questionnaire.

\[ F_1 \] – Vector of latent factors to assess driving behavior.

5.2 **Section B – Self-Report – Attitudes and Perceptions**
In this part of the model we will be handling the drivers an attitude and perception questionnaire. We expect to find a much weaker connection between the attitudinal responses than from the former questionnaire in which the drivers were asked directly to report about their driving behavior. Still we want to identify an intention to commit certain driving behaviors in order to be able to affect it by feedback or training.

The attitude and perception questionnaire might also show the differences among the attitudes of the drivers prior to the experiment and at the end of the experiment. The model is given by:

\[ Y_2 = f_2(F_2) \]

\[ Y_2 \] – Responses to the attitude and perception questionnaire.

\[ F_2 \] – Vector of latent factors to assess driving behavior.

5.3 **Section C – IVDR**
IVDR continuously records data on drivers’ actions while traveling. The variables recorded by the IVDR include the vehicle’s speed and two-dimensional accelerations. The data recorded may be analyzed in two modes:

1. Raw data of speed and acceleration profiles
2. Predefined events, normally with two or three severity levels of driving behavior, such as speeding, fast accelerating, strong braking, etc.

Self-Report questionnaires are an indicator for driving style. Drivers are asked to describe their habitual actions and reactions while driving in general with question such as “I often purposely tailgate other drivers” drivers are expected to evaluate their actions over a period of time and translate them into a scale which eventually gives an average indication of their driving style. IVDR records actual drivers’ behavior over time. The second model will try to assess the relations among the factors that we found from the self-report questionnaires in the first model and the measurements of the IVDR.

In addition to the factors, the explanatory variables will include environmental data (day light and weather) in order to include drivers’ interaction with the environment.

\[ Y_3 = f_3 \left( F_1, F_2, E \right) \]  

\( Y_3 \) – Measurements of the various driving events

\( E \) – Environmental data

5.4 Section D – Accident risk & operational costs

We use two different data sets in order to evaluate drivers’ risk of involvement in car accidents:

1. Accidents records provided by the fleet safety manager. Data is collected regularly before the beginning of the experiment and during the experiment. It is including data on car accidents, injuries, severity and damage to the vehicle. In the army, data might be limited because of high turnaround of both personal and vehicles.

2. Operational cost provided by the fleet safety manager including fuel consumption and wear and tear.

Accidents involvement

The purpose of this model is to assess the relationships among car accidents involvement expressed by costs with:

1. Factors derived from self-report data

2. IVDR measurements and
3. Integration of both

\[ R = f_4(F_1, F_2, Y_3, E) \]  \hspace{1cm} (4)

\( R \) – Risk expressed by accident costs

**Operational Costs**

We assume that aggressive driving affects the operational cost of the vehicle. Therefore we will examine the relationships between vehicles operational costs and:

1. Factors derived from self-report data
2. IVDR measurements and
3. Integration of both

\[ C = f_5(F_1, F_2, Y_3, E) \]  \hspace{1cm} (5)

\( C \) – Risk expressed by accident costs
6. Experiment steps

The steps of the experiment are described in the following sections.

6.1 Pilot Validation Study

Prior to the start of the IVDR experiment a validation trial was conducted. Four potential IVDR manufactures participated in the validation study trial. The main purpose of the study was to validate the IVDR accuracy of measurements such as speed and acceleration. The second objective was to examine whether or not the IVDR’s are able to identify driving events and to evaluate the rates of false identification. For this purpose, the army experiment unit (NASA) installed their own IVDR system along with four commercial IVDR’s. In addition to the IVDR measurements, driving safety instructions were manually recorded in details every planned event. 68 different events were performed during a two hours driving experiment, which was composed of 8 time intervals of 15 min. each. This included two intervals of aggressive driving in which the driver had performed different aggressive events. Events included high acceleration, strong braking, slalom with high lateral acceleration and speeding. Four intervals of normal driving in which the driver performed regular driving with several preplanned events and two careful driving intervals with very few events.

The event definitions are not uniform among the IVDR companies. The various manufacturers defined different boundary values for vertical and lateral acceleration. Therefore, when analyzing the data and comparing the various events, we have to consider and accept these differences. In addition, we considered gaps of 0.05g as an acceptable error that might be caused by several reasons such as differences of the IVDR relative location in the vehicle.

