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PhD Program in Environmental and
Building Risk and Development

Coordinator: Prof. Michele Mossa

XXIX CYCLE - Curriculum:
Infrastructures, Transport and Territory

DICATECh
Department of Civil, Environmental, Building
Engineering and Chemistry

Route Familiarity in Road Safety: Theory and Applications

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Dottorato di Ricerca in Rischio e Sviluppo
ambientale, territoriale ed edilizio

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Coordinatore: Prof. Michele Mossa

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Dipartimento di Ingegneria Civile, Ambientale,
del Territorio, Edile e di Chimica

La Familiarità col Tracciato nella Sicurezza Stradale: Teoria e Applicazioni

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LIBERATORIA PER L'ARCHIVIAZIONE DELLA TESI DI DOTTORATO

Al Magnifico Rettore
del Politecnico di Bari

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iscritto al III° anno di Corso di Dottorato di Ricerca in RISCHIO E SVILUPPO AMBIENTALE, TERRITORIALE ED EDILIZIO ciclo XXIX

ed essendo stato ammesso a sostenere l'esame finale con la prevista discussione della tesi dal titolo:

ROUTE FAMILIARITY IN ROAD SAFETY: THEORY AND APPLICATIONS

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EXTENDED ABSTRACT *(eng)*

Research in road safety matters is highly dependent from the knowledge about human factors. In fact, they are related to the causation of most of the road accidents and they are considered in the road design guidelines. In this work, the influence of route familiarity on road safety is investigated, since familiarity can be included in behavioural variables able to affect the act of driving. In fact, drivers who have become familiar with a given route (and so, with all the road elements included in the route), can experience modifications in their behaviour due to the familiarization process. Becoming route familiar can be associated to a decrease in the response of drivers connected to the repetitions of the stimulus of driving on the same route (habituation effect). A decrease in response could imply a greater tendency to distracted and inattentive driving. However, at the same time, the acquired familiarity is related to a greater confidence with the route, which can be associated to changes in driving performances, also towards more dangerous behaviours, according to the different risk inclinations of drivers. According to the perspective of economic utility theories, the drivers normally aim to maximize the travel utility, tending to minimize the costs and to maximize the benefits. The costs include safety costs (accident risk) and the benefits include mobility benefits (travel time). Therefore, the increased confidence of drivers with the road environment could lead them to choose behaviours objectively more dangerous (such as speeding or curve-cutting) even if probably felt by them as still acceptable, for the aim of increasing the travel utility. However, these changes can be largely subjective and to different extents accentuated according to the different drivers' tendencies. Moreover, the unfamiliarity of drivers is considered as a safety concern while designing roads: unfamiliar drivers do not know the road and so, roads should be designed in order to always meet their expectations, by avoiding dangerous surprises. Moreover, the presence of unfamiliar drivers in the traffic flow is considered in the traffic engineering as a possible cause for the worsening in the level of service (by increasing equivalent flow rates), highlighting the matter of the interactions between familiar and unfamiliar drivers in the traffic flow.

These theoretical expectations were verified through the research conducted. It was mainly based on data belonging to an on-road experiment and on a traffic and accident database. The experimental repeated measures of speeds and lateral positions in the cross section were used in order to evaluate the possible evolution of driver behaviours over time with the acquired route familiarity. The same data were further employed to verify the hypothesis that drivers modify their behaviours in order to maximize the travel utility, making trade-offs between risk and travel time. In addition, the accident database was investigated in order to find relationships between route familiarity and road safety for two-lane rural roads. These relationships can be expected from similar studies or from theoretical expectations about the topic. In fact, an application also based on the framework relating accidents, speeds, speed variances and flow rates, considering the presence of unfamiliar drivers in the traffic, but in the case of multi-lane highways and freeways, was further developed.

Some general results based on the available data can be highlighted about changes in driving performances and perceptions. In particular, speeds were found to increase in the first days of travel and after they settled on an approximately constant value, showing a habituation effect, which can last also in the long term. The same tendency was inquired for trajectories of drivers at curves based on lateral position data. A similar tendency over time, even if not confirmed for the long term and having a less strong magnitude, was found for the curve trajectories. It was also shown how these processes can be dependent from the different individual attitudes, from the road geometry and from the diverse test conditions. Furthermore, trade-offs between accident risk and travel time were observed for the drivers while becoming more familiar with the road environment, based on experimental data and on the utility framework used. Drivers seem to be willing to reduce their travel times on the road section in order to maximize the travel utility (by increasing speeds). However, this leads to an increase in the accident risk, according to the different risk attitudes of drivers and to the road geometry. Furthermore, an integration of the framework for calculating the levels of service, in which the presence of unfamiliar drivers in the traffic flow is considered, with some road safety concepts was proposed. In detail, the presence of unfamiliar drivers in the

traffic flow can be associated to a greater speed variance, which in turn can be related to an increase in the accident risk. These expectations can be valid for muti-lane highways and freeways, due to the framework used as a basis. However, some relationships between route familiarity and road safety were found by investigating the crash database for two-lane rural roads. While a macro-analysis considering the accident rates in different scenarios was found as useless for acquiring information about familiarity based on seasonal traffic and accident variations, a more detailed look based on statistical analyses on the sample of accidents and vehicles was more helpful. Actually, some types of accidents and accident dynamics were associated to familiar and unfamiliar drivers. Further, the strategy of the micro-analysis tried at last for individuating accident patterns at some specific sites highlighted for their high share of accidents to familiar/unfamiliar drivers, was found instead as inadequate too for making general remarks about the topic.

The results from the research conducted were used to make some considerations about the possible implications of route familiarity in the road safety practice and for future researches. Furthermore, a more detailed definition of route familiarity based on both travel frequencies and drivers' distance from residence was proposed, to be potentially used by researchers on the same topic.

key words: Route Familiarity, Road Safety, Driving Behaviour, Risk Perception, Road and Traffic Engineering, Speed Choice, Curve Trajectories, Travel Utility, Accident Analysis, Adaptation to Safety Measures.

EXTENDED ABSTRACT *(ita)*

La ricerca nel campo della sicurezza stradale dipende fortemente dalle conoscenze nel settore dei fattori umani. Infatti, essi sono collegati alla maggior parte degli incidenti stradali, oltre ad essere considerati nelle linee guida di progettazione stradale. In questo lavoro viene studiata la possibile influenza della familiarità col tracciato sulla sicurezza stradale, dal momento in cui tale variabile è uno dei possibili parametri comportamentali che possono influenzare la guida. Infatti, gli utenti che sono diventati familiari rispetto ad un determinato tracciato (e quindi, con tutti gli elementi stradali che lo compongono), potrebbero essere soggetti a modifiche comportamentali dovute al processo di familiarizzazione. Tale processo può essere associato ad una diminuzione della risposta allo stimolo consistente nel ripetere l'atto della guida sullo stesso tracciato (effetto di abitudine). Una diminuzione della risposta potrebbe essere legata ad una maggiore tendenza alla guida disattenta e distratta. Comunque, parallelamente a tale fenomeno, la acquisita familiarità potrebbe comportare una maggiore confidenza, associata a possibili tendenze verso comportamenti più pericolosi, a seconda delle diverse inclinazioni al rischio degli utenti. Gli utenti normalmente tendono a massimizzare l'utilità del proprio viaggio, tramite la massimizzazione dei benefici e la minimizzazione dei costi. I costi includono quelli legati alla sicurezza (costi di incidentalità) e i benefici quelli legati alla mobilità (tempo di viaggio). Quindi, la maggiore confidenza degli utenti con l'ambiente stradale potrebbe portarli ad assumere comportamenti più pericolosi (come l'eccesso di velocità o la tendenza a tagliare le curve) anche se probabilmente ritenuti da loro ancora accettabili, con l'obiettivo di aumentare l'utilità di viaggio. Comunque, queste modifiche comportamentali possono risultare largamente soggettive e più o meno accentuate a seconda delle diverse tendenze personali degli utenti. Invece, la non familiarità degli utenti è considerata come un problema di sicurezza da affrontare nella progettazione stradale: gli utenti non familiari non conoscono la strada e quindi, le strade dovrebbero essere progettate per incontrare sempre le loro aspettative, per evitare pericolose sorprese. Inoltre, la presenza di utenti non familiari nel flusso di traffico è considerata dall'ingegneria del traffico come una possibile causa del peggioramento del livello di servizio (poichè causa un incremento del flusso di traffico equivalente), evidenziando la questione delle interazioni tra utenti familiari e non nel traffico.

Queste aspettative teoriche sono state verificate attraverso la ricerca effettuata. Essa è stata principalmente basata su dati derivanti da una sperimentazione su strada e su di un database composto da dati di traffico e incidenti. Misure di velocità e posizione laterale nella sezione ripetute nel tempo (sei volte in sei giorni diversi) per mezzo di una sperimentazione su strada condotta su venti utenti, sono state utilizzate per valutare la possibile evoluzione del comportamento alla guida con la familiarità acquisita nel tempo. Gli stessi dati sono stati in seguito utilizzati per verificare l'ipotesi avanzata: gli utenti potrebbero modificare I loro comportamenti per massimizzare l'utilità del viaggio, tramite compensazioni tra rischio e tempo di viaggio. Invece, il database di incidentalità è stato impiegato per l'obiettivo di trovare possibili relazioni tra la familiarità col tracciato e la sicurezza stradale sulle strade extraurbane a due corsie. Tali relazioni potrebbero essere attese come emerge da studi simili preesistenti o da considerazioni teoriche sull'argomento. Infatti, è stata sviluppata in questa sede anche una applicazione basata su relazioni teoriche tra incidenti, velocità, varianza e flussi di traffico, considerando la presenza di utenti non familiari nello stesso, ma nel caso di strade multi-corsia.

In base alle analisi svolte sui dati disponibili, e tramite le analisi statistiche effettuate, possono essere evidenziati alcuni risultati generali a riguardo delle modifiche nelle performance di guida e nella percezione degli utenti. In particolare, è stato mostrato come le velocità aumentino nei primi giorni di prova e in seguito rimangano stabili su di un valore circa costante, rivelando un effetto di abitudine, che può perdurare anche nel lungo termine. La stessa tendenza è stata ricercata per le traiettorie degli utenti in curva, basandosi sui dati di posizione laterale. Una simile evoluzione temporale, anche se non confermata nel lungo termine e con una intensità minore, è stata osservata anche per le traiettorie in curva. E' stato inoltre mostrato come tali processi possano essere stati influenzati dalle differenti attitudini individuali, dalla geometria stradale e dalle diverse condizioni di prova. Inoltre, partendo dal modello di utilità considerato, sono state osservate compensazioni tra rischio di incidentalità e tempo di viaggio ("trade-offs") parallele al processo di familiarizzazione, sulla base dei dati sperimentali. Gli utenti sembrano portati a ridurre i tempi di viaggio sul tracciato per massimizzarne la relativa utilità, tramite l'aumento delle velocità. Comunque, ciò implica un aumento del rischio di incidentalità, maggiore o minore a seconda della diversa inclinazione al rischio degli utenti e della diversa geometria stradale. Inotre, è stata proposta un'integrazione della teoria di calcolo dei livelli di servizio che considera la presenza di utenti non familiari nel traffico, con alcuni concetti di sicurezza stradale. In particolare, la presenza di utenti non familiari nel flusso di traffico può essere associata ad una maggiore varianza di velocità, che a sua volta è collegata ad un aumento nel rischio di incidentalità. Tali aspettative possono essere valide per strade multi-corsia, a causa della teoria di partenza utilizzata. Invece, tramite l'analisi del database di incidentalità e volume di traffico Norvegese, sono state individuate alcune relazioni tra la familiarità col tracciato e la sicurezza stradale per strade extraurbane a due corsie. Nonostante una analisi mirata al confronto tra tassi di incidentalità in diversi scenari (definita "macro-analisi" a causa del macro indicatore utilizzato) tramite analisi statistiche si sia dimostrata inutile al fine di acquisire informazioni sulla familiarità considerando variazioni di traffico e incidentalità stagionali, si è invece dimostrato più utile uno sguardo più dettagliato al campione di incidenti e veicoli coinvolti tramite analisi statistiche. Infatti, alcune tipologie e dinamiche di incidenti sono state associate agli utenti familiari/non familiari. Invece, un'ultima strategia tentata per l'analisi di incidentalità ha riguardato il livello di dettaglio più disaggregato possibile (a livello dei singoli incidenti, denominata "micro-analisi"). Tale analisi era mirata ad individuare pattern di incidentalità in corrispondenza di siti specifici individuati per la loro elevate percentuale di incidenti a utenti familiari/non familiari. Essa si è dimostrata comunque inadeguata per trarre conclusioni generali sull'argomento.

I risultati della ricerca sono stati utilizzati per effettuare alcune considerazioni sulle possibili implicazioni dei concetti esposti nella pratica della sicurezza stradale e per future ricerche. Inoltre, si è proposta una definizione più dettagliata della familiarità col tracciato basata sia sulla frequenza di viaggio che sulla distanza degli utenti dalla residenza, potenzialmente utilizzabile dai ricercatori per futuri studi sull'argomento.

key words: Familiarità col Tracciato, Sicurezza Stradale, Comportamento alla Guida, Percezione del Rischio, Ingegneria Stradale e del Traffico, Scelta di Velocità, Traiettorie in Curva, Utilità di Viaggio, Analisi di Incidentalità, Adattamento alle Contromisure Ingegneristiche.

INDEX

1.0 INTRODUCTION

Road safety is a multidisciplinary subject, in which mainly road and traffic engineering, psychology, economics merge. For design, operation, maintenance and safety interventions on roads, it is necessary to consider the driver behaviour, which plays a crucial role in all these matters. In fact, since roads are currently traveled by vehicles driven by humans, then roads cannot be designed, operated or adjusted without considering the behaviour of drivers.

As it will be explained later, road design standards consider the behaviour of drivers for the design criteria. Furthermore, human factors are strongly related to the accident causation. For these reasons, they are studied and investigated by road safety researchers, in order to address design and safety-based road isssues. The influence of age, gender, income, health conditions, risk-taking attitudes, experience, drivers' psychology and many other factors were considered in literature studies about the topic. Among them, a matter which can be very influential on driving behaviour is the familiarity of drivers with the road layout. This influence is deepened in this work and its potential practical application to road safety concepts is remarked, since it will be shown how some issues related to this topic need to be further investigated.

For this aim, the next Section 2.1 (General Background) is devoted to the explanation of some basic concepts of road safety and to the introduction of the topic of route familiarity, showing how this topic is related to road and traffic engineering in theory and practice. Then, the research about the topic is conducted through the use of the data sources and general methods explained in Section 2.2 (Data Sources and General Methods). The detailed discussion of the research carried out is described in Section 2.3 (Research Discussion). Some general conclusions coming from the analysis of the highlighted results are drawn in Section 3.0 (Conclusions and Practical Developments) showing also some possible applications and practical developments of the research.

2.1 CHAPTER 1 – GENERAL BACKGROUND

In this chapter, the general background related to the reseach topic of the route familiarity in road safety is given. It includes a presentation of the recent literature studies and a description of the state of the art of the engineering practice about the matter. Since the inquired topic concerns the human behavioural studies in the field of road safety, some essential concepts taken from psychological theories and studies are presented. They were used for the development of the research in addition to the road safety and traffic engineering theories and practice.

The chapter is organized in subsections. *Section 2.1.1* (*Key Concepts of Road Safety*) is devoted to the presentation of the basic concepts of road safety, useful for the detailed description and development of the research topic. In S*ection 2.1.2 (Route Familiarity in Road Safety – Theoretical Background),* the theoretical illustration of the topic of route familiarity in road safety is given. Recent literature studies are there summarized in order to support the description. *Section 2.1.3 (Route Familiarity in Road Safety – Practical Implications)* includes a characterization of the state of the art of the road and traffic engineering practice concerning the research topic, showing its practical involvement. Finally, in *Section 2.1.4 (Research Questions)* the research questions kept open about the inquired topic, highlighted in the previous sections, are listed. They were used as a basis for the development of the research.

2.1.1 Key Concepts of Road Safety

Theories and applications in the field of road safety are focused on guaranteeing a safe travel on the infrastructure for all the road users. Therefore, the main aim of road safety scientists and practitionners is the prevention of road accidents, which are an urgent and worldwide problem. In fact, the World Health Organization (2015) estimated that more than 1.2 million people die per year for traffic accidents all over the world. Since decades, the research in the field of road safety have tried to acquire a complete knowledge about the process of road accidents occurring in order to promote campaigns aimed to their reduction.

Normally, the road accident is an unwanted outcome resulting from the interaction in the road system between the user, the vehicle and the road environment (see Fig. 1). There are several factors related to these three spheres which can influence the occurring of the accident.

