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JTS is an international multidisciplinary refereed journal the purpose of which is to present manuscripts that are linked to all aspects of transport, shipping business and related issues. Areas of interest include business, management and organizational studies, applied economics, finance, planning and forecasting, logistics, systems engineering, digital decision support systems, new technologies, law, geopolitics and geo-economics. The journal welcomes all points of view and perspectives and encourages original research or applied study in any of the areas listed above. The views expressed in this journal are the personal views of the authors and do not necessarily reflect the views of JTS.

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This issue is devoted to our beloved colleague Dimitris Petrogonas, who lost his life in a road traffic accident.
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EXPLORING TEENAGERS’ DRIVING AND TRANSPORT BEHAVIOR. CASE STUDY: A GREEK INSULAR AREA.

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Abstract. Teenagers are amongst the segment of the driving population with the highest accident rate. Improving our understanding of their driving and transport behavior, and developing methods and tools to modify and improve it, will contribute towards increasing their safety, and that of the whole population. This research aims to identify the factors that affect teenagers’ transport and driving behavior, especially in suburban/island areas. Teenagers’ culture and values, their perceptions and attitudes, daily travel behavior (to school and after school), socio-economic characteristics, and social networking are all examined. A case study of high school students’ driving and transport behavior was carried out on the island of Chios in Greece. Surveys were administered in 15 high schools in the city of Chios and in the suburbs in 2009. A sample of 214 high school students, aged between 12 and 18 years old, responded to the survey. The analysis of the collected data shows that the majority of the students performs simple tours from home to school in the morning and has more complicated activity chains in the afternoon. The majority of these relate to school and tutorial lessons. 58% of male and 33% of female students drive a motorcycle. Of these, 76% of the male and 84% of the female drivers are driving illegally, without the appropriate license. Moreover, boys from both rural and urban areas are found to exhibit more risky and careless driving behavior than girls. The findings of this research are discussed in relation to measures for increasing safety awareness and a change of culture among high school students.

Keywords: Teenagers, Transport Behavior, Driving Behavior, Transport to School, Safety, Illegal Driving

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1. INTRODUCTION

Road traffic accidents are one of the most common causes of death and permanent disability worldwide. Nearly 43,000 drivers and passengers are killed in traffic crashes in the European Union every year (ETSC, 2009). The majority of the people involved in car accidents are youths (ETSC, 2011; Hel. Stat., 2010). In particular, injuries suffered in motor vehicle accidents are the major cause of death and disability among adolescents and young adults (WHO, 2008).

Young people today are driving in a more complex traffic environment than ever before. There are more cars, there is more congestion, and there are more complex intersections and roadways. Additionally, it has been shown that, during the last few decades, drivers have become ruder, more aggressive, and more distracted when driving (Papakostas and Synodinos, 1988; Pelz and Schuman, 1971; Turnbull and Mackenzie, 1997; Shinar, 1998; Rizzo et al., 2001; Boyce and Geller, 2002; Stutts and Wilkins, 2003; Stutts, 1998; Al Balbiss, 2003; Yannis and Antoniou, 2007; Marshall et al., 2002; Deffenbacher, 2008). In spite of safer vehicles and roadways, driver behavior remains frustratingly far from ideal, and traffic enforcement alone will never be able to adequately control driver behavior. Novice drivers are influenced by the complexity of this environment as well as the many other factors in their lives (Shope et al., 2001; Shope, 2006).

Furthermore, teenagers represent a special group of drivers who have not yet fully developed their driving behavior. By investigating the factors that affect driving style and transport choice, training methods can be proposed that could improve, not only their driving behavior, but road safety as a whole. Moreover, the proposed methodology can be applied in other cities facing the same safety issues and concerns.

This research aims to study the factors that influence high school students’ transport and driving behavior, especially in suburban areas and islands, where social networks are closely bonded. In these areas, the loss of a loved one, especially a teenager, affects the lives of not only the family members but the whole community. A case study was carried out on the island of Chios in Greece. During recent years, Chios has seen a number of road accidents, the majority involving high school students. The need to reduce the accident rate has become imperative. Therefore, a series of initiatives have been instigated, aiming to change driving behavior by informing citizens, and especially teenagers, about road safety (Kamargianni, 2010a). The goal is for Chios to be the first Greek county with a high level of road safety awareness (Kamargianni, 2010b).

This paper consists of six sections. Section 2 presents a brief literature review of studies on teenagers’ driving and transport behavior. Section 3 develops an extended framework of high school students’ driving behavior. The framework specifically incorporates the effects of teenagers’ culture and values, their perceptions and attitudes, daily travel behavior, socio-economic characteristics, and social networking. Section 4 presents the case study conducted
on the island of Chios and Section 5 analyzes the results. Finally, Section 6 concludes the paper and proposes extensions for further research.

2. LITERATURE REVIEW

In developed countries, considerable attention is being directed at implementing countermeasures to reduce the high number of crashes involving young drivers. A growing body of research has examined the characteristics of teenage crashes and the factors contributing to teenagers’ higher propensity to be involved. Some of the factors identified as affecting teenagers’ driving and transport behavior are as follows:

1. gender (Chen et al., 2000; Preusser et al., 1998; Hennessy and Wiesenthal, 2001)
2. attitudes towards risk (Karlsson and Romelsjo, 1997; Dahlen et al., 2005; Esiyok et al., 2007; Sullman et al., 2007)
3. lack of driving experience (Shope, 2006)
4. lifestyle and alcohol use (Cohen et al., 2001; Simpson and Beirness, 1992; 1993)
5. parental restriction (McCatt et al., 2003; Grube and Nygaard, 2001; Simons-Morton, and Ouimet, 2006)
6. social interactions and peer pressure (Allen and Brown, 2008; Pileggi et al., 2006)
7. other personality characteristics such as hyperactivity disorder (Barkley et al., 1993)
8. residence area - rural residence / infrastructure (Abdel-Aty and Abdelwahab, 2000; Abdel-Aty and Essam Radwan, 2000).

Gender differences play an important role in determining driving practices. Eustace and Wei (2009), using FARS data for the three-year period 2001-2003, found that teenage male drivers, especially those between 16 and 18, were more likely to be responsible for the deaths of people other than themselves. The 16-year-old male drivers had the highest average vehicle occupancy of 2.2 passengers and the highest fatal involvement ratio. A study by Williams and Shabanova (2003), using the FARS 1996-2000 databases, found that young male drivers aged 16-22 years old had the highest rate of fatal crash involvement and the highest rate of deaths for which they were considered to be at fault across all licensed drivers. They also found that young males were more likely to be responsible for fatal crashes than young females. Young males are more likely to overestimate their driving ability (Gregersen and Bjurulf, 1996), and this overconfidence has been shown to be correlated with increased risk-taking behavior and involvement in accidents and violations (Elander et al., 2003; Insurance Institute for Highway Safety, 2000; Elliot et al., 2006).

Adolescent drivers tend to exhibit numerous risky behaviors, including speeding, which has been found to be significantly correlated with a greater risk of accidents (Elander et al., 2003). They are also more likely to follow the car in front too closely, perform unsafe acceleration, and make rapid lane changes (Jonah, 1990; Preusser et al., 1998; Simons-Morton et al., 2005). Simons-Morton et al. (2005), by recording the speed and headway of passing traffic using video and LIDAR technology close to 10 high schools, found that teenage drivers drove faster
than the general traffic and allowed shorter headways, particularly in the presence of a teenage male passenger. Young drivers and passengers have also been found to put themselves at a greater risk of injury in crashes by wearing safety belts less often than more mature drivers and passengers (Dellinger et al., 2004).

Lack of experience has been viewed as a major contributing factor in adolescent driving problems (Storie, 1977; Sarkar and Andreas, 2004; Shope, 2007). Teenagers’ perceptions of their own skills and those of the drivers around them contribute to their risky behavior. Furthermore, licensing a younger driver poses substantially more risk to other road users (Evans, 2000).

Lifestyle issues can be involved as well. Karlsson and Romelsjo (1997) found that early social and behavioral factors, including alcohol and other substance use, predicted men’s subsequent drunk-driving offenses. Begg et al. (1999) used injury-causing crashes, non-injury-causing crashes, and all crashes as separate outcome variables to study explanatory factors among 15- and 18-year-old youths. Several measures were found to be significant in predicting involvement in at least one type of crash: alcohol use, substance dependence, depression, having a motorcycle license, and low levels of family involvement.

Risky driving is found to be related to parenting. Hartos et al. (2002) examined relations between risky driving, parenting, and deviance, and the stability of risky driving over time. 261 licensed adolescents were interviewed by telephone about these three aspects and were then interviewed again about risky driving three months later. The results indicated that risky driving at the follow-up point was predicted by risky driving at the initial interview, by parental restrictions on driving, and by sensation-seeking behavior.

Other individuals who can influence young people’s driving are their peers. Gregersen and Bjurulf (1996) developed a model in which factors such as the attitudes of others were shown to influence driver behavior. Teenagers who socialize with others who display risky behaviors are more likely to engage in that type of behavior themselves (Allen and Brown, 2008; Pileggi et al., 2006). Shope et al. (2003) analyzed statewide driving data for 4,813 subjects. They concluded that those who are susceptible to peer pressure have more offenses and crashes. The driving behavior of one’s peers sets a norm that is an understandable influence on young drivers. Peer passengers can also influence young drivers’ behavior, as seen in the negative influence of a young male passenger on male drivers, and the moderating effect of a young female passenger on drivers of both genders (Simons-Morton et al., 2005).

Moreover, official driving records show that hyperactive teenagers receive more traffic citations and license suspensions than others. Barkley et al. (1993) conducted a driving survey of adolescents who had been clinically referred for hyperactive disorder (HD). The study found that teens with HD were more likely to have driven an automobile illegally prior to becoming eligible for a license, were more likely to have received repeat traffic citations, most notably for speeding, and were nearly four times more likely to have had an accident while driving than other teenagers.
Situational factors, such as living in a rural area, geographical location and family living arrangements, are also reported to affect driving behavior (O’Malley and Johnston, 1999; Poulin et al., 2006) but little is known about how environmental variables (e.g. living arrangements, residence and infrastructure) affect sensation seeking and driving behavior (Zakletskain et al., 2009). Abdel-Aty and Abdelwahab (2000), by analyzing the 1994 and 1995 Florida accident databases, found that place of residence plays an important role in driving behavior. By classifying residency as in-state (local and in-state drivers) and out-of-state (out-of-state and foreign drivers), they concluded that out-of-state young drivers experience higher percentages of alcohol/drug-related accidents than other younger drivers. In an other survey, Abdel-Aty and Essam Radwan (2000), using traffic and roadway data from the Roadway Characteristics Inventory (RCI) database for State Road 50 and a negative binomial modeling technique, found that heavy traffic volumes, narrow lanes, more lanes, urban roadway sections, narrow shoulders and a reduced median width all increase the likelihood of an accident. Clearly, more research is needed to define the relationships between place of residence and transport and driving behavior.

In the past, active transportation (e.g. walking or cycling) to school offered an important source of daily physical activity for youths. More recently, however, factors related to distance, safety, or the physical or social environment may have contributed to the proportion of children who now travel to school by motorized vehicle (Fulton et al., 2005). Fulton et al. (2005) used a sample of boys and girls aged 8 to 18 years old and found that, overall, 14% reported using active modes of transport to get to school, more frequently among boys (16.6%) than girls (11.1%), and among children in lower than upper grades.

The abovementioned factors are used in this paper to develop an extended framework of high school students’ driving behavior. Following this, the case study used to investigate the relationships described in the behavioral framework in small cities and suburban areas will be presented. Exploring factors such as attitudes and perceptions, licensing, past experience, parental behavior, social networking and demographics provides a better understanding of the causes of accidents involving teenagers and allows for the development and implementation of specific preventive measures.

3. BEHAVIORAL FRAMEWORK

The behavioral framework illustrated below in Figure 1 was inspired by the work of Ben-Akiva et al. (1999, 2002) and Litinas et al. (2010) on travel behavior modeling.

The exogenous variables affecting teenagers’ behavior fall into four categories:

1. personal characteristics, e.g. gender, age, schooling, grades, holding a license, years of driving experience, hyperactive disorder, etc.;

2. household characteristics, e.g. number of siblings, whether parents are divorced, raised by a single parent, number of cars, family income, social status, etc.;
3. residential location and corresponding transport infrastructure, e.g. road conditions, proximity to school, etc.;
4. safety-related policies and measures, police control and enforcement.

In the long run, teenagers’ behavior and decision making is formed by the general culture, lifestyle and values of the environment in which they live. Values reflect people’s ideals and ambitions and may include the desire for power or to take risks, as well as solidarity with friends and social groups (Giddens, 1989). In turn, these values determine the activities that are carried out, such as schooling, entertainment, sports, etc., and how they are carried out.

Two major categories of factors influence the lifestyle and activities of teenagers, especially with regards their choice of transport and their driving behavior:

1. information/awareness: may come from prior experience with accidents, word-of-mouth, advertisements and promotions for safe driving, etc.; and

2. social behavior patterns, which are influenced by two sources:
   • social network, such as the behavior of friends; and
   • parental guidance and restrictions.

These values in turn lead to the development of teenagers’ transport choices and driving behavior, through:

- beliefs, such as an overconfidence regarding driving skills, the perceived relationship between alcohol and driving, the importance of wearing safety belts and motorcycle helmets, etc.;
- attitudes, such as risk aversion, aggressiveness, or carelessness when driving; and
- preferences towards certain activities, such as the use of electronic devices (such as the internet, email etc.) and mode of transport (i.e. walking, cycling, or motorcycle).

This driving behavior can in turn lead to a greater or lesser occurrence of accidents. In a short time horizon, i.e. on a trip-by-trip basis, the probability of an accident occurring may be influenced by the following factors:

(1) driving environment, such as visibility, weather conditions, reliability of transport mode used, roadworks, familiarity with network, purpose of trip;

(2) destructive factors, such as a lack of concentration due to drowsiness, alcohol, or the use of other substances, the use of a cell phone, writing sms or emails while driving, eating, drinking, or smoking while driving, or the number of other teenage passengers in the car; and
(3) Other people’s errors: Drivers’ decisions are usually based on the natural feeling of being in “control” or the “illusion of control” (Makridakis, 2009), with no account given to the number of fatal road accidents that are caused by other peoples’ errors.

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**Figure 1: Behavioral framework**
Finally, the occurrence of a traffic accident may lead to post traumatic stress disorder (PTSD) (Butler et al., 1999). PTSD is the development of certain symptoms following direct or indirect exposure to a traumatic event in which one’s physical harm is threatened, or when one has witnessed another person being harmed. PTSD can also occur after the death of or serious injury to a loved one. It can be diagnosed at any age, and can occur as a sudden, short-term response (acute stress disorder) or develop gradually and become chronic or persistent. Patients with PTSD experience disabling memories and anxiety related to the traumatic event. They may feel stressed or frightened even when they are no longer in danger. Teenagers can have extreme reactions to trauma, but their symptoms may not be the same as adults’. They may develop disruptive, disrespectful or destructive behaviors leading to depression and reduced quality of life (Baranyi et al., 2010). Moreover, PTSD influences driving behavior as can be seen in Figure 1.

The proposed methodology can be applied in any country or city facing the same safety issues and concerns.

4. CASE STUDY: HIGH SCHOOL STUDENTS’ TRANSPORT & DRIVING BEHAVIOR AT THE ISLAND OF CHIOS

Road traffic accidents in Greece result in around 1,600 deaths, 2,000 severe injuries and 17,000 minor injuries per year (Hel. Stat., 2010). Young drivers aged between 16 and 28 years old are involved in the majority of these accidents. Teenagers (from 12 to 18 years old) are also involved in a significant proportion of traffic accidents. Figure 2 depicts the numbers of deaths and injuries from road accidents in Greece between 2000 and 2010.

![Road Traffic Accidents in Greece](image)

*Figure 2: Road traffic accidents in Greece, 2000-2010 (Traffic Police, 2010)*
Teenagers in Greece may obtain a driving license for a 50cc motorcycle at the age of 16. However, driving schools do not teach people in this license category, as Greek law only imposes a responsibility for educating drivers of over-125cc motorcycles, cars and vans. Therefore, teenagers tend to learn to drive motorcycles from their friends or family.

In order to better understand the factors affecting teenagers’ transport and driving behavior, a case study was carried out on the island of Chios in Greece. It is worth noting that Chios’ population is approximately 50,000, but this figure doubles during summer, as Chios is a tourist destination. Chios has about 3,000 high school students aged from 12 to 18 years old. It is the city with the third highest number of cars owned per person in Greece (429 per 1000) and has the highest ownership of motorcycles per person (265 per 1000) (Koutoura, 2009). Chios sees a significant number of traffic accidents, especially during summer, Christmas and Easter (Hel. Stat., 2010; Polydoropoulou and Litinas, 2010). Figure 3 shows the deaths and injuries between 2005 and 2009.

Due to the limited availability of public transport, citizens mainly use motorcycles and cars to get around. Teenagers in particular, and especially those from rural areas, tend to use their motorcycles to get to school or to take part in leisure activities, with the consent of their parents. Furthermore, in Greece, tutorial lessons after school are very common. The majority of students attend them and this increases the need for transportation.

Many of the accidents that occur involve teenagers and, although the total number of accidents is not extremely high, the post-accident effects, including PTSD, can extend to family members and bystanders (Voutierou, 2010).

5. DATA COLLECTION AND ANALYSIS

A questionnaire survey was designed to investigate the factors affecting teenagers’ transport and driving behavior. Self-reported, it was administered at 15 high schools on Chios. The data collection took place over two time horizons: March 2009 and November-December 2009. A
total of 350 high school students, aged between 12 and 18 years, responded to the survey. From this sample, 213 questionnaires were valid and used in our analysis. The researchers explained the purpose of the study and assured the adolescents in each class visited that their responses were confidential.

The questionnaire includes five sections. Section 1 asks about the high school students’ travel behavior and the activities and journeys they conduct in a typical day. Section 2 includes questions about their usual mode of transport, whether they hold a driving license, and at what age and how they learnt to drive. Section 3 looks at their attitudes and perceptions about driving and eco-driving. In Section 4, the teenagers are asked about their personal experiences of accidents, as drivers or passengers. The last part of the questionnaire looks at socio-economic (grades, pocket money) and household characteristics (parents’ education and employment, number of siblings, etc.). The data collection reveals the participants’ preferences and takes behavioral measurements based on attitudinal/perceptual indicators.

Table 1 presents the descriptive statistics of the high school students’ characteristics. Of the 213 participants, 98 were male and 115 female.

### Table 1: Personal characteristics

<table>
<thead>
<tr>
<th>Age</th>
<th>Males N=98 obs</th>
<th>Females N=115 obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-13</td>
<td>11%</td>
<td>10.5%</td>
</tr>
<tr>
<td>14-15</td>
<td>46.5%</td>
<td>47%</td>
</tr>
<tr>
<td>16-17</td>
<td>33.5%</td>
<td>36%</td>
</tr>
<tr>
<td>18</td>
<td>9%</td>
<td>6.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Males N=98 obs</th>
<th>Females N=115 obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>58%</td>
<td>33%</td>
</tr>
<tr>
<td>No</td>
<td>42%</td>
<td>67%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Licensed drivers</th>
<th>Males N=57 obs</th>
<th>Females N=38 obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>24.5%</td>
<td>16%</td>
</tr>
<tr>
<td>No</td>
<td>75.5%</td>
<td>84%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age when first time drove</th>
<th>Males N=57 obs</th>
<th>Females N=38 obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-9</td>
<td>10%</td>
<td>2.5%</td>
</tr>
<tr>
<td>10-12</td>
<td>32%</td>
<td>14%</td>
</tr>
<tr>
<td>13-15</td>
<td>58%</td>
<td>67.5%</td>
</tr>
<tr>
<td>16</td>
<td>0%</td>
<td>6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ages of unlicensed drivers</th>
<th>Males N=43 obs</th>
<th>Females N=33 obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-15</td>
<td>44%</td>
<td>32%</td>
</tr>
<tr>
<td>16-18</td>
<td>56%</td>
<td>68%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Males N=57 obs</th>
<th>Females N=38 obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycle &lt;=50cc</td>
<td>49%</td>
<td>51%</td>
</tr>
<tr>
<td>Motorcycle &gt;50cc</td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>Car</td>
<td>47%</td>
<td>53%</td>
</tr>
</tbody>
</table>

Table 2 presents the activities that the participants engage in. Boys in rural areas seem to have less free hours, both in a typical day and on weekends, than boys in the city, whereas girls in rural areas have more free time in a typical day than girls in the city. Graph 3 depicts the
frequencies with which different activities are carried out. The most frequent are tutorial lessons and going out for entertainment. These activities increase the need for transportation and, in combination with the limited public transport, lead many students (especially those from rural areas) to use private motor vehicles in order to get around.

Table 2: Type of activities engaged in

<table>
<thead>
<tr>
<th>Activities</th>
<th>City (N=82 obs.)</th>
<th>Rural Areas (N=131 obs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males (N=31 obs.)</td>
<td>Females (N=51 obs.)</td>
</tr>
<tr>
<td>Free Hours per Typical Day</td>
<td>4.48 hours</td>
<td>3.98 hours</td>
</tr>
<tr>
<td>Free Hours per Weekend</td>
<td>14.06 hours</td>
<td>13 hours</td>
</tr>
<tr>
<td>Tutorial Lessons</td>
<td>Yes</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0%</td>
</tr>
<tr>
<td>Sports</td>
<td>Yes</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>55%</td>
</tr>
<tr>
<td>Going out</td>
<td>Yes</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>39%</td>
</tr>
<tr>
<td>Watching TV</td>
<td>Yes</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>55%</td>
</tr>
<tr>
<td>Internet</td>
<td>Yes</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>55%</td>
</tr>
<tr>
<td>Playstation</td>
<td>Yes</td>
<td>32%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>68%</td>
</tr>
<tr>
<td>Reading books</td>
<td>Yes</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>97%</td>
</tr>
</tbody>
</table>

Table 3 shows the types of tours that students make in the city and in the rural areas of Chios. 68% of the trips that teenagers make in the mornings are simple, whereas in the afternoon the majority (53%) are combined trips. Once again, it can be ascertained that the majority of the trips are to get to tutorial lessons and for entertainment.

Figure 4 presents the tour types that teenagers conduct during the morning and the afternoon of a school day. In order to better understand the travel patterns the sample is divided in Non-Driver (these who either escorted or walk/cycle to their activities), Legal Drivers (teenagers who drive with holding the appropriate driving license) and Illegal Drivers (these who drive a motorized vehicle unlicensed). The majority of the students use to make simple trips in the morning, while combined in the afternoon. Drivers generally, either legal or illegal, use to make more combined trips in the afternoon than in the morning.
Table 3: Type of tours

<table>
<thead>
<tr>
<th>Tour types - Morning</th>
<th>City</th>
<th>Rural Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-School-Home</td>
<td>72%</td>
<td>64%</td>
</tr>
<tr>
<td>Home-School-Tutorial Lessons-Home</td>
<td>26%</td>
<td>31%</td>
</tr>
<tr>
<td>Home–School –Tutorial Lessons-Entertainment-Home</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>Home–School-Entertainment-Home</td>
<td>2%</td>
<td>2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tour types - Afternoon</th>
<th>City</th>
<th>Rural Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home-Tutorial Lessons-Home</td>
<td>48%</td>
<td>38%</td>
</tr>
<tr>
<td>Home-Tutorial Lessons–Entertainment-Home</td>
<td>23%</td>
<td>18%</td>
</tr>
<tr>
<td>Home-Entertainment-Home</td>
<td>22%</td>
<td>30%</td>
</tr>
<tr>
<td>Home-Entertainment-Tutorial lessons-Home</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Home-Tutorial Lessons-Sports-Home</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>Home-Work–Entertainment-Home</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Home-Sports-Home</td>
<td>0%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Table 4 shows the modes of transport used by the students to move around between their activities. These differ between the genders, between urban and rural residents and depending on the purpose of the trip. Boys both from city and rural areas use motorcycles more than girls, both for going to school and tutorial lessons and for going out for entertainment. On this point, it is also worth noting that the students generally use motorcycles over 50cc, which mean that they are driving illegally, as teenagers can only obtain licenses for 50cc motorcycles.
Table 4: Transport mode

<table>
<thead>
<tr>
<th></th>
<th>City Boys (N=31obs)</th>
<th>Rural Areas Boys (N=67obs)</th>
<th>City Girls (N=51 obs)</th>
<th>Rural Areas Girls (N=64obs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport to School</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle &lt;50cc (as driver)</td>
<td>8%</td>
<td>2%</td>
<td>7%</td>
<td>2%</td>
</tr>
<tr>
<td>Motorcycle &gt;50cc (as driver)</td>
<td>15%</td>
<td>6%</td>
<td>20%</td>
<td>3%</td>
</tr>
<tr>
<td>Bus</td>
<td>7%</td>
<td>20%</td>
<td>33%</td>
<td>47%</td>
</tr>
<tr>
<td>Walk</td>
<td>60%</td>
<td>43%</td>
<td>25%</td>
<td>29%</td>
</tr>
<tr>
<td>Passenger in car</td>
<td>10%</td>
<td>29%</td>
<td>15%</td>
<td>19%</td>
</tr>
<tr>
<td><strong>Transport to Tutorial Lessons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle &lt;50cc (as driver)</td>
<td>6%</td>
<td>8%</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>Motorcycle &gt;50cc (as driver)</td>
<td>16%</td>
<td>16%</td>
<td>19%</td>
<td>6%</td>
</tr>
<tr>
<td>Bus</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Walk</td>
<td>62%</td>
<td>49%</td>
<td>24%</td>
<td>30%</td>
</tr>
<tr>
<td>Passenger in car</td>
<td>16%</td>
<td>27%</td>
<td>45%</td>
<td>51%</td>
</tr>
<tr>
<td><strong>Transport to Entertainment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motorcycle &lt;50cc (as driver)</td>
<td>10%</td>
<td>6%</td>
<td>12%</td>
<td>3%</td>
</tr>
<tr>
<td>Motorcycle &gt;50cc (as driver)</td>
<td>22%</td>
<td>12%</td>
<td>28%</td>
<td>8%</td>
</tr>
<tr>
<td>Bus</td>
<td>0%</td>
<td>2%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Walk</td>
<td>58%</td>
<td>43%</td>
<td>28%</td>
<td>22%</td>
</tr>
<tr>
<td>Passenger in car</td>
<td>10%</td>
<td>37%</td>
<td>31%</td>
<td>67%</td>
</tr>
</tbody>
</table>

Table 5 presents the social behavior factors, in particular relating to parental guidance and restrictions. A five-point scale is used, where 1=completely disagree and 5=completely agree. The students seem to have good relationships with their parents (4.4/5.0 for males, 4.4/5.0 for females) and neither boys nor girls seem to disagree much with their parents on the subject of buying a motorcycle. On the other hand, parents allow boys to drive motorcycles (3.8/5.0) more than girls (2.9/5.0) and also trust boys to drive (4.1/5.0) more than they do girls (3.7/5.0). They also worry more about female drivers (3.9/5.0) than male drivers (3.3/5.0).