6.2 Findings

Three companies have passed the trial. All three have identified more than 88% percent of the events. There where up to 8 (12%) false alarm events, most of them due to inaccuracy. In most cases, the company identified an event but their values were slightly different from the one that were measured by the army equipment. Out of the three companies that passed the validation test, one company dropped after the validation test
and another company dropped at the beginning of the experiment. Currently, only one company is participating in the experiment.

Table 1 presents the number of identified events by each company participating in the pilot.

**Table 1 – Identified Events by Participating Companies**

<table>
<thead>
<tr>
<th>Company C</th>
<th>Company B</th>
<th>Company A</th>
<th>NASA</th>
<th>Identified Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>64</td>
<td>67</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>(88%)</td>
<td>(94%)</td>
<td>(98%)</td>
<td>-</td>
<td>(%)</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>5</td>
<td>-</td>
<td>False Alarm</td>
</tr>
<tr>
<td>(3%)</td>
<td>(12%)</td>
<td>(7%)</td>
<td>-</td>
<td>(%)</td>
</tr>
</tbody>
</table>

Table 2 presents an example from the pilot in which the experimental unit of the army (Nasa) recorded data using a similar unit as the IVDR. In this example, slalom event can be identified and is colored in orange (on x axis).
## Table 2 – an Example showing Slalom Event Recorded by IVDR during the Pilot

<table>
<thead>
<tr>
<th>Events No.</th>
<th>Nasa events list</th>
<th>Not identified</th>
<th>Event</th>
<th>Speed&gt;100(km/h)</th>
<th>x(g)&gt;0.4</th>
<th>y(g)&gt;0.5</th>
<th>x(g)</th>
<th>y(g)</th>
<th>vel(km/h)</th>
<th>Time(H)</th>
<th>time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>L</td>
<td>0.43</td>
<td>0</td>
<td>0.41</td>
<td>0.41</td>
<td>0.3</td>
<td>79.39</td>
<td>10:07:14</td>
<td>434.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>R</td>
<td>0.47</td>
<td>0</td>
<td>-0.46</td>
<td>-0.46</td>
<td>0.03</td>
<td>79.25</td>
<td>10:07:16</td>
<td>436.10</td>
</tr>
<tr>
<td>8 Slalom</td>
<td></td>
<td>A</td>
<td>R</td>
<td>0.45</td>
<td>0</td>
<td>-0.45</td>
<td>-0.45</td>
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7. Experimental Design

The experiment is planned to last six months and includes two phases. In the initial month, drivers are not exposed to the IVDR system and no feedback is provided to them. In the next months, drivers are informed about the IVDR and get access to the information collected by the system. After the initial exposure, drivers receive periodical feedback about their driving behavior. In addition, drivers are asked to respond to two types of questionnaires: driver behavior questionnaire and attitudes and perceptions questionnaire. They will also be asked to report about their driving records and some socio-demographic information. The questionnaires will be handled to the drivers only after the initial exposure of the IVDR in order to avoid change in their behavior. These data will provide the measurements required to estimate a model based on the framework described in this paper.

8. Questionnaire

In the next few weeks, right before the stage that driver will be exposed to the IVDR performance, they will be asked to fill in questionnaires. Drivers are asked to respond to two types of questionnaires during the experiment:

1. A driving behavior questionnaire in which drivers are asked directly about their actions and reactions in certain situations. The questionnaire is based on several validated types of questionnaires reviewed from the literature. Drivers receive the questionnaire one month after the installation of the IVDR in order not to affect their driving behavior in the pre-feedback term. We will repeat the process at the end of the experiment in order to see if there are any changes in their reported behavior. Currently in the experiment we are about to expose the drivers to the IVDR and handle the questionnaires.

In addition to the driving behavior questions, two other types of questions are asked:

• Socio-demographic characteristics questions such as gender, age and level of education.

• Safety record history - Drivers are asked to report about their violations, accidents, severity and injuries in the past few years.
2. **An attitudes and perceptions questionnaire** in which drivers are asked about attitudes that might be related with certain driving behaviors. The questionnaires are based on experience reported in the literature review. By asking questions about attitudes and perceptions towards driving we may affect driving behavior. Therefore, the questionnaire will be conducted at the end of the experiment.