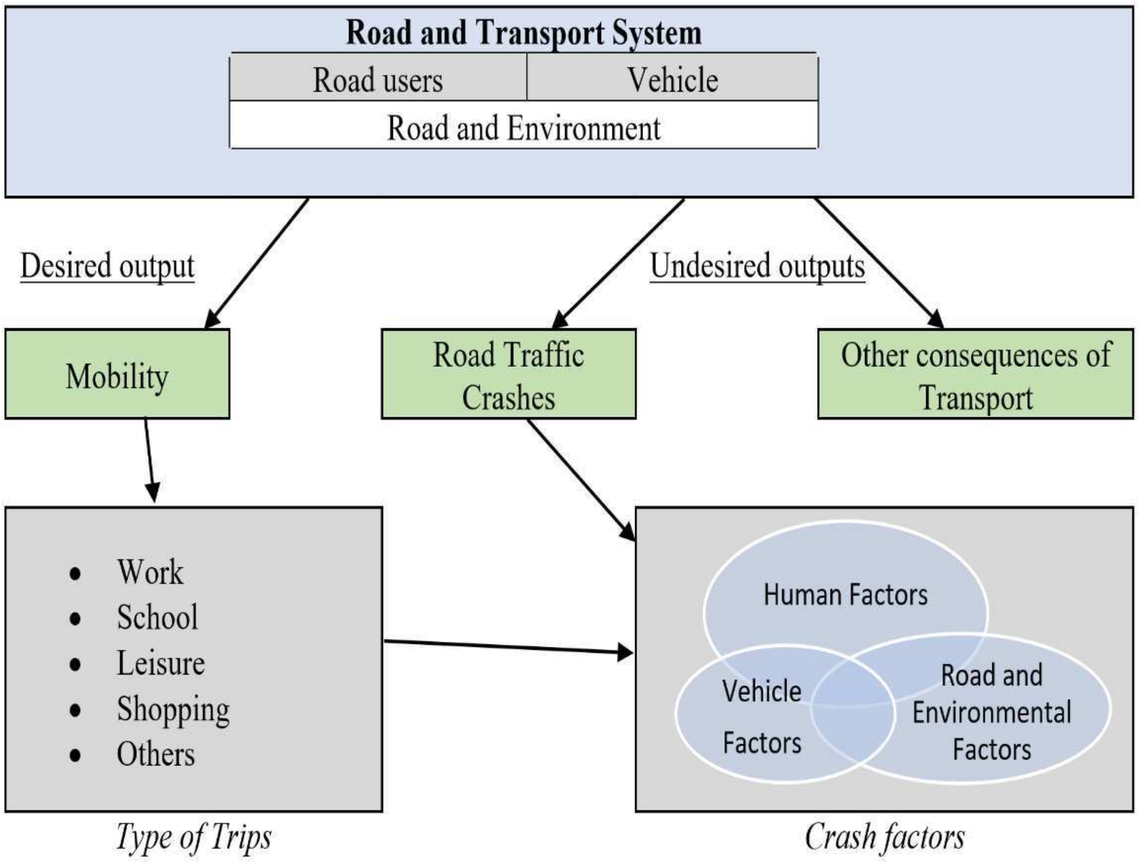

Fig. 1 – Summary of the Road and Trasport System (adapted from WHO and IIT. Road Safety Training Manual, 2006; based on Muhlrad and Lassarre, 2005).

The three spheres are: the human factors, the vehicle factors and the road and environmental factors. The latter can be further divided into three sub-factors: the roadway, the environment and the traffic (Colonna, 2002). A brief exemplification of all the factors is given below.

- Human factors. All personal factors related to the driver involved in the accident (and/or the pedestrian involved). Age, gender, experience (mileage, familiarity), income, risk perception, attitude to risk-taking behaviours (e.g. speeding), fatigue, health issues, driving under influence, use of protective systems (helmet, seat belts), distraction, use of other devices while driving or walking, sensation seeking, attitude to break rules, social pressure etc.

- Vehicle factors. All factors related to the vehicle involved in the accident. Type, model, mass, age, maintenance, presence and/or quality of in-vehicle safety systems etc.
- Roadway factors. All roadway factors which can be related to the accident. Type of road (number of lanes, road section or intersection, urban or rural, divided or undivided), quality of the road design (compliance of the road elements with standards and good practices, visibility, consistency of subsequent elements), pavements, maintenance, road signs, lighting, roadside elements, lateral objects, drainage systems, presence and quality of facilities for vulnerable users etc.
- Environmental factors. All environmental factors present at the moment of the accident. Weather conditions (presence and intensity of rain, snow, fog), intensity and direction of wind force, sun position, temperature etc.
- Traffic factors. All factors related to the traffic conditions at the moment of the accident. Traffic volumes, mix of different vehicles, high share of heavy vehicles, presence of congestion, free flow condition, high share of vulnerable users in the traffic flow etc.

The above-reported list represents a part of all the several factors which can be related to the road accidents. A comprehensive list of them, together with an indication about their influence, can be found for example in the deliverable (Shick, 2008) obtained by the Project TRACE (Traffic Accident Causation in Europe).

Therefore, a road accident can be related to several factors belonging to different areas of influence, interacting one with each other. They can intervene in the pre-crash stage (before the occurrence of the accident), in the crash stage (while the accident is happening) and in the post-crash stage (when the accident has already occurred). A common framework used for definining and classifying the factors related to different phases of the crash is the Haddon Matrix (Haddon, 1970), shown below in Table 1. It can be used for the analysis of a single accident, the comparison of several accidents of the same type or the analysis of different accidents on the same road section. The reason of its application could be the selection of road safety countermeasures once some recurrent problems (resolvable through modifications in the road system) are highlighted. In fact, this is a strategy proposed by the Highway Safety Manual (AASHTO, 2010) for the stage of selection of the countermeasures.

Table 1 – Scheme of a Haddon Matrix (based on Haddon, 1970).

Stage	**Human Factors**	**Vehicle Factors**	**Road and Environmental Factors**
Pre-crash			
Crash			
Post-crash			

The differentiation in three stages is important since studies and research can be conducted by focusing on particular factors related to different features of the accident considering different perspectives (i.e. the aim of post-crash analyses could be more oriented towards the mitigation of the severity of the consequences). In fact, after the identification of recurring problems through the accident analysis, the safety measure (or the safety campaign to a larger scale) can be oriented to particular targets. These targets can be the mitigation of specific types of accidents (e.g. the run-off road at curves) or the aim of reducing the level of severity of the accidents (e.g. the reduction of fatal and severe injuries accidents).

Anyway, among all the factors, the human factors play the most important role in the accident occurring, as shown in multiple researches conducted since decades (see e.g. Treat, 1979 for a former study about the influence of different factors on accident causation). In fact, more than the 90 % of the accidents can be related to human factors in the process of accident occurring, as lately confirmed by a recent statistic based on American data (Singh, 2015; see table below).

Table 2 – Critical Reasons[1] related to the Motor-Vehicle Accidents in United States divided by Factors (adapted by Singh, 2015).

Critical Reason Attributed to	**Estimated percentage[2] (± 95 % confidence limits)**
Drivers	94 % ± 2,2 %
Vehicles	2 % ± 0,7 %
Environment	2 % ± 1,3 %
Unknown Critical Reason	2 % ± 1,4 %
Total	100 %

[1] The critical reason is reported by the author as the immediate reason for the critical pre-crash event which often corresponds to the last failure in the causal chain of events leading up to the crash (not to be confused with the cause of the crash or the assignment of the fault).

[2] Estimated percentages based on unrounded estimated frequencies. The total sample is of 2189000 accidents, based on the National Motor Vehicle Crash Causation Survey (NMVCCS) 2005-2007.

As a consequence, a significant part of the research in the field of road safety has been devoted to the study of the influence of the human factors in the causation of the accidents. Particular attention was focused on the driving behaviour and all the user-related factors, resulting in the proposal of several behavioural models, such as the zero-risk model (Näätänen and Summala, 1974), the risk homeostasis theory (Wilde, 1982), the rule-based model (Michon, 1989), the risk allostasis theory (Fuller, 2011), the risk monitor model (Vaa, 2013) and the external and internal risk model (Colonna, 2011). They are only some examples of all the models proposed and revised in the last decades. Some of them will be further analyzed in the following sections.

However, the discussion about human factors and driving behaviour involves a huge list of possible particular fields of study. Therefore, it is interesting to look at another table reported by Singh (2015) in the same study cited above, which analyzed in detail the driver-related critical reasons of motor-vehicle accidents in the United States.

Table 3 – Driver-Related Critical Reasons[1] of Motor-Vehicle Accidents in the United States (adapted by Singh, 2015).

Critical Reason	**Estimated percentage[2] (± 95 % confidence limits)**
Recognition Error (*inattention, internal and external distraction, inadequate surveillance*)	41 % ± 2,2 %
Decision Error (*speeding, false assumption of others' actions, illegal manoeuver, misjudgement of gap or others' speed, etc.*)	33 % ± 3,7 %
Performance Error (*overcompensation, poor directional control, etc.*)	11 % ± 2,7 %
Non-Performance Error (*sleep, etc.*)	7 % ± 1,0 %
Other	8 % ± 1,9 %
Total	100 %

[1] See footnote n. 1 to Table 2 for the definition of critical reason.

[2] Estimated percentages based on unrounded estimated frequencies. The total sample is the 94 % (2046000 accidents) of the total sample described in footnote n. 2 to Table 2.

The analysis of Table 3 reveals that the most frequent driver-related errors found to be critical reasons for the accident occurring were recognition errors. This means that, by combining the percentages, about the 39 % of the total motor-vehicle accidents can be related to the driver's inattention, distraction or inadequate surveillance. Hence, among all the studies about human factors, this seems a critical problem to address.

Anyway, as stated in the Road Safety Manual (PIARC, 2015), finding the human factors to be over-represented in the accident-related factors, should not lead only to focus most of the attention on the driver as a "criminal" to be corrected through enforcement and education. Moreover, the design of safer roads and the development of safer vehicles should not be considered as separate and independent problems. The Road Safety Manual supports the "Safe System Approach". While the traditional approach to road safety interventions were focused on safer vehicles, safer roads and safer users, the safe system approach (by using the same words of the cited manual) addresses the "*critical interfaces between them*". The idea is that the human is fallible and that road accidents are unavoidable. Anyway, the road and the vehicles should be designed in order to overcome at a system level (user-road-vehicle) the errors of the drivers by reducing at minimum the consequences of the accident (reduction of fatal and severe injuries). Detailed explanations of these concise concepts here reported can be found in some key studies cited in the same manual (see e.g.: Koornstra et al., 1992; Tingvall, 1995; Wegman and Elsenaar, 1997; Tingvall and Haworth, 1999; Wegman and Aarts, 2006; Yidenius, 2010). Some of them describe the two European strategies known as: "Dutch Sustainable Safety" and "Swedish Vision Zero".

In practice, road designers should support these theoretical concepts by tending to "forgiving" and "self-explaining" roads. This means that roads should forgive some unavoidable errors made by drivers by reducing severity of the accidents and that a user completely ignorant about the road can navigate it without any problem because the road is able to explain itself (see Bekiaris and Gaitanidou, 2011 and all their references, for a recent detailed explanation of these concepts). In other words, the design of the roads should be coherent with the expectations of the road users and it should induce drivers to safe behaviours only through its own features (Theeuwes and Godthelp, 1995).

On summarizing in few words, since the aim of the studies in road safety is the reduction of the traffic accidents (or at least of their level of severity), then the understanding of the process of the accident occurring and all its related factors is crucial. Among all the factors, the human factors were recognized as the most important issues to study and analyze. Anyway, the approach is integrated: the final aim is to give to practitionners the right instruments for a safer road design and the development of the vehicles on considering the road as a system where the three factors interact with each other.

2.1.2 Route Familiarity in Road Safety – Theoretical Background

2.1.2.1. Definitions of familiarity

Among the human factors which can be related to the road accidents, there are still some features which need further clarifying studies. One of them is the familiarity of the drivers with a given road environment. Why can familiarity of the drivers be considered as an important factor in road safety? The answer to this question needs a detailed discussion about what is "familiarity" and what is the "route familiarity" and about the implications of these concepts in road safety issues.

The definition of the adjective familiar is: "*well known from long or close association*" (Oxford Dictionary of English). This means that the repeated exposure to a given situation, scene, object, process or whatever, makes people familiar, giving them an accurate knowledge about that. This concept can be ideally applied in any field.

In the case of driving, the repeated act of driving for several times on the same road, can make people familiar with that road. "Road" is a general word: it can be referred to a road section (of some meters or some kilometers), to a road intersection, to an unspecified type of road (urban or rural, divided or undivided, with two or more lanes). A "route" is instead a given path connecting an origin A to a destination B. A given route from A to B is composed of a sequence of road elements (each of them with their specific features). Normally, people spend most of their travel time by repeating specific routes (e. g. home to work, home to school, home to given shops, work to given shops etc.). In Fig. 2, some concise statistics based on Italian data from samples of interviews, about the distribution of trips into different purposes and the different frequencies of the same repeated trip are shown (ISFORT, 2014).

Based on Fig. 2, more than 60 % of the surveyed Italian people repeat a given trip at least 3 days a week and more than 50 % repeat a given trip daily. Moreover, on average, about the 40 % of all trips made by the surveyed Italian people are for working/studying (that could mean going always to the same school/place of work by using often the same path). It is also probable that part of the travels during the free time or for familiar reasons is often directed to a given fixed place. Statistics shown are related to Italy (and for the Italy itself they represent a rough average estimate) and so, they cannot be applied anywhere else as they are. Anyway, they were shown with the only intent of giving an idea of the very large amount of travel repeatedly made by people most likely by using the same paths. Furthermore, a noticeable part of these travels is made by car (i.e. a variable percentage from 57 % to 70 % in the period 2000 – 2014, in Italy as it emerges from the same source, but it can vary from nation to nation). Therefore, it is most likely that a high share of car travels is repeated on the same routes.

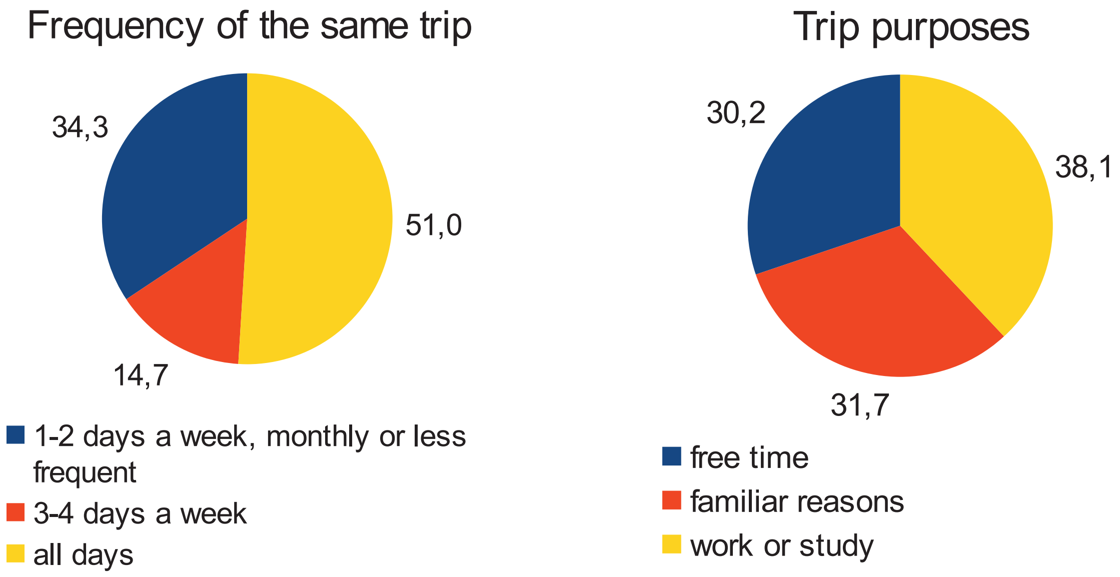

Fig. 2 – Synthetic statistics about trip purposes and frequencies related to a repeated trip, based on average Italian data over the period 2000 – 2014 (adapted from estimates by ISFORT, 2014).

Hence, the concept of “route familiarity” (Yanko and Spalek, 2013) can be better introduced at this point. There are several routes from a given fixed point A to a given fixed point B that drivers repeat with a noticeable frequency during the week. It can be assumed that those drivers are familiar (they well know the route for long or close association) with the route on which they are traveling. As a consequence, they well know the road elements of which the familiar route is composed of.

2.1.2.2. Familiarity and Driving Tasks

Route familiarity is a matter of interest for road safety studies because the act of repeatedly driving on the same route can have some influence on the driving task and any factor influencing the driving task is potentially able to influence the drivers' performances with respect to safety. Normally, the driving task is considered as a complex process. It can be considered as a hierarchic task composed of three levels (Michon, 1985): the strategical (planning) level, the tactical (maneuvering) level and the operational (control) level. At the strategical level, the driver makes plan about his travel before starting it (i.e.: mean of transport, route). These choices are considered as stable in the long term. At the maneuvering level, the driver faces some situations to be addressed in the short term through an action (e.g.: avoiding obstacles, turning, overtaking). At the lowest level, the operational one, the driver acts some automatic patterns in very short time e.g. related to adjusting speed (braking, accelerating, decelerating), steering or changing gears in order to respond to some external inputs. Anyway, these three levels normally communicate one with each other during the driving task. From the analysis of this early classification proposed by Michon, it emerges how driving behaviour is formed by addressing to external inputs both consciously and/or automatically depending on the type of decision.

More in detail, the driving task can be analyzed by considered the three behavioural levels of performance proposed by Rasmussen (1983): the skill-based, the rule-based and the knowledge-based behaviours. By using the words of the author, the skill-based behaviour is a "*sensory-motor performance during acts or activities, which, following a statement of an intention, take place without conscious control as smooth, automated, and highly integrated patterns of behaviour".* This behaviour commonly takes place in a familiar context, already encountered in past situations, where some behavioural rules to follow were previously defined. Conversely, in unfamiliar contexts, where no behavioural rules are already defined, the person acts by searching for a rule among different possible solutions in order to address the specific situation by trials and errors, to be potentially followed in future. In this case, the behaviour is defined as “knowledge-based” and it is thought as a higher-level behaviour, since it requires greater efforts by the person than the skill-based. Finally, the third level: the “rule-based”, is an intermediate behaviour between the two above-mentioned. In fact, it requires a familiar environment, for which some rules were been previously defined. However, there is an active effort by the person to select which rule is the best for the task. Hence, it cannot be considered automated as well as the skill-based behaviour.

Levels of performance considered by Rasmussen were summarized in Table 4, taken from Embrey (2005), in which the hierarchy of the tasks is graphically depicted, highlighting the passage from the conscious to the automatic.

Table 4 – Shift between conscious and automatic driving (Embrey, 2005; based on Reason, 1990).

• Knowledge-based	From CONSCIOUS
Improvisation in unfamiliar environments No routine or rules available for handling situations	
• Rule-based	
Pre-packaged units of behaviour released when appropriate rule is applied: IF the symptoms are X THEN the problem is Y IF the problem is Y THEN do Z	
• Skill-Based	
Automated routines requiring little conscious attention	To AUTOMATIC

From a preliminary analysis of the early theory by Rasmussen, used by different authors for further developments (see e.g. Reason, 1990), it emerges how essential is the role of familiarity in determining behaviours at different levels of performance. On summarizing in very few words, with the help of Table 4, one should say that conscious tasks are associated to unfamiliarity (knowledge-based performances) and that automated tasks are associated to familiarity (skill-based performances). In the intermediate performances governed by some preexisting rules (rule-based) the activity is a mix of conscious and automatic. In this case, a certain amount of familiarity is present with similar or connected tasks in the past.