Table 5: Social behavior affects

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>My relationship with my parents is good</td>
<td>4.4</td>
<td>.8</td>
</tr>
<tr>
<td>I spend a lot of time with my parents</td>
<td>3.6</td>
<td>.9</td>
</tr>
<tr>
<td>I have disagreements with my parents about buying a motorcycle</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>I have disagreements with my parents about buying a car</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>My relatives influence my decisions</td>
<td>2.8</td>
<td>1.1</td>
</tr>
<tr>
<td>My parents allow me to have my own motorbike</td>
<td>3.8</td>
<td>1.3</td>
</tr>
<tr>
<td>My parents allow me to have my own car</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>My parents allow me to drive without a license</td>
<td>3.0</td>
<td>1.3</td>
</tr>
<tr>
<td>I drive without a license</td>
<td>3.4</td>
<td>1.5</td>
</tr>
<tr>
<td>My parents trust me to drive</td>
<td>4.1</td>
<td>1.1</td>
</tr>
<tr>
<td>My parents worry when I drive</td>
<td>3.3</td>
<td>1.5</td>
</tr>
</tbody>
</table>
The teenagers’ attitudes and driving behavior are presented in Table 6. A five-point Likert scale is used, where 1=never and 5=always. Boys wear helmets more than girls do (3.2/5.0 for males and 2.8/5.0 for females). Girls seem to be slightly more courteous than boys, as they say they often slow down to allow children and pedestrians to cross the road. However, boys report that they are more courteous towards other drivers (2.8/5.0 for boys, 2.6/5.0 for girls). The boys seem to take more risks when they drive (2.5/5.0) than the girls do (1.8/5.0). The boys also report themselves as more careless drivers (2.1/5.0) than the girls do (1.6/5.0).

**Table 6: Driving behavior**

<table>
<thead>
<tr>
<th>5-point scale: 1 =&gt;Never, . . ., 5=&gt; Always</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>I use a helmet</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>1.3</td>
</tr>
<tr>
<td>I use a seat belt</td>
<td>3.4</td>
<td>1.6</td>
</tr>
<tr>
<td>When I see children crossing the road, I slow down</td>
<td>4.2</td>
<td>1.2</td>
</tr>
<tr>
<td>When I see someone at the side of the road when it’s raining, I slow down</td>
<td>3.6</td>
<td>1.1</td>
</tr>
<tr>
<td>I stop at pedestrian crossings</td>
<td>3.8</td>
<td>1.2</td>
</tr>
<tr>
<td>I drive at high speed</td>
<td>3.1</td>
<td>1.0</td>
</tr>
<tr>
<td>I yield for other drivers to pass</td>
<td>2.8</td>
<td>1.0</td>
</tr>
<tr>
<td>When I drive I take risks</td>
<td>2.5</td>
<td>1.4</td>
</tr>
<tr>
<td>I am aggressive when I drive</td>
<td>2.7</td>
<td>1.2</td>
</tr>
<tr>
<td>I shout to other drivers</td>
<td>2.2</td>
<td>1.2</td>
</tr>
<tr>
<td>I drive when I am drunk</td>
<td>1.7</td>
<td>1.1</td>
</tr>
<tr>
<td>I drive only when I feel I am in a good physical condition</td>
<td>4.0</td>
<td>1.2</td>
</tr>
<tr>
<td>I drive carelessly</td>
<td>2.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Table 7 presents the results relating to the participants’ prior experience with accidents. About one third of both the male and female participants had been involved in a traffic accident. The majority of these accidents had occurred on. The teenagers do not seem to have been affected psychologically by the accident (2.04 for males and 2.29 for females). Moreover, the majority of the participants observed that a peer had been in a traffic accident, while a fairly high proportion stated that their parents had been in one.

**Table 7: Experience of traffic accident**

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>I have had a traffic accident</td>
<td>Yes</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>61%</td>
</tr>
<tr>
<td>Mode of transport being used when the accident happened</td>
<td>Motorcycle</td>
<td>72%</td>
</tr>
<tr>
<td></td>
<td>Car</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Pedestrian</td>
<td>25%</td>
</tr>
<tr>
<td>The accident has affected me psychologically (5-point scale: 1=not at all, . . ., 5=extremely)</td>
<td>Mean</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>1.2</td>
</tr>
<tr>
<td>A peer of mine has had a traffic accident</td>
<td>Yes</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>20%</td>
</tr>
<tr>
<td>My parents have had a traffic accident</td>
<td>Yes</td>
<td>49%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>51%</td>
</tr>
</tbody>
</table>
6. CONCLUSIONS AND FURTHER RESEARCH

This paper presents an innovative behavioral framework of high school students’ driving behavior. This framework borrows insights from travel behavior modeling, as well as from the fields of sociology and psychology and applies them to driving behavior. A case study was used to collect data for the model.

It should be noted that most – if not all – high school students in Greece attend private tutorial lessons on a daily basis, usually after school. This creates a need for transport for this educational activity during the afternoon. Not all parents are able to drive their children themselves, while public transport in the afternoon is basically non-existent. This means that parents tend to allow their children to own/use motorcycles in order to attend tutorial lessons or other activities, sometimes even without a driving license.

The analysis of the data collected in Chios provided the following findings:

1. Boys versus girls
   - The majority of the activities that both boys and girls are involved in are related to school and tutorial lessons. This increases the need for transportation.
   - A significant proportion of both boys and girls use motorcycles to commute and the majority of these drivers are unlicensed (illegal drivers).
   - 10% of the male students drove for the first time between the ages of 7 and 9 years old.

2. City versus rural areas
   - The students’ activities are quite similar in the city and rural areas, concerning schooling and going out for entertainment.
• Male students from rural areas are more likely than those from urban areas to drive motorcycles that are under 50cc.

• On the other hand, girls from urban areas are more likely to drive unlicensed than girls from rural areas.

• Rural residence increases the need to use a motor vehicle in order to carry out regular activities.

The findings of this research demonstrate that there is a need to increase high school students’ safety awareness. It is apparent that the social view of driving and the overall culture need to be modified. Special advertising campaigns addressing teenagers should be implemented, along with other activities aimed at encouraging teenagers to walk to school and so reduce their use of motor vehicles. In addition, public transport services should be improved and expand their timetable and network of coverage. A discount student card for public transport modes would also favor the usage of public transport.

It is also apparent that the police enforcement needs to be increased. Police controls should be made stricter in order to deter unlicensed/illegal drivers and unsafe driving behavior in order to reduce the number of road traffic accidents.

Future research will need to include the development of factor analysis. Based on the data collected regarding attitudes and perceptions, socio-economic characteristics, driving reactions, past experience and types of daily journeys, further research will model teenagers’ transport and driving behavior more fully. This will support the development of methods and tools to modify such behaviors and properly train teenage drivers, thus contributing to road safety.

Acknowledgements
The authors would like to thank Ms. E. Voutierou from the Sectoral Committee of Mental Health of Chios, and Mrs. D. Kalogeraki from the Direction of Secondary Education of Chios for their instrumental support in the conducting of this research, as well as students from the Department of Shipping, Trade, and Transport, Mrs. A. Boi and Ms. A. Mari, for their assistance with the data collection.

REFERENCES


PEDESTRIAN ROAD SAFETY WITHIN THE ISRAELI ARAB MINORITY SECTOR AND WITHIN THE GENERAL POPULATION OF JORDAN

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1Department of Civil and Environmental Engineering, Technion, Haifa, Israel

Abstract. This study analyses and compares child pedestrian road crashes within the Israeli Arab minority and within the general population of Jordan. In both communities children are exposed to high level of pedestrian crash risks. The objectives of this study are firstly to identify both common and contrasting pedestrian road crash characteristics between the two communities: the Israeli Arab minority and the general population in Jordan; secondly, to demonstrate the relationship between the exposure to traffic and pedestrian road crash risks, thirdly, to examine the relationship between the demographic and socio-economic characteristics related to the risk of pedestrian road crash involvement. The methodology of this study is based on descriptive statistics comparing the Jordanian and Israeli Arab pedestrian road crashes using data collected from various resources in Israel and Jordan: the Central Bureaus of Statistics, police files and a household survey which includes trip diaries. The comparison between Israel and Jordan includes many variables including: road accident rate and severity, accident causes, road and traffic conditions at the accident location, driver age, gender and experience. Additionally, the socio-economic characteristics and daily activity patterns of the drivers and pedestrians involved in traffic accidents were analysed. At the last stage, based upon the diary, a risk index was developed for evaluating the risk of being injured in pedestrian road crashes per walking time and per number of trips. The results of the study show that there is some similarity among the various characteristics of pedestrian road crashes within the two communities, such as age group, gender, day of week, time of day, speed and pedestrian behavior. Nevertheless, the road safety situation in Jordan is more severe than among Israeli Arabs. Additionally, the findings indicate that despite the fact that the Arab children in Israel take more trips by foot and walk longer than their Jordanian counterparts; the Jordanian children are at higher risk of being injured in pedestrian road crashes. In summation, pedestrian road safety is of major concern in Jordan and within the Israeli Arab minority, and a great deal of effort is needed to effect an enhanced traffic safety situation in both countries.

Keywords: Pedestrian, Road Crashes, Socio-economic Characteristics, Exposure Risk, Arab Communities

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1. INTRODUCTION

Child pedestrian injury and fatality in road crashes is an overall world concern and a major public health burden (Mabunda et al., 2008). Pedestrian-vehicle crashes are responsible for more than a third of all traffic-related fatalities and injuries worldwide (Crandall et al., 2002; Serre et al., 2010). This percentage is about 15% in Europe and 11% in France (ONISR, 2005; Serre et al., 2010).

Among these pedestrian injuries, most concern elderly people over 70 years of age and children less than 15 years of age (Berg et al., 2000; Fontaine and Gourlet, 1997). If adults run a high risk of severe injury and mortality, children run an even greater one, as noted by Henary et al. (2003), and pedestrian road crashes are the second greatest causes of child mortality (Peden et al., 2004).

A large body of literature has attempted to examine the involvement of ethnic minority children in pedestrian road crashes and has showed that they have a higher level of involvement in road crashes than does the general population (Voas and Fisher, 2000; Harper et al., 2000; Race, 1998; Lawson and Edwards, 1991; Campos et al., 2002). For example, in the United Kingdom, child pedestrians of Asian origin aged 0-4 and 5-9 were found to be twice as likely to be injured as were their non-Asian counterparts (Lawson and Edwards, 1991), and in Arizona, Native Americans aged ten had pedestrian death rates 6-13 times higher than those of non-Hispanic whites (Campos-Outcalt et al., 2002).

In addition, in developing countries suffering from a low socio-economic level, children under 10 years of age are at a high risk of being injured and killed in pedestrian road crashes (Graham and Stephens, 2008; Mabunda et al., 2008; Christie, et al., 2007). Thus, child pedestrian injury in road crashes appears to be positively associated with socio-economic deprivation (Graham and Stephens, 2008). The situation is not so different in Arab developing countries in which children below age 10 are exposed to the highest level of pedestrian road crashes risk (Al-Masaeied, 2009; Al-Ghamdi, 2001; Jadaan and Bener, 1993; Al-Balbissi, 1990). In Riyadh, the capital of Saudi Arabia, children as well as the elderly are more likely to be involved in fatal pedestrian road crashes, and 77% of pedestrians involved in road crashes were probably struck while crossing a roadway while either not being in a crosswalk or where no crosswalk existed (Al-Ghamdi, 2001). Furthermore, in the Gulf countries, Saudi Arabia, Kuwait and United Arab Emirates, young pedestrians were found to be particularly at risk accounting for 40% of total pedestrian fatalities (Jadaan and Bener, 1993). In Libya, road traffic accidents are the number one killer, and young children are knocked down by speeding drivers during school hours (Abdulhmajid, 2007).

Although Jordan and Israel are dissimilar in terms of transport systems as well as economic structure, culture and social practices and behavior, the Israeli Arab minority is similar to the Jordanian population. Both communities (Jordanian and Israeli Arabs) have a similar culture, language and religions, and pedestrian safety poses many similar problems and challenges in
both communities. Among the Israeli Arab minority, pedestrian fatalities account for about 30% of all road crash fatalities, while children aged 0-14 account for 60% of the total pedestrian fatalities - eight times higher than for Jewish children (Shiftan and Elias, 2011). In Jordan, children are exposed to the highest level of pedestrian accident risk, and forty percent of all traffic fatalities involve pedestrians - half of them among children under the age of 15 (Shbeeb and Salim, 2003). This high rate of pedestrian road crashes and the similarity between the Israeli Arab minority and Jordanian society make Jordan a unique country for comparison with the Arab minority in Israel.

Generally, children belonged to age group of 5-10 years are considered a high risk pedestrian group (Fontaine and Gourlet, 1997; Hotz et al., 2004; Pitt et al., 1990; Elias et al, 2010). This may be due to their small physical stature and their undeveloped abilities for dealing with traffic situations (Serre et al., 2010; Gibby and Ferrara, 2001). Children have problems perceiving direction of moving traffic, locating signs and judging speed (Cross and Hall, 2005; Fontaine and Gourlet, 1997; Schieber and Veggia, 2002).

However, these child factors are common among all children and thus the differences in child pedestrian involvement in road crashes could derive from the gap in child awareness and knowledge of risky behavior on roadways while walking as well as their exposure to traffic (Barton and Barbara, 2011). Pucher and Renne (2003) pointed that walking rates are highest among lower socio-economic people, and in developing countries almost 40-60 percent of the trips are made by walking (Sayer and Downing, 1996; Gharaybeh, 1994). On the other hand, survey data from European countries has shown that only15-25% of all trips are made by walking (Ekman et al., 1999). Furthermore, in many developing countries child pedestrians and their parents have poor knowledge on safety behavior in traffic. For example, the majority of pedestrians in developing countries did not use Crosswalks when crossing roads. At the same time drivers do not respect pedestrians’ rights, and fewer than 20 percent of drivers stopped for pedestrians in the road in developing countries, whereas more than 70 percent stopped in Northern European countries (TRL, 1997).

Therefore, it is easy to say that a better education for children is necessary (MacGregor et al., 1999). However, improving child behavior is not sufficient without changing driver behavior, in addition to improving urban planning and transportation. Many studies in Israel (Elias et al., 2010; 2011;Getilman, 2004) and Jordan (Suliman and Awad, 2003; Al-Masaeid, 2004; 2009) have pointed to the low level of urban planning and transportation such as very narrow roads, lack of enforcement, and the absence of shoulders, pedestrian crossing, traffic signs and parking facilities. Additionally, they indicate a paucity of public parks and open spaces for children and the absence of social activities and. As a result, the roads become a place for play and social gathering (Elias et al., 2010; Al-Balbissi, 1990; Al-Masaeied, 2009). Suliman and Awad (2003) show that improper engineering design, inadequate traffic control, lack of traffic management, and traffic congestion are the main factors leading to aggressive driving and road rage on Jordanian roadways.
The objectives of this study are firstly, to identify both common and contrasting pedestrian road crash characteristics between two communities: the Israeli Arab minority and the general population in Jordan; secondly, to demonstrate the relationship between the exposure to traffic and pedestrian road crash risks, thirdly, to examine the relationship between the demographic and socio-economic characteristics related to the risk of pedestrian road crash involvement. This comparison will provide deeper insights into how travel behavior and socio-economic characteristics, which indicate in many cases, the inequity in the investment distribution among different groups in society, affect child involvement in pedestrian road crashes. In addition, this research will examine the impact of the physical environment on child exposure risk to pedestrian road crashes.

This paper is organized as follows: the following section presents the methodology including the employed data; Section Three presents the background for the case studies; Section Four discusses the various results, and the final section offers conclusions.

2. METHODOLOGY

The methodology of this study is based on descriptive statistics comparing the Jordanian and Israeli Arab pedestrian road crashes based on data collected from various resources in Israel and Jordan: the Central Bureaus of Statistics, police files and a household survey which includes trip diaries. This comparison is presented at two levels: the first is a comparison between the entire Israeli Arab population and the general population in Jordan. Based on CBS, this comparison includes many variables, among which are pedestrian road crash rate and severity, accident causes, road and traffic conditions at the accident location, age group of pedestrians involved in road crashes and gender. The second is based on collecting data by means of a household survey, which includes trip diaries for three case studies from communities in both countries (Shefaram and Majd-Alcrum are both Arab Israeli towns and Husn is a Jordanian city). The survey was conducted in 2008, and encompassed 480 randomly selected households, 200 in Jordan and 280 in Israel. Travel diaries were completed for each household member over age five for the day preceding the visit. The survey provided socio-economic characteristics and travel patterns (number of trips, mode, purpose, destination, land use, departure and arrival times) and involvement in road crashes. At the last stage, based upon the diary, a risk index was developed for evaluating the risk of being injured in pedestrian road crashes per walking time and number of trips.

The resulting sample consisted of 753 and 837 individuals in Jordan and Israel, respectively; 52.5% of the Jordanian sample and 51.0% of the Israeli sample are males, the average age being 30.9 (s.d=16.22) and 33.0 (s.d=18.9) in the Jordanian and Israeli samples, respectively. The Jordanian sample consists of 169 children aged 6 to 14 and the Israel sample 181 children.
3. BACKGROUND

Israel has an area of 22,072 km$^2$, roughly the size of New Jersey. The state is populated primarily by Jews and Arabs, both groups being non-assimilating (Yiftachel, 1996). As of 2007, 1.4 million people or 20 percent of the Israeli population was Arab. This community is primarily Moslem (82.9 percent), but includes prominent Christian (8.6 percent) and Druze (8.3 percent) minorities (Statistical Abstract of Israel, 2007). The Druze are a religious community of between a half a million and a million adherents living within Syria, Lebanon, Israel, and Jordan. They trace the origins of their beliefs to Islam, but have been a distinct community for almost a millennium.

These three religious communities have distinct socio-economic characteristics. Christians most resemble Jewish Israelis in their levels of education and household size, and are the highest earning Arab group; however, on average, Arab Christian Israeli wage rates are only 86.3 percent of those of Jewish Israelis. In contrast, Moslems and Druze report lower levels of education and larger household sizes than Christians. Interestingly, despite very similar levels of education among Moslems and Druze, the latter earn far larger salaries than Moslems. Arab Israelis account for the majority of the population in the Galilee region of the country, which contains the two surveyed cities, Shefaram and Majd-Alcrum. Yiftachel (1996) notes that Israeli planning policy has viewed this area as an “internal frontier” and has sought to constrain the spatial and economic growth of the Arab villages located in this region. As a result, these towns do not enjoy the same level of development as Israel as a whole. One example of this is the virtual absence of public transit service in Arab towns (Elias et al., 2008). This research postulates that the economic disadvantage in the Galilee contributes to the high rate of road crashes and aggressive driving behavior.

Jordan, with an area of 90 thousand sq. km, has a population of about 5.8 million people. More than 92 percent of the population is Sunni Muslim. Official government figures estimate that Christians make up 6 percent of the population; there are between twelve and fourteen thousand Druze, a small number of Shi’a Muslims, and approximately one thousand Bahá’ís.

The population distribution in Jordan is affected by a variety of factors, among which are reciprocal migration streams and socio-economic development regional disparities. About two-fifth of the total population (37 percent) lives in the Amman Governorate alone, followed by the Irbid and Zarqa governorates (18.4 percent and 14.8 percent respectively). Irbid contains the surveyed city, Husn.

During the past few years in particular, the number of registered vehicles and registered drivers in Jordan and among Israeli Arabs has considerably increased (Israeli CBS, 2004; 2009, Al-Masaeeid, 2009). Among Israeli Arabs from 2004 to 2008, the number of registered drivers increased about 22%, compared with 8% for the Jewish community. As a result, traffic volumes and Vehicle Miles of Travel (VMT) have significantly increased, leading to deteriorating traffic flow and escalating traffic congestion and jams. Consequently, the number
of traffic accidents has also noticeably increased in Jordan and among Israeli Arabs in the past decade.

Shefaram and Husn are medium-size cities, whose populations are 33,600 and 20,000, respectively, while Majd-Alcrum is a small town, whose population is 12,700. The three communities share distinct socio-economic characteristics - in particular, low socio-economic status, large household size, and high growth rates. Majd-Alcrum is entirely Moslem while Shefaram is mixed with a Muslim majority (58.8%), a significant Christian community (27.0%), and a Druze minority (14.4%). Table 1 shows that the income level among the Israeli Arab communities is higher than that of Jordan. In Shefaram and Majd-Alcrum, the income of 56.0% of the households is above the average, while in Husn only 22% of the households have incomes above the average. In addition, the average number of cars in Shefaram and Majd-Alcrum is 1.12, compared to 0.82 in Husn.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Jordan</th>
<th>Israeli Arabs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>5,723,000</td>
<td>1,468,800</td>
</tr>
<tr>
<td>Population growth rate</td>
<td>2.8</td>
<td>Moslems=2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Christians=1.3</td>
</tr>
<tr>
<td>Household size</td>
<td>6.1</td>
<td>5.04</td>
</tr>
<tr>
<td>Motorization rate*</td>
<td>147 per 1000 vehicles</td>
<td>187 per 1000 vehicles</td>
</tr>
<tr>
<td>Income*</td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Below the average**</td>
<td>54.0%</td>
<td>30.6%</td>
</tr>
<tr>
<td>About the average</td>
<td>24%</td>
<td>13.4%</td>
</tr>
<tr>
<td>Above the average</td>
<td>22.0%</td>
<td>56.0%</td>
</tr>
<tr>
<td>Average number of cars in the household</td>
<td>0.82</td>
<td>1.12</td>
</tr>
</tbody>
</table>

*Based on the study survey  
** The average income in Israel is 8300 NIS and in Jordan is 500 Dinar

4. RESULTS AND DISCUSSION

4.1 Trends and characteristics of pedestrian road crashes

Figure 1 shows the fatality rate (number of fatalities per 100,000) in Jordan and Israel (only Israeli Arabs; henceforth, for Israel, the paper only refers to Israeli Arabs). As shown in the figure, there have been significant increases in the fatality rate over the years in Jordan and the traffic fatality growth supersedes population growth; the fatality rate shows an upward trend from 2001 to 2007 (5182.0 thousand in 2001 to 5723.0 thousand in 2007). In contrast, the fatality rate in Israel indicates a downward trend, which is similar to the trends in various developed countries (Jorgesen, 2002; Jacobs et al., 2000). Furthermore, throughout this period, the fatality rate in Jordan was higher than that in Israel. The injury rate per 100,000 in both Jordan and Israel shows a slight downward trend; however, throughout this period, the injury rate among Israeli Arabs was higher than among Jordanians (Figure 2).
Figure 1: Fatalities trend in Jordan and among Israeli Arabs

Figure 2: Injury trend in Jordan and among Israeli Arabs

Figure 3 shows the pedestrian casualty rate per 100,000. The pedestrian casualty rate in both Jordan and Israel indicates a downward trend, but the rate in Jordan is twice that of Israel throughout this period (data for Jordan which refers to pedestrian casualties were available only from 2004).
Figure 3: Pedestrian casualty rates by year

Figure 4 shows pedestrian fatality rate per 100,000 between 2001 and 2008. As shown in the figure, there is a downward trend in pedestrian fatality in both Jordan and Israel, while in Jordan, if one discounts the year 2008, the rate is stable, and even a slight upward trend is observed. Throughout the years, though, the rate in Jordan has been higher than that in Israel. Nevertheless, comparing the rates of severe injury per 100,000 as shown in Figure 5, there is a slight decreasing trend in Jordan, whereas in Israel the decline is significant.
Evaluating the percentage of fatalities and high severity injuries by mode within each community shows that in Jordan, the highest percentages of the total number of fatalities were among pedestrian road users (Figure 6). About 36% (more than one third) of the total number of fatalities was actually among pedestrians, and 33% (about third) of the total number of high-severity injuries also involved pedestrians. In contrast, Israeli Arab pedestrian fatalities accounts for the second highest percentage of the total number of fatalities. About 28% of the total number of fatalities involved pedestrians, and 29% of the total number of high-severity injuries also involved pedestrians (Figure 7). In comparing the distribution of fatalities and severe injuries by mode, significant differences were found between the Israeli Arabs and the Jordanians. Despite the fact that pedestrian accidents constitute about 5% of all traffic accidents in both Israel and Jordan, they resulted in about third of the total traffic fatalities and severe injuries. The corresponding percentages for pedestrian fatalities in Europe and USA were 20% and 11%, respectively (Jacobs et al., 2000; NHTSA, 2007). This result is not unexpected since pedestrians are not given sufficient consideration in transport and urban planning (Al-Masaeid, 2009). For example, Al-Masaeied et al. (1994) pointed out that many rural towns were developed along and on both sides of major Jordanian roads without any advanced planning. Furthermore, many schools were located adjacent to main roads. This situation creates hazards to local and through traffic as well as to residents. The situation in the Jordanian town is not much different from that in the Israeli Arab towns and the transportation system and urban planning do not take pedestrian needs and safety into consideration (Elias et al., 2010; Gitelman and Dayan, 2003).
Figure 6: Distribution of fatalities by road users in 2007
(Pearson Chi-square P= 0.001, statistically significant)

Figure 7: Distribution of severe injuries by road users in 2007
(Pearson Chi-square P= 0.000, statistically significant)

Figure 8 shows the distribution of the total number of pedestrian fatalities by age group. There are significant differences between the distribution of pedestrian fatalities in road crashes by age group in Jordan and in Israel. In Israel, children under the age of 9 comprise 52% of the total number of pedestrian fatalities, while in Jordan the figure is 30%. This difference may be derived from the difference in the independency of these children in walking back and forth to school and playing outside, and consequently are more exposed to the traffic due to the high motorization rate - which is higher in Israel than in Jordan. Based on the study survey, the average number of cars in Israeli Arab households is 1.12 while it is only 0.82 in Jordan. In addition, 55% of the total number of trips to school taken by Israeli Arab children under the...
age 9 is by foot, while only 14% of the trips to school taken by Jordanian children are by foot. In contrast, 57% of the trips taken by Jordanian children under the age 9 are by bus (school bus) compared to 8 percent for the Israeli Arab children. In Jordan, however, the percentage of pedestrian fatalities between 9-17 years of age is about 5.5 times more than the percentage for the same age group in Israel. The situation is similar concerning the percentage of pedestrian seriously injured in road crashes (Figure 9). In a comparison of the distribution of severe pedestrian injuries by age group, significant differences were found between the Israeli Arabs and the Jordanians. Israeli Arab children under the age of nine comprise 48% of the total number of seriously injured pedestrians, while in Jordan the same age group comprises 37%. In contrast, Jordanian children, aged 9-17, are at the highest risk of being seriously injured in pedestrian road crashes, which is about twice the percentage for the same age group in Israel. Though about 23% of the population is under the age of nine, this group accounted for nearly 50% of all traffic fatalities in Israel and 30% in Jordan. In addition, about 12% of the population is over 53 years of age; this group accounted for nearly 15% and 21% of all traffic fatalities in Israel and Jordan respectively.