### 8.1 Pilot

An extensive literature review was conducted in order to study self-reported questionnaires and their reliability. Based on this literature review an appropriate questionnaire was developed. The initial questionnaire included about 100 questions on driving behavior, attitudes, perceptions and socio-demographic questions. A pilot with 143 army soldiers was conducted in June, 2007. Most respondents were native Israelis, 8 were immigrants between 2 to 17 years in Israel. The questionnaires were in Hebrew and included two parts: drivers' behavior questionnaire and perceptions and attitude. Drivers were asked to fill in first the driver behavior questionnaires so that their attitudes won't affect their reported behavior. Two types of the same questionnaire were used in a different order. Respondents were also asked to mark questions that were not clear to them. The scale was between 1 to 5 where high score pointed on unsafe behavior in the driver behavior questionnaire and on negative attitude towards safe driving in the perception and attitude questionnaire.

### 8.2 Findings

143 driver behavior questionnaire and 127 perception and attitude questionnaires were received in the pilot. 65 out of the driver behavior and 14 out the perception and attitude questionnaires were not seriously filled (e.g. same answer was signed throughout the questionnaire, there were specific patterns of the answers or many responses were missing). Drivers signed very few questions as unclear and there was not one question signed by few respondents as unclear.

Statistical analysis was conducted on those responses that were acceptable. The spread in question responses showed that there are personality differences among the drivers. Component analysis conducted on both questionnaires found five factors in the behavior questionnaire and seven in the perception and attitude questionnaire.
The main feedback and conclusion from the pilot was that the questionnaire is too long and it is essential to reduce the number of questions. As a result we decided to shorten the questionnaire and use a driving behavior scale that was developed in Israel by Taubman-Ben-Ari et al. (2004). We dropped two factors and added about 10 attitude questions.

The questionnaire that is used for the experiment is given below.
השאלות בטבלה זו נועדו למדוד על האופנים ובתיו של הצבעהпередיךفاءشورו אפיין אתך/ה נוהג/ת.

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אני מרבה לחבר או להס.  
אני מדריך לכל הנשים מצוינות של נسفر מפרסון.
לפניך עד 12 משפטים המ-describes דעות של נהגים. לברך כל משפט, ציין עד כמה אתה מסכים עם.

המשטף. سمנים ביעול את התשובות המ-describes.

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9. Experiment Initial Findings

The experiment is carried out in different army units and with one IVDR manufacturer, Traffilog, which completed the installations in three air force bases. Traffilog provides data to the safety officer of Tel-Nof fleet and to the research team. Various technical problems delayed the project and Traffilog along with the army fleet are working to solve these problems in order to successfully conclude the experiment. Currently, we started analyzing data received from the company. Data summary and some findings are given in table 3. Due to confidentiality, we cannot expose some of the data.

Table 3 – Data summary for April 2008

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<td>Number of Drivers</td>
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<td>Number of trips</td>
<td>31716</td>
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<td>Number of Identified Trips</td>
<td>25618</td>
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<td>Percentage of Identified Trips</td>
<td>80.8%</td>
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<td>Summary of the Fleets Driving Hours</td>
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<td>Driving Time for Identified Drivers (hours)</td>
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<td>Average Time for Identified Driver (hours)</td>
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<td>Number of Drivers Driving Over 5 Hours</td>
<td>222</td>
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Below are few diagrams introducing summaries of driving events.
Figure 2 – Monthly Number of Events for Drivers
Figure 3 – Monthly Number of Events for Drivers Driving over 5 Hours a Month
Figure 4 – Monthly Number of Events per Trip Duration
Figure 5 – Monthly Number of Events per Trip Duration for Drivers Driving Over 5 Hours a Month

![Graph showing the monthly number of events per trip duration for drivers driving over 5 hours a month. The x-axis represents the number of events per trip duration, while the y-axis represents the number of events.]
10. Summery and Conclusion

This research developed and presents a general theoretical framing of driver behavior, including IVDR and available measuring tools to express the relations among the different factors of driving behavior. The framework includes a set of structural equation models that is still to be estimated. We are currently conducting an experiment that will provide the data to calibrate and examine these models. The experiment that lasts six months is based on two main stages: the first two months are a blind stage in which drivers are not exposed to the IVDR performance. In the following four months drivers are aware of the IVDR and receive periodically feedback from the system. Along with the IVDR data, we are collecting supplementary data which includes driving attitude and perception questionnaires, drivers’ accident and violation history data and environmental data.