The framework proposed by Rasmussen is generally applicable to the human behaviour. However, the three behavioural levels proposed by Rasmussen (1983) were combined by Hale et al. (1990) with the three driving task levels proposed by Michon (1985). The result of this combination is the matrix of driving tasks shown below.

Table 5 – Matrix of tasks (driving/performance) (Aasman and Michon, 1992; based on Hale et al., 1990).

		Level of Driving Task (Michon, 1985)		
		Planning	**Maneuvering**	**Control**
Level of Performances (Rasmussen, 1983)	**Knowledge**	Navigating in unfamiliar town	Controlling a skid on icy roads	Learner on a first lesson
	Rule	Choice between familiar routes	Passing other cars	Driving an unfamiliar car
	Skill	Commuter travel	Negotiating familiar junctions	Road following around corners

Table 5 is useful for the aims of recognizing the importance of familiarity in the driving-related behaviours. In this matrix, for each combination of level of driving task and level of performance, an example of a situation commonly faced by drivers is given. By looking at Table 5, it appears that familiarity of drivers is taken into consideration for distinguishing different driving situations between the diverse combinations included in the matrix of tasks.

In particular, considering the skill-based level (compared by Rasmussen with an automated process), the authors decided to give a particular importance to familiarity in explaining the different levels of driving tasks. For example, at the planning level, the commuter travel was included as example: commuters do not need to rationally think about which is the best travel to reach work from home, they do it likely automatically.

Moreover, at the maneuvering level, drivers negotiating familiar junctions are taken as examples: a driver who exactly knows the junction, likely automatically chooses the maneuvers to negotiate the junction. Conversely, the task of navigating in unfamiliar towns was remarked as an example of a planning task acted at a knowledge-based level: unfamiliar drivers do not know which is the best way from A to B in an unknown environment. Moreover, the car control is classified as not automatic in case of a driver on a first lesson (he has to learn how to drive, then the appropriate performance level is knowledge-based) or driving an unfamiliar car (he knows how to drive but he has to apply well known rules in an unknown context: the appropriate level is the rule-based).
In this work, the attention is focused on the implications of route familiarity in road safety. As shown above, familiarity can potentially influence all levels of driving tasks. Anyway, for the purposes of studying and preventing road accidents, the most interesting levels of driving task are the maneuvering and control tasks. In fact, the planning level implies medium/long term choices, while the accident happens or it is determined in a short period of time. Therefore, the choice between different routes in a familiar or unfamiliar environment (that is anyway a matter of interest for other researches in the transport sector, see e.g. Lotan, 1997; and in several other sectors such as the human choices in emergencies; see Sime, 1985) is not addressed here.
Moreover, it should be specified that “familiarity” is different from “experience”, even if in some ways the two features can be related. A driver can be very expert in the act of driving itself (i.e. he/she has been licensed for driving since many years and he/she has high values of annual mileage), but he can be totally unfamiliar with a given road environment and vice versa (see e.g. Milliken et al., 1998, who cite the cases of drivers familiar, inexperienced and experienced in unfamiliar environments when speaking about possible inappropriate speed decisions). It is important to note this fact, since the two matters can be confused. In Table 5, the learner at a first lesson is novice (has no experience with driving) and so, he is also unfamiliar with the road environment as a driver (but he can have some familiarity with the route as passenger). A peculiar case is the driver who drives an unfamiliar car (Table 5, control-level driving task acted at a rule-based level of performance). In fact, even if the driver is familiar with the road on

which he is driving and he is expert about the act of driving itself, he can be also more or less familiar with the vehicle (e.g. he does not know exactly where the commands are, or he is not familiar with the steering wheel, the pedals). However, a common situation for a non-novice driver is to drive a familiar vehicle, that is, not shifting vehicles often, or, at least, shifting between a limited number of familiar vehicles.

The point is that, as explained in section 2.1.1, drivers are included in a system: users-road-vehicle-environment. Therefore, in defining who are the familiar and the unfamiliar drivers, one should be careful in considering all the possible factors. For example, Lotan (1997) suggests that drivers can be familiar with a given route only at specific hours of the day or under given boundary conditions. This is an opinion that can be easily shared: the effects of familiarity (switching behaviour to automation) can present themselves if the driver is familiar with all the components of the system. Indeed, the driver can be considered as familiar if he is familiar with the act of driving (he is not a learner or recently licensed), he is familiar with the vehicle, he is familiar with the road and he is familiar with the environmental conditions (e.g. there are no unexpected conditions such as snow or unusual traffic volume for that kind of road). Instead, if there is no familiarity with one or more of these features, the driver can still be considered familiar with the other concurrent components of the system, but the driving task will likely require more attention, not making possible the switch to automation. In this work, focused on the "route familiarity", the familiarity/unfamiliarity of the driver is referred to the route traveled. However, for the reasons explained above, all other factors will be considered, if possible, when planning methods or discussing results.

2.1.2.3. Familiarity and Habituation

While speaking about driving tasks, great attention was paid to the possible shifts from the conscious sphere (more related to unfamiliarity) to the automated sphere (more related to familiarity). This shift can be explained from a psychological point of view, on considering that the repeated exposure to a given stimulus produces an automated response to the stimulus itself. This consideration is based on the early dual-process theory by Groves and Thompson (1970), who suggested that the behavioural output to a given stimulus depends on two parallel and interacting processes: the sensitization and the habituation process. In particular, the mechanism of the habituation process is shown in Figure 3. If a person is exposed to the same stimulus over time, then the response to it decreases with the repetitions of the stimuli, until it gets to an asymptotic value (decay of the response with the stimuli in the left part of the diagram in Fig. 3). However, if the stimulus is suspended, a variable part of the response can be recovered or, if a new stimulus is submitted after the habituation effect, then the response increases again (dishabituation effect, shown with the dotted line in Fig. 3). Anyway, independently from the continuation or not of the repetition of the new stimulus, the response decays again to the previous level corresponding to the habituation (right part of the diagram in Fig. 3).

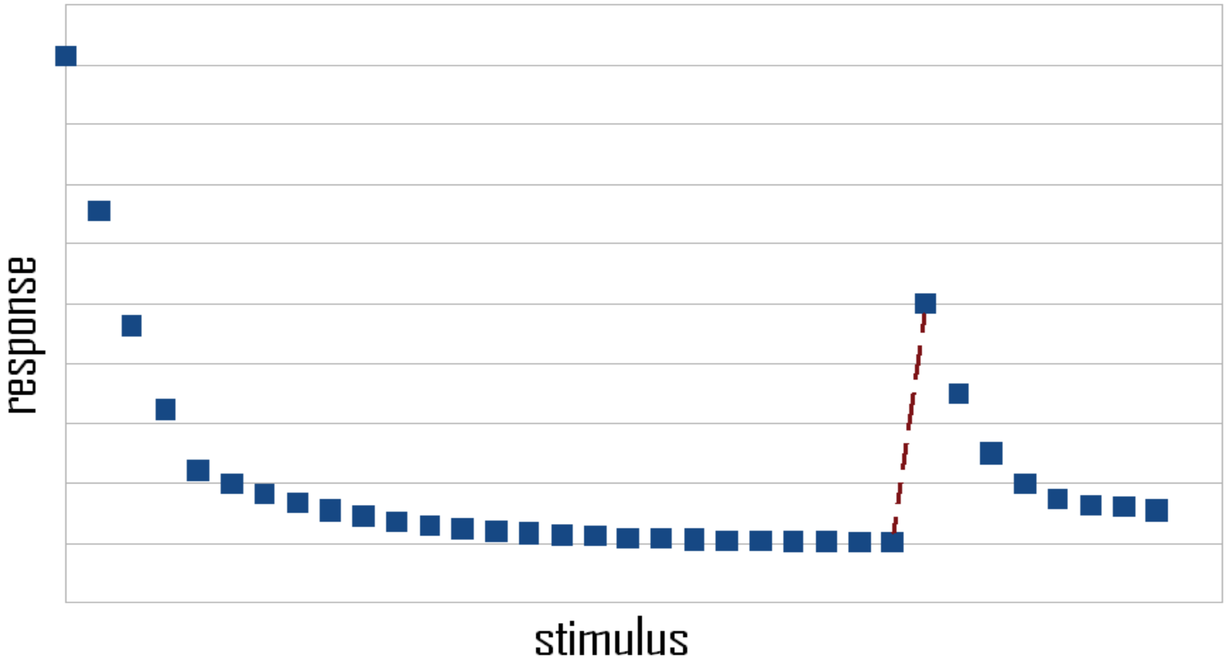

Fig. 3 – Habituation and Dishabituation effects (based on Groves and Thompson, 1970). The term "response" has to be intended as a measure of the response to a given stimulus.

The decrease of the response after the repetition of the stimuli can last for different time periods (from days to weeks) depending on the stimulus, resulting in a phenomenon called long-term habituation (Rankin et al., 2009).

If one think to the act of driving on the same route as a repeated stimulus over time, then the habituation effect is likely to be observed. Therefore, the response of a commuter, who drives almost daily on a given route could stay always on a constant low level given by the habituation effect. A low level of response means, according to the MART (Malleable Attentional Resources Theory) by Young and Stanton (2002), a reduction in the attention capacity due to a limited mental workload. It seems a natural process for the drivers' mind to search for a state in which the consumption of energy is minimum and the mind can be occupied by other thoughts different from driving. This state can be defined as “mind wandering”, often associated to driving (see Yanko and Spalek, 2014) and closely related to the phenomenon of distraction while driving.

All these theoretical expectations found confirmation in some studies which related the phenomenon of route familiarity to the driving performance. In particular, results from two experimental studies are here summarized. Yanko and Spalek (2013) highlighted that familiar drivers seem to respond slower than unfamiliar drivers to external dangerous events. In fact, 20 drivers participated in a driving simulator experiment, being assigned to two groups: the familiar group and the unfamiliar group. Drivers assigned to the familiar group drove four times on the same route (familiar route), while the others drove four times on four different routes. The fifth test was performed for both groups on the familiar route, asking drivers to follow a test car which was programmed for braking at selected locations. This test was further repeated by making the test car traveling at a speed, selected so that the heading distance with the following car is kept constant for all the participants to the experiment (with the aim of fixing one variable). Familiar drivers with the route shown longer reaction times both for braking (considered by the authors as the “central response”) and for noticing the lateral obstacles (considered by the authors as the “peripheral response”). In a further test, participants were asked to maintain a constant speed in order to keep them focused on the driving task. In this case, no significant difference was found between the two groups of drivers, suggesting that the increase in reaction times (decrease in response, if the theory by Groves and Thompson, 1970, is considered) is influenced by mind wandering. Similar results came from Martens and Fox (2007), who noticed from a driving simulator experiment, that the response of drivers to road signs (in terms of glance duration) decreases with the repetitions of the times that they have traveled on the same route. Moreover, most of the drivers who became familiar with the road after several repetitions of the travel, failed in notice a change in the priority of an intersection as suddenly modified by the experimenters.

Therefore, familiarity seems to be associated to greater inattention and distraction (mind wandering) from experimental studies. However, drivers' distraction and inattention were found to be as main contributors to errors related to accidents from the statistics by Singh (2015) presented in 2.1.1 (similar results can be found in Sandin, 2009 and Staubach, 2009). Thus, if familiarity can be related to inattention due to the decrease in response to external stimuli, the study of drivers' familiarity can contribute to the understanding of a potentially significant part of the accidents.

2.1.2.4. Familiarity, Speed and Risk

In other studies, familiarity was related also to more risk-taking behaviours potentially due to the over confidence in the driving task. Rosenbloom et al. (2007) found e.g. that drivers were responsible of more traffic violations and dangerous behaviours (included speeding) when driving in more familiar locations (the sample was composed of female drivers who drove in both familiar and unfamiliar locations). Moreover, results from a driving simulator study planned by Bertola et al. (2012) suggest that both speeds and standard deviations of the lateral position of drivers increased with the acquired familiarity with the test route.

This tendency can be explained by the fact that the driver acts for maximizing the utility related to his travel (see Noland, 2013 and his references for a detailed description of this concept). In fact, he aims at minimizing costs and maximizing benefits about his travel by making trade-offs between risk and mobility (Noland, 2013). Utility is presented by the author as derivable from the following equation:

$$U = f(P, T, C, A, R) \tag{1}$$

where P is the Price, T is the Travel Time, C is the capability of the driver, A are the in-vehicle activities, R is the Risk. P and T are variables related to the mobility, while C, A and R are variables related to safety. The driver aims at maximizing U by modifying his behaviour (e.g. in terms of speed choice, which could be seen as a main indicator of the driver's behaviour) making trade-offs between the listed variables. For example, in the speed selection process, if he can, he will try to reduce travel times by increasing speed. However, the increase in speed is related also to an increase in the price (cost of fuel), a greater need of capabilities by the driver and a shift to greater risk (higher speeds are generally related to higher accident risk: Nilsson, 2004; Elvik, 2013a). It can be argued that a route familiar driver has (or supposes to have) more capabilities than an unfamiliar driver about that road, since he knows very well all its features. Thus, this detailed knowledge can potentially lead the driver to travel at higher speeds (since his previous experience of traveling on that route could have indicated which is the maximum “safe” speed to follow) for the need of maximizing the utility. However, as explained above, higher speeds generally mean higher risks, which were observed for the familiar drivers in the above-mentioned studies (Rosenbloom et al. 2007; Bertola et al., 2012).

Another similar interpretation of the utility is given by Tarko (2007), who considers the subjective trip disutility (the opposite of the utility) as sum of the value of time, the perceived risk and the perceived enforcement. If the driver associates his speed to the three above listed variables, then the curve of disutility can be plotted against speed, as depicted in Fig. 4. The preferred speed for a driver could correspond in this case to the minimum of the curve (minimum disutility – maximum utility).

These considerations could imply in some way that the process of speed selection is rational and that the process of formation of speed could follow some algebraic rules. The formation of speed in different situations is likely to come from trial-and-error stages instead, in which the driver tries and learns from previous experience in a continuous process, which is the more suitable speed for that specific condition, that after can become the “habitual” speed for that condition (Fuller, 2007). This can complete what considered in the three-levels model of the situation awareness

(Endlsey 1995, 2000). People firstly perceive the situation, after comprehend its meaning and finally take a decision based on the projections of future events; considering choices based on time and space. Moreover, Fuller (2007) states that the "rewarding" speed (speed allowing to maintain control and avoid collision, while pursuing travel goals) learned for a particular situation (e.g. curve with a specific radius) can be potentially transferred to similar situations without the need for the trial-and-error process. Thus, the formation of speed seems to present some conscious and unconscious components. However, even if it is most likely that all drivers want to rationally maximize their utility (independently from the more or less rational way in which this maximization is reached), it is evident that the process of formation of the speed is subjective, since it can depend on the internal trial-and-error process. Moreover, higher speeds are related to higher risks and lower travel times, but these relationships are subjective. In fact, often, the speed selection must take into account misperception of risk and travel time by the drivers (Elvik, 2010).

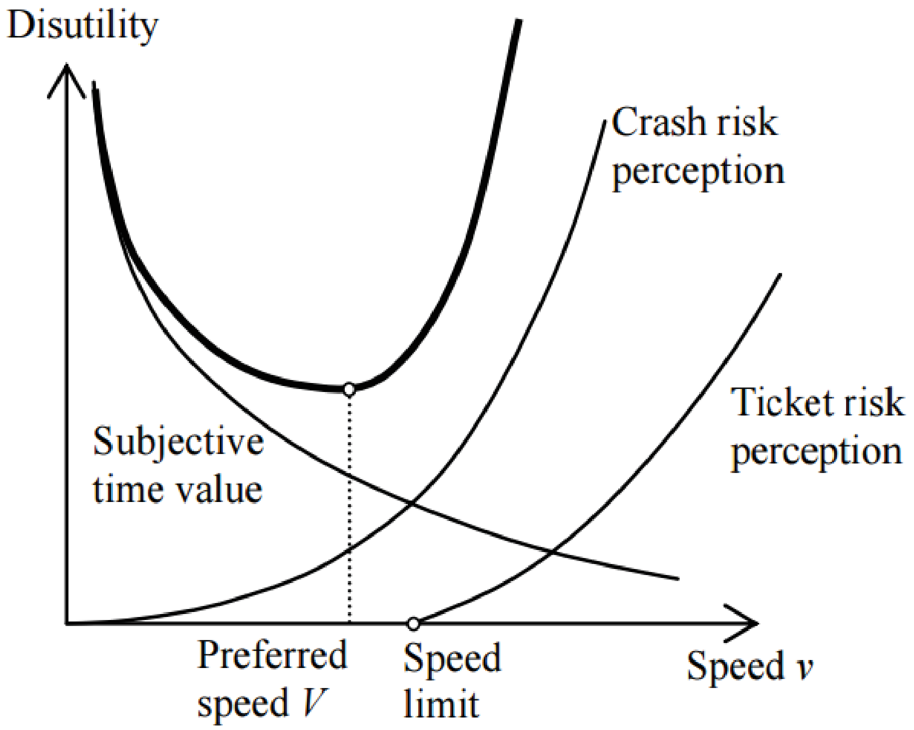

Fig. 4 – Speed deterrent and enticement curves in speed selection (taken from Tarko, 2007).

Therefore, it can be suggested that familiar drivers could be led to higher speeds than the unfamiliar drivers, since by the trial-and-error process, they learn the most rewarding speed by remaining in safety conditions. However, this process is negotiated by their subjective perception of risk, travel time and so, of the utility too. Since higher speeds mean higher risks, it could seem that only familiar drivers are potentially exposed to higher risks. This interpretation is partial, since the risk can be seen as composed of two components: one internal to the driver and the other external to the driver, as suggested by Colonna and Berloco (2011). A summary of this model is given here, since it can further explain different implications of familiarity in driver's risk.