In summary, in both the Jordanian and Israeli Arab communities, about half and more than half, respectively, of the pedestrian fatalities and serious casualties were under the age of 18, while the corresponding worldwide percentage is only 30% (Toroyan and Peden, 2007) and the corresponding Israeli Jewish percentage is less than 25% (Shiftan and Elias, 2011).

Figure 8: Distribution of pedestrian fatalities by age group
(Pearson Chi-square P= 0.008, statistically significant)
This study also examines the distribution of pedestrian road crashes by day of the week, time of day and by the speed limit of the roadway on which the pedestrian road crash took place. By comparing the distribution of pedestrian casualties and fatalities by day of week (Figure 10), insignificant differences were found. In Jordan it was noticed that the maximum number of pedestrian fatalities took place on Fridays and Thursdays, while among Israeli Arabs, the maximum number of pedestrian fatalities occurred on Fridays and Tuesdays. In both Jordan and Israel, Friday is a vacation day; therefore, on the one hand, it might be that people, especially children, are more exposed to traffic seeing that there is a need to play or participate in various leisure activities by foot. On the other hand, Thursday is the last day of the week and the last weekly business or school day; thus children rush home to engage in activities and enjoy their leisure time. Yet there is no explanation for the high percentage of Israeli Arab pedestrian fatalities on Tuesdays (Figure 10).
Figure 11: Distribution of pedestrian severe injuries by day of week
(Pearson Chi-square $P= 0.412$, statistically insignificant)

Figure 12 shows the distribution of pedestrian casualties by time of day. As can be seen, most of the casualties occurred between 12:00 and 8:00 pm. In Israel, the maximum shares are between 1:00 and 2:00 PM and between 3:00 and 4:00 PM (8.7 percent) and between 7:00 and 8:00 PM, while in Jordan it is between 1:00 and 2:00 PM (8.9 percent) and between 4:00 and 5:00 PM. Actually, the time period between 1:00 pm and 2:00 PM is considered a hectic rush hour for both Jordanians and Israeli Arabs, since this time period includes the closing time for businesses, private companies, establishments and agencies, among others. Moreover, government and private schools release their charges in most grades at 2:00 PM.

Figure 12: Distribution of pedestrian casualties by time of day
(Pearson Chi-square $P= 0.064$, statistically insignificant at 0.05 level)
Not surprisingly, most pedestrian road crashes occurred on roads having a speed limit of 50 km/h or lower. Approximately 86% and 70% of the Jordanian and Israeli Arab pedestrians were injured on such roads, and 1.6% and 23% injured on roads with speed limits of 60 km/h respectively (Figure 13). Speed limit cannot be correlated to road crashes without taking into consideration further factors such as geometric design, traffic volume, land use and the extent of pedestrian exhibition. Generally speaking, these roads (with speed limits below 60 km/h) probably reflect urban surroundings where most people are, and go on foot. Therefore, the results reflect exposure more than speed limit and, relative to the extent of exposure, the risk of being seriously injured or killed per collision is higher at higher speeds.

![Figure 13: Distribution of pedestrian casualties by speed limit](image)

Examining road crash casualties by gender shows that 80% and 85% of the fatalities in road crashes are male in Jordan and Israel respectively. In addition, men comprise 80% and 77% of the total number of severe injuries in Jordan and Israel, respectively. In Jordan, girls aged under 15 compose about 40% of the total number of female road crash fatalities, while the percentage of boys in the same age group is half that of the girls. Similarly, among Israeli Arabs, girls under 15 comprise about 29% of the total number of female road crash fatalities, which is half of that for boys. However, percentages in both Jordan and Israel indicate that girls under 9 are at higher risk of being killed in road crashes than boys of the same age group.

In order to facilitate the examination of the behavior of the injured pedestrian in road crashes, data was collected from both the Israeli and the Jordanian CBS, but since the same categories were not found, two tables are presented separately. Tables 2 and 3 show the casualties in pedestrian road crashes and pedestrian behavior in Israel and Jordan respectively.

As shown in Table 3, most of the pedestrian (about three quarters) fatalities in Israel and Jordan occurred while crossing the road. In Israel, however, there are more details about the pedestrian behavior crossing as Table 2 shows. In Israel, dart–outs while crossing roads
compose about 60% of the total number of pedestrian fatalities. This result is similar to Jordanian (1998) results, which showed that dart-outs, other non-intersection crossings, traffic signals, and playing in the street are the principal crash types for children.

Table 2: Casualties in pedestrian road crashes and pedestrian behavior in Israel

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Fatalities and severe injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking on road in the direction of traffic</td>
<td>5</td>
</tr>
<tr>
<td>Walking on road against the direction of traffic</td>
<td>1</td>
</tr>
<tr>
<td>Playing on the road</td>
<td>3</td>
</tr>
<tr>
<td>Standing on the road</td>
<td>4</td>
</tr>
<tr>
<td>Standing on median island</td>
<td>1</td>
</tr>
<tr>
<td>Was on sidewalk</td>
<td>2</td>
</tr>
<tr>
<td>Rushing into the street while crossing</td>
<td>47</td>
</tr>
<tr>
<td>Was hidden while crossing the street</td>
<td>13</td>
</tr>
<tr>
<td>Usual crossing</td>
<td>15</td>
</tr>
<tr>
<td>While crossing (other)</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 3: Casualties in pedestrian road crashes and pedestrian behavior

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Fatalities and severe injury Israel</th>
<th>Fatalities and severe injury Jordan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking on road in the direction of traffic</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Walking on road against the direction of traffic</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Standing on median island</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Was on sidewalk</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Walking on road (crossing)</td>
<td>76</td>
<td>75</td>
</tr>
<tr>
<td>Unknown</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Developing risk index based on the study survey

Car-crash involvement is a by-product of participation in activities and the travel this requires. Many studies showed that the greater the traffic exposure, the greater the risk of being involved in road crashes. The question is, though, whether distance or time travelled and the number of trips is sufficient to explain child exposure to this risk. Of course, exposure to roads at a high level standard, and urban planning that takes pedestrians’ safety into consideration, in addition to non-violent drivers will affect child exposure to the risk. Therefore, child injury in road crashes is derived from child exposure to the risk, which is affected by a variety of factors: road and traffic characteristics, driver, car, environment and the injured child.

Figure 14 shows the distribution of trips for children aged 4 to 14 by the mode of travel. In comparing the distribution of children's trips by mode, significant differences were found
between the Israeli Arab and the Jordanian children. Based on the diaries, 72% of the total number of trips taken by Israeli Arab children is by foot, while only 37% of the trips taken by Jordanian children are by foot. In contrast, 43% of the trips taken by Jordanian children are by bus compared to zero percent for the Israeli Arab children.

![Figure 14: Distribution of children's trips by mode](image)

The average number of trips for children aged 6-14 years is 1.9 and 3.7 trips per day in Jordan and Israel, respectively. This means that the Israeli Arab children make twice as many trips than the Jordanian children. The more striking result is that the average number of trips by foot for Jordanian children is 0.5 trips per day, which is five times less than the average number for the Israeli Arab children. Thus, the exposure of the Israeli Arab children to road traffic is more than that for the Jordanian ones, and due to this result, the Israeli Arab children should be at higher exposure to the risk if the same is measured only by travel time or distance and the number of trips.

Equation 1 presents a risk index for children aged 6-14 for Irbed (Irbid is the region of the country which contains the surveyed city, Husn) and Shefaram, (an Israeli Arab city). The development of this index is based on data that includes the number of total trips by the various modes of travel (based on the study survey), children population size for the 6-14 year age group, and the total number of pedestrian casualties based on CBS (2007).

\[
\text{ERM} = \frac{TCA}{\text{POP} \times \text{TN}}
\]

(2) \[
\text{ERM} = \frac{TCA}{\text{POP} \times \text{TN} \times \text{TT}}
\]

where:
ERM = risk index of being injured in road crash;
TCA = total number of child casualties aged 6-14;
POP = Total number of children aged 6-14;
TN = average number of trips by foot for children aged 6-14; TT = average travel time for one trip by foot for children aged 6-14.

The child pedestrian risk index (ERM) in Jordan is 1.5 casualties per one-thousand trips which is twice the Israeli Arab children risk index of 0.7 casualties per one-thousand trips. However, the number of trips is not sufficient to predict the exposure to the risk without considering travel time; therefore, the risk index was calculated per travel time (walking) instead per the number of trips (Equation 2).

The average travel time for one trip pertaining to children of age group 6 to 14 is 23 minutes in Jordan and 12 minutes in Israel. The child pedestrian risk index in Jordan is 3.9 casualties per one-thousand walking hours which is higher than the Israeli Arab children risk index of 3.4 casualties per one-thousand walking hours. Despite the fact that the Arab children in Israel take more trips by foot and walk longer than the Jordanian children, the latter are at higher risk of being injured in pedestrian road crashes.

4. CONCLUSION

The main purpose of this study was to identify both common and contrasting pedestrian road crash characteristics within the two communities - the Israeli Arab minority and the general Jordanian population – that share some similar characteristics. The results show that there is a similarity among the various characteristics of pedestrian road crashes within the two communities, such as age group, gender, day of week, time of day, speed and pedestrian behavior. Nevertheless, the road safety situation in Jordan is more severe than among Israeli Arabs. Despite the downward trend in the number of casualties in road crashes in Jordan and among Israeli Arabs, there have been significant increases in the Jordanian fatality rate throughout the years, the traffic fatality rate has increased faster than the population growth and the fatality rate is indicating an upward trend. In contrast, the Israeli fatality rate indicates a downward trend, which is similar to the trends in various developed countries (Jacobs et al., 2000).

As in other Arab countries and ethnic minorities children comprised the highest percentage of the total number of fatalities and injuries in general in Jordan and within the Israeli Arab minority and children are at the highest risk of being killed or severely injured in road crashes.

The study results highlight the importance of the exposure to the various environmental and traffic characteristics further to driver and child behavior patterns. Despite the fact that the Arab children in Israel take more trips by foot and walk longer than their Jordanian counterparts, the Jordanian children are at higher risk of being injured in pedestrian road crashes.
Shbeeb and Salim (2003; 2007) and Elias et al. (2010) show that improper behavior of the road user is the main contributory factor to pedestrian problems in both Jordan and Israel. The driving environment in Jordan and within the Israeli Arab communities is considered hostile one, and aggressive driving is a typical driving pattern (Suliman and Awad, 2003; Gitelman et al., 2003).

In summation, pedestrian road safety is of major concern in Jordan and within the Israeli Arab minority, and a great deal of effort is needed to improve traffic safety in both countries. Child pedestrian safety should be seen as the core of any national safety policy for pedestrians. Based on these results, it can be expected that in order to improve safety, there is a need to improve child awareness by means of education programs, to alter driving behavior via increased traffic enforcement along with an improvement in the physical environment and by bettering traffic arrangements, road systems and urban planning that take child pedestrian safety into consideration.

REFERENCES


Abstract. This paper aims to provide a comprehensive picture of the impact of driver distraction on road safety in Greece and internationally. For that purpose a review of international literature and a synthesis of the results were carried out, concerning both in-vehicle distraction sources (e.g. mobile phone use, reading, adjusting the radio) and external distraction sources (e.g. advertising signs, destination search, pedestrian or cyclist). Subsequently, the results of analyses concerning basic in-vehicle and external driver distraction factors are presented. More specifically, the results of three studies on the effect of mobile phone use on road safety in Greece are presented and discussed. In these studies, the effect of mobile phone use on driver speed and headways was examined by means of different methods, including a naturalistic driving experiment, a roadside survey and a simulator experiment. All studies reveal a significant effect of mobile phone use on driver behavior and safety. Furthermore, the results of a study on the effect of advertising signs on road safety in Greece are discussed. More specifically, the results of 'before-and-after' analysis of the placement or removal of advertising signs on 9 sites are presented. The results suggest that the effect of advertising signs on road safety is non significant. Overall, distraction related road accidents appear to be a relatively small yet non negligible proportion of road accidents, whereas in-vehicle distraction sources appear to have a far more significant effect than external ones. These results highlight the need for measures for the improvement of driver's behavior due to distraction, given that more wireless communication, entertainment and driver assistance systems proliferate the vehicle market, and consequently the incidence of distraction related accidents is likely to escalate.

Keywords: Road Safety, Driver Distraction, In-vehicle, External

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1. BACKGROUND AND OBJECTIVES

Driver distraction constitutes an important factor of increased risk of road accident in Greece and internationally. The level at which drivers' distraction affects the traffic circulation and the road safety has not been investigated sufficiently in the international literature. However, in existing research, it was revealed that approximately 30% of drivers that were involved in a road accident reported some source of distraction before the accident occurred (McEvoy et al., 2007). The penetration of various new technologies inside the vehicle (mobile telephones, navigation systems, sound system, other systems of assistance of driving etc.), but also the expected increase of use of such appliances in the next years, makes the further investigation of their influence on the attention of drivers, on traffic flow and on road safety very essential (Olsen et al., 2005).

Most existing researches emphasize on the in-vehicle sources of distraction, such as the use of mobile phone or a navigation / recreation system, discussing with another passenger, smoking, eating or drinking etc. (Yannis et al., 2008; Johnson et al., 2004; Lesch and Hancock, 2004; Strayer et al., 2003; Neyens and Boyle 2008; Bellinger et al., 2008) and report useful results on their influence on both traffic flow (e.g. in terms of driver speed and headways) and road safety (i.e. in terms of accident probability).

Moreover, driver distraction is also examined in terms of external distraction sources. These may concern various visual and mental stimuli, ranging from landscape and traffic (e.g. other vehicles or pedestrians), to traffic control and road signs, incidents, destination seeking and advertising signs (Stutts et al., 2001; Horberry, 1998; Sagberg, 2001; Regan et al., 2005). The related studies examine the influence of these distraction factors on both driver's attention (e.g. in terms of eye glances to the source of distraction), behavior (e.g. in terms of speeding), and safety.

Within this framework, this paper aims to provide a comprehensive picture of the impact of driver distraction on road safety in Greece and internationally. For that purpose a review of international literature and a synthesis of the results were carried out, concerning both in-vehicle and external distraction factors. Subsequently, the results of analyses concerning basic in-vehicle and external driver distraction factors are presented. More specifically, the results of three studies on the effect of mobile phone use on road safety in Greece are presented, on the basis of different methods, including a basic naturalistic driving experiment, a roadside survey and a simulator experiment. Furthermore, the results of a study on the effect of advertising signs on road safety in Greece are discussed. The results of the international literature and the examined studies in Greece lead to the identification of critical parameters of driver distraction and their effect on traffic flow and road safety.
2. REVIEW OF ROAD ACCIDENT CONTRIBUTORY FACTORS

According to existing research results, human factors are the basic causes of road accident in 65-95% of road accidents (Sabey and Taylor, 1980; Salmon et al., 2011; Treat, 1980). The remaining factors include the road environment (road design, road signs, pavement, weather conditions etc.) and the vehicles (equipment and maintenance, damage etc.), as well as combinations of these three contributory factors.

Moreover, human factors include a large number of specific factors that may be considered as accident causes, including (Department for Transport, 2008):
- driver injudicious action (speeding, traffic violations etc.);
- driver error or reaction (loss of control, failure to keep safe distances, sudden braking etc.);
- behavior or inexperience (aggressive driving, nervousness, uncertainty etc.);
- driver distraction or impairment (alcohol, fatigue, mobile phone use etc.).

Driver distraction constitutes therefore a particular human factor of road accident causation. Driver distraction occurs when a driver's attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object to the extent that the driver is no longer able to perform the driving task adequately or safely (Regan et al., 2008). More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four distinct elements: visual, acoustic, motor and mental distraction (Ranney et al., 2000), which are often difficult to isolate.

In any case, it is noted that distraction may be considered to be a typical part of every day driving (Stutts et al., 2001). In several studies, the quantification of the effect of driver distraction on the number of road accidents is attempted. However, the results lie on a range of values, mainly due to the different definitions of driver distraction in each case, and the different distraction sources taken into account in each case. More specifically, it is reported in the international literature that driver distraction may be a contributory factor in a proportion of road accidents ranging from 10-15% (MacEvoy et al., 2007; Wang et al., 1996), whereas driver inattention may, together with other factors, affect up to 70% of road accidents (Dingus et al., 2006).

For example, Figure 1 shows the percentage of accidents in which each contributory factor was reported in Great Britain in 2008, including a breakdown by accident severity. Four of the five most frequently reported contributory factors were some kind of driver error or reaction, which includes 'failed to look properly' and 'failed to judge other person’s path or speed'. Impairment or distraction factors account totally for 12% of all contributory factors.

Moreover, in Table 1 the results are further analyzed in terms of the number of accidents reported in Great Britain for the contributory factor 'impairment or distraction'. The accidents are classified by severity and divided as per the type of impairment or distraction involved. It
can be seen that distraction contributory factor account for less than 30% of all 'impairment and distraction' factors.

Figure 1: Road accident contributory factors by accident severity (Department for Transport, 2008)

Table 1: Number of accidents for contributory factor 'impairment or distraction' (Department for Transport, 2008)

<table>
<thead>
<tr>
<th></th>
<th>Fatal Accidents</th>
<th></th>
<th>Serious Accidents</th>
<th></th>
<th>Sight Accidents</th>
<th></th>
<th>All Accidents</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>%</td>
<td>Number</td>
<td>%</td>
<td>Number</td>
<td>%</td>
<td>Number</td>
<td>%</td>
</tr>
<tr>
<td>Impairment of distraction</td>
<td>479</td>
<td>22</td>
<td>2,924</td>
<td>14</td>
<td>12,159</td>
<td>11</td>
<td>15,562</td>
<td>12</td>
</tr>
<tr>
<td>Impaired by alcohol</td>
<td>237</td>
<td>11</td>
<td>1,485</td>
<td>7</td>
<td>5,036</td>
<td>5</td>
<td>6,758</td>
<td>5</td>
</tr>
<tr>
<td>Impaired by drugs (illicit or medicinal)</td>
<td>56</td>
<td>3</td>
<td>207</td>
<td>1</td>
<td>424</td>
<td>0</td>
<td>687</td>
<td>1</td>
</tr>
<tr>
<td>Fatigue</td>
<td>64</td>
<td>3</td>
<td>374</td>
<td>2</td>
<td>1,374</td>
<td>1</td>
<td>1,812</td>
<td>1</td>
</tr>
<tr>
<td>Illness or disability, mental or physical</td>
<td>90</td>
<td>4</td>
<td>402</td>
<td>2</td>
<td>1,356</td>
<td>1</td>
<td>1,848</td>
<td>1</td>
</tr>
<tr>
<td>Not displaying lights at night or in poor visibility</td>
<td>4</td>
<td>0</td>
<td>92</td>
<td>0</td>
<td>321</td>
<td>0</td>
<td>417</td>
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<tr>
<td>Cyclist wearing dark clothing at night</td>
<td>9</td>
<td>0</td>
<td>84</td>
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<td>247</td>
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<td>323</td>
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<td>69</td>
<td>3</td>
<td>339</td>
<td>2</td>
<td>2,406</td>
<td>2</td>
<td>2,814</td>
<td>2</td>
</tr>
<tr>
<td>Distraction outside vehicle</td>
<td>34</td>
<td>2</td>
<td>219</td>
<td>1</td>
<td>1,650</td>
<td>2</td>
<td>1,903</td>
<td>1</td>
</tr>
</tbody>
</table>
3. REVIEW OF DRIVER DISTRACTION FACTORS

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Although different studies report different specific distraction factors in each category, one of the most complete and comprehensive approaches is presented in Table 2 (Regan et al., 2005).

**Table 2: Driver distraction sources by category (in-vehicle / external)**

<table>
<thead>
<tr>
<th>Driver distraction sources</th>
<th>In-vehicle</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passengers</td>
<td>Traffic control</td>
<td>Other vehicle</td>
</tr>
<tr>
<td>Communication</td>
<td>Seeking location / destination</td>
<td>Pedestrian / cyclist</td>
</tr>
<tr>
<td>Entertainment systems</td>
<td>Vehicle systems</td>
<td>Accident / incident</td>
</tr>
<tr>
<td>Eating / drinking</td>
<td>Smoking</td>
<td>Police / Ambulance / Fire brigade</td>
</tr>
<tr>
<td>Animal / insect in the vehicle</td>
<td>Coughing / sneezing</td>
<td>Landscape / architecture</td>
</tr>
<tr>
<td>Stress</td>
<td>Stress</td>
<td>Animal</td>
</tr>
<tr>
<td>Daydreaming</td>
<td></td>
<td>Advertising signs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Road signs and markings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sun / other vehicle lights</td>
</tr>
</tbody>
</table>

Moreover, the distraction factors that occur inside the vehicle seem to have greater effect on driver behavior and safety. Horberry et al. (2006) confirm that in-vehicle distraction sources have a more important effect on driver performance, compared to the increased complexity of the stimuli received from the road and traffic environment. Moreover, a couple of studies report that external distraction factors are less than 30% of the total distraction factors (Stutts et al., 2001; Kircher, 2007). Other studies specify that external distraction factors account for less than 10% of all distraction factors (Sagberg, 2001; MacEvoy et al., 2007).

It is noted that a recent exhaustive research conducted in the Great Britain, in which the effect of more than 70 road accident contributory factors was examined, driver distraction was found to be a contributory factor in only 3% of all accidents. Out of this 3%, in-vehicle distraction sources accounted for 2%, whereas external distraction sources accounted for only 1% of all accident contributory factors (Department for Transport, 2008).

The distraction caused by interacting with in-vehicle devices while driving appears to impair the driver’s ability to maintain speed, control and lateral position on the road, to a more important degree compared to external distractions.

Moreover, a study carried out by Patel et al. (2008) examined perceived qualitative characteristics of 14 driver distractions. Survey participants were asked to complete a questionnaire in which ranked a list of distractions according to certain criteria. Table 3 shows the mean perceived risk ratings of each of the 14 driver distractions. The highest perceived risk ratings were associated with the use of mobile phones, followed by 'looking at a map or
book' and 'grooming'. The lowest perceived risk ratings were associated with 'listening to music', 'talking to passengers' and 'looking at road signs'. It is noted that advertising signs and landscape have a non negligible perceived risk level as external distraction sources.