The research helps identifying the effects of driver characteristics (e.g. age, gender), road and traffic conditions, attitudes and perceptions towards driving on driving behavior. It may be used to identify and classify drivers for purposes of training, monitoring, setting insurance rates and developed policies toward improved road safety. These models will improve our understanding of the characteristics associated with different patterns of driving behavior, will support the development of methods and tools to modify such behaviors and hopefully contribute to road safety.
11. References and relevant bibliography


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Appendix A

This appendix includes a paper presenting this work that was presented at WCTR 2007 in Berkeley, California and published in the Proceedings of the 11th World Congress on Transport Research, Berkley, CA, 2007.
Framework for Analysis and Modeling of Driving Behavior

incorporating In-Vehicle Data Recorders

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Abstract

This paper develops a general theoretical framing of driver behavior expressing the relations among the different factors of driving behavior. Several sources of data should be used in order to estimate models based on this framework. This paper uses newly available In Vehicle Data Recorders (IVDR) data, as well as data about driving behavior, characteristics, attitudes and perceptions from traditional self-reported questionnaires. The modeling framework integrates these various data sources in addition to costs and environmental data to identify relevant driving behaviors that may be related with the risk of accident involvement.

Introduction

Driver behavior and errors are a major cause of vehicle accidents. Driver behavior is related to the driver’s character and socio-economic background. However, it may be influenced through education, training, publicity campaigns and police enforcement. Thus, understanding and influencing driver behavior is a key ingredient for the improvement of road safety. One of the main obstacles in understanding the relations between drivers’ characteristics and their driving behavior is the lack of reliable tools to collect detailed information about individuals, such as the level of skill and driving abilities and to monitor and interpret their driving behavior, as captured for example by acceleration and speed profiles.

This paper develops a general theoretical framing of driver behavior expressing the relations among the different factors of driving behavior. Several sources of data should be used in order to estimate models based on this framework. This paper uses newly available In Vehicle Data Recorders (IVDR) data, as well as data about driving styles, characteristics, attitudes and perceptions from traditional self-reported questionnaires. Self-reported data includes two forms of questionnaires: a driving
behavior questionnaire in which drivers report about their actions and reactions while driving, and a questionnaire that measures attitudes and perceptions towards driving. The modeling framework integrates IVDR data, self-report questionnaires, operational costs and environmental data to identify relevant driving behaviors that may be related with the risk of accident involvement. IVDRs’ various events allow developing indices to evaluate driving behavior during a certain trip or a period of time. The aim of this model is to develop an index expression that will best reflect the risk of accident involvement.

**Background**

Most studies that evaluate driving behavior focus on drivers’ self-estimation, perceptions and attitudes. These studies are often based on responses to self-reporting questionnaires, in which drivers are asked to evaluate their own driving behavior, attitudes and perceptions towards driving, such as risk taking and law-obedience, as well as report their past safety record (e.g. accidents, police citations). This method has several important advantages. Most importantly, it can be used to collect a large amount of data in a relatively short time and low cost. As a result, this approach has been used extensively for a wide range of applications, including the study of aggressive driving (Parker et al., 1998; Lajunen et al., 1998; Chliaoutakis et al., 2002; Ulleberg & Rundmo, 2002; Iversen, 2004; Maxwell et al., 2005), alcohol and drugs use relations to driving behavior (Shinar, 1995; Schechtman et al., 1999; Caetano & Clark, 2000; Begg & Langley, 2004), socio-economic characteristics that affect driver behavior (Yagil, 1998; Lourens et al., 1999; Golas & Karlaftis, 2001; Boyce & Geller, 2002) and more.