A driver normally behaves in a different way with respect to his/her possible limit driving conditions (e.g. the travel to the hospital caused by an emergency under ideal boundary conditions). This difference depends on several factors belonging to the human (i.e. health conditions, experience, familiarity, type of travel etc.) and the other factors (road, vehicle, traffic, environment). This behavioural difference between the real behaviour and the driving limit conditions is named "Safety Margin": δi, which can be related to the driver's aversion to risk for the uncertainty of boundary conditions. The driver chooses his safety margin according to his psycho-physical conditions, his perception about the external world and the uncertainty about the determination of the margin itself. The authors suggest that the process required for setting the safety margin is able to affect the driving performance (e.g. the speed chosen, minor than the speed related to the limit conditions) in a medium-long term, representing a "strategic" behavioural level, mainly unconscious. However, when the driver feels that boundary conditions are changing (e.g. it starts raining), the authors suggest that the driver's attention is required to address the change ("attention" level, more conscious) in order to keep his safety margin constant with respect to the limit conditions. The time interval in which the driver's performance is affected by this attention request could be a short-medium term (one minute or less), after which he falls again under the unconscious strategic level, if boundary conditions are constant again. Moreover, when an unexpected and not predictable event presents itself (e.g. an animal suddenly crossing the road) the driver has to consciously react in a very short time (about one second) by braking or maneuvering, according to his/her reaction time and general conditions ("reaction" behaviour). The authors suggest that the driver can keep a safety margin also regarding this type of behaviour: δe, that represents the driver's proneness to risk deriving from unexpected events. It can be able to affect the driver's performance (i.e. speed and steering) in the very short term. Anyway, the authors state that drivers are not able to recognize and consciously distinguish those margins, mainly because a part of these processes happens unconsciously.

Risk can be considered as:

$$R = P \times I \qquad (2)$$

where
p is the probability of the unwanted event,
I is the intensity of its consequences.

However, on considering what stated above, it could be important to distinguish between the “real” risk faced by the driver and the risk “perceived” by the driver; and to consider the risk that the driver is willing to take (named “Safety Budget”). Apart from the case of suicides or accidents in which risk was not possible to detect (such as objects suddenly falling on the vehicles), accidents normally happen because drivers underestimate risk of their occurrence (errors in perceived risk); otherwise they would have reacted accordingly to avoid the accident.

Then, the authors propose to divide the risk into two contributes, belonging to different spheres of the driver:

$$R = Re + Ri \qquad (3)$$

where
Re is the External Risk, affecting the driver's very-short term reactions.
Ri is the Internal Risk, determining the driver's medium and long term behaviours.

The External Risk Re is defined as the difference between the real risk given by the external world (External Real Risk, Rre) and perceived risk (Rpe, Perceived Risk at External level):

$$Re = Rre - Rpe \qquad (4)$$

When there is equilibrium at the external level, the real risk is equal to what perceived and the external risk is null. If the difference is not null (real risk greater than the perceived one) instead, the driver has to face a risk which depends on his proneness to risk deriving from unexpected events ($Re = \delta e$). The more is the risk proneness of the driver, the more will be the finite risk he has to face. This equilibrium between the driver and the surrounding reality affects the driver's reaction in the very short-term period. The more the difference is high and suddenly revealed, the more critical is the driver’s condition.

The Internal Risk Ri is defined instead as the difference between the inner perceived risk (Rpi, Perceived Risk at the Internal level) and the Budget of Safety (bS) subjectively defined by the drivers:

$$Ri = Rpi - bS \qquad (5)$$

When there is equilibrium at the internal level, the perceived risk is equal to the budget of safety and the internal risk is null. Conversely, if the difference is not null (that is if the driver behaves in order to keep the perceived risk below the budget of safety, which is by definition the maximum risk that the driver is willing to take), the internal risk is negative. It depends on the driver’s aversion to risk for the uncertainty of boundary conditions ($Ri = -\delta i$). The more is the risk aversion of the driver, the more he will take a risk far lower than the budget of safety. This equilibrium between the driver’s perception and his unconscious reality (as defined by Freud, 1913: all psychological contents that do not appear in the current horizon of consciousness) affects the driver behaviour in the medium-long term. This equilibrium is dynamic, coherently with the Homeostatic Theory by Wilde (1982): if the boundary conditions change and the perceived risk changes as well, then the drivers adjust their behaviour in order to maintain constant the difference δi, representing their aversion to risk in the long term.
The equation of risk is presented by the authors as an addition, but they state that the two terms (internal and external risks) cannot be algebraically added up. Indeed, the hypothesis is that, in potentially risky events, the driver’s behavioural output depends on those above

defined concurrent equilibria based on the perceived risk at different levels: one external (influencing the short-term reactions) and the other internal to the driver (influencing the medium-long term attitudes).

This model describing the internal and external risk by Colonna and Berloco (2011) was discussed in detail since it suits well in explaining behavioural differences between familiar and unfamiliar drivers. In fact, for a familiar driver, knowing very well a given road, all other conditions being equal, it is most likely that his perception of risk always matches the real risk (if other unexpected events do not occur). For example, a sudden curve after a long tangent cannot be surprising for a familiar driver since he already exactly knows where the curve lies. For an unfamiliar driver, instead, all other conditions being equal, that curve will represent a sudden finite risk to face, since his expectations (perceived risk) will unlikely match reality (real risk). For the familiar driver, potential pitfalls could come from the internal sphere: he can misperceive the value of risk and he could shift to higher investments in the safety budget (higher acceptable risks, i.e. more dangerous speed and steering behaviours) due to his likely unconscious over-confidence produced by the familiarity. Hence, both familiarity and unfamiliarity can be related to different risky situations even if belonging to different spheres of the driver (internal and external).

However, the expectations about the role played by route familiarity in the driving behaviour, based on the utility-related and risk-related model above presented, need to be supported by experimental results. In particular, a more detailed analysis of the influence of familiarity on driving performances, given its expected potential importance, can be useful. Results from studies on the topic previously shown provide some remarks by answering to specific questions, while a more comprehensive and wide analysis could be needed. Indeed, the subjective partly non-rational nature of these processes should be considered in some way while developing relationships between driving performances (i.e. speed and position), perceived risk, travel utility and familiarity.

In this section, the word “risk” was mainly used considering the perception of the drivers and how this perception can be different for familiar and unfamiliar drivers. However, there are some studies in literature who analyzed the relationships between familiarity and the real drivers’ accident risk based on post-crash surveys or on accident database analysis. The problem is that the definition of “familiarity” was not homogeneous in these studies. Some works found in literature based on post-crash surveys used a frequency-based measure for defining familiarity (based on the frequency of traveling on the road, e.g. daily) and they focused on a particular type of accident. Liu and Ye (2011) found that familiar drivers (driving the road from daily to monthly) show higher percentages of run-off crashes than the unfamiliar drivers, among the total single-vehicle crashes. Baldock et al. (2005) found that familiar drivers reported to have been struck more than have struck other drivers in rear-end accidents even if based on a very small sample of interviews.

Further, some other works based on data analysis were focused on analyzing differences between urban and rural drivers and between foreign and national drivers (a distance-based measure of familiarity). Visitors were found to be more likely at fault than the national drivers by Kim et al. (2012), Yannis et al. (2007) and Wilks et al. (1999, but only for some types). Moreover, Blatt and Furman (1998) found that most of the rural residents were involved in fatal crashes on rural roads; while urban drivers, according to Donaldson et al. (2006) show the highest risk of fatality when involved in rural compared to urban crashes. The different perspectives of these studies (different methods and nations, different focus on accident types or on the origin of drivers), together with the different measures used for familiarity, do not allow to make some clear conclusions about the relationships between familiarity and accidents. Anyway, it is important to note how the matter is considered also while performing analyses on the accident risk based on observed data.

2.1.2.5. Familiarity and Adaptation

Another important topic, closely related with the aims of this research is the adaptation to road safety measures. The behavioural adaptation for road users is defined by Rudin-Brown and Jamson (2013) as "*the collection of unintended behaviours that follows the introduction of changes to the road and transport systems*". This means that the drivers can adapt to the changes made in the road environment by modifying their behaviour accordingly. If the implementation of a road safety countermeasure thought to solve a safety problem is taken into account, one should think that the countermeasure itself could be affected by adaptation by the drivers. This could lead to the uselessness or to the less effectiveness of the measure and, indeed, van der Horst (2013) provided a wide list of examples of engineering countermeasures undergoing to adaptation.

The problem of adaptation is closely related to the phenomenon of "risk compensation". A well-known (and debated over time) theory about the topic is the "theory of risk homeostasis" by Wilde (1982). In the Wilde's theory, the main factor controlling the adjustments in drivers' behaviour is the "target level of risk" (Wilde, 1994). Drivers tend to continuously compare their perceived risk with a target level of risk constant in the long term for each driver, with the aim of making the differences between them at the minimum, through short-term fluctuations. This is because the target level of risk represents a compromise between individual perceptions of costs and benefits defining an acceptable risk related to a given activity. The process is summarized in Figure 5, and it is represented as a loop, because the results of behavioural adjustments can influence the future risk perception through the experience of negative feedbacks in a homeostatic mechanism.

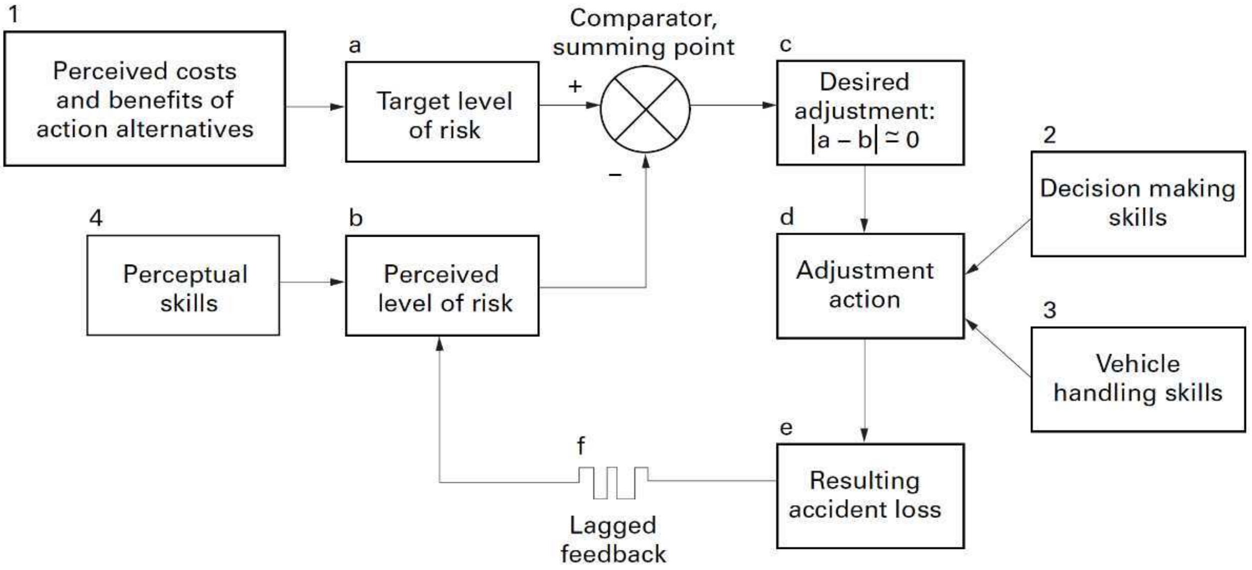

Fig. 5 – Scheme of the homeostatic process (taken from Wilde, 1998).

This approach was subsequently developed and used as a reference for further developments, such as the model presented in the previous sub-section (Colonna and Berloco, 2011) or the risk allostasis theory by Fuller (2011). However, in this latter theory, the preferred levels of risk are expected to be more related to the perceived capabilities, goals and motivations, giving more space to decisions based on feelings and emotions (see e.g. Slovic et al., 2004; Damasio,1994, 2003).

However, apart from the specific behavioural theory used as reference, most of them agree with a dynamic process in which a risk compensation can occur due to some changes in the road environment. If a road safety measure is implemented (e.g. the increase of a curve radius), then a change in the driving performance could be expected (considering the tendency to get closer to the target level of risk since the perceived risk is likely reduced or considering the will to maximize the utility of the travel through trade-offs between risk and travel time). As an example of a real case, the study by Montella et al. (2015) can be considered. In that study, the effects on speeds and safety of a new activated point-to-point speed enforcement on an urban motorway were evaluated. The system was associated to a significant decrease in the mean speed, the S_{85}, the standard deviations of speed and the crash frequencies. However, over the 3-years period of study, the effectiveness of the system seemed to decrease over time in terms of reductions in speeds and accidents. This could imply adaptation: driver could learn by experience which are the speed margins for being not sanctioned (e.g. the precision error of the system) and/or the periods in which the system is really active.

Furthermore, it could be argued, by the analysis of the previously explained results, that the familiarity of drivers could play a not negligible role in this adaptation process. In fact, as stated before while defining the “route familiarity”, a driver can be defined as familiar with the route if he is familiar with all the road features of the route in given boundary conditions. The introduction of a speed enforcement system is perceived by the drivers as a change in the boundary conditions. This could lead to a change in the drivers’ performance (e.g. the noted effect of speed reduction) because the perception of the risk related to a speed ticket arises, leading to a decrease in the perceived utility of the travel due to the potential increase of its cost (Tarko, 2007; Noland, 2013). However, a driver who travels repeatedly on the road on which the new enforcement system has been implemented, could learn in the long term if the system is really active (or the periods in which it works) or which is the maximum speed to do not get a speed ticket. Therefore, the familiar driver could have enough time to test the new conditions and to get used with them, following the usual process of habituation. Perhaps, the system should be more effective on unfamiliar drivers, since they have no time to get used with it. This could be especially valid if the driver is sure about the presence of the enforcement and of its operation. In fact, as suggested by Ryeng (2012) basing on stated preference surveys, the drivers can largely mispercept the amount of police enforcement (in that case a monthly police surveillance and not a fixed point-to-point system), even if they make more realistic estimates about possible sanctions. However, the same author found that familiar drivers (driving at least twice a year on the road) were able to make better estimates (even if slight better) about the enforcement than the unfamiliar ones, confirming that in some way the familiarity can influence these processes.

This latter section was focused on speed enforcement in order to show, through a concrete example, the possible influence of familiarity on the adaptation to road safety measures. However, these concepts could be theoretically applied to any safety measure different from enforcement. Hence, since route familiarity can be considered as a matter for road safety, by influencing the process of formation of driving behaviour, at different levels, both conscious and unconscious, and the reactions to different stimuli (novel or repeated); the theoretical background shown in this Section will be used together with the results presented in the research discussion Section (2.3) in order to make further considerations about the topic with the aim of their applications to the road safety practice.

2.1.3 Route Familiarity in Road Safety – Practical Implications

In this section, the practical implications of route familiarity in road safety are shown. The words "practical implications" mean the discussion about the consideration of the concept of route familiarity in the road and traffic engineering practices. This is useful in order to understand how practitioners have to face this issue in their field of interest while designing or planning. On the other hand, it will be useful for showing the potential applicability of this research to practical matters.

2.1.3.1. Familiarity and Road Design

The road design guidelines and standards include several concepts which are based on the assumption of some "design" conditions for the driver behaviour. In fact, in all the design requirements about speed, sight distance, geometric consistency, some assumptions about the driver behaviour are necessarily needed. While these features are addressed later in detail, it is firstly important to introduce the following basic concept.

Clearly, roads are designed by engineers considering that human drivers have to safely travel on them (and road design guidelines are indeed written for this aim, see Campbell et al., 2012). This means that the road layout should be easily understandable by the driver allowing (in the ideal design), simply through its features, the safe behaviour of drivers, by meeting their expectations. This is the concept of "self-explaining road" (see Theeuwes and Godthelp, 1995; for some applications see Charlton et al., 2010, Mackie et al., 2013).

Anyway, also for this ideal design process, one should think that not all possible drivers' behaviours can be considered in a design stage. For the explanation of this sentence, a comparison with the structural engineering practice can be useful. In structural engineering calculations, a structure is made of a given material and geometry (with some design characteristics) and it is loaded by a given stress. However, while most of the stresses can be accurately computed (e.g. the permanent loads), there are some unexpected events (e.g. earthquakes) inducing extra-loads which cannot be precisely estimated. Hence, some hypotheses considering "design" events with given characteristics based on historical and other available data, to be combined with the known loads in unfavorable conditions, have to be used. In the road design process, an infrastructure is made of a given material and geometry (with some design characteristics) and it is loaded by a given stress. Apart from the physical stress given by the vehicles to the road, let us consider the "stress" in a figurative sense as the traffic flow streaming on the road. As explained in the previous section 2.1.2, the drivers tend to travel by minimizing the travel disutility and by minimizing the mental workload to be used for the travel on the road. Therefore, an average behaviour is expected for all drivers in terms of speed and steering considering that they want to maximize the utility of the travel (i.e. reducing travel times) by remaining in safety conditions. However, in this case too, some scenarios difficult to estimate are present as long as not all users behave uniformly: some extreme behaviours can be noticed due to different drivers' characteristics (e.g. risky drivers, sensation seekers) or to particular travel purposes (e.g. reaching the hospital for an emergency). Predicting all possible drivers' behaviours could be more demanding than predicting unexpected events for structures, given the subjective and partly unconscious evaluations made by the drivers about safety and travel benefits. But, as well as in the structural engineering, some "design" conditions are normally considered by road design guidelines, including also the estimate of non-average behaviours, based on available data or expected estimates.