Table 3: Perceived risk associated with driver distractions. (Patel et al., 2008)

<table>
<thead>
<tr>
<th>Driver Distraction Hazard</th>
<th>Risk rating</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listening to music</td>
<td>3.3</td>
<td>1.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Talking to passengers</td>
<td>3.8</td>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Looking for/at road signs</td>
<td>4.2</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Satellite navigator use</td>
<td>4.6</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Hands-free kit use</td>
<td>4.7</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Looking at Landscape</td>
<td>5.2</td>
<td>3.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Adjusting device</td>
<td>5.3</td>
<td>4.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Smoking</td>
<td>5.3</td>
<td>3.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Looking at advertising sign</td>
<td>5.7</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Eating or drinking</td>
<td>6.3</td>
<td>5.3</td>
<td>8.0</td>
</tr>
<tr>
<td>Looking for object</td>
<td>7.4</td>
<td>6.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Grooming/make-up</td>
<td>8.5</td>
<td>8.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Looking at a map or book</td>
<td>8.5</td>
<td>8.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Mobile phone use</td>
<td>8.6</td>
<td>8.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Table 4: Odds ratio for secondary tasks in the 100-Car study (NHTSA, 2008)

<table>
<thead>
<tr>
<th>Type of Secondary Task</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaching for a moving object</td>
<td>8.82</td>
</tr>
<tr>
<td>Insect in vehicle</td>
<td>6.37</td>
</tr>
<tr>
<td>Reading</td>
<td>3.38</td>
</tr>
<tr>
<td>Applying makeup</td>
<td>3.13</td>
</tr>
<tr>
<td>Dialling hand-held device</td>
<td>2.79</td>
</tr>
<tr>
<td>Inserting/retrieving CD</td>
<td>2.25</td>
</tr>
<tr>
<td>Eating</td>
<td>1.57</td>
</tr>
<tr>
<td>Reaching for non-moving object</td>
<td>1.38</td>
</tr>
<tr>
<td>Talking/listening to a handle-held device</td>
<td>1.29</td>
</tr>
<tr>
<td>Drinking from open container</td>
<td>1.03</td>
</tr>
<tr>
<td>Other personal hygiene</td>
<td>0.70</td>
</tr>
<tr>
<td>Adjusting the radio</td>
<td>0.50</td>
</tr>
<tr>
<td>Passenger in adjacent seat</td>
<td>0.50</td>
</tr>
<tr>
<td>Passenger in rear seat</td>
<td>0.39</td>
</tr>
<tr>
<td>Child in rear seat</td>
<td>0.33</td>
</tr>
</tbody>
</table>

More analytical results on the actual relative importance of different distraction factors were sought in the reports of the 100-Car naturalistic driving study carried out in the USA. Table 4 shows results on the odds ratio (i.e. increased risk) of engaging in various secondary
distracting tasks over “just driving” (statistically significant results are in bold). A significant odds ratio indicates an important increase in risk associated with that activity.

These results suggest that 'reaching for a moving object' is associated with the highest risk, increased by more than eight times compared to just driving, followed by 'reading' and 'applying make-up', increasing risk by more than 3 times. Subsequently, the use of mobile phone is associated with 2.8 times increased accident risk.

The use of mobile phone while driving has raised strong concerns about the impact of on road safety and several research actions are under way (NHTSA, 2006; McEvoy et al., 2007). Early research results showed that cell phone communication is a quite demanding cognitive and operational task, which may compromise decision making while driving (McKnight and McKnight, 1993). Recent studies confirm that mobile phone use while driving may significantly affect driver's behaviour and safety. Drivers tend to reduce their speed during a mobile phone conversation (Strayer and Drews, 2004; Yannis et al., 2010a). Although reduced speed is generally associated with lower accident risk, drivers using their mobile phone while driving present up to 4 times higher accident risk (MacEvoy et al., 2005; Redelmeier and Tabshirani, 1997), most probably as a result of increased workload and delayed reaction time (Caird et al., 2008).

Nowadays, the use of a cell phone while driving is prohibited by road traffic regulations in most European countries, because it is blamed for increased risk of provoking or failing to avoid a road accident. In this context, in the next section, the results of existing studies on the effect of mobile phone use on road safety in Greece are presented.

4. IN-VEHICLE DISTRACTION: THE EFFECT OF MOBILE PHONE USE IN GREECE

The research results presented above suggest that mobile phone use may be the most important in-vehicle distraction source for drivers. In Greece there are three researches carried out in the National Technical University of Athens, related on the impact of mobile phone use on traffic characteristics. The first one concerns a basic naturalistic driving experiment (Yannis et al., 2010a), the second one concerns a roadside survey (Yannis et al., 2010b) and the third one concerns a simulator experiment (Roumpas, 2010).

4.1 A basic naturalistic driving experiment

In this experiment, the effects of mobile phone use while driving on traffic speed and headways were examined, with particular focus on young drivers. A basic naturalistic driving experiment was carried out, in which drivers' speeds and headways were measured while
using or not a mobile phone. The experiment concerned 37 participants and took place within a selected University Campus area.

Linear and loglinear regression methods were used to investigate the effects of mobile phone use and several other young driver characteristics, such as gender, driving experience and annual distance travelled, on vehicle speeds and headways. The modeling results presented in Table 5 concern the statistically significant parameter estimates of the models ($\beta$), their t-tests ($t$), their elasticities ($e$), the normalization ($e^*$) of the elasticities to the lowest value, and the $R^2$ coefficient. The results show that mobile phone use leads to statistically significant reduction of traffic speeds of young drivers.

**Table 5: Modeling driver speed in relation to mobile phone use in Greece (naturalistic driving experiment) - Parameter estimates and elasticities**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total average speed ($V_t$)</th>
<th>$\beta$</th>
<th>t-test</th>
<th>Elasticities</th>
<th>$e^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile phone use</td>
<td>-0.047</td>
<td>-3.909</td>
<td>0.017</td>
<td>2.46</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.032</td>
<td>-2.671</td>
<td>0.007</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Annual distance</td>
<td>0.020</td>
<td>1.861</td>
<td>0.008</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>Average headways</td>
<td>-0.033</td>
<td>-5.123</td>
<td>0.069</td>
<td>10.33</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.609</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: A t-test value higher than 1.96 indicates a statistically significant effect at 95% confidence level.

Furthermore, it was found that male and female drivers reduce their speed similarly when using a mobile phone while driving. Moreover, male drivers using their mobile phone drive at lower speeds than female drivers not using their mobile phones. Variables sensitivity analysis revealed that, among all explanatory variables, the effect of mobile phone use on speed was the most important one.

### 4.2 A roadside survey

The objective of this research was the analysis of the impact of cell phone use on vehicle traffic speed and headways. In the experiment carried out, traffic data were recorded on a four-lane urban arterial segment, in which more than 3,000 vehicles were captured by means of a video camera and a speed gun.

Linear regression models were developed for the analysis of the effect of cell phone use and other variables on traffic speed and time / space headways. The modeling results presented in Table 6 concern the statistically significant parameter estimates of the models ($\beta$), their elasticities ($e$) and the normalization ($e^*$) of the elasticities to the lowest value, as well as the t-tests ($t$) for parameter estimates and the models fit ($R^2$).
The results confirm that mobile phone use decreases driver speed. It was also found that vehicle speed is increased for young drivers (aged 18-25 years), male drivers and taxi drivers, and decreased for older drivers (>55 years) and for drivers using their cell phone while driving.

Vehicle headspaces, estimated as the product of vehicle speed and time headways, were found to be decreased for drivers using their cell phone, young drivers and older drivers. Moreover, headspaces increased with the difference in speed and in headway of the vehicle ahead.

**Table 6: Modelling driver speed in relation to mobile phone use in Greece (roadside survey) - Parameter estimates and elasticities**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Vehicle speed (V)</th>
<th></th>
<th></th>
<th></th>
<th>Headspace (Hs)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>t-test</td>
<td>e</td>
<td>e*</td>
<td>β</td>
<td>t-test</td>
<td>e</td>
<td>e*</td>
</tr>
<tr>
<td>Taxi</td>
<td>0.692</td>
<td>1.914</td>
<td>0.00154</td>
<td>1.13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.688</td>
<td>-2.537</td>
<td>0.00318</td>
<td>2.34</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Age 18-25</td>
<td>0.441</td>
<td>1.642</td>
<td>0.00228</td>
<td>1.68</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Age 25-55</td>
<td>-1.503</td>
<td>-3.828</td>
<td>0.00297</td>
<td>2.18</td>
<td>7.299</td>
<td>0.14733</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>Cell phone use</td>
<td>-0.726</td>
<td>-1.849</td>
<td>0.00136</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>0.09023</td>
<td>1.00</td>
</tr>
<tr>
<td>Speed difference dv</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.134</td>
<td>0.87752</td>
<td>9.73</td>
<td></td>
</tr>
<tr>
<td>Headways difference</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.174</td>
<td>128.655</td>
<td>14.26</td>
<td></td>
</tr>
</tbody>
</table>

Note: A t-test value higher than 1.96 indicates a statistically significant effect at 95% confidence level.

Overall, the distraction caused by mobile phone use is reflected in the reduced speeds and space headways for all drivers. The reduction is more pronounced when the speed and headway difference between successive vehicles was not significant in the first place, as is the case for vehicle platoons.

### 4.3 A simulator experiment

This research aims to investigate the interrelation between mobile phone use, driver speed and accident probability. For that purpose, a driving simulator experiment was carried out, in which 30 young drivers aged between 18 and 30 years old drove in different driving scenarios, covering urban and interurban areas, good or rainy weather conditions and with or without the occurrence of an incident (Roumpas, 2010).

Linear regression methods were used to analyse the influence of mobile phone use as well as various other parameters on the mean speed of drivers. Binary logistic regression methods were used to analyse the combined influence of mobile phone, driver speed and other
parameters on the probability of an accident. The modelling results in terms of statistically significant parameter estimates (\( \beta \)), their t-tests (t) and elasticities (e) are presented in Table 7. Moreover, models fit is presented by means of the \( R^2 \) coefficient for the linear regression model and by means of the likelihood ratio test for the logistic regression model.

It appears that mobile phone use leads to statistically significant decrease of the mean speed but simultaneously it leads to an increase of accident probability, suggesting that the speed reduction when using a mobile phone is not sufficient to counter-balance the overall increased risk of doing so while driving, especially when an unexpected incident occurs.

It was also found that drivers did not present a statistically significant different mean speed in rainy conditions; however, they had a higher probability of being involved in an accident. It was finally revealed that the effect of mobile phone use in case of speed increase and adverse weather conditions makes accident avoidance in case of an unexpected incident almost impossible.

Table 7: Model driver speed and accident probability in relation to mobile phone use in Greece (simulator experiment) - Parameter estimates and elasticities

<table>
<thead>
<tr>
<th>Variables</th>
<th>Driver speed</th>
<th></th>
<th>Accident probability</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \beta )</td>
<td>t-test</td>
<td>e</td>
<td>( \beta )</td>
</tr>
<tr>
<td>Mobile phone use</td>
<td>-0.071</td>
<td>-7.47</td>
<td>-0.023</td>
<td>-</td>
</tr>
<tr>
<td>Urban area</td>
<td>-0.107</td>
<td>-10.90</td>
<td>-0.034</td>
<td>-</td>
</tr>
<tr>
<td>Mean distance from the right border</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.134</td>
</tr>
<tr>
<td>% of the route the 4th gear was used</td>
<td>0.097</td>
<td>5.32</td>
<td>0.022</td>
<td>-</td>
</tr>
<tr>
<td>% of the route the 2nd gear was used</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.761</td>
</tr>
<tr>
<td>Mean motor revolutions</td>
<td>7.91*10^{-5}</td>
<td>10.36</td>
<td>0.147</td>
<td>-</td>
</tr>
<tr>
<td>Annual mileage</td>
<td>3.75*10^{-6}</td>
<td>4.90</td>
<td>0.022</td>
<td>-</td>
</tr>
<tr>
<td>2nd drive in rainy conditions</td>
<td>-0.032</td>
<td>-3.24</td>
<td>-0.011</td>
<td>-</td>
</tr>
<tr>
<td>Change in speed while using mobile phone</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.138</td>
</tr>
<tr>
<td>Rain</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.798</td>
</tr>
<tr>
<td>Occurrence of an incident while using mobile phone</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.295</td>
</tr>
<tr>
<td>Occurrence of an incident while not using mobile phone</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.100</td>
</tr>
<tr>
<td>Never using mobile phone while driving</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.726</td>
</tr>
<tr>
<td>1st drive</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.567</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.655</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood Ratio Test</td>
<td>-</td>
<td></td>
<td></td>
<td>72.62</td>
</tr>
<tr>
<td>Degrees of freedom</td>
<td>-</td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

Note: A t-test value higher than 1.96 indicates a statistically significant effect at 95% confidence level. A likelihood ratio test equal to 72.62 with 7 degrees of freedom leads to accepting the model at 95% confidence level.
5. EXTERNAL DISTRACTION: THE EFFECT OF ADVERTISING SIGNS IN GREECE

According to the international literature, external driver distraction sources are a minor proportion of road accident causes. However, the particular case of advertising signs is often associated with increased accident risk and several studies examine the effect of roadside advertising on driver attention, behavior and safety. In most countries, specific rules exist as per the size, location and type of roadside advertisements.

Although most studies are in concordance with one another as regards the fact that advertising signs do attract the attention of the majority of drivers, for a non negligible proportion of their driving time (Wallace, 2003; Regan et al. 2005), their contribution to road accident occurrence is low when compared to other distraction sources or other human factors. In particular, the potential risk associated with advertising signs may depend on their type, their height, their content and other characteristics (Chattington et al., 2009; Crundall et al., 2006).

Within this context, a recent research in Greece aims to investigate the effect of advertising signs on road safety. More specifically, it examines whether the placement leads to significant increase of road accidents, and whether the removal of advertising signs may lead to any significant reduction of road accidents.

On that purpose, a 'before-and-after' statistical analysis was carried out in eight different road axes within the greater Athens area to investigate the correlation between advertising signs and road accidents. The specific roads were chosen, as there was placement or removal of advertising signs during the last decade. A before-and-after statistical analysis with control groups was applied, in which special attention was given not only to the identification of the appropriate control groups, e.g. neighboring or not road axes with very similar geometric and traffic characteristics, but also that the sample size of all cases examined was statistically significant. Before and after periods vary from 2.5 to 6 years depending on the date of the placement / removal of the advertising signs and the availability of the road accident data.

From the statistical analysis of the road axes selected it was found that no statistical correlation between road accidents and advertising signs could be proved in none of the eight cases examined. More specifically, the global safety effects of placing / removing and their confidence intervals are presented in Table 8. These were estimated on the basis of the odds-ratio method for a number of treatment and control sites (Yannis et al., 2005). It can be seen that the estimated safety effects are non significant, given that their confidence intervals, estimated at 95% confidence level, are too large and thus not acceptable.
Table 8: Before-and-after analysis of the effect of advertising signs in Greece

<table>
<thead>
<tr>
<th></th>
<th>Advertising signs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Placement</td>
</tr>
<tr>
<td>Accidents 'Before' in the treatment sites</td>
<td>258</td>
</tr>
<tr>
<td>Accidents 'After' in the treatment sites</td>
<td>223</td>
</tr>
<tr>
<td>Accidents 'Before' in the control sites</td>
<td>527</td>
</tr>
<tr>
<td>Accidents 'After' in the control sites</td>
<td>523</td>
</tr>
<tr>
<td>weighted mean effect</td>
<td>1.125</td>
</tr>
<tr>
<td>safety effect</td>
<td>-12.5%</td>
</tr>
<tr>
<td>lower limit</td>
<td>-34.9%</td>
</tr>
<tr>
<td>upper limit</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

This finding can be explained by the fact that in the road axes selected drivers are overloaded by a lot of information (traffic signs, directions signs, several advertising labels of the shops on the road, pedestrians and other vehicle traffic, etc.) so that the additional information load from the advertising signs may not worsen their concentration on driving. These findings coincide with results from international literature using such statistical analyses. To conclude, advertising signs as drivers' distraction factors do not seem to have statistically significant impact on road accidents in general. However, further investigation is needed to extract specific conclusions for more specific cases (e.g. junctions, sign positioning etc.).

6. DISCUSSION

This paper aims to provide a comprehensive picture of the impact of driver distraction on road safety in Greece and internationally. Driver distraction is a safety problem that can increase accident risk due to the degradation in driving performance during multitasking, including slower reaction time and narrowed visual scanning. Moreover, as more in-vehicle systems, such as wireless communication, entertainment and driver assistance systems, become more widespread, the occurrence of distraction related crashes is likely to escalate.

A review of international literature and a synthesis of the results were carried out, concerning both in-vehicle distraction sources (e.g. mobile phone use, reading, adjusting the radio) and external distraction sources (e.g. advertising signs, destination search, pedestrian or cyclist). A comparative assessment of distraction sources with other contributory factors was carried out. Overall, distraction related road accidents appear to be a minor yet non negligible proportion of road accidents, whereas in-vehicle distraction sources appear to have a far more significant effect than external ones. Existing research also largely focuses on in-vehicle distraction sources, namely the use of mobile phones while driving. As regards external distraction, most studies examine the effect of advertising signs on road safety.
Within this context at international level, the results of analyses concerning basic in-vehicle and external driver distraction factors in Greece were presented. More specifically, the results of three studies on the effect of mobile phone use on road safety in Greece were presented and discussed. In these studies, the effect of mobile phone use on driver speed and headways was examined by means of different methods, including a naturalistic driving experiment, a roadside survey and a simulator experiment. All studies are in accordance with the international literature and reveal a significant effect of mobile phone use on driver speed (i.e. speed reduction). However, the simulator experiment allowed to conclude that this speed reduction cannot counterbalance the reduced headways and reaction times, and therefore mobile phone use increases accident probability.

Furthermore, the results of a 'before-and-after' study on the effect of advertising signs on road safety in Greece were presented. Both the placement or removal of advertising signs were examined, and the results suggest that the effect of advertising signs on road safety is non significant, at least for the particular locations that have been investigated.

These results highlight the need for measures for the improvement of driver's behavior due to distraction, especially as regards the use of mobile phones. Measures against driver distraction include enforcement of traffic rules, concerning the use of mobile phones, or other hand-held in-vehicle devices, as well as the appropriate placement of road signs, advertisements etc.. They also include driver information campaigns e.g. concerning the risk associated to mobile phone use and driver distraction in general.

The next steps of the research on driver distraction could focus on several open issues starting from establishing the most ergonomic way to design in-vehicle devices to minimize distraction. Furthermore, future research should focus on mobile phone use, in terms of both the isolation of their impact from the various distraction factors and the analysis of their combined impact with other distraction factors. In addition, it would be important to achieve a common international definition of driver distraction. Finally, the cross-validation of driver distraction results from experiments (e.g. driving simulator, naturalistic driving) and statistical analyses (before-after, comparison of sections) should be carried out.

REFERENCES


INFRASTRUCTURE-TO-VEHICLE COMMUNICATIONS: IMPACT ON DRIVER BEHAVIOR AND SAFETY FROM EUROPEAN DEMONSTRATION PROJECT

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Abstract. European countries are investigating on traffic safety research for a long time in order to improve safety standards on roads. In-vehicle technologies and co-operative services are attracting a lot of attention for their potential to deal with congestion problems and improve traffic safety. This paper aims to investigate the impact of infrastructure-to-vehicle co-operative systems, case of COOPERS, using data from field tests. Thirty five test drivers drove an instrumented vehicle twice, once with the system activated and once inactivated. Data related to driving performance was collected. The analysis of the data indicates that, on average drivers decrease their driving speeds and increase their headways when the system is activated. No significant impact of the system was found on drivers’ acceleration noise and lane-changing behavior. The overall results are promising indicating that providing dynamic and updated traffic information to drivers using infrastructure-to-vehicle communications has a positive impact on drivers’ behavior and safety.

Keywords: Co-operative Systems, Driver Behavior, Surrogate Safety Measures, Traffic Flow

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1. INTRODUCTION AND BACKGROUND

Road accidents and traffic congestion are widely recognized as critical transportation cost problems in most countries. In 2004 the estimated annual costs, both direct and indirect, of traffic injuries in the EU-15 countries exceeded 180 billion Euros.

Today, a wide range of new in-vehicle technologies are available, including Advanced Driver Assistance Systems (ADAS), In-vehicle Information Systems (IVIS) and intelligent co-operative systems. These technologies aim at assisting drivers in their primary and secondary tasks of driving. Systems that help drivers with their primary tasks of driving include for example the lane departure warning system and collision avoidance systems. Other systems like the in-vehicle navigation systems assist drivers in their secondary tasks of driving. Intelligent Co-operative Systems focus on vehicle-to-vehicle (V2V) and vehicle-to-Infrastructure (V2I and I2V) communications to give the vehicle the ability to better interact with its environment. A vehicle for example communicates wirelessly with another vehicle (V2V) or with roadside infrastructure (V2I and I2V). The goal is to support and improve traffic management and road safety with better exchange of information (CVIS, 2010). Cooperative systems do not only provide direct two-way communication (V2V, I2V and V2I), but also establish an open platform, which allows for multiple applications and services to be implemented by service providers (CVIS, 2010).

Earlier research work (Várhelyi et al., 2006) revealed that providing the driver with relevant and concise, but comprehensive, timely information is of paramount importance, allowing the driver sufficient time to understand and react to the situation.

The Demo 2000 of the JSK (the Association of Electronic Technology for Automobile Traffic and Driving, Tsugawa 2000) constituted a first proof of the concept for the cooperative driving by realizing a platooning convoy using the inter-vehicle communication. In Europe, many projects aim at defining the different levels of such cooperative systems: from the PROMETHEUS - Programme for a European Traffic with Highest Efficiency and Unprecedented Safety (Gillan, 1989) project in the 90’s to WillWarn - Wireless Local Danger Warning (Nöcker, 2004), Cartalk2000 (Reichardt et al., 2002), IVHW - Inter-Vehicle Hazard Warning system (Martial, 2002), Fleetnet (Enkelmann, 2003), Arcos (Ehrlich et al., 2005), Promote-Chauffeur (Harker, 2001), REACT and Com2React (De La Fortelle et al., 2007), SafeSpot (Vivo, 2007), Coopers (Böhm et al., 2007), CVIS (CVIS, 2010), etc. In the USA, the VII (Vehicle Infrastructure Initiative) and the VSC (Vehicle Safety Communication) regroup the research in this field (Ammoun and Nashashibi, 2010). As many research domains are related to the new vehicular network, each project attempts to address the inter-vehicle communication issue from a different point of view: the protocol definition, the technology standardization, the routing mechanisms, the economic model, the information security, the design of a new services, etc. For example, CVIS ambition is to begin a revolution in mobility for travellers and goods, completely re-engineering how drivers, their vehicles, the goods they carry and the transport infrastructure interact. CVIS will monitor and guide dangerous goods, deal with urban loading zone and highway parking slot management and monitor access
control to sensitive infrastructure (CVIS, 2010). It is based on Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication. SAFESPOT creates dynamic cooperative networks where the vehicles and the road infrastructure communicate to share information gathered on board and at the roadside to enhance the drivers' perception of the vehicle surroundings. The aim is to prevent road accidents developing a Safety Margin Assistant that detects in advance potentially dangerous situations and that extends in space and time drivers’ awareness of the surrounding environment. The Safety Margin Assistant is an Intelligent Cooperative System based on V2V and V2I communication (Vivo, 2007).

The scope of the COOPERS project is to develop and demonstrate a system that links vehicles with road infrastructure via continuous wireless communication to exchange data and information relevant for the specific road segment to increase overall safety and enable cooperative traffic management. COOPERS services are designed to improve traffic safety by providing early warning of hazardous traffic conditions such as: accident–incident, adverse weather conditions, roadwork information, lane utilization and traffic congestion.

Aide has a similar aim as COOPERS, i.e. to improve the road safety. However, in contrast to COOPERS it puts priorities on technologies of the human-machine interface in a driving environment. The user-focused design methodology shifts the users into the centre of the design process in order to understand their needs, expectations, interaction modes and problems, or to find effective ways to remove interaction difficulties and give them the information they need (Cherri et al., 2004).

In the first stage the impact of the COOPERS’ system on driver behavior was investigated in a virtual environment. The advantages of driving simulators, especially when testing the impact of a new system on driver behavior, is the safe environment, the possibility to simulate risky situations and the ability to repeat the same exact scenario for several drivers. Therefore, driving simulator tests were conducted at VTI (Swedish National Road and Transport Research Institute) with 50 participants performing a 2 hour test drive in the simulator using the in-vehicle system equipment to evaluate driver behavior and user acceptance. Results have shown that when driving with the system activated drivers brake earlier in critical situations, remain calmer and approach incidents with reduced speeds compared to the same situation without the assistance of the system. It was also found that participants from all age groups perceive the information to be useful and to enhance their driving safety significantly. User acceptance results show that test subjects agreed to purchase cooperative systems as soon as they are commercially available which underlines the positive attitude toward the system (Böhm et al., 2009).

The main focus of this paper is to analyse the impact of infrastructure-to-vehicle system on drivers’ behavior in real life conditions and to investigate what are the implications on traffic safety. Results of user acceptance and physiological measurements are not discussed in this paper but can be found in Farah et al., 2010.
The remaining parts of the paper are organized as following: The next section includes a description of the research methodology followed by data analysis section. The fourth section presents conclusions and further research directions.

2. METHODOLOGY

COOPERS system plans to connect vehicles on the motorway to the road infrastructure by means of continuous bidirectional wireless communication as illustrated in Figure 1. The time gap from the generation of the information in the traffic control center until its delivery to the end user is 30 seconds. Below 30second threshold, it is anticipated that direct vehicle-to-vehicle communication will take over. These information messages are attached to locations, either the point of an event (e.g., an accident or the dynamically moving end of traffic congestion) or the start and end points for segment-specific information (e.g., slippery road surfaces or speed restrictions), (Böhm et al., 2009).