Several methods for self-report questionnaires were developed over the years. One class of questionnaires is those in which the drivers are asked to describe his/her
actual behavior while driving or actions and reactions related to driving behavior.
Some of the main methods for driver behavior questionnaires that were developed
over the years include DBQ (Driver Behavior Questionnaire) by reason et al (1990)
that identified three main factors: driver violations, errors and lapses. Gulian et al.
(1988, 1989) defined driver stress scale using the Driver Behavior Inventory (DBI).
“Trait” (personal nature) driver stress was measured using a variation of the Driving
Behavior Inventory. Driving Style Questionnaire (DSQ), which is composed of six
independent dimensions of driving style, was developed by French at al. (1993).
Hennessy & Wiesenthal developed Driving Vengeance Questionnaire (DVQ) to
evaluate vengeful driving reactions and two types of questionnaires to evaluate levels
of driver aggression: Self-Report Driver Aggression Questionnaire and Self-Report
Wiesenthal et al., 2000). The Multidimensional Driving Style Inventory questionnaire
(MDSI) was developed recently in Israel in order to assess a wider range of driver’s
behaviors (Taubman Ben-Ari et al., 2004). Another class of questionnaires is attitude
and perception questionnaire. The approach assumes that it is possible to identify
certain attitudes associated with behaviors and that attitudes are causally related to
behavior. Most studies found a rather low correlation between the two (Forward,
1997). However, this result only led to increased efforts to establish a stronger
relation between the two. Several types of these questionnaires are the Theory of
Reasoned Action (TRA) that was developed by Fishbein and Ajzen (1975). The
theory states that the intention to commit a certain behavior can be predicted by a
person beliefs and attitudes towards that behavior. The theory was extended later to
the Theory of Planned Behavior (TPB) (Ajzen, 1985). TPB predicts behaviors based
on intentions and attitudes towards an act and perceived behavioral control.
Researchers were mostly dealing with intentions to commit behaviors such as
speeding or driving and drinking.
Despite its common practical use, several researchers raised doubts concerning the reliability of self reports for measuring drivers’ behavior since various biases may be introduced. These limitations of self-reporting as a basis for the study of driving behavior clearly indicate the need for other more reliable sources of information that can complement the self-reports. One such class of tools that has recently been developed is the In Vehicle Data Recorders (IVDR). IVDRs are installed in the vehicle and provide information about its position, speed, acceleration, maneuvers it performed and so on.

The first application of vehicle data recorders was the Event Data Recorder (EDR) which is similar to the “black box” used in aircraft. It records data when events, such as crashes, occur and stores the information in the unit. This information is later used to investigate and analyze the circumstances leading to the crash. The first experiments with EDRs were conducted by the NHTSA (National Highway Traffic Safety Administration – in the US) in the 1970’s. Today EDRs are widely installed and used by vehicle manufactures, insurance companies, law enforcement agencies and researchers. A comprehensive review of EDR research, use and history can be found in NHTSA (2005). While these tools are useful for the study of the crash event itself, the data they store is limited to a period of a few seconds prior to the event and they are not sufficient for a more general study of driver behavior.

More recently, the use of recorders has been expanded to the study of driver behavior in non-crash situations as well. IVDR were first introduced in the trucking industry over twenty years ago. The equipment was originally intended for fleet management tasks, such as routing and tracking. Since then several other functionalities have been added to these devices including some oriented at monitoring and improvement of driver behavior and safety.

Studies that evaluated the impact on safety of feedback to drivers about their driving
behavior generally found significant safety improvements. For example, Wouters and Bos (1997) conducted an experiment with 840 vehicles, 270 of which were fitted with IVDR. They found a 20% reduction in car crashes for drivers that were confronted with the data recorded by the IVDR. The success of IVDR can be partly attributed to the use of an objective technology-based system. Using focus groups, Roetting et al. (2003) found that drivers had positive attitudes towards feedback about their driving and in particular when it is provided by a new technology. On the other hand, Heinzmann & Schade (2003) who investigated whether the presence of Driving Data Storage Units in the cars of young male drivers had preventative effect by leading to more discipline and careful driving, showed that the installation of the unit alone had no significant effects on behavior or accident occurrence.