A key "design assumption" made in road design guidelines is the setting of the "design speed". The design speed was defined by the AASHTO (2001) as a "*selected speed used to determine the various geometric design features of the roadway*". For example, in the Italian Standards for road design (2001), an interval of design speed ranging from a minimum (safe speed of reference for the design of the more demanding elements such as sharp curves) to a maximum (safe speed of reference for the design of the less demanding elements such as tangents) is considered for different road types (urban/rural). The concept of design speed is used mainly for:

- Drawing the design speed profile, assigning a design speed value in each cross section of the road layout. Basically, it is used to check if subsequent elements show unacceptable speed differences requiring sudden braking, or if acceleration and deceleration are expected in unsuitable sections such as the horizontal curves.
- Drawing the sight distance profile, which assigns both an available and a required value of the sight distance in each cross section of the road layout based on the obstacles. It is used to compare the required sight distances for stopping, overtaking or lane changing with the available sight distances, for the aim of guaranteeing visibility. Required sight distances depend on speed: e.g. the more is the speed, the more is the distance necessary to stop.
- Setting geometric standards for road elements: the maximum length of a tangent (in order to avoid monotony, difficult evaluation of distances and dazzling), the minimum length of a tangent (in order to be easily perceived and correctly navigated, avoiding errors in steering), the minimum length of a curve (for the same purpose of the tangent), the shape of the spiral transition curve (in order to limit the sudden effect of lateral acceleration).

The use of the design speed shown above is based on the Italian Road Design Standards (2001) taken as reference. Anyway, apart from some differences, basic criteria of the Italian Guidelines are similar to other International Guidelines (see e.g. AASHTO, 2001; PIARC, Road Safety Manual, 2004).

Therefore, considering a design speed means considering a “design driver” traveling at that speed (or at a speed ranging from a minimum and a maximum design speed). However, although the maximum design speed can be noticeable high even for secondary rural roads (100 km/h according to the Italian Standards), the possibility of drivers exceeding those speeds is at the same time considered. Indeed, another key concept for the road design (and in particular, for safety-based maintenance of existing roads) is the “85-th percentile speed”. It is defined as the 85th percentile of the speed distribution usually measured (observed) at a given cross section in free flow conditions, daylight hours and dry conditions (see e. g. Esposito et al., 2011). This means that only 15 % of drivers were found to travel at speeds greater than the 85-th percentile (henceforth referred to as S_{85}).

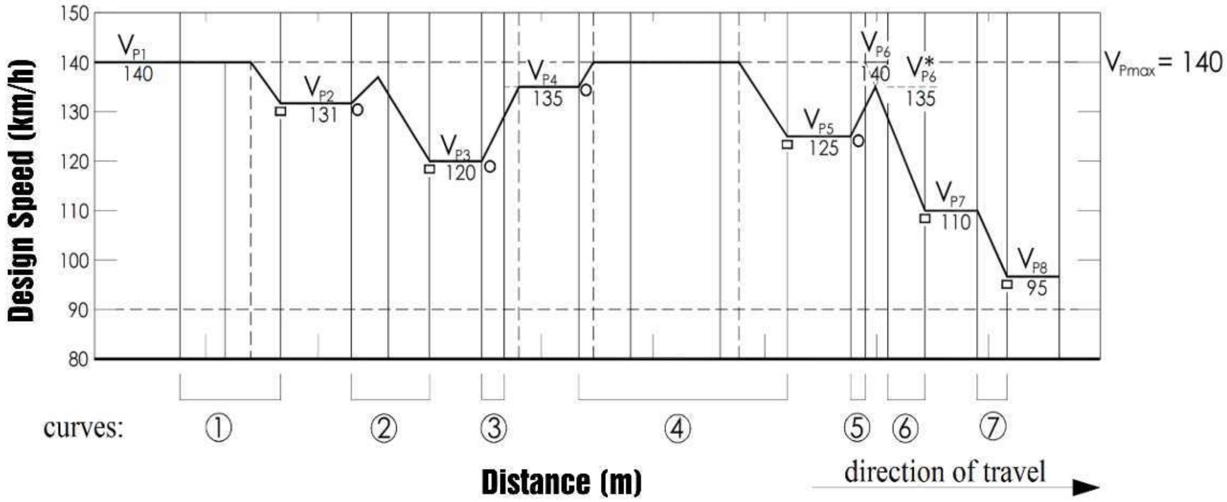

Fig. 6 – Example of Design Speed Profile (adapted from the Italian Road Design Standards, 2001).

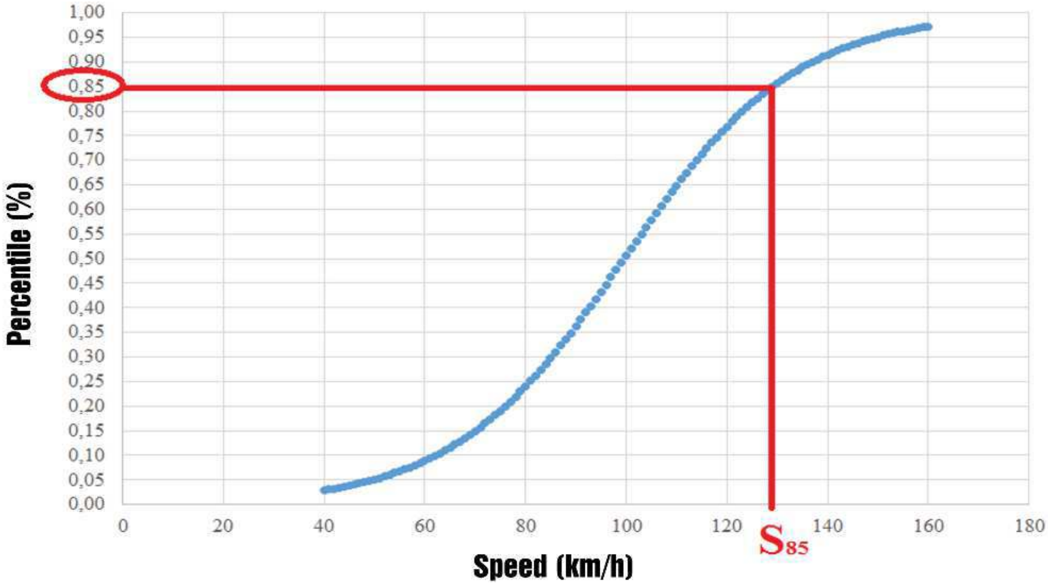

Fig. 7 – Example of 85th-percentile speed derived from an observed cumulative speed distribution curve.

Therefore, the S_{85} represents a speed which is passed only by drivers that can be considered as “outliers”, and it is based on available observed data or on models able to predict the S_{85} as a function of different road geometric and environmental features (see e.g. Lamm et al., 1999, Fitzpatrick et al. 2000, Discetti et al., 2011, Dell’Acqua, 2015). Based on the S_{85}, Lamm et al. (1999) proposed the following two safety criteria for the evaluation of the level of safety of an existing road:

- The first is based on the difference: S_{85} - Design Speed of a given road element, considered as acceptable if less than 20 km/h (or as good if less than 10 km/h).
- The second is based on the difference between the S_{85} of different subsequent elements. The difference is considered as acceptable if it is less than 20 km/h (or as good if less than 10 km/h).

Even if they could be not included in road design standards (expected operating speeds should be based on models developed for similar roads in similar environments), those criteria can represent a useful tool for safety diagnosis (where observed data could be available). In fact, for example, in the Italian Guidelines for Road Safety Management (2011, based on the EU Directive, 2008), the criteria for individuating safety problems while reporting results from inspections include the evaluation of the difference between the operating, design and posted speeds (see also Fitzpatrick et al., 2003 for a detailed discussion about those different speeds or De Luca et al., 2012, for some case studies). Operating speeds (which can be represented by the indicator S_{85}) should not be considerably higher than the design speeds, otherwise this could mean that safe speeds for which roads are designed are normally exceeded. Moreover, design speeds (and operating speeds) should not be considerably higher than speed limits, otherwise this could mean that speed limits could be meaningless and unlikely to be followed by the drivers. In fact, setting speed limits is another technical problem to address for safety purposes (see Milliken et al. 1998 for an early detailed discussion about the problem, one possible proposed solution is to set a posted speed close to the S_{85}).

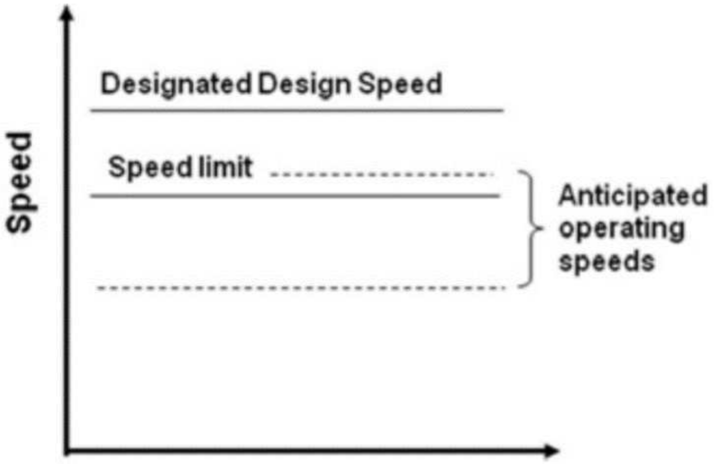

Fig. 8 – Ideally relationships between design speed, expected operating speeds and posted speed limits (taken from Donnell et al., 2009).

Apart from road design matters regarding speed, there is another important feature to consider about the relationships between human factors and road design guidelines: the road consistency, defined by Wooldridge et al. (2003) as the "*conformance of a highway's geometric and operational features with driver expectancy*" (see e.g. Gibreel et al., 1999, for an early review about road geometric consistency; Ng and Sayed, 2004, for a study of relationships between consistency and safety). Road consistency can be evaluated through different methods such as the model developed by Dell'Acqua et al. (2012), considering different measures of speeds. Road consistency requirements can be found for example in the provisions about speed homogeneity to be checked through the design speed profile, in the minimum lengths of tangents and curves or in the compliance of operating speeds with posted speeds. However, more in detail, road design guidelines consider geometric consistency while designing subsequent road elements: curves after tangents, a series of subsequent curves, spiral transition curves before circular curves. The key principle is that the driver should not be surprised by the road: subsequent elements should be not largely different or unexpected from the previous ones found by the driver on the same road layout (see e.g. Italian road standards, 2001).

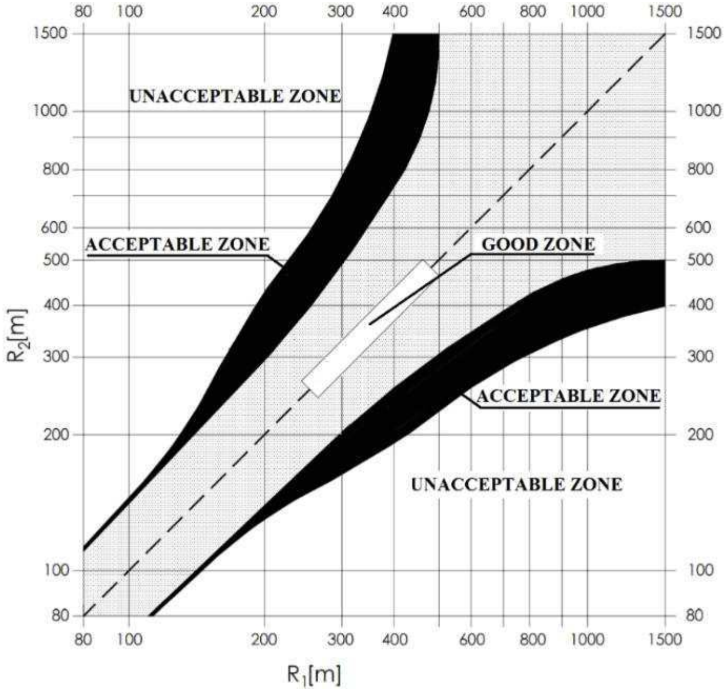

Fig. 9 – Example of geometric design consistency of subsequent radii of curvature, R_1 and R_2, of curves (adapted from the Italian Road Standards, 2001, based on Richtlinien für Anlage von Strassen, 1995).

This detailed description about the relationships between the human factors, the design speed (related to an ideal "design driver") and the operating speeds (related to real drivers, considering also "outlier drivers") is useful to introduce the importance of route familiarity as a human factor in the road design stage.

Indeed, it should be noted that most of the requirements above indicated in road design standards and guidelines are focused on a "design driver" which can be thought as unfamiliar with the road environment. In fact, the recurrent theme in those requirements is that the real road must always meet the drivers' expectations. But, there are evident differences between the expectations of a familiar driver and those of an unfamiliar driver, all other conditions being equal. A familiar driver already knows what to expect by the road (apart from sudden and unexpected changes in the boundary conditions), knowing its geometric features very well; while an unfamiliar driver could be more easily surprised by a demanding road layout which is not able to explain itself. Indeed, by reporting the words of Milliken et al. (1998) in their report about setting speed limits and enforcement: "*the designer should assume that motorists are driving on a roadway for the first time and that they have no familiarity with its features*". However, the same authors suggest also that familiar drivers could make decision errors due to fatigue or other variables. Therefore, the matter is explicitly considered when speaking about "design drivers". In light of these remarks, the above explained design concepts are recalled as follows, highlighting the possible relationships with route familiarity.

- The <u>check of design speed profiles</u> requires that high differences in design speed should be not allowed between two subsequent elements (i.e. approaching to a curve coming from a tangent). This is a requirement that concerns an ideal design speed related to an ideal design driver. However, this need for speed homogeneity can be thought as a way to preserve the driver from sudden brakes required to slow down to a very low speed at curves. The speed homogeneity between subsequent elements has to be considered especially for unfamiliar drivers, since they are more exposed to sudden brakes and then more risks, if the speed required to safely navigate a curve is too much lower than the free flow speed of the tangent, because they are not able to expect this circumstance. Hence, it emerges how the design driver can be thought as modeled on the unfamiliar driver, who does not know the road layout and then, he could not address a high unexpected speed difference with a safe deceleration.

- The lengths of tangent and curve sections have to abide by some rules (above referred to the Italian road standards as an example). Tangents and curves should have a minimum length, according to their design speed for the aim of being correctly and easily recognized. Again, in this case, the design driver can be reconducted to an unfamiliar driver who has not confidence with the road layout. This circumstance could lead to errors in steering due to misperceptions of the presence (or of the real length) of a curve (e.g. keep traveling straight) or of a tangent (e.g. keep assuming a curve trajectory). A familiar driver who acquired confidence with the route would instead have probably learned those possible pitfalls. However, also tangents should have a maximum length as a function of the maximum design speed. This is thought in order to avoid difficult evaluation of distances and dazzling (which can happen to both familiar and unfamiliar drivers), but also to avoid monotony. Since behaviour of familiar drivers was associated to both distraction and more dangerous behaviours (see 2.1.2), then this requirement for tangents can also address possible problems for them. Indeed, the monotony caused by a very long tangent could allow both distraction and the possibility of higher speeds, possibly related to familiar drivers' behaviour.
- The features of subsequent road elements should be geometrically consistent in order to meet expectations of the drivers. This is particularly addressed when choosing the curve radius as a function of the previous tangents (i.e. avoid sharp curves after long tangents) and previous curves (i.e. subsequent curves should be appropriately radius-homogeneous, see Fig. 9) or when designing geometric features of the spiral transition curve as a function of the following curve sections to be correctly perceived. Again, in this case, those design requirements can be thought to consider a design driver matching the unfamiliar condition. Indeed, the unfamiliar driver could make some expectations from the road section immediately traveled. For example, if it includes all curves showing a radius of 500 meters or more, than the driver's expectation is to find other similar curves. The placement of a curve with a radius less than 100 m after those curves in a row, would have been very surprising if the driver is not route familiar.

- The safety criteria about speeds remark that differences between design, operating and posted speeds should not be inadequately high. In the design stage, a posted speed too much lower than the design speed or the expected operating speeds could represent a technical error. At the safety-based maintenance stage, observed operating speeds (indicated by the S_{85}), too much higher than the design speed and the posted speed limit, could represent a safety issue to address. In this case, one could assume that, if the driving attitude on a given road is assumed as formed by trial-and-errors stages (Rasmussen, 1983), then familiar drivers choose their speeds based on their previous experience on that road for the aim of maximizing the utility of the travel (see 2.1.2). Based on this perspective, familiar drivers may choose to travel at their subjectively-defined maximum "safe" speed, which could be different from the posted speed limit, for maximizing the travel benefits, but considering also their personal perception of risks about crashes and speed tickets (Tarko, 2007). Instead, it is most likely that unfamiliar drivers at their first travel on a given route, could be not ready to choose the maximum possible speed, since they still do not have a clear perception about the risks of the road in terms of possible crashes or speed tickets (e.g. presence and effectiveness of speed cameras). Moreover, it should be considered also that a high share of drivers of a given road (except some particular roads, such as touristic routes) could be familiar with it. Therefore, those safety criteria could be thought mainly as tools focused on the safety of familiar drivers. Speed limits (with or without speed cameras) should be posted according considering expected (or observed, in case of interventions on existing roads) operating speeds in order to be realistically followed by the drivers and, in particular, by the familiar drivers (who possibly tend to higher maximum safe speeds).

Finally, another feature considered for road design and road safety in particular, is the road friction (see e.g. Lamm et al., 1999 or Colonna et al., 2016b, who updated the safety criterion by Lamm by taking into account all vehicle, environment and road-related characteristics). Considering that drivers unlikely notice that a skidding is about to happen before it starts effectively (Colonna et al., 2016b), then human factors could probably not be directly related to the risk of skidding. Anyway, the risk of skidding (at curves for example) increases with the travel speeds due to the centrifugal force. Based on what described in previous sections, once the maximum subjective safe speed is selected by a familiar driver for given boundary conditions at a curve section, it is most likely that he will follow his already fully formed behaviour and that he will not skid due to incorrect higher speeds. The risk of skidding could increase for familiar drivers if boundary conditions sudden change and the driver does not react accordingly (e.g. it starts snowing). Instead, unfamiliar drivers could be prone to incorrect curve navigations and incorrect speeds in approaching unexpected sharp curves. Therefore, also for the skidding risk, some possible pitfalls emerge for both the inquired categories of drivers.

2.1.3.2. Familiarity and Traffic Engineering

The familiarity of drivers with a given route can be taken into account also in the traffic engineering while considering the capacity of a road section.

Indeed, in the traffic engineering practice, as in the road design process, there is a need for considering a "design traffic" in order to define the levels of service of a road (and the required number of lanes of a given road in order to obtain a desired level of service). According to the methodology provided by the Highway Capacity Manual, for a given average speed of the traffic flow, the more is the traffic volume with respect to the capacity (the more is the V/C ratio), the worse will be the level of service of the road (from A to E), measured in car density: equivalent passenger cars per mile per lane (see Figure below).