![Figure 1: COOPERS vision of continuous bidirectional I2V communication along motorways (GPS = Global Positioning System, ESP = Electronic Stability Program), (Böhm et al., 2007)](image)

A direct measurement of the impact of cooperative systems on the overall traffic and the number of accidents is difficult. This is because of the limited testing period and number of test cars, difficulty in monitoring vehicles not equipped with the system, low number of measurable accidents and significant actual events related to the system’s services. However, a detailed observation of vehicle and driver behavior allows an evaluation of the tendencies and assessment of the expected impact of such systems on safety and traffic management.
There are several well-known safety measures that have been used in previous research studies (McDonald, 2004). These measures can be categorized into three categories: (1) **Longitudinal control indicators**: driving speed, speed variance, following distance to the vehicle in front (distance based), time headway (time-to-collision, TTC) and acceleration noise; (2) **Lateral control indicators**: steering wheel movement (Variance of Steering Angle, High Frequency Component Rate (HFC), Steering Wheel Reversal Rate (SSR)) and lane keeping; (3) **Event detection**: the main idea is to examine how fast drivers detect and react to an event or incident. This includes: Response time and distance and errors of omission (Pezo-Silvano, 2009).

### 2.1 Demonstration Site

The cooperative system has been demonstrated in four test sites spanning five different countries (Germany, Austria, Italy, France, and the Netherlands). However, this paper will present the results from the Austrian site only.

The Austrian site that is analyzed includes the transit connection between Germany and Italy, namely the A12 “Inntal Autobahn” from the German border at Kiefersfelden to Innsbruck. A12 is among the best equipped motorways in the ASFINAG (Austrian highway operator) network, due to its vicinity to the state capital Innsbruck, having considerable traffic, a lot of traffic events in general, a high density of sensors, multiple variable message signs, and highly automated traffic management.

The test section lies between the highway exits "Vomp" (km 52) and "Hall West" (km 70), for an overall length of around 17 km. The highway exits "Wattens" and “Hall Mitte” lie within the test section. The highway has a configuration of 2 lanes (plus the hard shoulder) at the test site. Along the test site are 8 overhead gantries with VMS, all of them spanning only a single direction. These gantries were equipped to be short-range communication points for COOPERS’ service messages. Figure 2 illustrates the locations of VMS gantries/IR-transceivers.

![Figure 2: Location of VMS Gantries / IR-transceivers (Faisstnauer, 2010)](image-url)
ASFINAG decided to test all services on a section of the A12 in the Innsbruck direction. During the tests, there were no significant events on the test site that would have triggered a COOPERS’ service message. No roadwork was scheduled in the allotted timeframe, congestion was not a problem in January, the weather was fair, and all lanes were open, only local speed restrictions were in effect in the morning and evening (Faisstnauer, 2010). Therefore, simulated messages were added for each test drives as summarized in Table 1:

**Table 1: Simulated COOPERS Service Messages**

<table>
<thead>
<tr>
<th>Service No.</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>S5</td>
<td>S5 Speed Advice 100km/h from km 52 to km 70¹</td>
</tr>
<tr>
<td>S1a</td>
<td>S1a Accident from km 54 to km 58</td>
</tr>
<tr>
<td>S6</td>
<td>Congestion from km 59.5 to km 62</td>
</tr>
<tr>
<td>S3</td>
<td>Roadwork from km 62 to km 64</td>
</tr>
<tr>
<td>S2</td>
<td>Rain from km 65 to km 68</td>
</tr>
<tr>
<td>S1c</td>
<td>Ghost Driver from km 68 to km 70</td>
</tr>
<tr>
<td>S4b</td>
<td>Lane Keeping – Lane 1 from km 68 to km 70</td>
</tr>
<tr>
<td>SL100</td>
<td>Speed limit 100 km/hr</td>
</tr>
</tbody>
</table>

¹ only when there was no real speed advice on the test site

Figure 3 illustrates the in-vehicle Human Machine Interface (HMI) of the on-board unit of the system:

![Figure 3: Illustration of the in-vehicle HMI (AustraiTech)](image)

Beside the information received about the warnings, the on-board unit provides also details about the direction of travel, current speed of driving, distance to a destination and to next exists, current time and the navigation map as shown on the on-board unit in Figure 3.
2.2 Participants

Test drivers representative of the population were recruited a month prior to the field tests, 50 drivers were recruited to participate between January and February 2010, ending with 48 drivers actually participating. Test drives were scheduled from Monday to Saturday with three time slots a day, lasting 3 hours each, from 8-11h, 12-15h and 15-18h. However, because of the complexity of data collection, valid data was available for only 35 drivers. Figure 4 presents the distribution of the 35 drivers according to their age and gender.

![Figure 4: Age and Gender Distribution](image_url)

2.3 Experiment

For the field tests the vehicle provided by the Technische Universitaet Berlin, an Audi A4 was used. The car is able to record the data from the CAN-bus, and is equipped with a stereo-camera capable of measuring the lane keeping behavior as well as with 2 LIDAR-Sensors capable of measuring the headways to preceding and the following vehicle’s behavior. Furthermore, a traditional camera is mounted in the car to record the environment behind the car (rear-view).

For each test drive the following procedure was adopted (Faisstnauer, 2010):

**Familiarization drive:** users made a short familiarization drive with the test car on the highway, in order to get familiar with the test car. The users were accompanied by an assistant who was seated in the back seat of the car. Duration: approx. 15 minutes

**Tutorial:** the driver was given a short description (5 minutes) about the system, focusing on the HMI (Human Machine Interface) and the type of messages (COOPERS’ services) the user would receive during the drive.
Pre-drive user questionnaire: the test driver was asked to fill out a questionnaire (15 minutes), which mainly focused on the expectations and assumptions of the driver concerning the system.

Biometric sensors fitting: the biometric sensors were fitted on the user and calibrated.

Test car initialization: the biometric sensors fitted on the user were connected to the recording equipment in the test car. The eye-tracking system was calibrated to the user.

Test drive: Each test driver made two test drives, one with the system, and one without the system. Half of the test drivers had the system activated on the first drive, the other half on the second drive.

Test drive 1: After entering the highway at AST Vomp, the test driver had to drive 0.5 km and then entered the test site at km 53, which ranges until km 70, for an overall length of 17 km. 8 overhead gantries (carrying VMS) along this section were equipped with 15 IR-transmitters, which transmitted COOPERS-messages to the vehicles as they passed. It took approximately 15 minutes to traverse the test section (depending on the traffic).

Return drive: at the exit (AST) Hall-West (at km 70), the user exited the highway. He changed to the passenger/back seat, while the assistant drove the car back to ABM Vomp at km 52 (travelling on the highway in east direction).

Test drive 2: back at the ABM Vomp, the assistant exited the highway, test driver and assistant switched place, and the test driver re-entered the highway in westward direction, to accomplish a second test drive. It took another 15 minutes to pass through the test section and reach the reversal point.

Return drive: after the second test drive, the assistant drove the car back to ABM Vomp.

Overall duration for the entire test drive: around 60 minutes, depending on traffic.

Test car shutdown, biometric sensor removal: the systems of the test car were shut down, the biometric sensors removed from the test driver.

Post-drive user questionnaire: the test drivers filled out another questionnaire (15 minutes), focused on the experience they had with the system. In comparison with the pre-drive questionnaire, it was therefore possible to determine whether the system was able to fulfill the expectations of the user.

In-depth interviews were conducted with 10 test drivers to gain in-depth information on drivers’ attitude towards the system. The overall duration of the entire test was around 120 minutes or 2 hours.

2.4 Data collection

Data about the participating drivers’ socio-demographic and socio-economic characteristics were collected by means of questionnaires. In order to be able to analyze the drivers’ behavior, the following data was collected:

(a) Vehicle-side data: the instrumented test vehicle record the data from the CAN-bus, cameras, and LIDAR-Sensors which mainly data about speeds, longitudinal and lateral distances, acceleration of the subject vehicle and all surrounding vehicles detected by the LIDARS-Sensors are recorded.
(b) **Driver-side data**: a driver was monitored with biometric equipment, which record eye tracking and heart rate variability measurements.

(c) **Roadside data**: the "roadside data" encompasses the sensor data used by the Traffic Control Center (TCC) to generate the Coopers messages (weather/traffic data, etc.), as well as the log data of the generation and transmission of the Coopers messages (recorded by the COOPERS Service Center-CSC and the Road Side Units- RSUs). During the tests the CSC will generate a log file containing all details of the message generation (message content, source data, timestamp of generation, etc.) and forwarding of the messages to the RSUs. The RSUs in turn will log the reception of the messages from the TCC, the transmission to the test cars, and the reception of the acknowledgments from the cars.

### 3. DATA ANALYSIS

In field studies in comparison to simulated studies it is difficult to control the different environmental variables like traffic, weather conditions, etc. However, in order to evaluate the impact of any system on the driver behavior, it is critical to try to conduct both drives with and without the system in similar conditions.

Analysis of cooperative systems based on I2V communication on drivers’ behavior starts with comparison of driving with and without the service information (Böhm et al., 2007). However, an important issue that needs to be examined in advance of the analysis of the impact of any service on drivers’ behavior is whether the traffic conditions were similar in both drives (with/without the system). In case of different traffic conditions, it is obvious that drivers’ behavior will also be different with no relevance to the cooperative system. This step is followed by comparison of macro level analysis of driving behavior, such as: the average driving speed, acceleration noise, lane-changing frequency, headway distributions, etc.

#### 3.1 General traffic conditions

For analysing the general traffic conditions when the system was activated versus when it was inactivated the available data provided from the Traffic Control Center- TCC was used. Table 2 summarizes the average traffic speed and occupancy for each driver in both drives.

According to Table 2 for most drivers (except for drivers 11, 24, 49) the average traffic conditions were almost similar when the system was activated versus when it was inactivated. This indicates that any changes in drivers’ behavior when the system was activated versus when it was inactivated are most likely not attributed to changes in the average traffic conditions as these were almost similar. A t-test analysis was conducted to examine if the null hypothesis of similar general traffic conditions could be rejected. The t-test results showed that the null hypothesis (traffic conditions are similar) can not be rejected at the 95% confidence level (P-value=0.47 for average speed and P-value=0.39 for average occupancy).
Table 2: Comparison of the general traffic conditions between system on/off

<table>
<thead>
<tr>
<th>Driver No</th>
<th>Average Speed</th>
<th>Average occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>2</td>
<td>106.62</td>
<td>106.16</td>
</tr>
<tr>
<td>3</td>
<td>108.07</td>
<td>106.29</td>
</tr>
<tr>
<td>5</td>
<td>100.71</td>
<td>101.98</td>
</tr>
<tr>
<td>7</td>
<td>106.47</td>
<td>107.66</td>
</tr>
<tr>
<td>8</td>
<td>107.09</td>
<td>107.88</td>
</tr>
<tr>
<td>9</td>
<td>103.81</td>
<td>105.02</td>
</tr>
<tr>
<td>10</td>
<td>106.86</td>
<td>100.61</td>
</tr>
<tr>
<td>11</td>
<td>85.50</td>
<td>100.11</td>
</tr>
<tr>
<td>12</td>
<td>102.69</td>
<td>101.01</td>
</tr>
<tr>
<td>13</td>
<td>102.39</td>
<td>103.51</td>
</tr>
<tr>
<td>15</td>
<td>100.21</td>
<td>100.18</td>
</tr>
<tr>
<td>16</td>
<td>106.15</td>
<td>107.27</td>
</tr>
<tr>
<td>17</td>
<td>99.76</td>
<td>101.98</td>
</tr>
<tr>
<td>18</td>
<td>99.51</td>
<td>101.59</td>
</tr>
<tr>
<td>19</td>
<td>100.58</td>
<td>101.22</td>
</tr>
<tr>
<td>20</td>
<td>95.52</td>
<td>96.897</td>
</tr>
<tr>
<td>21</td>
<td>103.86</td>
<td>98.299</td>
</tr>
<tr>
<td>24</td>
<td>86.36</td>
<td>96.540</td>
</tr>
<tr>
<td>25</td>
<td>102.26</td>
<td>103.22</td>
</tr>
<tr>
<td>27</td>
<td>101.17</td>
<td>100.10</td>
</tr>
<tr>
<td>28</td>
<td>112.14</td>
<td>111.49</td>
</tr>
<tr>
<td>29</td>
<td>104.29</td>
<td>102.95</td>
</tr>
<tr>
<td>30</td>
<td>104.2</td>
<td>102.01</td>
</tr>
<tr>
<td>32</td>
<td>99.81</td>
<td>100.53</td>
</tr>
<tr>
<td>33</td>
<td>97.4</td>
<td>99.730</td>
</tr>
<tr>
<td>36</td>
<td>105.27</td>
<td>105.19</td>
</tr>
<tr>
<td>37</td>
<td>101.91</td>
<td>100.68</td>
</tr>
<tr>
<td>38</td>
<td>100.83</td>
<td>100.48</td>
</tr>
<tr>
<td>42</td>
<td>98.18</td>
<td>97.360</td>
</tr>
<tr>
<td>43</td>
<td>100.32</td>
<td>100.88</td>
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<tr>
<td>44</td>
<td>97.86</td>
<td>99.680</td>
</tr>
<tr>
<td>45</td>
<td>100.62</td>
<td>99.150</td>
</tr>
<tr>
<td>48</td>
<td>102.24</td>
<td>103.15</td>
</tr>
<tr>
<td>49</td>
<td>99.79</td>
<td>104.56</td>
</tr>
<tr>
<td>50</td>
<td>98.82</td>
<td>100.16</td>
</tr>
</tbody>
</table>
3.2 Speed Profiles

Many factors are responsible for road traffic accidents, but excessive speed is often thought to be a major cause (Elvik et al., 2004; Aarts and Schagen, 2006). Speed not only affects the severity of a crash, but is also related to the risk of being involved in a crash (Aarts and Schagen, 2006). Therefore, driving speed and acceleration are important factors and indicators for safety and traffic flow and hence speed and acceleration profiles were created for each driver in both drives (system on and off). Figure 5 illustrates an example of the results of driver 02:

![Speed Profile System on/off - Driver 02](image)

(a) Speed profile

![Acceleration Profile - System on - Driver 02](image)

(b) Acceleration profile

*Figure 5: Impact of the system on driver 02: (a) Speed profile; (b) Acceleration profile*
Figure 5(a) is the speed profile of driver 02 along the road when the system was on (red line) versus when it was off (blue line). It can be noticed that when driving with the system been activated the driver’s speed is lower on average than when driving when the system been inactivated. Figure 5(a) also includes the type of messages that were sent to the driver and the exact distance when it was shown on the on-board unit. This is illustrated by vertical lines in Figure 5(a). The types of messages follow the description in Table 1. Therefore, information regarding the change in the driving speed after the message was received on the on-board unit can be also achieved from this figure. However, it should be noted that since there was no audio tone from the on-board unit when a new message was displayed, it is difficult to identify when exactly the driver noticed the messages. Also since these messages were simulated it wasn’t possible to compare the reaction of the driver to the event between the two drives. With respect to Figure 5(b), the acceleration profile, it was rather difficult to make conclusions, and therefore, further analysis was conducted by calculating the acceleration noise in both situations when the system was on versus when it was off. These results are described later on.

Figure 6 presents the average driving speed frequency distribution for both conditions (system on/off) when considering all the 35 drivers. The road section of total 17 kilometer was divided to smaller subsections of 250 meters. In each subsection the average driving speeds of all drivers was calculated for both conditions.

![Figure 6: Driving speed frequency distribution for system on versus off](image)

As can be noticed when the system is on the distribution is shifted to the left indicating a reduction of the driving speed. Also it can be noted that more drivers are now driving close to the speed limit (100 km/hr). This leads to a reduction in the speed variability on the road and therefore an expected increase in safety and traffic homogeneity. In order to test if this difference is statistically significant the Kolmogorov-Smirnov test (KS-test) was conducted.
This is a non-parametric test of the hypothesis that the two distributions differ significantly. The KS-test has the advantage of making no assumption about the distribution of data. In this test the hypotheses are:

\[ H_0: \text{The two distributions are almost the same}; \]
\[ H_a: \text{The two distributions are quite different than is claimed}. \]

The result of the KS test at the 95% confidence level indicates that there is a strong evidence against the null hypothesis (test statistic = 0.0001), which means that the two distributions are quite different. In other words drivers with the system on have lower driving speeds than when the system is off.

Figure 7 presents the average speed profile for all drivers and the 80% and 20% percentiles of the subjects driving speed for both drives (system on/off).

It can be seen from Figure 7 that when the system is on the average driving speed, 80% percentile and 20% percentile are lower than when the system is off. To test if these differences are significant t-tests were conducted. The results show that the average driving speeds and 80% percentile for when the system was on versus when it was off are significantly different at the 95% confidence level (p-value: 0.03 and 0.005, respectively). The difference in the 20% percentile was not found to be significant at the 95% confidence level.

Table 3 summarizes the results of the average driving speeds by gender when the system was on versus when it was off:
Table 3: Average driving speeds by gender for system on versus off

<table>
<thead>
<tr>
<th>Gender</th>
<th>Average driving speed (km/hr)</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COOPERS OFF</td>
<td>COOPERS ON</td>
</tr>
<tr>
<td>Male</td>
<td>100.08</td>
<td>99.84</td>
</tr>
<tr>
<td>Female</td>
<td>103.17</td>
<td>100.18</td>
</tr>
</tbody>
</table>

From the results in Table 3 it is clear that female drivers reduced their driving speeds more than male drivers when the system was on versus when it was off. Interesting to notice that female drivers’ speeds were higher than male drivers’ speeds.

It should be noted that it is not expected from the driver using the system to reduce his driving speed to a large extent since he should also adapt his behavior to the average traffic speed; otherwise it could be risky if she/he drives much slower than the average traffic stream speed.

3.3 Acceleration Noise

Acceleration noise was first proposed by Herman et al. (1959) as a means to measure traffic conditions and driving behavior. Earlier studies demonstrate that acceleration noise is a useful traffic parameter for evaluating traffic flow and that it is a parameter that might be employed to characterize the driver-car-road complex under various conditions (Herman et al., 1959). Acceleration noise, or standard deviation of the acceleration, is defined as the root mean square deviation of the acceleration of the car. The definition can be formulated as follows (Jones and Potts, 1962):

\[
ACN = \sqrt{\frac{1}{T} \int_{0}^{T} [a(t) - \bar{a}]^2 dt}
\]

\[
ACN = \frac{1}{T} \int_{0}^{T} [a(t) - \bar{a}]^2 dt
\]

\[
ACN = \frac{1}{T} \int_{0}^{T} [a(t) - \bar{a}]^2 dt
\]

The results of the acceleration noise for each driver calculated for the whole trip when the system was activated and when it was inactivated were almost similar. No significant differences were found in the acceleration noise of male and females, young or old when the system was on versus when it was off. However, for future research a micro-level analysis, such as the car-following behavior might reveal significant differences.
3.4 Lane-Changing Behavior

Lane-changing frequency has an impact on traffic safety. Transportation researchers estimate that lane change crashes account for between 4 and 10% of all crashes (Barr and Najm, 2001; Eberhard and Moffa, 1995).

A camera system continuously detects the lane marking in front of the vehicle. So the lane width and the distance of the vehicle to the side lines can be detected. The approach of standardized lane behavior describes the behavior of the vehicle within the lane. Therefore, the number of lane changes was based on left-marking recorded in the test. Since normalized distance from left marking was used, the range of values was between 0 and 1. Lane-changing profiles were created for each driver in both drives (system on and system off). Figure 8 illustrates the results for driver 2:

![Figure 8: Lane changing behaviour with the system on/off for driver 02](image)

The red line in Figure 8 presents the lane-changing behavior when the system was activated and the blue line when it was inactivated. The lane-changing frequency was lower for this driver when the system was activated. Table 4 summarizes the lane-changing frequencies for each driver when the system was on versus when it was off.
According to the results in Table 4 for some drivers we can see a positive effect of the system by the fact that those drivers reduced their lane-changing frequencies. However, for other drivers we can see almost no effect of the system on their lane-changing frequencies or even sometimes an increase of the lane-changing frequency. To test the significance of the differences the Wilcoxon Signed Rank Tests (Wilcoxon, 1945) was used. According to the Wilcoxon Signed Rank Test there was statistically no significant difference in the lane-changing frequency at the 95% confidence level. However, it is important to note that while the general traffic conditions were found to be similar in the two drives it is still not possible to capture cases where the subject vehicle was interrupted by a slow vehicle at a macro level analysis. In order to assure exactly similar conditions, assessment of the video records should be taken during the tests to identify those situations where drivers’ speed and position may have been affected by adjacent vehicles, i.e. due to non-system reasons.

Table 4: Frequency of lane-changing behaviour

<table>
<thead>
<tr>
<th>Driver</th>
<th>Gender</th>
<th>No. lane-changes</th>
<th>Driver</th>
<th>Gender</th>
<th>No. lane-changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Off</td>
<td>On</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
<td>10</td>
<td>4</td>
<td>25</td>
<td>Female</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>12</td>
<td>12</td>
<td>27</td>
<td>Male</td>
</tr>
<tr>
<td>5</td>
<td>Female</td>
<td>8</td>
<td>4</td>
<td>28</td>
<td>Female</td>
</tr>
<tr>
<td>7</td>
<td>Male</td>
<td>4</td>
<td>8</td>
<td>29</td>
<td>Female</td>
</tr>
<tr>
<td>8</td>
<td>Female</td>
<td>12</td>
<td>12</td>
<td>30</td>
<td>Male</td>
</tr>
<tr>
<td>9</td>
<td>Male</td>
<td>6</td>
<td>6</td>
<td>32</td>
<td>Male</td>
</tr>
<tr>
<td>10</td>
<td>Male</td>
<td>4</td>
<td>8</td>
<td>33</td>
<td>Female</td>
</tr>
<tr>
<td>11</td>
<td>Male</td>
<td>6</td>
<td>10</td>
<td>36</td>
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</tr>
<tr>
<td>12</td>
<td>Male</td>
<td>0</td>
<td>2</td>
<td>37</td>
<td>Male</td>
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<tr>
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<td>Female</td>
<td>6</td>
<td>4</td>
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</tr>
<tr>
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<td>Female</td>
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<td>4</td>
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<tr>
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<td>6</td>
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<td>Female</td>
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<tr>
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<td>4</td>
<td>50</td>
<td>Female</td>
</tr>
<tr>
<td>24</td>
<td>Male</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average and standard deviation of the number of lane-changes:

Male drivers - On: 5.6 (±3.14)  Female drivers - On: 5.40 (±2.68)
Male drivers - Off: 6.0 (±3.70)  Female drivers - Off: 6.20 (±2.82)
3.5 Headway distribution

Too short car-following distances (headways) contribute to a large proportion of collisions (Adell et al., 2010). Headway distributions were created for each driver in both drives (system on and system off). Figure 9 presents the headway distribution comparison for all the drivers when the system was activated versus when it was inactivated:

As can be seen from Figure 9 the distribution of the headways when the system is on is shifted to the right compared to when the system is off. In order to test if this difference is statistically significant the Kolmogorov-Smirnov test (KS-test) was conducted. The result of the KS test at the 95% confidence level indicates that there is a strong evidence against the null hypothesis (test statistic = 0.062), which means that the two distributions are quite different. In other words drivers with the system on keep longer headway distances from the vehicle in front of them, which is expected to have a positive impact on safety.

4. CONCLUSIONS AND FURTHER RESEARCH

An analysis of the impact of the infrastructure-to-vehicle system on the driver behavior in the Austrian test site was conducted. This analysis included drivers’ speed and lane-changing profiles, acceleration noise and headway distribution. The methodology of the analysis included first an examination of whether the traffic conditions were similar in both drives with the system activated and with system inactivated before analysing the impact of the system on the driver behavior.

It was found that the average traffic conditions for most drivers were almost similar when the system was on versus when it was off. On average drivers decreased their driving speeds when
activating the system. No significant differences were found between drivers’ acceleration noise and lane-changing frequencies when the system was on versus when it was off. An evidence of increased headways between the drivers and the vehicle in front of them was found when the system was activated compared to when it was inactivated. It is expected that the reduced driving speeds and increased headways when driving with the system will have a positive impact on traffic safety.

From this it can be concluded that the provision of dynamic and updated traffic information to drivers by infrastructure-to-vehicle communication can have a significant impact on the driver behavior. It was not expected from the drivers who used the system to change their driving behavior to a large extent since they should also adapt their behavior to the average traffic behavior otherwise a sharp change might cause an increase of the risk to be involved in critical situations.

While the results reported here are promising, this work has limitations that merit further research in several directions. These limitations include: (1) a two year field operational test with a statistically sound sampling of European sub-cultures is needed to generate reliable data before rolling-out co-operative services on a European-wide scale. A minimum duration of two years is needed to enable individual test drivers to experience the system under all weather conditions as well as in northern European winters and southern European summer holiday traffic conditions. Furthermore field tests should consider a broad spectrum of cars under all maintenance conditions to generate valid data and enhance the statistical power; (2) the field tests in this study included no audio tones when a message was provided. The audio tone is a crucial requirement in combination with the depiction of safety related services. Drivers are expected to notice and react earlier and also it would be of additional help in dense traffic where the driver’s attention is occupied with a more accurate driving. Therefore future field tests should include an audio tone; (3) compliance rates to the system messages; (4) simulation analysis to test the impact of the system at different penetration levels of the system and to investigate what penetration rate of co-operative services is needed in order to optimize traffic in terms of safety and efficiency; (5) it would be interesting to analyze reactions to specific messages such as: car accident in front or congestion ahead, however, as 100% of the message in the Austrian site were not real messages it was impossible to conduct such analysis in this site, however this should be considered in future research; (6) the analysis in this paper was focused at the macro level, an analysis of the results at the micro level might reveal other significant differences between driving with the system activated and with the system inactivated.