While these studies clearly indicate that IVDR technology can have a significant impact on road safety, there is only limited understanding of what data should be collected and how they should be interpreted and analyzed. For example, it is not yet clear how second-by-second speed and acceleration profiles translate to accident risk. As IVDR data becomes more accessible, the importance of their correct interpretation will increase. Some attempts in this direction have been initiated recently. The Drive Atlanta study (Georgia Tech, 2002) focuses on the collection of IVDR data from 172 equipped vehicles. The data was downloaded weekly and included trip level information, such as the distance traveled, trip duration and route choice as well as second-by-second speed and acceleration. The research was mainly followed after individual drivers’ speeding behavior capturing speed and location every second of operation. The purpose of the research was to analyze drivers speeding behavior using data from the IVDR in order to find out whether speeding behavior increases the risk of crashing. Nearly 40% of the vehicles were above the posted speed limit, while 12% found to be more than 10 mph above the posted speed limit. The group of young drivers had the highest mean levels of
speeding although not all young drivers perform extreme speeding behavior, only few individuals from this group were found to be well above the posted speed limit. The recommendation for future research included behavioral components such as acceleration and deceleration activity along with speeding behavior (Ogle, 2005). The 100-Car Naturalistic Driving Study is conducted by the Highway Traffic Safety Administration (NHTSA) and the Virginia Department of Transportation (VDOT). It was the first instrumented-vehicle study undertaken with the primary purpose of collecting large-scale, naturalistic driving data. The system included a box to obtain data from the vehicle. Information such as longitudinal and lateral acceleration, vehicle position, information about the distance from lead, following vehicles and both sides of the vehicle was detected in order to locate conflicts between the vehicles. Five cameras were installed in each vehicle monitoring the driver’s face, both sides of the vehicle, the front and the rear road views. The system reported events characterized into three levels: crashes, near crashes and incidents. In order to see whether driver behavior changes over time, Relative Risk (RR) analysis technique was used. Frequencies of events per different periods of time were examined. It was found that younger drivers had more events than older drivers and those drivers who had leased cars had more events than drivers that own the vehicle. Drivers were more careful when they were aware of the cameras but they return to normal behavior as time went on. In general, using this type of system allows much more detailed and accurate information of crashes, near crashes events and driver behavior. Since crash is relatively a rare event, the information gained from the system might be useful for understanding issues of driver behavior (NHTSA, 2006).

Recently in Israel, Or Yarok conducted a research study, which included 33 participants whose vehicles were equipped with IVDR Systems. During the first stage of the experiment drivers did not get any feedback from the IVDR, while in the second term drivers got an access to a personal web-page that summarized
information recorded by the IVDR. The results showed significant correlation between drivers’ historic crash records and the IVDR measurements. In addition, the results showed that the initial exposure to the system had significant positive impact on drivers’ behavior (Toledo & Lotan, 2006).

Individual monitoring provides better information and stronger basis for calculating individual risk than traditional methods of using personal and vehicle related data. Some insurance companies adopted the IVDR as a way to gain a better precision to evaluate individual’s risk. Yet, a problem that associated with this technology is the loss of privacy. Besides speeds and acceleration, IVDR monitors the duration of the trip, the exact vehicle location, the vehicle route and the time of the day. This information improves the precision of individual risk but it is also reveal information about individual preferences or consumption behavior. In order to overcome this problem, individuals who are buying insurance are offered to install the monitoring system which may decrease the negative impact of there record information but they have to trade it off against the loss of privacy by calculating insurance premiums according to the information derived from the IVDR. Filipova (2006) claims that insured have the right to choose among the IVDR contract and the conventional contract but the nature of the choice will be all or nothing. Once individuals choose the IVDR contract, their level of risk will be calculated exclusively based on the IVDR data. Filipova (2006) in her paper refers to the questions of the quality of information and the equilibrium and factors which influence the insured type of contract decision.

TripSense (TripSense, 2005) is a program conducted in Minnesota, USA. Besides the conventional insurance contract, the company offers the TripSense contract. An installation of monitor device is conducted if TripSense contract are chosen and continuously monitors and stores behavioral driving parameters during the whole trip. At the trip level the data collected includes the start and end time of trips, distance driven, and trip duration. Driver behavior data includes speeds at 10 seconds
intervals and the numbers of aggressive braking events and aggressive acceleration events. Aggressive braking and acceleration are defined, rather arbitrarily, as exceeding 7 mph per second. The experiment is conducted in conjunction with an insurance company, which allows drivers to view their own driving reports on a dedicated web page and compare themselves to other drivers. Insureds are able to evaluate their driving history and calculate their insurance premium corresponding to their individual risk. Based on this information insurers calculate the premium to the next insurance term.

Norwich Union is an insurance company from the UK. The company revealed that nine in ten people would prefer their motor insurance to reflect the usage of their car and the type of journeys they make - with the majority favoring pay as you go systems. The company uses GPS devise installed in the vehicle and the drivers pay a fixed monthly fee plus costs based on the miles they drive. Monthly insurance premiums are calculated based on the drivers' own habits. Drivers can choose among conventional insurance contract or a monthly bill based on a GPS device installed in the car (Norwich Union).

In summary, the literature covers only limited aspects of driver behavior. Self-reported questionnaires, which are often used to indicate on behavior, are exposed to biases caused by the respondents' tendency to overestimate their driving skills and to underestimate their mistakes and violations. IVDR systems are an innovative source of detailed and accurate data on driving behavior. However, so far, only limited use, both in terms of scope of the data and of the modeling frame, of these systems have been reported in the literature.