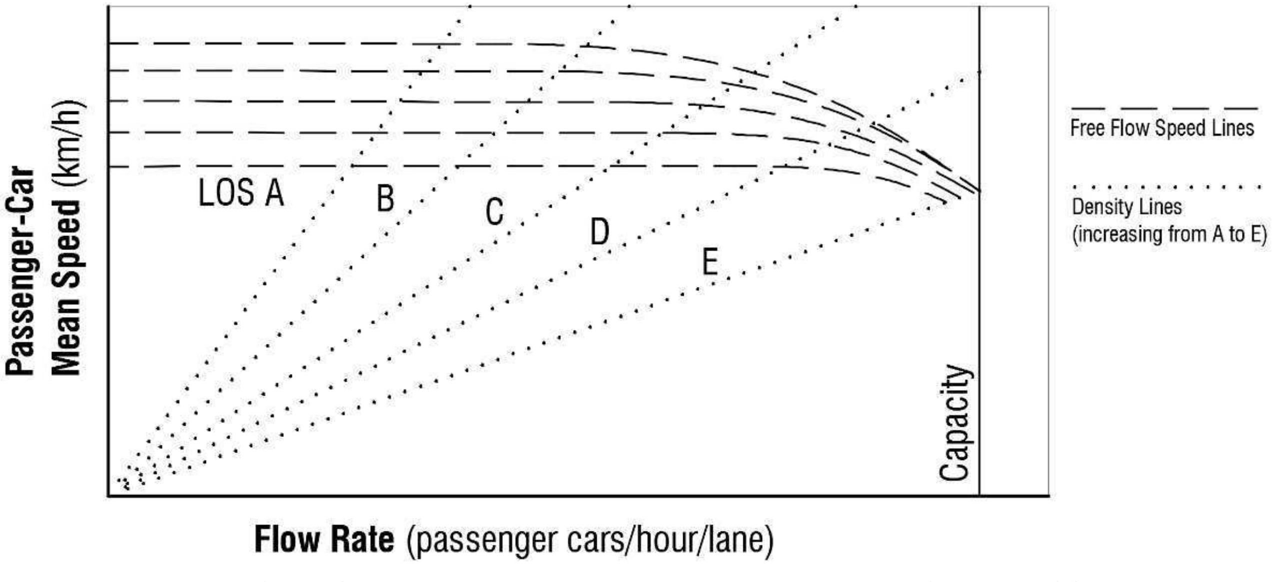

Fig. 10 – Example of Speed/Flow curves and individuation of the Levels of Service (LOS), based on the Highway Capacity Manual.

In the framework used by Highway Capacity Manual (HCM), the traffic volume used for the design is named "equivalent flow rate" (since 1985, until the last version in 2010) for the calculation of the levels of service for freeways and multi-lane highways. It is computed as:

$$Vp = \frac{V}{PHF*N*f_{HV}*f_P} \tag{6}$$

Where:

Vp = 15-minute passenger-car equivalent flow rate (passenger cars/hour/lane)
V = hourly volume (passenger cars/hour)
PHF = Peak Hour Factor
N = number of lanes in one direction
fHV = heavy-vehicle adjustment factor
fp = driver population adjustment factor

Therefore, the flow rate can be considered as the number of design "equivalent" passenger cars traveling per hour and per lane on a given road cross section, by taking into account peak differences in traffic volumes, the presence of heavy vehicles and different categories of drivers. The reason for introducing an adjustment factor for heavy vehicles can be easily understood by considering that, the passage of a heavy vehicle cannot be assimilated to a passenger car in terms of density and capacity. Therefore, the hourly volume has to be adjusted by considering a factor for heavy vehicles which is less than 1 to convert it into a passenger cars hourly volume. This means that the equivalent flow rate used for the calculation of the LOS is higher than the unadjusted flow rate and then, the LOS is worse than the one computed in absence of heavy vehicles, all other conditions being equal. Moreover, the reasons for introducing a driver population adjustment factor are not immediately understandable, but it represents a key factor for the studies about familiarity. Therefore, it will be analyzed in detail.

The fp factor was early introduced in the 1985 version of the HCM, remarking the possible presence of recreational drivers in the traffic flow. Therefore, drivers are considered as divided into two main categories according to their degree of familiarity with the given road section, mostly based on the reason of the travel:

- Regular drivers, such as commuters (traveling for work or educational purposes), which can be considered as more familiar with the road;
- Recreational drivers, such as who infrequently drives on the road (e.g. tourists), which can be considered more unfamiliar with the road.

This differentiation is important, since the fp value is set to 1 in the case of traffic mainly consisting of regular users and it can be set down to 0.75 for a traffic including a more or less significant share of recreational drivers. This means that other conditions being equal, a decrease of fp up to a minimum of 0.75, corresponds to an increase in the equivalent flow rate Vp up to about 30% more than the value computed for fp equal to 1. Therefore, according to the LOS framework, the presence of recreational users leads to an evident deterioration of the LOS of the road, other conditions being equal. However, despite the importance given in the HCM to this aspect, it was not easy to precisely evaluate fp within the range from 0.75 to 0.9 (in the case of traffic flow with recreational users).

Based on a study carried out by Sharma (1987) on main roads in two Canadian regions, the fp can be chosen following a road classification which takes into account the main users of the road. It considered two base parameters: the reason for travel and the distance traveled, as shown in Table 6.

Table 6 – Choice of the fp values according to Sharma (1987)

Type of road	**Type of traffic**	**fp**
Roads used by commuters on Urban scale	Urban commuters	1.00
Roads used by commuters on Regional scale	Regional commuters	0.95
Roads used by commuters and other users on Regional scale	Regional recreational/commuters	0.90
Roads used on Interregional scale	Interregional	0.85
Roads used for long distance travel	Long distance	0.85
Roads used for long distance travel and for tourism	Long distance/recreational	0.80
Roads almost exclusively used for tourism	Highly recreational	0.75

Later, the problem was analyzed by Lu et al. (1997), who conducted an experimental analysis using continuous counts of traffic data on freeways in Florida, USA. They proposed to correlate the driver population factor to quantitative indexes, able to take into account the share of non-local drivers present in the traffic flow, based on two different approaches. The first approach is based on locally derived data (tourist surveys) for estimating the share of non-local drivers; while the second is based on the Non-Local Driver Index (NDI), computed by evaluating the fluctuations of the traffic (both on a yearly base between different months and on a daily base between morning and afternoon). Based on their estimates, they suggest that a fp factor included between 0.85 and 0.9 could be appropriate in areas where the non-local driver population is considerable. Therefore, the previous lowest value of the fp range equal to 0.75 could seem too much pessimistic with respect to capacity. Indeed, since the HCM 2000, the lowest value of the fp range was increased up to 0.85 (until the last version in 2010).

Similar results were found by Al-Kaisy and Hall (2001) and Heaslip et al. (2008), for the long and short-term work zones. Al-Kaisy and Hall proposed fp values based on a study in which a Canadian touristic freeway was affected by a long-term lane closure. The periods of congestion were monitored and the differences between the capacity during the morning peak, with traffic mainly composed of commuters, and the capacity during the afternoon peak, with traffic including more recreational users were analyzed. The differences between the capacity during the morning peak on working days and on holidays were analyzed as well for the same reason. Experimental fp values, obtained as the ratio of the two capacity values in both the two conditions analyzed, are summarized in the following table.

Table 7 – Choice of the fp values according to Al Kaisy and Hall (2001), based on a observational study on a touristic highway affected by long-term lane closure.

Cases analyzed	**fp**
Morning peak/Afternoon peak	0.93
Morning peak on working days/Morning peak on holidays	0.82-0.85

Heaslip et al. (2008) analyzed the case of short-term work zones and they based their estimates of the fp value on considering also video recordings and some variables deducible from them (familiarity, adaptability, aggressiveness and accommodation). Through the

combination of those variables they proposed to introduce a fp adjustment factor also for the calculation of capacity at freeway work zones (included between 1.375 and 0.64).
In a more recent study, Seerheman and Skabardonis (2013) found minor effects of the non-local driver populations on the capacity instead, based on their experimental study on freeways in California, USA.
This detailed discussion about experimental results or estimates obtained for the fp value is useful to understand how the matter is currently debated. The main problem is that traffic engineers would consider that "*traffic streams with different driver characteristics* (e.g including recreational drivers) *can use freeways less efficiently"* (Al-Kaisy and Hall, 2001; based on HCM, 1985); but they often have problems in evaluating this efficiency. Indeed, in the HCM itself, there is no strict guidance on the determination of the fp value. However, for the aim of this study, it is important to go beyond the possible fp values and to focus on the reasons for its necessity. The fp value was reasonably introduced for the same reason of the f_{HV} factor for heavy vehicles. Considering to use the current minimum value for the fp factor (0.85) in the equivalent flow rate calculation, this will lead to an increase in the Vp of about the 20 %. This means that, all other conditions being equal, 100 real car passages (including a significant share of recreational drivers) should be equivalent to about 120 design car passages if all drivers were regular drivers (the base condition). Hence, the design Volume/Capacity (V/C) ratio is reduced, the design density is higher and the design free flow speeds are lower (as it can be noted from Figure 10 for higher flow rates, other conditions being equal). Therefore, the effect of this design process for the flow rate reflects what it was observed and expected for the presence of recreational drivers: a reduction of the capacity and a reduction of the speeds (Washburn and Bian, in 2014, proposed for this reason to consider the presence of recreational drivers directly through both a speed (SAF) and a capacity adjustment factor (CAF); rather than through a flow adjustment factor fp).
Since for the reasons explained in the section 2.1.2.1, recreational drivers could be considered as more unfamiliar with the route, while it can be argued that the base condition of regular drivers (such as commuters) could correspond to the familiar drivers; then also in traffic engineering, the familiarity is considered in the practice as affecting the design process, matching the reality of the traffic on real roads. A significant presence of the unfamiliar drivers in the traffic flow is related to a decrease in both capacity and speeds. This is

coherent with what it is expected, on average, for the unfamiliar drivers from the analysis of the section 2.1.2. They are likely less confident with the road environment and so, they could be prone to choose speeds lower than the speeds selected by the familiar drivers. Another possible feature to consider is the increase in following distances (see e.g. Seerheman and Skabardonis, 2013): drivers not knowing the road could be less prone to follow very close another vehicle. This could affect, as well as speed choice, the capacity, which was found to be reduced.

However, the point of view of traffic engineering does not include road safety parameters when considering the presence of unfamiliar drivers in the traffic flow (focusing on speed, flow and density) but, relating the knowledge in these two fields could be useful. In fact, some information about the potential impact of the remarkable presence of unfamiliar drivers in the traffic flow (which was found to be influential on it) on the road safety performances could be acquired.

2.1.4 Research Questions

In the previous sections, the relationships between route familiarity and driving behaviour were analyzed in detail, considering the implications in road safety, road design and traffic engineering.

However, some matters could benefit from an in-depth analysis. In particular, in the section 2.1.2.1, a discussion about how to define route familiarity was addressed. Some indications were given, but, considering also the variety of the measures of familiarity used in studies inquiring into relationships with accidents (see section 2.1.2.4), there is a need to deepen the background about this definition. More in detail, it should be useful to define a threshold both for frequency-based measures and distance-based measures of familiarity, in order to give more precise measures for defining route familiarity. Since route familiarity was related to the driving performances but only some studies analyzed the problem, a more detailed in depth-look at the possible influence of familiarity on two main driving outputs: speeds and trajectories will be useful. Moreover, the matter of familiarity was explained from the point of view of behavioural theories (see sections 2.1.2.2, 2.1.2.3, 2.1.2.4, 2.1.2.5). Therefore, it could be interesting to measure subjective parameters of drivers such as the risk perception or the travel utility based on observed data, and to match results with the theoretical expectations. Moreover, since the route familiarity is considered also from the perspective of traffic engineering (see 2.1.3.2), a more detailed discussion of the implications of the presence of familiar drivers in the traffic flow, starting from the HCM framework, could be addressed and further matched with the road safety findings. Finally, a detailed analysis of the relationships between familiarity and road accidents is necessary to overcome the gaps in the recent iterature about the topic.

Hence, the main aim of this research is to try to give an answer to the following research questions, previously highlighted:

- Need for a more detailed look into relationships between route familiarity and driving performances (with particular focus on speeds and trajectories).
- Need for experimental-based evidence of the changes in subjective drivers' perception related to the travel due to acquired familiarity with the road.
- Need for integrating the knowledge in the field of road safety with the traffic engineering practice, if the presence of unfamiliar drivers in the traffic flow is considered.
- Need for a more detailed analysis of the relationships between familiarity and road accidents.
- Need for more specific measures for defining route familiarity with respect to the frequency and the distance.

The results from the research will be further discussed from the point of view of road design, by considering some practical solutions to better take into account the matter of route familiarity in road safety measures, also in light of what shown in the section devoted to the adaptation to safety countermeasures.

2.2 CHAPTER 2 – DATA SOURCES AND GENERAL METHODS

In this chapter, the data sources used for the research will be presented. Apart from the concepts and the frameworks explained in the General Background (2.1 – Chapter I) which represent the theoretical foundation for the development of the research, two main sources of experimental and observed data were used: measures from an on-road experiment and an accident database.

Hence, the chapter is organized in subsections. *Section 2.2.1* (*On-Road Experiment*) is devoted to the description of the on-road experiment from which the data used for further elaborations come from. In S*ection 2.2.2 (Accident Database),* the source of accident data used for inquiring into the relationships between familiarity and road accidents is described.

2.2.1 On-Road Experiment

An on-road experiment previously conducted by researchers of the Technical University of Bari has been used as a source of data of speeds and lateral positions.

The on-road experiment was carried out on a two-lane two-way rural road layout placed near the town of Cassano delle Murge (Municipality of Bari, Apulia, Italy). Twenty young drivers recruited among the students of the Technical University of Bari were asked to drive their own car on the experimental test route. The main requirement for the test drivers was to be unfamiliar with the route chosen for the experiment, familiar with the act of driving in rural environments (in terms of mileage) and with the act of driving itself (being not freshly licensed to drive).

The road layout is depicted in the Figure 11. It is composed of two stretches of roads (belonging to the roads named SP31, stretch 1, and SP18, stretch 2). Together, the two stretches form the whole test road layout (from the Start to the End, see Figure 11). The test was composed of two stages. Firstly, the drivers were asked to drive freely a return journey from the Start to the End. On the second step, the drivers were asked to drive again by following these rules regarding speed choice for other three further laps (similarly to another experiment described by Colonna et al., 2013):

- “Low” Lap – Drivers were asked to drive by selecting a speed considered as low by themselves;
- “Medium” Lap – Drivers were asked to drive by selecting a speed considered as medium by themselves;
- “High” Lap – Drivers were asked to drive by selecting a speed considered as high by themselves.

These diverse conditioned speed laps were planned in order to acquire a measure of the different drivers’ attitude, indirectly obtaining information about their risk perception through the different speed choices and driving styles (see also Reymond et al., 2001). These rural very low-volume roads (especially the stretch 1, with traffic close to zero for many hours) were chosen in order to ensure free flow traffic conditions. However, users were asked to report about car-following situatons encountered during the tests, in order to exclude also this condition from the final dataset. Furthermore, in order to limit confounding factors, the tests were conducted in good weather and visibility conditions (in the case that adverse conditions such as rain or fog were present as reported by the drivers, the related data were discharged from the dataset). The chosen road is characterized by a very low traffic volume. Users drove without the presence of the researchers in the car during all tests in order to be not influenced by them.

Fig. 11 – Road test layout composed of the two stretches of roads, taken from Colonna et al., 2016e.

The drivers repeated the above reported test scheme, six times in six different days according to the following time schedule: first four driving tests four days in a row; the fifth test in the tenth day since the beginning of the test (after 6 days from the last test) and the sixth test in the twenty-seventh day since the beginning of the test (after 17 days from the fifth test and 23 days from the fourth test).

Table 8 – Calendar of the driving tests

Day	Driving Test	Day	Driving Test
1	1th	16	
2	2nd	17	
3	3rd	18	
4	4th	19	
5		20	
6		21	
7		22	
8		23	
9		24	
10	5th	25	
11		26	
12		27	6th
13		28	
14		29	
15		30	

Speeds and positions of the drivers were recorded through the technique of differential GPS positioning, based on data obtained by two receivers: a fixed station and an on-board rover antenna (which registered its position with respect to the fixed receiver on a connected device). Positions and speeds were recorded with a frequency of 1 Hz. The technique used could lead to an average location accuracy to within 10 cm and an average speed accuracy to less than 1 km/h. After, 137 cross sections were placed along the road layout with a pitch of 25 meters as in Figure 12 for both the stretches 1 and 2. The parts of the stretches near the intersections were excluded from the positioning of cross sections in order to ensure that data will be not influenced by those elements. The road layout was rebuilt in a CAD environment and therefore, for those sections, a value of the available sight distance was assigned to each section. Drivers were clustered into three behavioural classes (risky, average and prudent) based on the speeds measured from the on-road experiment (six risky drivers showing speeds greater than the mean, eight average drivers showing speeds close to the mean, five prudent drivers showing speeds lower than the mean), by using an automated clustering technique (K-means). For this aim, only free speed laps were used, since they are unbiased from the diverse perception of drivers about low, medium and high speeds.

Fig. 12 – Placement of cross sections along the road layout, taken from Colonna et al., 2016e.

Moreover, other twelve particular cross sections were assigned to three curves of the stretch 1 (and the related nearby tangents) as shown in Figure 13, in order to study in detail speeds and lateral positioning at both the approach to, and the departure from the curves. Curves near the intersections with the stretch 2 were not considered since they were close to some driveways nearby a residential area.

Hence, speeds and lateral positioning data were assigned for each driver to the nearest cross section along the road layout. In particular, the data of speed belonging to the first test in which the speed was freely chosen by the driver ("free" lap) were assigned to all the sections previously defined (stretch 1 and stretch 2, see Fig. 11). The data of speed and lateral position belonging to the driving tests made at the perceived low, medium and high speeds were assigned to the specific cross sections shown in Fig. 13, since it is particularly important to inquire into lateral positions at curves.