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REFERENCES


GEOSIMULATION, ACTIVITY MICROSIMULATION AND SAFETY ANALYSIS: COMMONALITIES AND THE POTENTIAL GAIN IN MERGING ANALYTICAL METHODS

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Abstract. Highway safety analysis and transportation system simulation share a wide spectrum of spatial and temporal resolutions. At the very fine level of space, forensic engineering techniques for accident reconstruction are applied to individual vehicles and their components, the analysis of conflicts among vehicles and traffic streams operates at the level of roadway intersections and segments of highways, risk assessments as hot spots operate at the level of a city or even higher geographical subdivisions. Similarly along the time dimension we have analyses of second by second movements, time of day of accident occurrence, weekly and monthly accident analysis, and the accident involvement and severity in the life span of individuals. Safety analysis also considers social determinants of accident occurrence and risk as well as perception and attitudes towards risk. Geosimulation and activity microsimulation (activity analysis herein) are also developed at similar levels of spatio-temporal multiplicity to study interactions among persons and to develop synoptic measures of quality of life, transportation system performance, and policy impact analysis. As one would expect there are many potential opportunities for synergy between these two fields of research and practice. On the one hand, activity analysis offers a tremendous amount of data about determinants of accident risk and background information where and when accidents occur. Safety analysis can also gain from a modeling movement to finer social, spatial, and temporal resolution for assessing accident risk in a more detailed, comprehensive, and informative way. On the other hand, perception of risk and attitudes toward risk may inform activity microsimulation in new ways never attempted in the past when theory development and data collection are done with the dual objective of informing safety and activity analysis. In this paper an overview of the methods in the two fields is provided first. This is followed by examples of potential analysis that can be done when merging analytical methods from safety and activity microsimulation. The paper concludes with data collection examples for this type of analysis and a few ideas of next steps in research.

Keywords: Safety, Activities, Microsimulation

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1. INTRODUCTION

Transportation safety analysis aims at surveying events that can cause death, injury, and property damage. It also aims at understanding the causes and contributing factors to accident occurrence, severity of accident occurrence, risk and exposure to risk, and the actions required to mitigate all these. Geosimulation and activity microsimulation create virtual worlds of transportation systems and the agents living within these systems to assess land use and transportation policies at a very fine spatial and temporal resolutions (named activity analysis herein). These relatively new methods can provide a variety of data for more informed safety analysis. This paper examines briefly surface transportation safety analysis and possible synergies with activity analysis. The aim is to illustrate the possibility of using similar analytical methods, sharing data to enhance the methods used, and ultimately build planning tools that enhance quality of life and minimize accident occurrence jointly.

As one would expect surface transportation safety analysis examines a variety of “agents” moving within the transportation system. These agents are individual vehicles (e.g., passenger cars or commercial vehicles) operated by drivers of a wide range of training and experience in a multitude of environments and individual psychophysical conditions. Moreover, operational and policy analyses of the behavior and performance of these agents and the performance of the system within which they act requires the use of a wide spectrum of spatial and temporal analytical fidelity and resolutions (Huang and Abdel-Aty, 2010). At the very fine level of space, forensic engineering techniques for accident reconstruction are applied to individual accidents with key objective the understanding of the physical and human factor causes of accident occurrence (Brach and Brach, 2005). At a somewhat coarser spatial resolution of a traffic system component, risk assessment uses a variety of tools to examine roadway intersections (e.g., analysis of conflicts among the different movements) and traffic and highway design principles to minimize accident occurrence at intersections and at different elements of roadways (FHWA, 2011).

At higher levels of spatial abstraction such as an urban environment we also aim at identifying high risk locations in a city (Nitz et al., 1995; Schneider et al., 2004), and even perform spatial analysis of much larger geographical regions such as counties of a US state or regional departments in a country (Aguero-Valverde and Jovanis, 2006; Chappellon and Lassare, 2010). Based on these analyses preventive designs and policies can be developed that change by jurisdiction to match local circumstances and the resident population (e.g., the resident mix of very old and very young drivers). Similarly along the time dimension, we have analysis of time of day of accident occurrence that shows there are specific times during a day during which most accidents occur (Folkard, 1997), we also find weekly and monthly accident analysis showing seasonality (Langlois et al., 1985), and studies of accident involvement and severity in the life span of individuals (e.g., the well-known high fatality rate of the very young and the very old – see Abdel-Aty et al., 1998) but also the differential rates of changing/improving accident occurrence among different age groups (Cheung and McCartt, 2011). We also have other “time” dimensions such as time-to-task, which is the duration of driving before an accident occurs, and the combination of temporal on and off driving patterns.
Many macro-temporal and daily rhythms are correlated and they also contain a variety of spatial and social context informants (Nitz et al., 1995; Radun and Radun, 2006). In fact, safety analysis also considers social determinants of accident occurrence and risk as well as perception and attitudes towards risk with many exogenous and endogenous determinants (Milia et al., 2011). All this motivates the increasing use of analytical methods that are more sophisticated, complex, but also more informative than simple descriptive statistics or basic regression techniques (see the review in Huang and Abdel-Aty, 2010, and the injury severity model review by Christoforou et al., 2010). The conference for which this paper was written is the ultimate demonstration of the complexity of safety analysis and the need for approaches that attach different issues within this field with multiple analytical tools. A similar increase in sophistication happens in urban transportation system simulation and focus here on one quantitative type of analysis.

Transportation system simulation, particularly in regional travel model building, aims at the development of a planning support system that allows planning agencies to build scenarios of change. These scenarios are used in regional transportation plans to draw policy pathways of possible actions and to assess the potential success of these policies (e.g., the introduction of electric vehicles, change in land use to increase density and mix diversity, introduction of pricing schemes for roadway and city centers). The use of this type of models can be traced back to the 1950s when the freeway beltways were planned for Chicago, Detroit, and Pittsburgh in the US. At that time simulation models were mostly based on spatial interaction regional science theories aiming at linking land use to transportation system performance. Over time we experienced a gradual movement away from coarse level analyses and increasing acceptance of behavioral theories and analytical methods motivated by policy questions moving away from the construction of major projects and closer to policies that require understanding of markets.

The use of these simulation models is increasing among practitioners and it is reaching unprecedented sophistication in terms of theories, data collection, and modeling and simulation techniques. A detailed review of the models used in terms of the wide spectrum of spatial, temporal, and social dimensions is provided for integrated land use transportation models by Hunt et al. (2005) and for activity and travel behavior models by Henson et al. (2009). The plethora of advances reviewed in those papers includes models and experiments to create computerized virtual worlds and synthetic schedules at the most elementary level of decision making unit using microsimulation and computational process models; data collection methods and new methods to collect extreme details about behavior and to estimate, validate, and verify models using advanced hardware, software, and data analysis techniques; and integration of models from different domains to reflect additional interdependencies among land use, transportation and telecommunications. Most important for the discussion here is to realize that recent developments of model building and regional simulation, in practice and in research laboratories, have created methods that simulate the life of people in a variety of contexts from the very long term to represent choices individuals make to form households and purchase homes to the extremely short term such as the route each person follows from an origin to a destination (see the examples in Salvini and Miller, 2005; Bradley
et al., 2010). In this way one can perform activity and travel demand analysis at any level of spatial and temporal aggregation.

Very important is also the use of synthetic population generation to recreate all residents and travelers of a region and simulate their behavior. In parallel, these same models are used in forecasting and they are integrated with land use and demographic models to create scenarios of possible change in space and time (called Geosimulation herein). In this way future populations are created for a given region and through simulation each person is assigned an activity and travel schedule under different scenarios of policies. In the next section an illustration of a typical regional simulation model system is offered. This is followed by a section on possible synergies between the two analytical fields.

2. GEOSIMULATION AND ACTIVITY MICROSIMULATION

Policy analysis is often done using software that creates scenarios of change to assess the impact of proposed policies on the environment. These are tools that are broadly defined as Planning Support Systems (see Geertman and Stillwell, 2004, for a wide ranging review). In modeling and simulation for travel behavior analysis these tools have a sixty year old history of development and they span a multiplicity of disciplines (see the review by Henson et al., 2009). Most important, however, for the review here is a modeling and simulation trend to build “integrated” models. Integration in this case is intended as the connection of models that were designed for different purposes but as they are applied for different time periods one model needs to provide input for another. To be more precise these are not just models but groups of models intended to perform major functions. For simplicity of presentation let us consider a case study of a large hypothetical region of many millions of residents. Typical simulation for this region will contain a backbone string of models that aims at recreating in a somewhat abstract form what happens in the region today and then create scenarios of future development that includes case studies of continuing current policies and scenarios of introducing major policy changes.

Schematically, Figure 1 shows a typical overall model structure that includes a few major components in the way they are practiced in a few leading US planning organizations. The entire modeling process starts with population synthesis that attempts to recreate the resident households and their household members. This is a person-by-person and household-by-household recreation based on a basic method called iterative proportional fitting algorithm and enhanced to account for data imperfections as in Beckman et al. (1996) for the use in TRANSIMS, Guo and Bhat (2007), Auld et al. (2008), and Ye et al. (2009). The input to this software and block of methods is the spatial organization of the simulated area in the form of geographic zone-specific univariate distributions of person and household characteristics provided by the US Census and other demographic projections provided by other agencies. For future years these distributions are forecasts based on either externally provided data
and/or internally simulated data using population evolution models that modify households as they progress in time.

The outputs from this block of models are persons and households and a short list of their characteristics. These need to be enriched by adding each person’s education level, driver’s license holding, and employment and their relevant longer term choices such as location of schools and jobs. This is the task of the block labeled long term choices. In the first year of the simulation workers are identified using a variety of regression models and lookup tables that allow us to assign these attributes in a probabilistic manner. Using these characteristics, household income is computed as a function of its major determinants (e.g., race, presence of elderly individuals, education level of members of households, and employment industry of workers in the household). In some applications we also find residential tenure models (i.e., to own or rent a dwelling unit) and housing type models (i.e., assigning households to specific dwelling units type such as single-family detached, single-family attached, apartment, and mobile home or trailer). In this portion of the simulation an important model is car ownership and type for each household. This eventually in the simulation is used to predict the composition of non-commercial regional vehicle fleet mix that is used as input to the emission estimation software later in the sequence schema. In one such application for California, models predict for each household vehicle holdings, body types, fuel types, age, and use

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**Figure 1: Typical Geosimulation Schema**

The diagram shows the sequence of models and their outputs. The baseline year starts with population synthesis, followed by long-term choices, daily schedules, and travel choices. This leads to household evolution, land use, regional economy, and accessibility by time of day. The output is then used to predict spatial distribution of people and activities, which is further refined with long-term choices, daily schedules, and travel choices. This process is repeated every year, with the addition of new data and the refinement of existing models.
(miles) simultaneously. Predicted household vehicles are then allocated to drivers in each household based on a suitably designed probabilistic model.

In this way the simulation cascade on the left hand side of Figure 1 produces the spatial distribution of all the residents in a region with as many social and demographic characteristics as desired and located at any geographic level needed, provided suitable methods to allocate residents to each level are created. This in essence yields a virtual Census of microdata that can be “mined” for information and spatial analysis and it can also be used to draw samples for in-depth analysis. It is also possible to focus (and zoom into) a specific subarea (e.g., a city, neighborhood, or even a roadway segment) to perform more detailed analysis and modeling or to develop synoptic measures at different spatial or temporal summaries. All this is then used as input for models that simulate the activity and schedule of persons and their households for multi-day periods (Auld and Mohammadian, 2009) or just a single day depending on the data available and planning applications.

For a given day the next set of models of Figure 1 (block labelled daily schedules and choices) simulates the life of persons by recreating their daily activities and travel by obeying relationships of interdependence within a household (e.g., assigning parents to give rides to children going to school, allocating time to household grocery shopping, and so forth). The models in this way create a complete description of the movement of each individual over space and time that is congruent with the movements of the rest of the household in which each person belongs. In this way, for each person, we have information about the type of activity, when, where, how long, with whom, in what sequence, and interrelationships with other persons and locations in the activity-travel engagement pattern. The end result resembles the data from a complete household travel diary.

Then, the output from this block is used in different ways. The data are analyzed to identify different behaviors or they can be converted into inputs for a routing and traffic assignment model to produce predicted traffic volumes on highway links. This can be done using the detailed time of day scheduling of activities. For example, in an application for the Southern California Association of Government, which is the largest US planning agency, we have developed policy scenarios and studied policy impacts on timing decisions of individuals (e.g., advancing or postponing the starting time of their trips) and changes in destination choices throughout a day. Figure 2 provides an example of this output from Santa Monica, California, which is a community along the Pacific Ocean. We also made assessments of pricing policies on a variety of social and demographic segments to illustrate the asymmetric impact of these policies. In addition, we coupled this output with the more traditional four-step model routines to perform traffic assignment and emission estimation. Moreover, we are also advancing along the path of using detailed routing algorithms that can track in the simulation individual vehicles and eventually compute emissions at fine spatial and temporal resolution. Subregions with all the detailed network and traffic data can also be extracted to use in traffic simulation.
The models of the middle panel of Figure 1 take the spatial distribution of residents and businesses in year t=0 and evolve them to the next year using again probabilistic models and a variety of urban economy simulation techniques (Hunt et al., 2005). The right hand side panel of Figure 1 is a repetition of the first year repeatedly applied for many years (there are currently running scenarios to the year 2035) at different levels of resolution depending on the analytical needs of the policy one wants to study.

3. SYNERGIES

The brief safety analysis review in the introduction and the example of the previous section hint to a few major elements that safety analysis and activity analysis have in common. Ideally, both behavioral models and safety models should be estimated using longitudinal data and the specialized literature has a few examples that also use multilevel and multiperiod regression models. In addition, the Transportation Research Board’s Strategic Highway Research Program 2 is currently funding a longitudinal naturalistic driving data collection study in many different driving environments to provide this type of data (SHRP, 2010). Similarly, for activity-travel behavior model building some of the most advanced methods are based on Geographic Positioning Systems combined with trip maker interviews to understand activity and travel scheduling as well as interactions among travelers spanning relatively longer periods (Axhausen et al., 2002; Auld and Mohammadian, 2009). This activity of longitudinal data collection complements the more traditional panel surveys that interview repeatedly households and their members over time to establish the determinants of their propensities to change behavior among years (Golob et al., 1997). Equally important is the “width” of data collection in which the subjects are observed in different spatial contexts and in fact this is a dimension recognized as extremely important in most industrialized countries with data collection that is spread throughout their territory.

As research and practice progress to more sophisticated methods we also realize that a third dimension in data collection, “depth”, is also required to provide context and inform about additional determinants of behavior and safety related events. In safety we know that social and situational circumstances impact a driver’s performance. Similarly, in activity and travel behavior situational factors are very important in understanding behavioral paradoxes. In fact, we see in safety analysis and travel behavior increasing acceptance that values and attitudes should be identified and relevant data collected to explain otherwise unexplainable occurrences. One can also envision household surveys designed to collect data for safety and behavior jointly to achieve economies of scale and to provide a common platform for cross-fertilization between the two fields of study. Data analysis as one would expect for safety analysis and travel behavior analysis employ the same multivariate regression models and in typical transportation statistics courses are taught with examples from both fields. In fact we are moving rapidly to statistical modeling methods that enable analysis of multiple causes and multiple effects recognizing the multiple scales in data structures and these somewhat more advanced techniques are also becoming practice. In addition, mapping and spatial statistics
techniques that are used to identify locations of special interest (e.g., hot spots vs high accessibility locations) or to explain phenomena that display spatial and temporal correlation and heterogeneity are also used in both fields.

**Figure 2:** Output of the activity analysis simulator SimAGENT
As research and practice progress to more sophisticated methods we also realize that a third dimension in data collection, “depth”, is also required to provide context and inform about additional determinants of behavior and safety related events. In safety we know that social and situational circumstances impact a driver’s performance. Similarly, in activity and travel behavior situational factors are very important in understanding behavioral paradoxes. In fact, we see in safety analysis and travel behavior increasing acceptance that values and attitudes should be identified and relevant data collected to explain otherwise unexplainable occurrences. One can also envision household surveys designed to collect data for safety and behavior jointly to achieve economies of scale and to provide a common platform for cross-fertilization between the two fields of study. Data analysis as one would expect for safety analysis and travel behavior analysis employ the same multivariate regression models and in typical transportation statistics courses are taught with examples from both fields. In fact we are moving rapidly to statistical modeling methods that enable analysis of multiple causes and multiple effects recognizing the multiple scales in data structures and these somewhat more advanced techniques are also becoming practice. In addition, mapping and spatial statistics techniques that are used to identify locations of special interest (e.g., hot spots vs high accessibility locations) or to explain phenomena that display spatial and temporal correlation and heterogeneity are also used in both fields.

Activity analysis, however, offers an additional unique opportunity for safety analysis because it provides added background to the different events (accidents, fatalities, injuries) with detailed statistics about population, infrastructure characteristics, and changes in the environment. Therefore, a few of the easiest to accomplish tasks are: (1) Develop exposure statistics that are based of the amount of traveling (vehicle kilometers, trips, or even congestion levels) and data on accident occurrence; (2) Perform risk assessments in space, time, and social groups and any combination of the above using the space-time evolution of geosimulation and any observed data on accident occurrence; (3) Develop background maps when studying risk based on population composition at specific localities and its change over time, including car ownership and type as well as fleet mix and its spatiotemporal evolution; and (4) Study changes through data matching and secondary data analysis in population values, norms, and attitudes and their correlation to specific behaviors as well as accident occurrence.

In addition to these data analytic research tasks there are other potential areas of synergy that can benefit both research areas. The first is in the development of a comprehensive conceptual framework that combines safety and behavior objectives (e.g., ecological socioeconomic models of change). Bronfenbrenner’s Biocological model of change is one candidate. The model is based on a developmental theory with its core the zone of proximal development: Human development in the life span is a journey through increasingly more complex reciprocal interaction between a human organism and other organisms, objects, and symbols in its environment (Vygotsky, 1978). This model is known as the Person-Process-Context-Time (PPCT) model (Bronfenbrenner, 2005). Person is defined as person factors representing individual differences in physiological and psychological states, tempo, and biological intensity of reactions. Process is the stream of psychological acts that are called
proximal processes and considered to be the primary engines of development. Context is the physical, socio-emotional, and mental setting in which behavior takes place. Time is ontogenetic (person development) time, cohort time, and historical time. Proximal and distal in terms of relationships in microsystems, mesosystems, exosystems, and macrosystems. I used this model to illustrate the need to think about car ownership and mobility from a developmental perspective and illustrated the continuity of behavioral processes in the life span of mobility decisions. Of course this is not the only conceptual framework that may apply to both settings but it is worth examining further.

With or without a common theoretical framework we can also envision a data collection activity/project that aims at satisfying objectives in a general inventory building effort that requires a large sample to represent the entire population. This type of data collection can happen immediately after major Census campaigns with the objective of describing the behavior in an area, state, or the entire country. Attached to this major “main” survey one can imagine the creation of “satellite” surveys with a much smaller sample that collect in-depth information about a focused topic (e.g., attitudes toward driving). The satellite design is such that enables expanding the answers to the entire population extracting a same sample from the sampling frame of the main survey. The combination of a set of safety related satellite surveys, activity and travel surveys, and a main household survey yields data of unprecedented coverage of diverse topics and may offer unique opportunities for research that bridges across different fields of inquiry.

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MACROSCOPIC TRAFFIC SAFETY DATA ANALYSIS AND PREDICTION

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\textbf{Abstract.} Macroscopic modeling of traffic safety can provide insight into this global health problem and help policy-makers in both under-developed and developing countries adjust their policies in reaction to the changing conditions. The objective of this paper is to illustrate how macroscopic road safety data analysis can be useful in explaining road safety trends and patterns and thus supporting road safety policies and initiatives. Statistical techniques for the macroscopic analysis of road safety data are presented, followed by case study results from European countries. Practical issues, such as measures of goodness of fit and model diagnostics are also discussed. A discussion on emerging trends and state-of-the-art in the field concludes the paper.

\textbf{Keywords:} Road Safety, Macroscopic Analysis, Generalized Linear Models, Non-linear Models, State-space Models

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1. INTRODUCTION

Modeling road safety is a complex task, which needs to consider both the quantifiable impact of specific parameters, as well as the underlying trends that cannot always be measured or observed. The sensitivity of users to road safety campaigns, the improved quality of the vehicle fleet, the improvement of the driving skills of the general population, and the overall improvement of the condition of the road network are only some of the aspects that cannot be easily modeled directly. Therefore, modeling should consider both measurable parameters and the dimension of time, which embodies all remaining parameters.

Macroscopic modeling can provide insight into this problem and support policy-makers in developing countries to adjust their policies in reaction to the changing macroscopic conditions. For example, developing insight e.g. regarding the expected breakpoints in road safety fatality trends, as identified from the developed countries time series, can be applied to performing more accurate future predictions for developing countries (which have still not reached the motorization levels of developed countries). Macroscopic, in this context, implies to the analysis of aggregate (monthly or annual) accident and fatality data, rather than the more detailed and disaggregate (in-depth) analysis of individual accidents.

The objective of this paper is to illustrate how macroscopic road safety data analysis can be useful in explaining road safety trends and patterns and thus supporting road safety policies and initiatives. Several types of models are presented in this context, including generalized linear models, non-linear models and state-space models. The paper follows a “why-how-what” approach, motivating the need for this analysis (why), showing which techniques can be used (how) and finally using selected case study results to illustrate typical results of the analysis (what). In this way, the reader is exposed to a thorough coverage of the models that can be useful in the context of macroscopic data analysis, so that it is then possible to follow specific research directions of interest.

The remainder of this paper starts with a literature review, summarizing the use of statistical techniques for the macroscopic analysis of road safety data, indicative examples of which are then presented, followed by a discussion of their key properties. The methods that can be used to analyse macroscopic road safety data are then presented; time series models are first introduced, with an emphasis on their functional form (linear, generalized linear and non-linear models). State-space models are also introduced, along with the concepts of multivariate and multilevel models. These approaches are then demonstrated using case study results from Greece and other European countries. A discussion on emerging trends and state-of-the-art in the field concludes the paper.

2. LITERATURE REVIEW

A macroscopic road-safety model commonly used in the late 60s was proposed by Smeed (1968) linking the number of fatalities with the number of vehicles and the population. Jacobs (1986) repeated this analysis for a number of developed and developing countries using data between 1968
and 1975 while Gharaybeh (1994) applied the same formula to assess the development of road safety in Jordan, relative to that of other middle-eastern and developing countries. Many studies have criticised Smeed’s model because it only concentrates on the motorisation level of country and ignores the impact of other variables (cf. Broughton, 1991; Andreassen, 1991; while another useful review is provided by COST329, 2004, where a detailed analysis of the debate surrounding Smeed’s formulas and analysis is available).

The comparative analysis of macroscopic trends in road-safety-related issues among countries and regions has attracted the attention of researchers for several decades. A critical review of a number of approaches for modelling road safety trends can be found in Hakim et al. (1991) and Oppe (1989). A review of these concerns, as well as several alternative approaches for the development of road safety models is provided by Al-Haji (2007). Lassarre (2001) presented an analysis of ten European countries’ progress in road safety by means of a structural (local linear trend) model, yielding two adjusted trends, one deterministic and one stochastic. Intervention functions related to the major road safety measures were introduced, while an indicator of the rate of progress given risk exposure trends (vehicle-km travelled) was defined.

Page (2001) presented an exponential formula that yields fatalities as the product of all explanatory variables’ influence, which could be transformed to a simple algebraic form (first order polynomial with an intercept) by taking the logarithm of both sides. Models with several exogenous variables are developed and attempts to rank countries based on their road mortality level were made. Beenstock and Gafni (2000) show that there is a relationship between the downward trend in the rate of road accidents in Israel and other countries and suggest that this reflects the international propagation of road safety technology as it is embodied in motor vehicles and road design, rather than parochial road safety policy. Van Beeck et al. (2000) examine the association between prosperity and traffic accident mortality in industrialized countries in a long-term perspective (1962-1990) and find that in the long-term the relation between prosperity and traffic accident mortality appears to be non-linear. Kopits and Cropper (2005) use linear and log-linear forms to model region specific trends of traffic fatality risk and per income growth using panel data from 1963 to 1999 for 88 countries. Abbas (2004) compares the road safety of Egypt with that of other Arab nations and G-7 countries, and develops predictive models for road safety.

Other analyses entail a specific road safety related problem, applying international macroscopic comparison techniques to a subset of road network users, such as novice or young drivers. Twisk and Stacey (2007) presented a general study of identified trends in young drivers risk and associated countermeasures in certain European countries. The relationship between general safety levels and young driver risks is stressed: the impact of general safety measures on the subgroup is greater than that of measures specifically targeting young drivers, especially for poorly performing countries.

Another big topic of research relates to the factors that affect road safety and the way that this impact is applied. Several researchers (Hakim et al., 1991; Cameron et al., 1993; Newstead et al., 1995; Lord, 2002), using road accident statistics, have presumed that the explanatory variables have a multiplicative effect on accidents (as opposed to e.g. additive). Henning-Hager (1986) presented a non-linear regression model to express the relationship between traffic fatalities, traffic volumes and
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the quality of transportation supply and demand in urban areas. Qin et al. (2004) showed that the relationship between crashes and the daily volume (AADT) is non-linear and varies by crash type, and is significantly different from the relationship between crashes and segment length for all crash types. On the other hand, vehicle fleet may affect the number of fatalities, given that an increase in the vehicle number leads to higher average traffic volumes, which in turn may translate to a reduction in average speeds. Moreover, an increase of the vehicle fleet and total mileage in a country increases the need for more and safer road environment, in which the drivers' behaviour tends to be also better (Koornstra, 1992; 1997).

Clearly, the topic of macroscopic road safety modeling and forecasting is an active research area, where active debate is taking place and interesting developments are still being made.