**Modeling Framework**

In this section we present a conceptual framework for modeling drivers' behavior.
This framework allows integrating different sources of data and measurement instruments, such as traditional self-reported driving behavior questionnaires and attitudes and perceptions questionnaires as well as IVDR data and environmental data in order to capture the relations among the different factors of driving behavior that may be related with the risk of accident involvement.

Figure 1 introduces the modeling framework describing the connections among the various factors affecting driving behaviors. In the figure, elliptic shapes represent latent variables, which are unobserved or cannot be measured. For example, drivers’ characteristics, perceptions and attitudes towards driving cannot be measured directly and therefore have to be estimated indirectly using indicators. IVDR data are detailed indicators of driving behavior that have not been available previously. Rectangular shapes represent measured variables. Wide arrows indicate cause and affect relations. For example, weather conditions affect drivers’ behavior and their risk for accident involvement. Dashed arrows represent measurement equations for unobserved variables using indicators. Accident risk and operational costs are both affected by drivers’ actual behavior and by environmental conditions. For example, with similar driving behavior the risk of accident involvement may be higher when driving in rainy conditions compared to sunny ones. Drivers’ actual behavior is affected by the drivers’ characteristics, attitudes and perceptions and by the environmental conditions. It is indicated on by IVDR measurements as well as by driving behavior self-reports.
IVDR data and other supplementary data collected are used as indicators to measure drivers’ behavior and risk for accident involvement. Four important classes of data are shown in the figure: IVDR data, which describes drivers’ detailed actions (e.g. speed, acceleration, braking and maneuvers). IVDR data can be measured second by second and may capture different driver behaviors such as speeding behavior or frequent braking. The second group of indicators is the self-report questionnaires. This group of data includes driving behavior questionnaires in which drivers report about their behavior while driving. Another type of self-report is the attitude and
perception questionnaires in which drivers report about their attitudes and perceptions towards certain driving behaviors. Self-report of accident involvement and violations are an indicator for evaluating driver behavior. Environment conditions, such as road traffic and weather conditions are an important part of the modeling framework since it influences the driver's decisions while driving. For example, drivers may adjust their driving behavior when driving through bad weather - drivers may decrease their travel speed and increase the time headways between them and the vehicles in front of them. Another source of data is driver history records, which may include accident reports, insurance and traffic violations records. Driver history data is relatively hard and expensive to collect but it can be used as an indicator for the driver behavior.

Accident risk depends on the drivers’ own characteristics. The driver’s actions depend on the acceptable level of risk and take into account the environmental conditions. Driver behavior is monitored and recorded by the IVDR. The IVDR data will also be processed using statistical tools to identify drivers' behavioral patterns that will allow us to define different patterns of behavior, which may lead to elevated risk for vehicle accident involvement.

**The model**

The overall model, as described in the framework shown in Figure 1, can be mathematically formulated as a set of measurement and structural equations. The structural equations describe the behavioral process among the drivers’ behavior, their attitudes and perceptions and the risk of accident involvement. Drivers’ attitudes and perceptions are influenced by their socio-demographic characteristics and affect their driving behavior. Driving behavior along with the environmental conditions determine the drivers’ risk of accident involvement. Yet, this behavioral process is not
measurable and so indicators are needed for estimating the unobserved variables. The measurement equations describe the connections of the indicators to the unobserved behavioral variables in the model. These indicators include IVDR measurements, self-reported questionnaires, drivers’ accidents and violations records and operational costs. We will next describe in further detail the measurement and structural equations that comprise the overall model.

Self-reported driving behavior questionnaires are commonly used as an indicator for the driver behavior. They normally includes 40-50 questions in which drivers are asked about their driving style and behavior. Factor analysis is performed to group response variables with high correlation into factors that represent a single type of driving behavior, such as, careful, angry, high-speed, risky and aggressive driving. This model is given by:

\[
Y_{Q1} = f_{Q1}(F_{i})
\]

(1)

\(Y_{Q1}\) - Responses to the driving style questionnaire.

\(F_{i}\) - Vector of latent factors to assess driving behavior.