Data of speed and lateral position so defined were used for the development of the research.

Fig. 13 – Placement of further specific cross sections along the stretch 1, adapted from Colonna et al., 2015.

2.2.2 *Traffic and Accident Database*

Another part of the research concerned the analysis made on a Norwegian accident database. This database was obtained during my research period at the Norwegian University of Science and Technology, Trondheim, Norway, in 2015. The database was provided by the Norwegian Public Road Agency (NPRA).

It includes the accidents over a 10 years-period, from 2005 to 2014, occurred on two important Norwegian highways (E6 and E39). The accident database was used in combination with a database of 179 traffic counts (provided by the same Agency), including the AADT (Annual Average Daily Traffic) volumes and some details about the fluctuations of the traffic values. The accident database is composed of three separate (but related) spreadsheets: the first including general information about the accidents, the second including information about the vehicles involved in the accidents and the third including information about the units (drivers and passengers) involved. All the accidents included in the database are fatal and injury accidents and they involved at least one vehicle.

Since for the aims of the research, the accidents were analyzed together with traffic volumes, then only the accidents occurred at road segments on which the traffic data were available were chosen. Only two-way two-lane rural road segments were included in the database, in order to allow coherence with the other experimental results. Those road segments were chosen according to the criteria summarized in Figure 14, that are: avalaible traffic count, length greater than 1 km, no significant intersections included (buffer zones of 150 meters were considered to remove the influence of significant intersections with roads of similar importance as in the Fig. 14). Stretches of road segments included in urban areas were not considered as well.

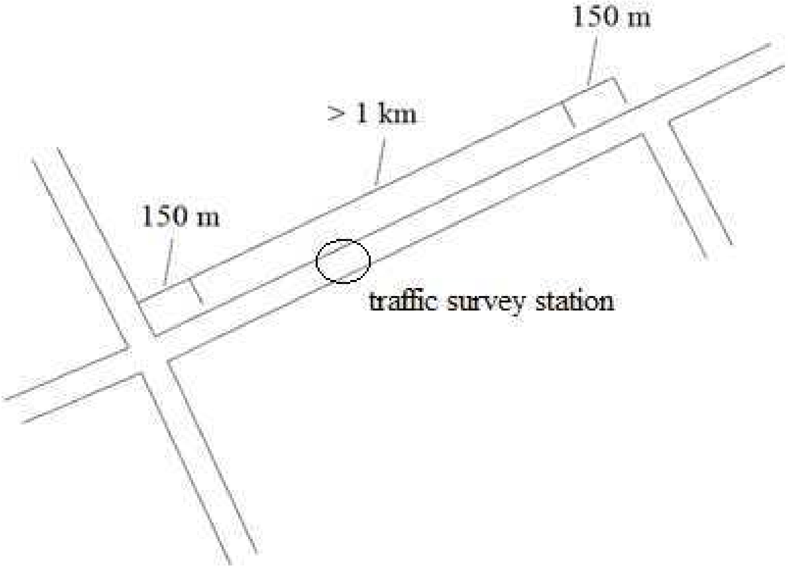

Fig. 14 – Criteria for defining the rural road segments to be analyzed.

After the process of selection of sites, 84 road segments were individuated (37 for the E6 and 47 for the E39). Details about the sites and the accidents occurred at them are given in next table.

Table 9 – Some details about the sites to be analyzed.

	Number	Mean	Standard Deviation	Max. Value	Min. Value
Sites	84	-	-	-	-
Length (m)	-	6144	5841	35604	1030
AADT[1] (veh/day)	-	5626	4738	18706	544
SDT[1] (veh/day)	-	6712	5117	21856	721
SDT/AADT	-	1.30	0.21	1.91	0.99
Accidents	633	-	-	-	-
Accidents/Site	-	7.5	6.3	35.0	0.0
Accident Rate (acc./MVKT[1])	-	0.103	0.093	0.728	0.000

[1] Averages computed over the period: 2005-2014.

[1] MVKT = MillionVehiclesKilometersTraveled.

Since the main aim of the research is to inquire into the relationships between familiarity and road accidents, then the information present in the database were used for defining the familiarity or unfamiliarity of drivers. In particular, zip codes associated to the drivers were chosen as a variable to be used for this aim (see Blatt and Furman, 1998). Then, the distance between the place of the accident and the place of residence (deduced from the zip codes) was used as a measure representative of the familiarity. The threshold below which a driver was defined as familiar with the place of the accident was set to 20 km (mainly based on a Norwegian report by Hjorthol et al., 2014, in which the average commuting trips were defined: 15.8 for car drivers and 21.7 for car passengers). The threshold above which a driver was defined as unfamiliar with the place of the accident was set to 200 km instead (mainly according to the definition of long trip or to the choice for diverse modes of transport different from car, according to the same above cited report and to Thrane, 2015). Drivers coming from a distance included between 20 and 200 km were not considered neither familiar nor unfamiliar in order to limit the bias due to the wrong classification of real familiar drivers into the unfamiliar category and vice versa. These thresholds were based on transport studies in order to rationally define a plausible “familiar” or “unfamiliar” distance and to avoid arbitary definitions of it. This choice is coherent with what presented in the section devoted to the definitions of familiarity (2.1.2.1), in which it was shown how the familiarity can be related to the commuting trips. This classification of drivers into familiarity categories based on distance from residence could be affected by some errors (e.g. residence not matching the actual address or drivers repeating many times the same long trip travel for example in holidays). However, it seems reasonable for the aims of this research based on a crash database analysis. In any case, a more detailed discussion about this topic will be made in the section devoted to the improvement of the definitions of familiarity (see 2.3.5).

Data about traffic, accidents and distances between the place of the accident and the place of residence (representing familiarity) so defined were used for the development of the research.

Clearly, there could be behavioural differences between Italian and Norwegian drivers. Therefore, by looking at results, it should be taken into account that experimental data are collected in Italy and that the crash database was acquired in Norway. However, some of the results shown in next sections are coherent with the expectations from the background section including other International studies, especially for what concerns experimental data. Moreover, results about the relationships between familiarity and accidents were compared, when possible, with similar International studies. In any case, results obtained from this research are based on the data collected.

A flow chart representing the different steps of this study is presented in next page, summarizing all the main topics and strategies of analysis considered and the obtained outputs.

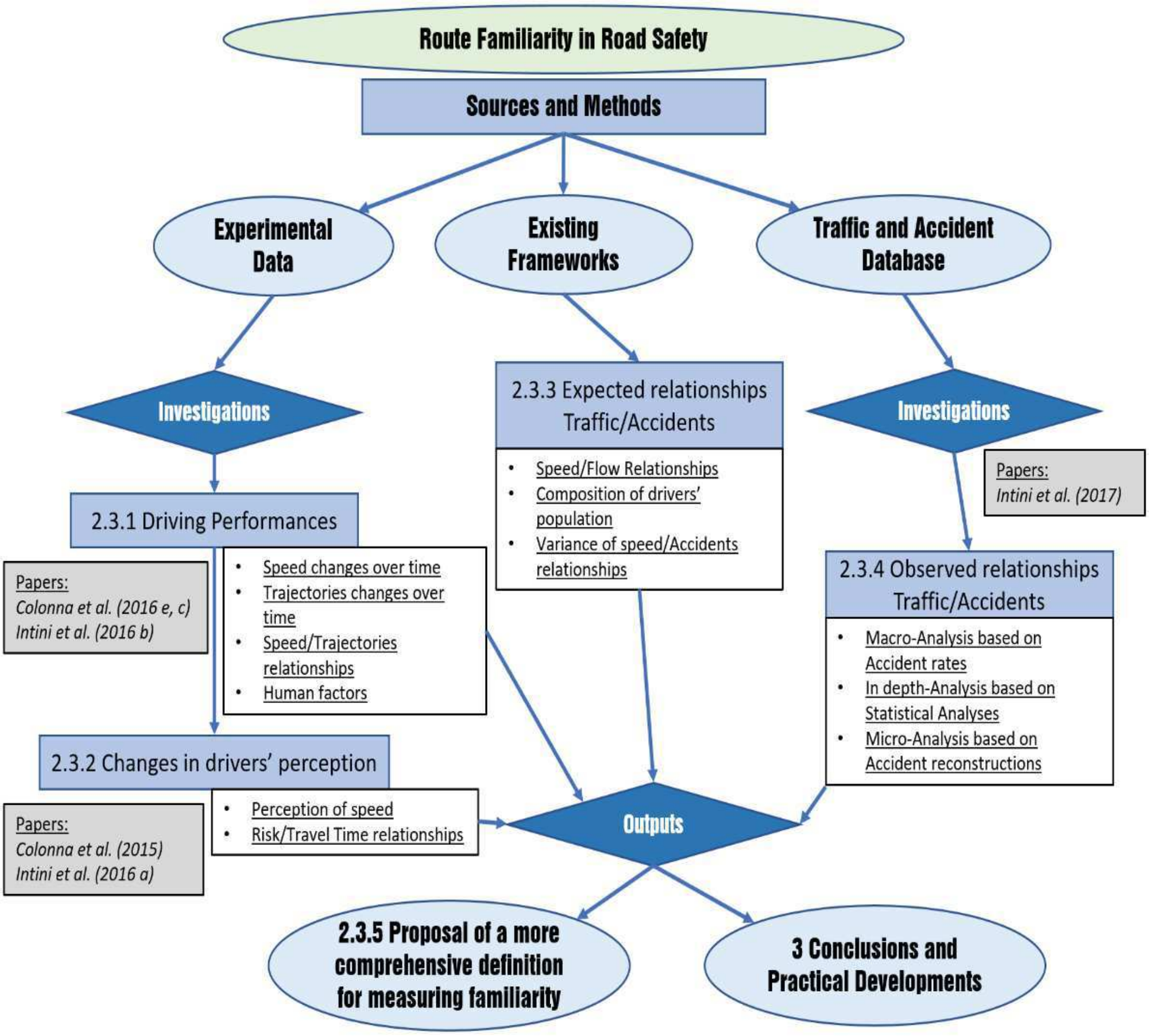

Fig. 15 – Flow chart of the different steps of the study.

2.3 CHAPTER 3 – RESEARCH DISCUSSION

In this chapter, the research conducted is presented. The chapter is divided into sub-sections, organized in order to separately answer to the research questions presented in section 2.1.4. In the first sub-section (2.3.1), the research about the relationships between route familiarity and driving performances based on the results from the on-road experiment is discussed. In the second sub-section (2.3.2), the research about the changes in subjective drivers' perception due to the familiarity of drivers based on the on-road experiment and the framework defining the utility of a travel are presented. In the third sub-section (2.3.3), the research about the relationships between traffic engineering practice and road safety is deepened, using the HCM framework as a basis. In the fourth sub-section (2.3.4), the research about the relationships between familiarity and road accidents based on the analysis of the accident database is discussed. In the last sub-section (2.3.5), the concept of route familiarity with respect to the frequency and the distance is better defined in light of the results from previous sections.

2.3.1 Relationships between route familiarity and driving performances

The observation of the behaviour of drivers exposed to repeated driving tests over days is useful to deduce how route familiarity can influence the driving performances. Indeed, the repetition of the same driving test over the days of testing can be seen as a repetition of the same stimulus over time. The latter process was related to the habituation effect (see Fig. 3), in which the driver potentially gets used to that stimulus showing a decrease in response. In this case, the "response" of the driver can be measured in terms of speeds and trajectories (deduced from the lateral positioning), by taking into account also the different test conditions about perceveid speed (a possible measure of the risk subjectively perceived). Based on the habituation effect, one should expect that a driver completely unfamiliar with a given environment could show some behavioural changes over time due to acquired familiarity of the road. Those possible behavioural changes are measured in this case by looking at changes in speed and trajectories over time in the different test conditions. A first look at speed changes over time is shown in paragraph 2.3.1.1, in which the results coming from the analysis of all the cross sections (see Fig. 12) are presented, by considering the differences due to sight distance and behavioural classes. After, a concurrent detailed description of both changes in speeds and trajectories over time is given in paragraph 2.3.1.2, with particular regard to some sections individuated in Fig. 13 and the different test conditions.

2.3.1.1. Overview about speed changes over time

Basic descriptive statistics about speeds in the six days of testing are shown below, and graphically depicted in Figure 16.

Table 10 – Some basic descriptive statistics about speeds in the six days of testing.

Day	Mean Speed (km/h)	Standard Deviation (km/h)	Mean Speed Percentage Differences[1] (%)
1	79.07	12.65	-
2	83.80	15.46	6.1
3	87.21	16.20	4.1
4	88.80	15.85	1.8
10	88.44	16.83	-0.4
27	89.52	14.74	1.2

[1] referred to the mean speeds of the different days and computed as: $\frac{Speed_{,i+1} - Speed_{,i}}{Speed_{,i}}$ (%).

As it can be noted from a first look to all the speed data in the different days of testing, a speed increase is evident in the first four days of testing. After, the speed settles on an about constant value, even if the last two driving tests are repeated after some days from the fourth day (5th test after 6 days and 6th test after 23 days). However, considering the first four days of testing in a row, the mean speed percentage change is maximum between the first and the second day (6.1 %), and after it decreases over days (between the 3rd and the 4th days is equal to 1.8 %). Hence, it seems that the acquired familiarity obtained after four days of testing is related to an increase in the mean speed. The driver starts his learning process of the road in the first day and after, with the repetitions of the stimuli represented by the driving tests, he tends to increase the speeds. Since speed choice can be closely related to risk perception, an increase in speed can imply a potential decrease in the perceived risk (see e.g. Tarko, 2007), that is a decrease in response to that specific risk. In this case, since speed firstly increases (and the increasing rate slightly decreases over time) and after stays on a constant value, it could be argued that the response by the drivers decreases and after tends to an asymptotic value, as expected from the theoretical assumption about the habituation process (see Fig. 3).

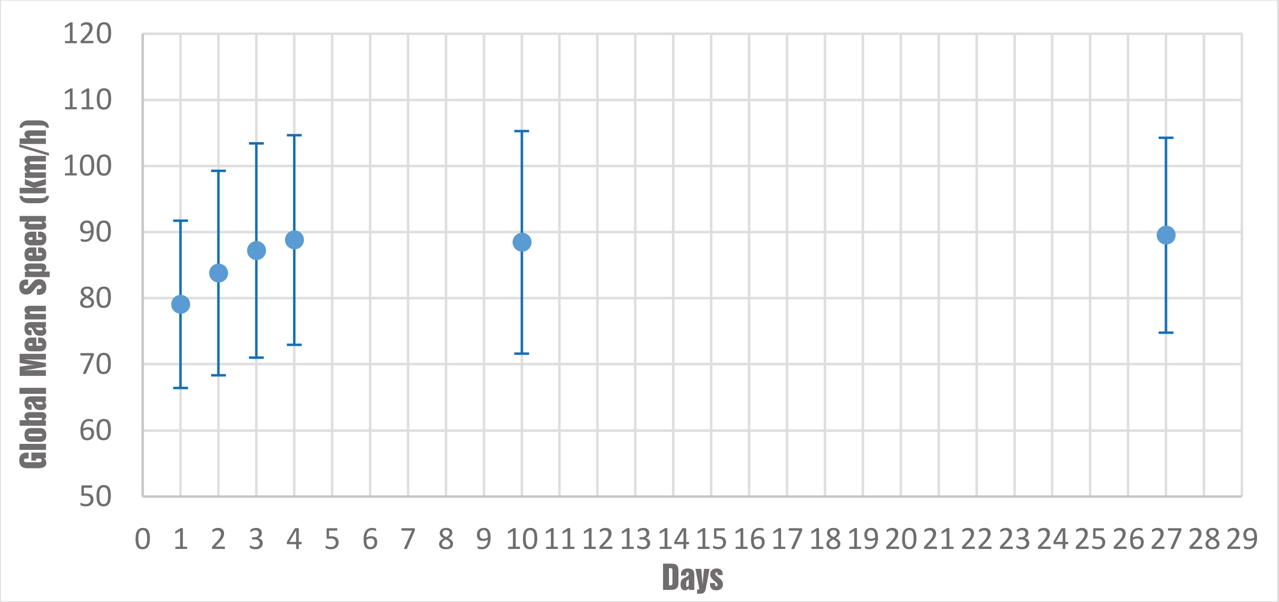

Fig. 16 – Global mean speeds plotted against days.

Moreover, in order to have an immediate overview of the speed data distribution among the different days, the boxplots of speeds in the six days of testing are reported as follows.

By looking at standard deviations in Table 10 and boxplots in Fig. 17, it is evident that there is a great variabiity in the speed data among the drivers around the mean (or the median). However, it can be noticed also that, the interquartile range, IQR (the distance between the first quartile, Q1 and the third quartile, Q3; which are the limits of the boxes in Fig. 17), as well as the range out of which are present extreme values (delimited by the quantities: Q1 – IQR and Q3 + IQR in the Fig. 17), show the highest value in the 5th day of testing (10th day). The standard deviation of day 10 is the highest among all the days as well. This means that, on day 10, the dispersion of the data around the mean is maximum. Conversely, the dispersion is minimum on day 1, as it can be noted from the same sources.