3. A LOOK AT THE DATA – (WHY?)

In order to understand why it is useful (and practical) to analyse macroscopic road safety data, as well as some of the caveats involved in doing so, it is useful to look at some indicative data that can be used for demonstration purposes. Figure 1 presents the number of persons killed and seriously injured per month in Greece for the period between 1998 and 2004 (demonstrating the clear road safety improvements obtained between 2000 and 2004 in Greece). Besides a rather clear decreasing trend, perhaps the most striking feature of this graph is the periodicity (annual seasonality) in the data. A failure to identify, capture and analyse this trend can result in loss of understanding of the underlying phenomenon.

Figure 1: Example of seasonal trends / periodicity in macroscopic road safety data
Many statistical techniques assume independence of observations. Road safety data, however, as shown in Figure 1, are often in the form of time-series of counts observed during successive time periods, e.g. days, months or years. In practice, such observations often tend to be correlated with the respective observations from previous years, months or days, i.e. are usually temporally correlated. The linear regression model - an attractive and simple method - has stringent assumptions that are therefore usually violated when applied to road safety data. Another similar assumption is that of linearity (in the parameters). In later sections, alternative modeling assumptions are presented within the more flexible generalized linear modeling and non-linear regression frameworks.

Figure 2 presents an overview of key road safety indicators (personal risk defined as fatalities per 100,000 population) in several European countries. The main observation that one can make from this data is that – in general - there seems to be an increasing trend in road accident fatalities/personal risk up to a point where this trend is reversed. Understanding why this breakpoint and trend reversal happens is clearly an important element of improving road safety in countries that have yet not experienced this level.

Exposure data are very useful in road safety analysis, as they help illustrate the underlying trends that lead to the road safety situation. Key exposure measures are the vehicle-kilometers or the person-kilometers traveled, or the time traveled. However, collecting or estimating exposure data is a much more difficult endeavor and these data are often unavailable for analysis. One way to overcome this limitation is to seek proxies, i.e. available (or more easily collectable) data that have a high correlation with the actual exposure data. Examples of these are the number of vehicles in circulation or the amount of fuel sold at gas stations.

In this case, as shown in the bottom subfigure of Figure 2, motorization data can be used as a proxy to exposure data. The data suggest that there may be a point, as the motorization level increases, that personal risk stops increasing and starts to decrease. If this point can be located, then this may mean that road safety decision makers in countries that have not yet reached that breakpoint, might be able to foresee it and incorporate it in their strategies and policies. Alternatively, knowing about this breakpoint might protect road safety decision makers in countries that have not yet reached that point, from believing that they have achieved a road safety breakthrough, when they reach it.

Furthermore, it is worth noting that several countries (such as the Czech Republic and Poland in Figure 2) show more than one clear peaks. (In this case, one could argue that they are due to the “opening” of their economies in the late 80s/early 90s, but of course further exploration and verification is required.) Similarly, one can identify smaller peaks in all subfigures and explaining them could lead to the development of interesting insight into the road safety of these countries.
The increased understanding of trends and the systematic steering of road safety related policies and campaigns could improve their effectiveness. For example, previous research in Greece analysing data at the county level has shown a significant 2-months time halo effect of enforcement (Agapakis and Mygiaki, 2003), which – if not explicitly considered- may result in misleading observations regarding the effectiveness of the considered measures. Especially as regards the distance halo effect, this would concern the case that the effect of enforcement would “cross” a county’s borders to the neighbouring counties of the same or neighbouring regions. However, given that the intensification
of enforcement was not individually decided by local authorities, but was instead applied on all counties of Greece, it is considered that the cross-county effects of neighbouring counties (and regions) do not significantly affect the within-county (or region) effects.

Of course, it needs to be clearly stated that aggregated, macroscopic data are only one aspect of the overall topic of road safety that can provide only part of the answer. Other types of data sources that can shed light from different angles into the parameters that govern road safety include in-depth accident data (Yannis et al., 2010) and medical information data (Petridou et al., 2009).

4. METHODS - (HOW?)

Time-series methods have been used to account for and correct temporal correlation, such as that observed typically in macroscopic road-safety data. It is recognized however that traffic fatality risk also depends on other parameters, such as vehicle quality, traffic safety initiatives and regulations, and intensity of police enforcement, which however are not expected to affect the results of such macroscopic analysis. Therefore, this section includes a presentation of methodological instruments that can be used to develop models linking road safety measures and related explanatory data in flexible ways and thus possibly offer insight on the existing or future trends for the same or other environments.

4.1 Generalized linear models

The linear regression model is simple, elegant and efficient, but it is subject to the fairly stringent Gauss-Markov assumptions (Washington et al., 2003). If these assumptions hold, it can be shown that the solution obtained by minimizing the sum of squared residuals (‘least squares’) is BLUE, i.e. best linear unbiased estimator. In other words, it is unbiased and has the lowest total variance among all unbiased linear estimators. These assumptions, however, are often violated in practice. Yannis et al. (2007a) illustrate how two of these violations can be explicitly considered, in particular correlated disturbances; and non-normal error structures. The choice of these two violations is not arbitrary; instead it is motivated by the fact that these two violations are more relevant to the nature (time-series count data) of the road safety data. Generalized linear models (GLM), a generalization of the linear regression, can be used to overcome the restriction on the normality of the error structure (McCullagh and Nelder, 1989; Dobson, 1990). Specific treatment of the application of GLM in the presence of serially correlated count data is also presented.

The objective of GLM is to allow for more flexible error structures, besides the Gaussian, which is assumed by –linear and nonlinear– regression. The Poisson distribution has been considered suitable to counts of car crashes for a long time (Nicholson and Wong, 1993). However, the Poisson model - while arguably more appropriate than the Gaussian- is not without weaknesses and technical difficulties. For example, the assumption of a pure Poisson error structure may prove inadequate in the presence of "overdispersed" data (Maycock and Hall, 1984). Overdispersion reflects more variation in the response than what is expected by the Poisson assumption, which assumes that the
variance equals the mean. An implication of overdispersion is that the estimates of the standard errors of the parameters will not be correct, and in fact the standard errors will be underestimated.

A straightforward approach to overcome this issue is to use a quasi-Poisson model; i.e. estimate a dispersion parameter for the Poisson model, thus allowing it to take values other than one. Maycock and Hall (1984) showed that the negative binomial model could also be used as an extension to the Poisson. Miaou (1994) and Wood (2002) have also used the negative binomial model for road safety applications. Maher and Summersgill (1996) mention that, quite often, the two approaches (quasi-Poisson and negative binomial) may provide very similar estimation results. One may then be tempted to think that the two models are equivalent and that it does not really matter which model is selected. Maher and Summersgill further warn that this may not be the case, as the two models may have different prediction properties, as measured, e.g. by the prediction error variance. Lord et al. (2005) present the results of an examination of the applicability of different models, including Poisson, negative binomial (or Poisson-gamma) and zero-inflated Poisson and negative binomial models, to the modeling of accident data.

Furthermore, the generalized linear modeling framework allows the consideration of a limited amount of non-linear structures in the developed models. For example, several researchers have shown that conventional linear regression models lack the distributional property to adequately describe collisions. This inadequacy is due to the random, discrete, non-negative, and typically sporadic nature that characterize the occurrence of vehicle collisions. Several researchers (including Hauer et al., 1988; Hakim et al., 1991; Cameron et al., 1993; Newstead et al., 1995), using road accident statistics, have presumed that the explanatory variables have a multiplicative effect on accidents, i.e. $y = ax_1 x_2^c$ (as opposed to e.g. additive, i.e. $y = a + bx_1 + cx_2$).

Examples of road safety applications involving the use of GLM in temporally correlated data include before/after analysis on the impact of red-light camera presence in crashes (Retting and Kyrychenko, 2001), investigation of relationships between accidents, flows and road or junction geometry, allowing for the presence of a trend over time in accident risk (Maher and Summersgill, 1996), traffic safety comparisons among several counties in France, where the time trend of each index (incidence and severity) is the same across counties and across road types (Amoros et al., 2003), and estimation of expected junction accidents (both in total and disaggregated by severity, road surface condition and lighting condition), which allow for the possibility of accident risk varying over time (Mountain et al., 1998). White and Washington (2001) developed a logistic regression model to gain insight into the relationship between enforcement and the use of safety restraint.

Generalized linear models facilitate the analysis of the effects of explanatory variables in a way that closely resembles the analysis of covariates in a standard linear model, but with less confining assumptions. This is achieved by specifying a link function, which links the systematic component of the linear model with a wider class of outcome variables and residual forms.

A key point in the development of GLM was the generalization of the normal distribution (on which the linear regression model relies) to the exponential family of distributions. This idea is not new and
was developed by Fisher (1934). Many well-known distributions belong to the exponential family, including –for example– the Poisson, normal, and binomial distributions. On the other hand, examples of well-known and widely used distributions that cannot be expressed in this form are the student’s t-distribution and the uniform distribution. The generalized linear model can be defined in terms of a set of independent random variables, each with a distribution from the exponential family.

4.2 Non-linear regression

Besides not conforming to the normality and other assumptions, many interesting processes may be more adequately modeled by non-linear models in practice. Linear regression models might have been a practical necessity in the past, but theoretical and computational developments have made the use of more elaborate (appropriate, accurate) methods practical. This can also be seen in road safety research, where while early work used multiple linear regression modeling (assuming normally distributed errors and homoscedasticity), over the past two decades there has been a departure from this model. In the previous section it was shown that generalized linear models allow for some nonlinear relationships to be modeled and relax some restrictions on the distributional assumptions of linear regression. Although many scientific and engineering processes can be described well using linear models, or other relatively simple types of models, there are many processes that are inherently nonlinear. Non-linear models can then be used (see e.g. Bates and Watts, 1988). The biggest advantage of nonlinear regression over many other techniques is the broad range of functions that can be fit.

A non-linear regression model can be written as:

\[ Y_m = f(x_m, \theta) + Z_m \]

where \( f \) is the expectation function, \( x_m \) is a vector of associated regressor variables or independent variables for the \( n \)th case, \( Y_m \) is the dependent variable, \( \theta \) is a vector of parameters to be estimated and \( Z_m \) are random disturbances. This model is of the same general form as the linear model, with the exception that the expected responses are nonlinear functions of the parameters. More formally, for non-linear models, at least one of the derivatives of the expectation function with respect to the parameters depends on at least one of the parameters. Non-linear regression has been widely used in road-safety related research (e.g. Hakim et al., 1991; Qin et al., 2004; among many others).

The Gauss-Markov assumptions from ordinary least square (OLS) procedures still apply in non-linear regression. Therefore, whenever time or distance is involved as a factor in a regression analysis, it is important to check the assumption of independent residuals. When the residuals are not independent, the model for the observations must be altered to account for dependence (e.g. moving average or autoregressive models of variable order).

Of course many other types of models find common use, but not all of them can be covered in detail in this article. Examples of such models include multilevel models, see e.g. Yannis et al., 2007b, multivariate models, see e.g. Yannis et al., 2008, for an example of multivariate multilevel models and state-space time-series analysis, see e.g. Commandeur and Koopman (2007) for an introduction to the topic with practical examples from road safety applications.
5. CASE STUDIES RESULTS – (WHAT?)

Examples of case study results demonstrating the modeling techniques introduced in the previous sections are presented in this section. The following cases are illustrated:

- Modeling of past data in order to obtain insight into past trends and breakpoints
- Modeling of data for prediction of future trends (using multiple techniques)
- Analysis of distributional assumptions through appropriate model diagnostics

All models have been estimated using the R Software for Statistical Computing (RDCT, 2011).

Analysing road safety data, such as those presented in Figure 2, can provide answers to many interesting questions from multiple perspectives. For example, from a road safety point of view, the following questions are interesting:

- Is the trend “universal”? What causes it?
- Does the trend happen at the same time in all countries?
- Can we use this to make predictions?

But even from a purely statistical point of view there are interesting question relating to the way that these structural changes can be estimated: starting from simple piece-wise regression, to estimation of consistent trends given an exogenous number of breakpoints, to simultaneous estimation of breakpoints and trends.

Figure 3 summarizes the estimated models using the data in Figure 2 (estimated using the segmented R package, Muggeo, 2003; 2008) providing a concise overview that can be used to draw conclusions, including the following:

- Different countries reached specific motorization rates at different (and sometimes distant) moments in time (temporal landmarks);
- Some of those countries exhibit a break point within a narrow range of motorization rate values, implying perhaps similar social and economic conditions and/or similar road safety culture;
- This range is different for certain subgroups among the examined countries, providing a hint that some grouping may be of meaning in geographic and socioeconomic context.

It is noted that the estimated models are linear (between breakpoints) and have been estimated using motorization rate as the explanatory variable (top subfigure). In the middle subfigure the same data are plotted against time for visualization purposes.

Before strong conclusions can be drawn based on the interpretation of such results, several considerations must be made to ensure that the models are indeed directly comparable, e.g. the data definition across countries. The numerator of the motorization rate (fatalities), for example, may be regarded more or less well-defined, after many efforts put at pan-European level for a common definition (30-day fatalities). As far as the denominator is concerned, however, available data of vehicle fleet show some slight discrepancies, e.g. the total number of vehicles in Spain reveals some irregular steps for specific years. Furthermore, each vehicle class is ruled by specific particularities, presumably implying a camouflage for systematic errors (Katsochis et al., 2006). The application of
common definitions should be further examined, so that there is an as-common-as-possible base for comparison.

Figure 3: All estimated models. Top → personal risk vs. motorization, Bottom → personal risk vs. time
(Adapted from Yannis et al., 2011)

Figure 4 shows the values predicted by the quasi-Poisson model. The dashed line shows the actual observed number of persons killed and seriously injured in Greece (excluding the two major metropolitan areas of Athens and Thessaloniki). The thick solid line represents the model predictions and 95% confidence intervals are also shown with thinner solid lines. The data show a clear seasonality, which is maintained even as the magnitude of the fatalities considerably decreases over time. Interpreting this annual periodicity is an involved process that requires additional data, relating e.g. to weather conditions. During the winter months fatalities decrease. The climate in Greece is mild, meaning that there are limited extreme dangerous conditions during the winter (e.g. frost, ice). On the other hand, daytime is shorter and in general people tend to limit their discretionary trips, which translates into a decrease in the vehicle-kilometers traveled. On the other hand, during the
summer the day is longer, people drive more and therefore are exposed more to risk. Furthermore, August is typically the vacation month in Greece. This may have several implications, e.g. more interurban and less urban traffic due to holidays, which may result in higher accident severity. Another possible cause for the increase in the fatalities in August is that drivers spend more time in unknown roads (while on vacation) or perhaps drive more while tired or after having consumed alcohol.

![Quasi-Poisson prediction](image)

**Figure 4: Quasi-Poisson model predictions (adapted from: Yannis et al., 2007a)**

State-space models offer another way to analyse macroscopic road safety data. Figure 5 presents the prediction results from a latent risk time-series (LRT) analysis of annual fatality and motorization data in Greece. Data from the period 1960-2008 have been used to make predictions up to 2020, including confidence intervals. The model specification allows for the incorporation of “interventions”, i.e. modeling points in time during which significant events occurred that influenced the evolution of the modeled phenomenon, shown by the broken lines in the model results. One question that arises from Figure 5 relates to the expanding margins of the prediction. Considering that road safety is a very complex process, affected by a number of natural causes (such as weather) and man-made effects (such as the economic conditions, the development of new motorways and traffic-related laws and regulations), it is reasonable to expect such a wide range. Disseminating this information to the general public, or even policy-makers and decision-makers, who might not be as comfortable with the underlying statistics, might require a different action plan. For example, instead of showing this one scenario, including prediction and confidence intervals, one might choose to show the prediction from a small number of scenarios (e.g. pessimistic, most likely, optimistic). Certainly, this is not a trivial exercise.
6. MODEL DIAGNOSTICS

The advent of powerful computers and sophisticated software has made the specification and estimation of complex model forms possible. However, with power come perils and responsibility, as it is not uncommon for researchers to estimate complex models without being fully aware of the assumptions that these models must comply to and the issues that originate from their violations. Knowing which diagnostics to use and how to apply and interpret them correctly is at least equally important as specifying and estimating a model. While a small number of model diagnostics are mentioned in this section, the appropriate tools for each model application should be sought from the relevant literature.

A large number of aggregate tests have been developed for the assessment of the goodness of fit of alternative models. However, there are several pitfalls that should be avoided when attempting to use such measures. For example, it should be noted that the usual tests for comparing nested models estimated using maximum likelihood estimation, such as the Akaike Information Criterion, AIC, (Akaike, 1973) or the Schwarz/ Bayesian Information Criterion, BIC, (Schwarz, 1978), are not suitable for comparison across these (non-nested) models. For example, AIC or BIC could be used to compare models with different numbers of parameters and the same likelihood function (except for the number of parameters), e.g. two normal or two Poisson models, but not one normal and one Poisson.

Some model diagnostics for the analysis of model residuals are presented in Figure 6 for two models: one in which the dependent variable is assumed to follow a Poisson distribution and one in which it is
assumed to follow a quasi-Poisson distribution. Normal scores plot (QQ plot) of standardized deviance residuals are presented in the top subfigures. The x-axis represents the standardized deviance residuals, while the y-axis represents the quantiles of the standard normal. The dotted line in the QQ plot (top) is the expected line if the standardized residuals are normally distributed, i.e. it is the line with intercept 0 and slope 1. If the deviance residuals were normally distributed, all points on the plot would fall on this dotted line. The Poisson model residuals clearly do not follow a normal distribution. The quasi-Poisson model deviance residuals, on the other hand, are practically normally distributed.

The bottom subfigures feature plots of the Cook statistics against the standardized leverages. The standardized leverage of the i-th observation $x_i$ can be computed as (Belsley et al., 1980):

$$ h_i = \frac{1}{n} + \frac{(x_i - \bar{x})}{(n-1)s_x^2} $$

(7)
where \( n \) is the number of observations, the overbar indicates the predicted value, and \( s_x \) is the standard error. There are two dotted lines on each plot. The horizontal line is at \( 8/(n-2p) \) where \( n \) is the number of observations and \( p \) is the number of parameters estimated. Points above this line may be points with high influence on the model. The vertical line is at \( 2p/(n-2p) \) and points to the right of this line have high leverage compared to the variance of the raw residual at that point. If all points are below the horizontal line or to the left of the vertical line then the line is not shown. For example, in the quasi-Poisson plots, the horizontal line is not present, since no point lies above it.

![Figures showing residual autocorrelation plots](image)

**Figure 7: Residual autocorrelation plots**

Finally, an important consideration when dealing with serially correlated data is the autocorrelation of the residuals. Residual plots should be analyzed to check for autocorrelation, while autocorrelation (ACF) and partial autocorrelation function (PACF) plots are also very helpful. Figure 7 shows the ACF and PACF plots for the Poisson and quasi-Poisson models discussed above, indicating that there are no serious autocorrelation issues in the residuals of either model (as the only value that exceeds the threshold is in the partial ACF for a lag of five).

Tests for other properties and assumption may also be used as needed (e.g. normality, heteroscedasticity, skewness). Tests for serial correlation are of particular interest in time-series contexts (e.g. “portmanteau” and Ljung-Box tests; Ljung and Box, 1978). A large number of
measures have also been developed for the assessment of the predictive performance of these models, such as RMSPE, MPE, ME, MEN (Pindyck and Rubinfeld, 1997).

7. DISCUSSION

Many other techniques can and have been used for the analysis of macroscopic road safety data, including classification of data. For example, Wegman and Oppe (2010) used Singular Value Decomposition and Multiple Correspondence Analysis of a number of observed characteristics to group European countries into more homogeneous classes in terms of road safety, while Gitelman et al. (2010) used Principal Components Analyses and Factor Analyses on European countries’ data in an attempt to design a composite indicator for road safety.

Another way that the analyses presented in this paper could be further enhanced is through stratification involving specific vehicle types and population subsets (e.g. age groups or gender) (Stipdonk et al., 2010). It will then be much easier to distinguish cases and consider the presence of true impact due to GDP, vehicle fleet or other growth-related parameters; so, it is not advised to neglect the study of such elementary indicators, especially when difficulties are encountered in the reliability of more exposure-oriented analyses (e.g. using vehicle-kilometres travelled). Further research directions include the enrichment of the model with additional macroscopic parameters, as well as the investigation of other functional forms and model specifications. Additional parameters (such as the Gross Domestic Product, GDP) may help separate exogenous effects and isolate road safety trends and can be used to construct appropriate indicators. Hollo et al. (2010) use road safety performance indicators to analyse the trends in casualties in several Central European countries.

Other functional forms may also provide valuable insight into the road-safety problem. One relevant question is whether road safety trends are similar for best and worst performing countries and subsequently to find the inflection points defining the thresholds between the changing trends. This question may be proved very beneficial mainly for the less developed countries from a road safety point of view. An alternative modeling approach would have been the use of structural time-series models, such as those proposed by Harvey and Shephard (1993), Harvey (1994), which belong to the family of unobserved component models.

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INTELLIGENT TRANSPORTATION SYSTEMS AND ROAD SAFETY (SERS CIS Approach)

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Abstract. Intelligent Transportation System (ITS) refers to efforts to add information and communications technology to transport infrastructure and vehicles in an effort to manage factors that typically are at odds with each other, such as vehicles, loads, and routes to improve safety and reduce vehicle wear, transportation times, and fuel consumption. On the other hand eSafety (= electronic safety) is a joint initiative of the European Commission and many industrial and other stakeholders having an interest in road safety. The initiative's aim is to increase road safety by deploying and developing safety systems based on modern information and communication technologies (ICT). To deal with tomorrow's transportation challenges, systems allowing vehicles to communicate with other vehicles and with the infrastructure, also known as co-operative systems, are needed. In order to cope with these requirements Service-Oriented Architectures (SOA) have introduced in e-safety concept. In the paper we are presenting a service oriented architecture to make interconnected ICT systems for e-safety more manageable, allowing dynamic adaptation to manage changing situation and counter the risk amplification effect of interconnectedness

Keywords: ITS (Intelligent Transportation Systems), Safety

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1. INTRODUCTION

Transport is a key factor in modern economies: the sector corresponds to more than 10% of gross domestic product for each country and in European Union the industry employs more than 10 million people. Motor vehicles are the biggest contributor to mobility, estimated that some 80% of travel calculated in passenger – km is currently by car.

The enlarging markets with increasing demand for transport services needs an efficient transport system, and has to tackle the problems caused by transport: congestion, harmful effects to the environment and public health, and the heavy toll of road accidents. The price paid for mobility in Europe is too high. In 2000, road accidents killed over 40 000 people in the European Union and injured more than 1.7 million. The directly measurable cost of road accidents is of the order of 45 billion €. Indirect costs are three to four times higher. The annual figure is put at 160 billion €, equivalent to 2% of the EU’s GNP (ECE, 2010; Fuente Layos, 2007).

More and more of the added value – and also manufacturing cost - of vehicles comes from more sophisticated electronic systems which can replace entire mechanical and hydraulic subsystems. An increasing number of vehicle control, safety and comfort functions are controlled by processors and software.

New systems, which use advanced information and communication technologies in new intelligent solutions for improved road efficiency, can reduce the number of accidents on roads, in particular when the accident can still be avoided or at least its severity significantly reduced. We know that almost 95% of the accidents are partly due to the human factor. In almost three-quarters of the cases the human behaviour is solely to blame. This apparent mismatch between driver skills and situation complexity can be addressed by improvements in three factors: the driver (education and training); the environment (intelligent infrastructure) and the vehicle (vehicle safety systems). This is the area where Intelligent Transportation Systems, offer their greatest potential.

2. INTELLIGENT INTEGRATED ROAD SAFETY SYSTEMS (IIRSS)

Integrated Intelligent Road Safety Systems will use information society technologies and intelligent transport systems (ITS) in vehicles and the infrastructure for improving the safety of the vehicle, taking an integrated and global approach to safety, where the involvement of and interaction between the driver, the vehicle and the road environment are addressed together. Integrated Safety Systems will help the driver in vehicle control and use new sensors for collision warning and mitigation, lane keeping, vulnerable road user detection, driver condition monitoring and improved vision. Other technologies will provide for automatic emergency calls, adaptive speed limitation, traffic management and parking aids.

All safety systems which are introduced into the vehicles should be designed to meet certain basic requirements: reliability over time and with regard to external influences, robustness in case of a
system malfunction or misuse, perceptibility of the human machine interface, comprehensibility and predictability of system functionality, controllability in every situation and consideration of foreseeable misuse. These systems should have the capability to communicate with other vehicles or with an intelligent infrastructure, which could bring further benefits, including the extension of the functionality for preventive safety.

eSafety, is an attempt to deal with the above tomorrow’s transportation challenges. By its very nature, is a field of activity that requires involvement of parties with partially diverging interests and goals.

Beside the driver as the one who benefits from the results of eSafety activities, there are usually several public and industrial partners involved even in the provision of a single service to the end user.

As of today, the required collaboration among these partners is established mostly through proprietary and domain specific interfaces (e.g. standard interfaces for road authorities). The consequences are manifold: services are usually fragmented, generally not interoperable and inflexible; partnerships set up between industrial and public partners are “point-to-point” so investments cannot be leveraged in new partnerships; local and SME service and content providers have difficulties to interface their offerings to several large providers; all this resulting in a fragmented and slow developing market.

IT technology like Service Oriented Architecture –SOA- is one way to loosely couple applications from different partners to achieve a joint service provisioning which will allow most of the safety services to be interoperable, guaranteeing users seamless coverage when travelling abroad.

In such an approach, Public Authorities and service providers would expose and consume “Services” according to certain standards and Service Level Agreements (SLA) between parties. The specific transfer of information between defined parties could happen according to the best available communications system and protocol allowing for effective interoperability between communication systems. Such a SOA-based approach would provide for the flexibility of standards-based integration and orchestration of business processes.