Another type of questionnaire that is used as an indicator is self-reported attitude and perception questionnaire. In the proposed framework, an indirect, much weaker, connection is expected between the attitudinal responses and driving behavior compare to the driving behavior questionnaire. The importance of this set of responses is to identify an intention to commit certain driving behaviors in order to be able to affect it by publicity campaign, feedback or training. Administration of these questionnaires might influence driving behavior in the short-run. In order to avoid this sort of bias, the questionnaire should be handed to the drivers separately from the driving style questionnaire and the IVDR measurements. The model is given by:
\[ Y_{Q2} = f_{Q1}(F_2) \]  

(2)

\[ Y_{Q2} \] - Responses to the driving style questionnaire.

\[ F_2 \] - Vector of latent factors to assess driving behavior.

IVDR provides continuously recorded data on drivers’ actions while traveling. Variables recorded by the IVDR include the vehicle’s speed, position and two-dimensional accelerations. The data recorded may be analyzed in two modes: raw data of speed and acceleration profiles or predefined events, normally with two or three severity levels of driving behavior, such as speeding, fast accelerating, strong braking, etc. IVDR is a new available indicator for driving behavior and it is given in the model by:

\[ Y_{IVDR} = f_i(F_i) \]  

(3)

\[ Y_{IVDR} \] - Measurement of driving events.

Two additional indicators are drivers’ accident risk and operational costs. Accidents records include data on car accidents, injuries, severity and damage to the vehicle. Data can be collected as a self-report or provided by other authorities such as the police or fleet managers. Driving behavior may affect not only the risk of accident involvement but also the operational cost of the vehicle, such as fuel consumption and wear and tear:

\[ Y_R = f_R(R) \]  

(4)

\[ Y_C = f_C(C) \]  

(5)

\[ R \] - Risk expressed by accident costs.

\[ C \] - Operational costs.
As discussed above, a set of structural equations describes the behavioral process. The socio-demographic characteristics affect the attitudes and perception of a person towards driving. For example, age, sex or level of education may affect driver’s attitude towards driving. This connection is given in the model by:

\[ F_2 = g_B(D) \]  

(6)

\[ D \text{ - Socio-demographic characteristics.} \]

The following relation in the model is the affect of the driver's attitudes and perceptions on driving behavior considering the environmental conditions. As mentioned above, driving behavior is affected by the drivers' attitudes and perception. Yet, this is not the only factor affecting behavior. While driving, drivers are also affected by environmental conditions such as weather or light conditions.

\[ F_1 = g_B(F_2, E) \]  

(7)

\[ E \text{ - Environmental data.} \]

Accident risk and operational cost are the outcome of the driver behavior along with the environmental conditions. These two connections are given in the model by:

\[ R = g_R(F_1, E) \]  

(8)

\[ C = g_C(F_1, E) \]  

(9)

Once the sub-models described above have been estimated, the driving behavior model can be used to examine related questions, such as the impact of socio-economic characteristics and the potential of providing feedback from the IVDR to drivers to change their behavior.
**Experimental design**

In order to estimate the model we are conducting an experiment includes all sections of the modeling framework. The experiment is designed around installation of IVDR systems from one manufacture in several driving fleets in units of the Israeli Defense Forces. Detailed operational costs and drivers safety records for the period before and during the experiment are available through the fleets’ management officers. The experiment is planned to last six months and includes two phases. In the initial month, drivers are not exposed to the IVDR system and no feedback is provided to them. In the next five months, drivers are informed about the IVDR and get access to the information collected by the system. After the initial exposure, drivers receive periodical feedback about their driving behavior. In addition, drivers are asked to respond to two types of questionnaires: driver behavior questionnaire and attitudes and perceptions questionnaire. They will also be asked to report about their driving records and some socio-demographic information. The questionnaires will be handled to the drivers only after the initial exposure of the IVDR in order to avoid change in their behavior. Currently, we are at the end of the first month which drivers are not exposed to any feedback from the system. In these days, drivers will be asked to complete the questionnaires and will get access to the IVDR information and data. The fleet management and the research team are provided with periodically data from the manufacturer. These data will provide the measurements required to estimate a model based on the framework described in this paper.

**Summary**

This paper presents a definition of a general theoretical framing of driver behavior, including available measuring tools, which express the relations among the different factors of driving behavior. The research will help to identify the effects of driver
characteristics (e.g. age, gender), road and traffic conditions, attitudes and perceptions towards driving on driving behavior. It may be used to identify and classify drivers for purposes of training, monitoring, setting insurance rates etc. These models will improve our understanding of the characteristics associated with different patterns of driving behavior, will support the development of methods and tools to modify such behaviors and hopefully contribute to road safety.
References