The use of Service Oriented Architectures would also give the possibility to Public Authorities and service providers to easily reuse the eSafety platforms deployed to support a wide range of value-added services like information and comfort services. In addition, the SOA approach would allow for seamless integration of eSafety, and generally associated telematics services, into the back-office operations of Public Authorities and Service Providers allowing, for instance, integration with Customer Relationship Management (CRM) platforms, billing platforms for toll services, Business Activity Monitoring platforms for real-time monitoring of operations and reporting, etc.

Systems build according to the SOA best practices will also enhance and facilitate the testing, validation and certification of safety oriented ITS Systems. SOA makes it possible to integrate
distributed and existing reference services and components into test bed systems thus without the need for additional developments.

This would produce relevant benefits for businesses and the society, including enhanced and widespread access to safety and rescue services, and improved sustainability of road transport, by reducing its impact on communities in terms of traffic congestion and pollution.

3. SEMANTICALLY ENHANCED RESILIENT AND SECURE CRITICAL INFRASTRUCTURE SERVICES (SERSCIS)

The SERSCIS (“Semantically Enhanced, Resilient and Secure Critical Infrastructure Services”) project aims to support the use of interconnected resources which are used to plan and manage operations in critical infrastructure such as transportation, airports etc. Failure or underperformance of any of the interlinked systems owing to faults, mismanagement or (cyber-)attack compromise the ability of any or all the interconnected businesses to plan their use of resources, to maintain high levels of efficiency, and to continue providing information needed by others. The SERSCIS approach is to develop service-oriented technologies for creating, monitoring and managing systems, allowing dynamic adaptation to manage changing situations.

Here we adapt the above concept to the transportation business model which will allow us:

• to devise ways to encode dependability commitments in a machine readable way, so they can be included in SLAs
• to develop service governance mechanisms to ensure these commitments will be met, using autonomous monitoring and management of available resources (which may themselves be services), and adaptive workflow technology to orchestrate and utilise these resources;

4. SERSCIS COMPONENTS

The SERSCIS project proposes a service-oriented architecture with SLA-based management that builds on semantic models. This architecture comprises the following four main areas of component technology

A. System Modelling

System modelling covers the development of (semantic) models of critical infrastructure requirements and behaviour. These models are used throughout the SERSCIS framework as computer-understandable descriptions that provide the basis for automated, dependable ICT operation and feedback. The Web Ontology Language, OWL-DL, is used to model ontologies describing critical infrastructure aspects. Models contain valuable system knowledge as well as performance and pricing-models (Benkner and Engelbrecht, 2006)
B. System Governance
System governance covers the development of monitoring mechanisms and management actions and policies to maintain the dependability (including security and trust relationships) exhibited by SERSCIS-enabled services. The service-oriented infrastructure middleware GRIA (Surridge et al., 2005) is used as a basis for the governance technological framework. The emphasis is on controlling available resources such that dependability requirements can be met, and where the system provides services, describing their non-functional characteristics in (semantically tractable) Service Dependability Agreements (SDAs).

C. System Composition
System composition covers the development of automated composition and orchestration of services to implement workflows at the system level to meet dependability requirements, using Service Dependability Agreement terms to control the selection of services from those made available by the system governance mechanisms. The emphasis is on development of dynamically adaptive workflow orchestration mechanisms based on semantic descriptions of workflows, dependability requirements, and (via SDA) available resources.

D. Decision Support
Decision support covers the provision of tools to present information to human operators of critical components. SERSCIS will make use of autonomic service management models driven by high-level policies supplied by the operators, who may also be involved in initiating or carrying out management actions. It is therefore necessary to provide tools to help component implementers understand how a SERSCIS-enabled network will behave. Decision support tools aid operators that decide how to deploy applications in defining high-level policies in a SERSCIS-enabled framework, and in understanding the resulting (dynamically adaptive) behaviour that changing these policies has in an operating critical infrastructure.

5. CRITICAL INFRASTRUCTURE MANAGEMENT

The key to SERSCIS is that it helps to manage risks and interdependency in the use of resources within critical infrastructure, by adapting the resource composition in response to events. Management in this context is concerned with sending controlling signals to the critical infrastructure ICT components when monitoring data indicates a need to do so. Without SERSCIS, the operators can of course monitor information supplied by ICT components used within the critical infrastructure, and take action when they consider this information indicates a need to do so. This provides a ‘humanised’ or ‘slow’ management loop between the operators and the infrastructure. However, without SERSCIS, the interconnectedness of ICT systems used makes human decision-making very difficult, as problems (or actions taken) elsewhere may affect the quality of information available with which to make decisions. Moreover, any action a human operator takes may have an adverse impact elsewhere. Thus the risk of incorrect responses and the damage this might do are both
increased. One of the key goals of SERSCIS is to address this ‘risk amplification’ effect from ICT interconnectedness.

The SERSCIS framework monitors the critical infrastructure and uses a common Web service management interface to manage the dynamic composition of services and underlying resources. This process represents an automated management loop in which the SERSCIS framework takes action as and when required by management policy. The management policy is defined by a SERSCIS-assisted operator and may be dynamically updated.

In addition to the above, SERSCIS governance components may conclude that some action is required that cannot be implemented autonomously. In such cases a signal is sent to the human operators. These signals may simply advise the operator that management action may be needed, leaving the human to decide what action to take (if any). In some cases, the signal may also propose the action, but leave the human to decide whether or how to carry out this action.

The operators can also provide control inputs to the SERSCIS framework, e.g. to change the models it uses to analyse the critical infrastructure, or to change the range of monitoring inputs or automatic actions available to it. These control inputs do not directly affect the critical infrastructure itself, but do change the way SERSCIS uses agile service composition models to support its future management. It is important to recognise that this facility to define SERSCIS models and policies is relevant even before the critical infrastructure and associated ICT is deployed, as well as during its operation. In the pre-deployment phase, this interaction can be used to support the resource implementers, helping them to design and configure interconnected resources in a way that allows risks to be managed by design as well as through subsequent adaptation.

6. HIGH-LEVEL SERVICE ARCHITECTURE

The management of critical infrastructure resources and interconnections is considered an integral part of the overall SERSCIS approach. This is addressed by treating all components as services, whose dependability can be specified via machine-understandable SDAs, allowing automatic and semi-automatic management of components dependability and interdependence, along with the rest of the critical infrastructure.

Thus the SERSCIS Framework contains the following:
- services whose purpose is to establish and keep track of the SLA that specify how critical infrastructure ICT services should interact;
- services to monitor each critical infrastructure component and to ensure (through automated or assisted control actions) that it behaves in accordance with its SLA;
- services or other components to support dynamic adaptation of critical infrastructure, especially its access control policies, interconnectedness and resourcing levels.
The high-level architecture provides a preliminary decomposition of these SERSCIS Framework facilities into software components, and explains how they interact with the critical infrastructure services they monitor and manage. To derive this architecture, we first consider how the lifecycle of SLA (which are new entities introduced by SERSCIS) should relate to the critical infrastructure services (the application to which SERSCIS is being applied).

This will lead to a decomposition of the SERSCIS Framework needed by each service provider into components for managing the SLA, the critical infrastructure services, the resources available to those services, and the way services are composed and interact with each other.

### 7. SLA ARCHITECTURE

The most important architectural issue in developing for resilience is to have a common understanding regarding the lifecycle of SLAs, services and resources, a lesson learned previously in the GRIA project (Surridge et al., 2005). Unfortunately, these lifecycles are only loosely coupled, which leads to a large variety of possible scenarios. SERSCIS builds on the SLA definition and lifecycle developed under the NextGRID project (Hasselmeyer et al., 2007) as implemented in the GRIA middleware (Boniface et al., 2009; Boniface et al., 2006).

In practice, the following four main state models implemented:

- the service itself: its definition including its implementation as a piece of software and description via models of its behaviour, configuration (by specifying management models) for use at a service provider, and deployment to make it executable using allocated resources;
- resources: their acquisition by the service provider, and their allocation (or deallocation) for use by a particular service according to the provider’s management policies;
- the SLA offer (or template): the specification by the service provider of terms (including dependability commitments) under which they can make the service accessible, and the publication of these terms to potential consumers;
- the interaction between a service provider and a service consumer: this includes the initial request for an SLA based on a published template/offer, the granting (or otherwise) of the request leading to an SLA being made between the two, and enabling access to the service under this SLA.

### 8. SERVICE PROVIDER ARCHITECTURE

Given the above model for the life-cycle, it is possible to define a high-level service provider architecture for SERSCIS Framework components to manage services (and consumer interactions), SLA and resources during each phase of their respective lifecycles. The software components include the service interface and workflow orchestrator, along with SERSCIS governance components to support the management of services, resources and SLA. These components depicted in Figure 1 are:

- a security Service Access Control Point, able to restrict access to the service according to a
security policy that must be dynamically updatable (Boniface et al., 2005);
• an SLA Manager that hosts SLA templates and handles requests from clients for SLA based on them: the SLA manager grants new SLAs, provides information to the clients on their status, and may terminate existing SLAs if required;
• a Service Manager that monitors the Quality of Service (QoS) and Quality of Experience (QoE) reports and analyses them using the service model against the provider’s service commitments and management policy, and initiates appropriate management actions;
• a Resource Manager that handles the acquisition/allocation and removal of resources, and maintains a registry (Radetzki et al., 2007) of these resources in which the orchestrator can discover resources when it has to execute a service workflow

![Diagram of Service-Provider Architecture](image)

**Figure 1: High-level Service-Provider Architecture**

Actions taken by the Service Manager may induce changes in the available resources, according to the management policy of the provider. For example, it may ask the Resource Manager to negotiate additional SLAs to provide greater resource volume or redundancy, or allocate more in-house resources. Alternatively it may seek to manage demand on the service. For example, it may simply revoke the SLA template so that no new SLAs can be granted by the SLA Manager, preventing any further increase in the level of service commitments. It may go further, by updating the security access policy to restrict access if the SLA allows this. It may even ask the SLA Manager to breach or to terminate the SLA. The service itself may also support some management actions to influence its behaviour, and the Service Manager can use these if the management policy allows it. These actions can in principle be taken automatically, implementing the ‘automated’ management loop.
SERSCIS components also provide administration interfaces giving operators direct access to the Service Manager, SLA Manager and Resource Manager, and to the associated models, policies and monitoring data. In many situations, the management policy will instruct the Service Manager to inform an operator that action is needed, leaving a human to decide whether and if so how to act. The operator can then implement their action directly on the critical infrastructure, by accessing SERSCIS components or by changing the models and policies used to control them. This provides the ‘assisted’ management loop.

Finally, SERSCIS provides decision support facilities to help operators understand the behaviour of the system, based on events generated by the components. As noted above, this facility will also be useful prior to operation of the SERSCIS-enabled resources, allowing an analysis of risks using the service model during the design phase, and providing insights into the commitments that can be made and the management policies needed to meet them. These tools will also play a role in auditing processes used to analyse and verify/improve the management of the infrastructure.

A number of application services are managed by a single governance component, comprising a service manager, SLA manager and resource manager. The orchestration component coordinates workflows involving ‘local’ resources as well as resources encapsulated in services from other organisations. A SERSCIS-assisted operator has an overview of all the services within a given organisational/operational domain. The operator’s situational awareness is supplemented by a decision support component, which uses a model of the whole system. The ‘whole system’ may include details of concepts outside of the operator’s immediate control, i.e. involving the repercussions that local actions will have on the wider system of systems. These system models may be shared across organisational boundaries.

9. LAYERED APPROACH

Figure 2 shows three concentric dependability management loops that arise from the SERSCIS architecture. Similar to Kramer and Magee’s model for autonomic systems [8], this allows runtime information to propagate up to system decision makers and governance actions to flow down to control service execution. System modelling and decision support components are closely linked and may run synchronously; however, with respect to governance and workflow components, the execution is entirely asynchronous.

The inner runtime loop runs at the speed of the application services, selecting the most appropriate resources and executing the workflow. The governance loop monitors and manages resources against SLA commitments, at a slower rate. This loop has to be asynchronous with respect to application responses because it is often infeasible for the orchestrator to wait while a new SLA is negotiated and approved. Finally, the outer loop runs even more slowly so SERSCIS-assisted human operators can be involved, making changes to autonomic governance policies in response to changes in key performance indicators (KPI).
10. CONCLUSIONS

A high-level service architecture has been introduced for a SERSCIS Framework to support and manage critical infrastructure services. This allows risks in operating critical infrastructure to be managed by augmenting current ‘slow’ human-initiated management with automated and assisted management of resources and services. The service architecture maps to the lifecycle of an SLA: the definition of a service, the description of SLA templates, the negotiation of SLA, and the selection and invocation of services as part of a workflow (including renegotiation/revocation of SLA). To create and execute such a workflow comprising distributed services, while maintaining an overall level of dependability, requires models of information regarding performance characteristics, threats and countermeasures. The SERSCIS architecture takes a layered approach to help solve the conceptual integration, while the use of common components (a resource registry and ESB) addresses the pragmatics of integration and allows for loose coupling between the components.

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PRACTICING ROAD SAFETY

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Abstract. The paper summarises more than 30 years of experience in training licensed drivers. The first part reviews the basics of the driver / vehicle / road system. The second and third parts apply this model to single events, where road and vehicle conditions may be seen as invariants. Education focuses on what can be adapted: the driver's behaviour and reaction. Three categories of educational objectives are defined: sensitizing the drivers, promoting tolerance, and developing technical skills. The fourth part focuses on the safety margin, showing that substantial gains can be obtained solely by adapting the speed; other gains stay marginal. The fifth part extends the single-event view over a long time span, to conclude that spontaneous learning is seldom achieved. The overall conclusion is that road safety training sessions should focus mainly on sensitizing the drivers, and use the development of technical skills as a "vehicle" to convey more basic and abstract messages.

Keywords: Road Safety, Drivers Training
This is not a research paper but merely one based on more than 30 years experience of the author in training experienced (licensed) drivers, at first, then in educating trainers later on. The paper deals in 5 parts with the framework, the stakes, and the objectives of "continuous" drivers' education on road safety. The main thesis promoted here is that training should mainly focus on improving situational awareness and a better understanding of traffic conditions and interactions. Gains obtained through the improvement of drivers' technical skills, although real, are usually marginal in terms of road safety.

The first part sets the scenery, i.e. the basics of the classical system with three interacting components: driver / vehicle / road. Obviously enough, exposure to risk occurs whenever there is an inadequacy between the driver's capabilities of handling a given situation, and the challenges this situation represents to him/her. The second and third parts apply this model to a single event, such as those used in short-term drivers' training (short-term training is defined here as training courses planned over a one- to few-days period). In this type of training programmes, the situation itself, the road, and the vehicle conditions may be seen as invariants/constraints. Educational effort focuses on what can be adapted "on the spot", i.e. the driver's behaviour and reaction. More precisely, the third part concludes with defining 3 main categories of educational objectives: sensitizing the drivers to increase their situational awareness, promoting tolerance in dealing with a given situation, and developing the drivers' technical skills in handling emergency.

The fourth part deals with assessing the safety margin in a given event. By analysing 2 equations of basic dynamics (lateral forces in cornering and stopping distance), it links the variables that may be used to improve the safety margin, and the actions the driver can consider on the spot to increase this margin. This section concludes in that substantial gains can be obtained solely by adapting the speed; comparatively, gains resulting from acting on all the other variables stay marginal, at best.

The fifth part extends this single-event view over a long time span, by taking into account the variability (random component) involved in setting the safety margin over multiple critical situations, and also by explicitly reckoning that the occurrence of critical situations is quite low. As a result, spontaneous learning through experience is seldom achieved. Moreover, short-term training effects, for the same reasons, do not last if they are not periodically revived through repetition.

The paper's overall conclusion is that road safety training sessions should strongly focus on sensitizing the drivers, and use the development of technical skills mainly as a "vehicle" to convey more basic and abstract messages.

In many analyses dealing with road safety, a system's approach is used. Safety is seen through the interaction of a system involving three interlinked and interacting components (Figure 1): the infrastructure (road and traffic control devices and signals, markings, etc.), the car (and its so-called active and passive safety), and the driver (whose behaviour depends on education, training, personality, attitude, experience, and so on).
Interactions among those three components take place within a continuously evolving instantaneous context. (It may seem curious, at the first, to consider that infrastructure interacts too. This is not the case, of course, in many situations, where infrastructure is static and influences the behaviour of the 2 other components, without changing itself. This is however changing with adaptive traffic control. In a general case, thus, we may speak about 3 interacting components). What we have here is a dynamic system, which is widely used to analyse and assess safety in a given instantaneous context, and to quantify the risk. Moreover, this is neither an isolated nor a closed system: weather, traffic, and externals events may interfere with it, and the system itself interferes with other "parent" and "child" systems.

Therefore, a given situation at any given moment corresponds to a discrete state of the system, and the unfolding of this situation can be traced through the various states of the system.

In training courses that last one or two days, the training objectives are set according to what can be taught within this timeframe. Quite naturally, existing programmes usually focus on what one can change on the spot, i.e. on what the driver can do when he/she faces a critical situation. When dealing with a critical situation, only the driver's actions can be seen as variables that may be exploited to obtain the best possible outcome. The other two system components, the road and the vehicle, cannot be changed during the management of the critical situation. The corrective actions are available on the driver's side only, his/her objectives being to take full advantage of the given road conditions and his/her vehicle capabilities. We may therefore change slightly the basic model, to better reflect this condition (Figure 2).
Safety level depends on the differential between the driver's skills and capacity and the car performances (*what can be done*), in one hand, and the amount of challenge the situation represents (*what should be done*), on the other hand. This comparison discriminates also safe from dangerous situations (Figure 3) The point made here is that we never can qualify a situation as safe or unsafe per se, based only on its configuration, and without taking into account the specific driver who faces it. It is the difference between what can be done and what should be done that determines the safety margin.

![Figure 3: The "instantaneous" model to discriminate between safe and unsafe situations](image)

There is not an absolute level of safety. Viewed under thins angle, safety is assessed relatively to the driver's capabilities. Now, the latter are bound: They have a maximum, when a driver uses all his/her personal skills and exploits at the best the car's capabilities and the infrastructure. This maximum is a threshold, against which we may compare the amount of challenge a given situation represents, and that sets the safety margin in any given situation (Figure 4).

![Figure 4: Stating the obvious: an accident occurs when there is no safety margin left](image)

Driver's skills belong broadly to three main categories: a) purely technical skills, b) situational awareness and his/her capacity to understand and interpret correctly, and c) attitudinal qualities
(linked also with his/her possibilities to handle emotional stress). If we use as an example the case of a driver, running on a main road, and facing a vehicle coming from a secondary road and entering the main road without giving way, we may expect 3 possible outcomes, provided that there is enough room to stop the vehicle running on the main road if reacted correctly:

A) A concentrated and skilled driver triggers an emergency braking and stops his/her car, before an accident occurs.

B) A less concentrated driver, with poorer technical skills, attempts and succeeds an avoidance manoeuvre by temporarily using the opposite traffic lane, which - by chance - is empty.

C) The avoidance manoeuvre ends up with an accident, either because there is a vehicle on the opposite traffic lane, or due to loss of car control.

Only the first of those three outcomes stays within what we can consider as acceptable safety conditions (Figure 5).

![Figure 5: On-time safe recovering, and area outside of driver's control](image)

This also sets the frame of the educational objectives in training, where we seek to:

- **Sensitize** the drivers (to cultivate and to improve their situational awareness)
- **Promote** positive, efficient attitudes, oriented towards problem solving (vs. judicial stance, startling, confusion, anger, desire of vindication…)
- **Train** the drivers (to increase their technical skills)

What the rest of the paper tries to demonstrate is that purely technical training is the playful alibi to develop the other two pillars of safe driving: situational awareness and attitudinal qualities.

Basic laws of movement mechanics makes it possible to quantify the challenge, at least for two specific situations that cover a fair share of the actual accidents: missed cornering or missed braking.

Regarding cornering, what may qualify as safety margin is the difference between the maximum lateral guidance that adhesion can provide and the centrifugal force:
\[
SF = mg(\mu \pm i_t) - m \frac{v^2}{r}
\]

where:
- \(SF\) safety margin
- \(m\) vehicle mass
- \(\mu\) adhesion coefficient
- \(i_t\) cross slope of the road (+ if the inclination makes the inner part of the road lower than the outer)
- \(v\) vehicle speed
- \(r\) curve radius

In a given situation, a driver can reduce the challenge (the centrifugal force) marginally by adapting his/her line (increasing thus the radius), and more significantly through by lowering speed.

Regarding braking, what we can qualify as safety margin, is the difference between the observable distance (the distance over which the driver is able to see and to detect any problem) and the stopping distance. The latter has two components: a) the reaction distance (the distance run between the moment a driver is able to see any reason requiring to stop the vehicle and the moment full braking is applied), and b) the braking distance (the distance needed for a fully braking vehicle to come to a halt from any given initial speed). Putting it to equations, it gives:

\[
SF = DistObst - \left( t_r v + \frac{v^2}{2g(\mu \pm i_l)} \right)
\]

where:
- \(SF\) safety margin
- \(DistObst\) distance from obstacle when first visible
- \(t_r\) reaction time
- \(v\) vehicle's initial speed
- \(g\) the so-called g-force, i.e. the acceleration due to Earth's gravity
- \(\mu\) adhesion coefficient
- \(i_l\) longitudinal slope (grade) of the road (+ if upwards)

A driver, in a given situation, can marginally improve the safety margin by being concentrated (increasing the observable distance and reducing the reaction time). If the car provides no assistance (ABS- and BAS-type devices), he/she may also obtain some marginal gains by means of a better braking technique (the \(2g(\mu \pm i_l)\) component). Substantial gains may be obtained, thanks again to the square power, through speed reduction.

The main conclusion that can be drawn out of this, quite elementary, analysis is that we may expect only marginal gains, in both cases, through the improvement of technical skills. **Substantial gains in safety margin can solely be obtained by setting the speed accordingly.** This is due to two different reasons. First of all is that magnitude of possible speed variations is huge, especially
compared on radius variations through line setting, or extra braking efficiency offered by a better braking technique. Secondly, speed variations enter non-linearly in the equations: there is a square power for cornering, and a 1.2 to 1.8 power for stopping (in usual initial speed conditions).

There are also two additional remarks that should be expressed here. The first is that, in most current situations, improvements of car performances lead also to minor increases of the safety margin, mainly thanks to better tires (adhesion coefficient) and electronic assistance (increasing of the observable distance, reduction of the reaction time thanks to BAS, or more efficient braking thanks to ABS, although the latter may also lead to increased braking distances under some specific conditions). The second remark is valid for the contribution of both the on-board technologies and the driving technique. The gains expected through the technical improvements of the car and/or the driver have been qualified as marginal. This is true only if we start from a good initial condition (i.e. flawless vehicles and well-educated drivers). Poorly educated drivers or obsolete and badly-maintained cars may strongly benefit through technical improvements.

Analysis until now has treated the maximum level of capabilities (the "what can be done") as a fixed threshold. This does not take into account variability of several factors (including chance) that makes it vary around an average value (Figure 6). When being on the edge, the same configuration may lead to a catastrophe, if we are unlucky, or remain eventually manageable, with a little bit of luck on our side.

![Figure 6: Taking into account variability of the maximum response level](image)

Taking into account variability and combining it with a fair dose of cautiousness as shown by a majority of human beings, makes it possible to spend a whole life driving without experiencing a major accident. And this is actually the case for a significant share of drivers. Exposure to edge events, where the challenge greatly exceeds the capabilities is quite infrequent for most of the drivers. For many of them, edge-type events seldom occur (Figure 7). Moreover, in some of those occurrences, the criticality of the situation may remain hidden if the challenge is located within the variability bracket.
All-in-all, that means that we cannot count on learning by doing, because the very opportunities of learning are very scarce. This is why adult training in road safety is necessary. Natural training is not sufficient and one needs additional explicit training to be able to better cope with edge situations. The contribution of self-learning is poor. Moreover, lessons learnt from explicit training tend to fade with time, as they are almost never put into practice. There is a need therefore for additional, repeated training.

On the other hand, analysis shows that among the three fields of driver's skills involved in post-education (Figure 8), only the situational awareness, which leads to adapt the speed in any given situation, is able to offer substantial pay-offs in increasing the safety margin. Improvement of technical skills provides marginal gains, at best, and working with attitudinal qualities needs a sustained effort, which involves important cultural and privacy-related issues that make it mostly impossible in real-life conditions.
Behind the whole paper, there is a hidden assumption, the one stating that no human being wants normally to get hurt. Therefore, accidents are unwanted events; they result mainly of ignorance and loss of awareness, exasperated for some drivers by their lack of risk aversion.

Training of licensed drivers focuses on improving their technical skills, their situational awareness, and their attitudes. Besides training on techniques, the objectives are to sensitize and to promote. When looking directly at the potential to increase one's safety margin, it becomes obvious that potential gains through improvement of technical skills are only marginal. Consequently, the main effort should focus on promoting and sensitizing. However, teaching based only in promotion and sensitizing has low rates of return, especially when it focuses on what can be perceived as "abstract risks". Scarcity of critical situations, and their dilution through time, combined to misplaced self confidence (I am among the best or - at least- a good driver) reduces even more the rate of success in educational programmes based only in sensitization.

The most successful programmes this author is aware of, combine a strong technical part, which is (and should be) used as a vehicle to pass more complex messages aiming to develop situational awareness, by showing in practice that apparently anodyne situations may eventually evolve in critical events. It is through practice that we may convince experienced drivers that coping with edge situations offers no guarantee of success, and that the best strategy is to prevent by any means a situation in evolving towards criticality. Training in practice edge situations induces high emotional involvement for the trainees. That lays the ground for efficiently conveying more complex messages on situational awareness and attitudes, the only fields from which we may expect significant gains in road safety.
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