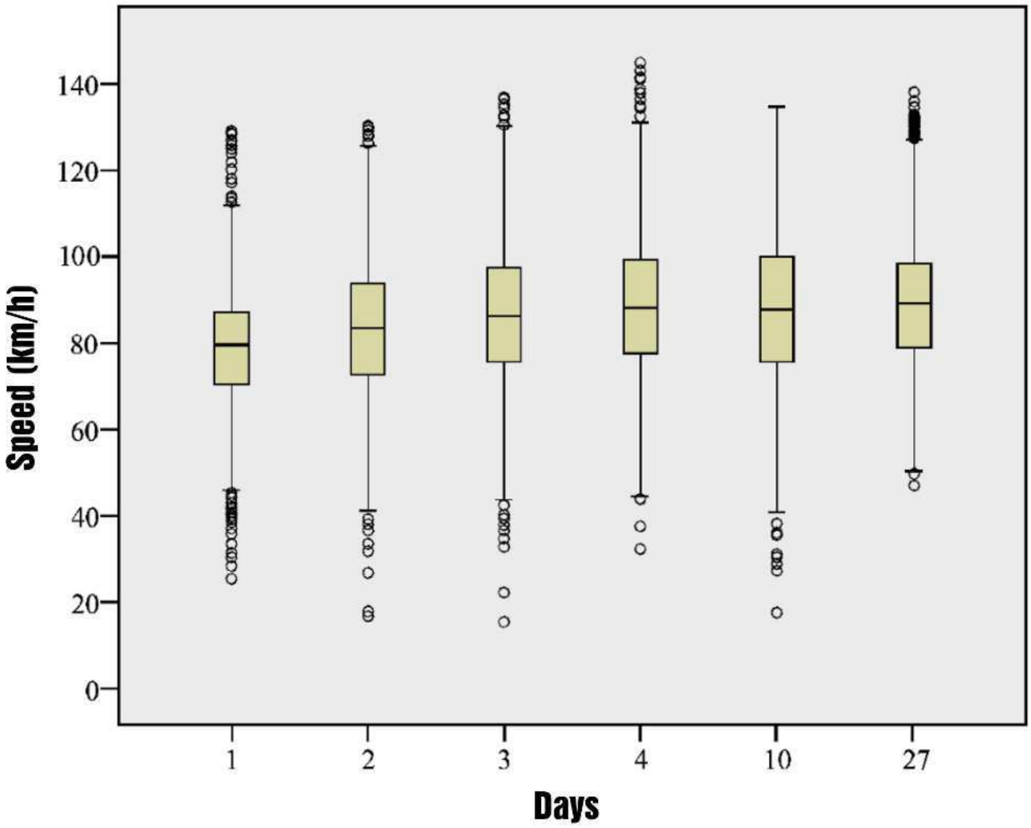

Fig. 17 – Boxplot of speeds in the six days of driving tests (day 1 = 1st test, day 2 = 2nd test, day 3 = 3rd test, day 4 = 4th test, day 5 = 5th test), taken from Colonna et al., 2016e.

Therefore, it seems that the behaviour of drivers is more homogeneous in the first day, while it is highly eterogeneous in day 10. This can be logically explained by the fact that drivers were unfamiliar with the route chosen for the experiment and therefore, all drivers did not know the road environment and they started to learn the route in the following days. “Learning” the road means that, as stated in the general background section, the drivers will behave by trying to maximize the utility of their travel. Anyway, this is a process highly dependent from the subject. Therefore, as expected, the dispersion of data around the mean is higher in the days following the first, in which the subjective differences between the drivers start to present themselves. Moreover, the maximum dispersion noted in day 10 can be explained by the fact that the drivers can respond differently to the interruption in the stimuli presentation (a pause of six days between the fourth and the fifth test).

It is interesting to note that, if speed changes over time[1] are considered for different categories of sight distance related to the analyzed cross sections individuated in Figure 12 (low visibility, 53 cross sections, from 0 to 100 m; medium-low visibiility, 110 cross sections, from 100 to 200 m; medium visibility, 38 cross sections, from 200 to 400 m; high visibility, 73 cross sections, from 400 to 600 m[2]), the same general tendency about speeds can be found for all visibility classes.

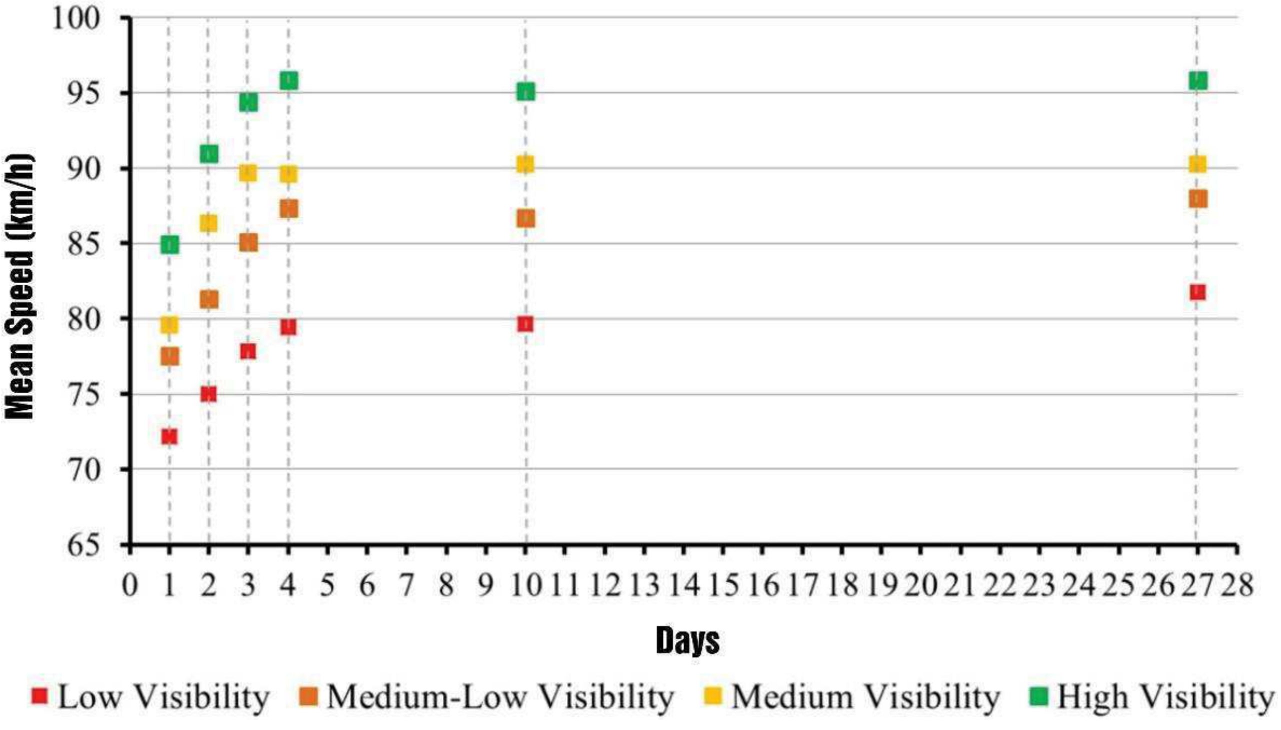

Fig. 18 – Mean speeds in the four visibility classes plotted against days, based on Colonna et al., 2016e.

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[1] However, results from a similar experiment performed in Norway (even if with different instruments, less drivers and on a more winding road section) did not confirm this tendency about speed increase over days (Intini, 2014).

[2] The low visibility interval was chosen considering that the accident rate increases rapidly for sight distances smaller than 100 m (Fambro et al., 1997). The high visibility interval was chosen according to Lamm et al. (1999) who found that overtaking-related accidents increase for sight distances smaller than 400–600 m. The intermediate interval was further divided in order to obtain subsets numerically more homogeneous.

Indeed, as highlighted in Figure 19, the increasing tendency on the first four days is similar for the four visibility classes (even if a slightly smaller increase rate as deduced from the regression line can be noted for the low visibility class, in which the possibility of a high increasing rate is likely limited by the demanding geometry). Since the sight distance depends on the geometric design of the road, this means that, on average, the drivers tend to increase speeds over time independently from the road geometry (the increasing tendency is noted also in the more demanding sections).

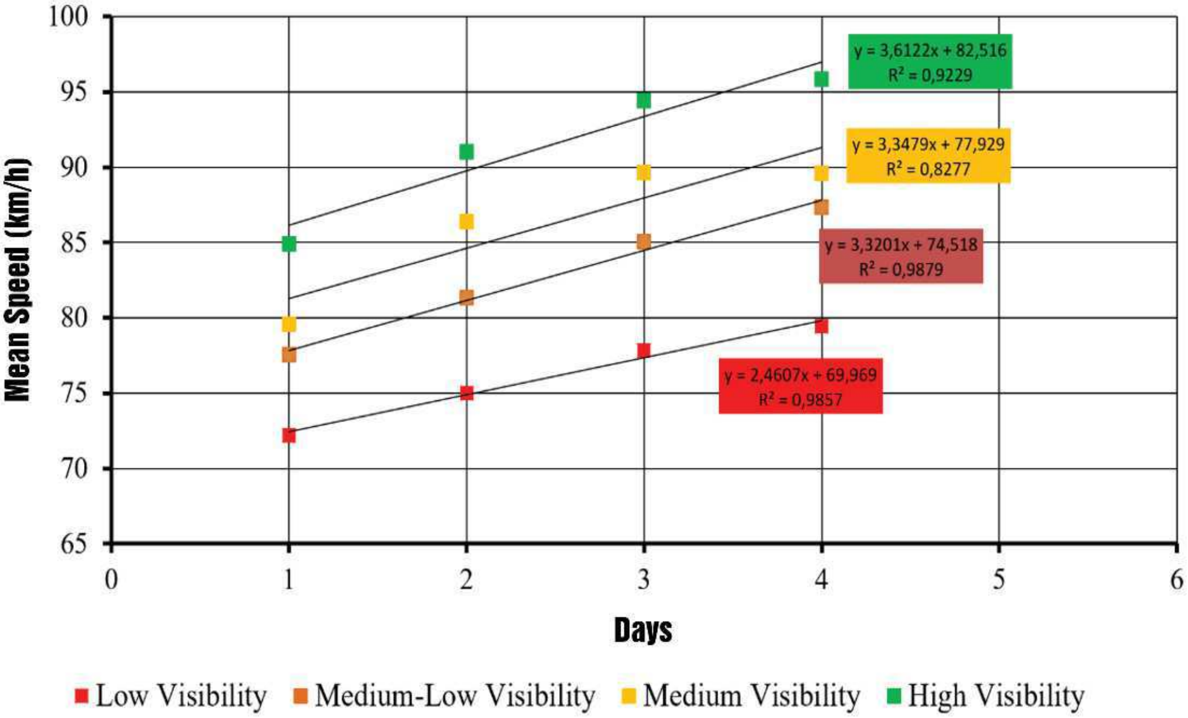


Fig. 19 – Increasing speed tendencies in the first four days of testing for different visibility classes, based on Colonna et al., 2016e.

Moreover, if the different attitudes of drivers with respect to speed are taken into consideration (by dividing drivers into “prudent” drivers, showing speeds smaller than the average, “average” drivers with speeds consistent with the average and “aggressive” drivers, showing speeds greater than the average), other tendencies can be noted. The general trend previously highilighted about the speed increase in the first four days and a further settlement on a constant value can be noted even if dividing drivers into three behavioural classes.

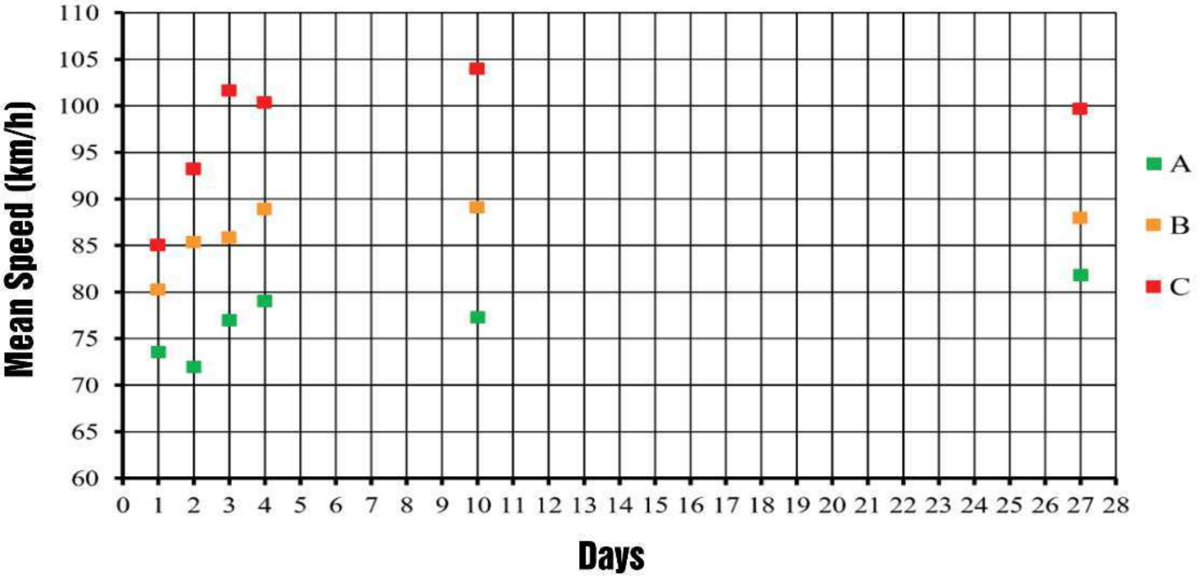


Fig. 20 - Mean speeds for the different behavioural drivers' classes plotted against days of testing, based on Colonna et al., 2016e, A = Prudent Drivers, B = Average Drivers, C = Aggressive Drivers.

However, while for the average and the aggressive drivers, the speed in the fifth day of testing is at the same level (or higher) than the speed in the fourth test, the prudent drivers show a speed decrease in the fifth test, after the first interruption in the stimuli presentation. This could be explained by the fact that prudent drivers need a further test (a sort of "re-test") about the more appropriate speed to be chosen along the road layout if they lose the continuity of different consecutive stimuli. This could mean that they can show a partial recovery of response when the stimulus is interrupted and further given again. Aggressive and average drivers are more prone to trust on their memory instead, even after the interruption.

The other difference can be found in the increase rate over the first four days of testing, as can be noted from Figure 21. The average speed increasing rate for the aggressive drivers is about double with respect to the other two categories. Indeed, not only speeds in each day of testing are greater for the aggressive drivers, but also the way in which they adapt to the road environment over days is different. This concept will be further addressed in the sub-section 2.3.2.

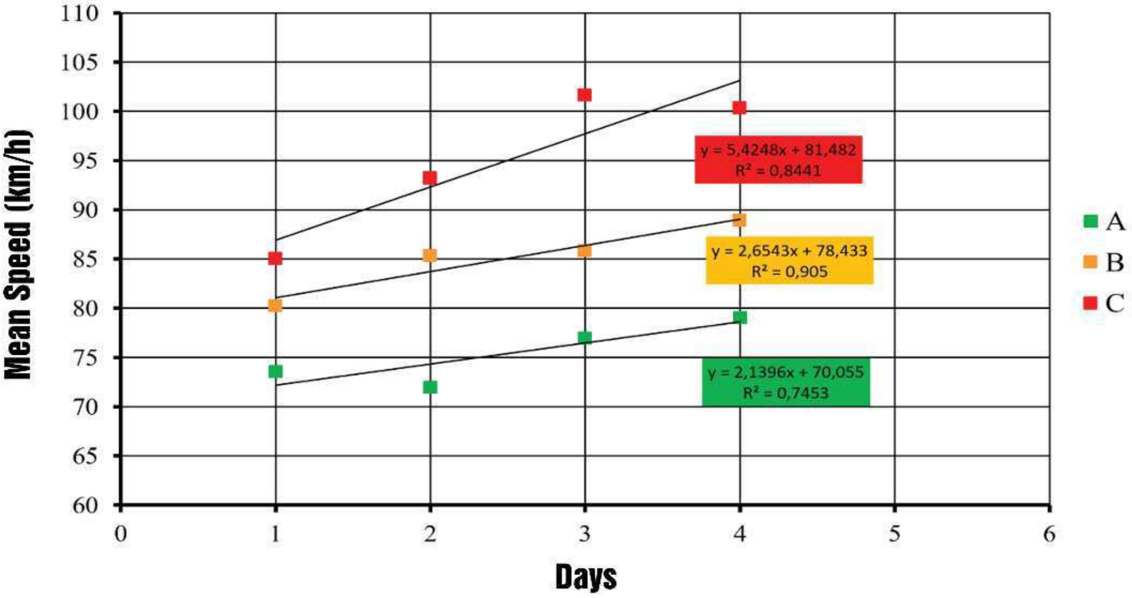


Fig. 21 – Increasing speed tendencies in the first four days of testing for different drivers' behavioural classes, based on Colonna et al., 2016e, A = Prudent, B = Average Drivers, C = Aggressive Drivers.

Another trend to be noted is that speeds in the sixth days of testing are generally similar to the speeds in the previous two driving tests. This is surprising considering the pause of 17 days in the driving tests and the fact that (at least for prudent drivers) an average decrease in speed was noted in the fifth test. However, this could represent a long-term memory effect (long-term habituation), which is a possibility contemplated by theoretical behavioural studies (see Rankin et al., 2009). Hence, it seems that a sufficient degree of familiarity with the route, able to be maintained in the long-term period, can be reached with four consecutive tests on the same route.

However, the general remarks presented here for average speeds based on descriptive values will be further addressed by considering together the two main driving outputs (speeds and trajectories) at specific curve sections. In fact, these are the sections in which accidents often cluster and they can be mainly associated to errors in speed choice and steering (to be avoided through curve design improvements, see Campbell et al., 2012). However, a more detailed analysis of these concepts with respect to familiarity is needed. It is addressed in next sub-section, in which inferential statistics are considered for testing trends of speeds and trajectories.

2.3.1.2. Familiarity, Speeds and Trajectories: Experimental results

For the aim of analyzing the relationships between route familiarity and the choice of speed and trajectory, the attention was focused on some specific sections of the road layout used for the experiment. The geometric features of the stretch of the road layout shown in Fig. 13, in which three curves were present, were reconstructed in a CAD environment. In particular, two curves were further selected (curve 1 and curve 3 in Figure 13), since only for them the presence of spiral transition curves was detected. A different radius can be considered if the whole curve (including transition curves) is rounded with a unique circular arc, without considering the presence of the spiral transition curves. Anyway, the presence or not of the transition curve can influence the driver behaviour and then, curve 2 was discharged from this analysis for the purpose of a larger comparability and homogeneity of results. The geometric features of the selected curves are reported below (with the radius being referred to the circular curve).

Table 11 – Geometric features of the two curves (notation taken from Fig. 13 for the outward direction).

	Curve 1		**Curve 3**	
	No.	**Width (m)**	**No.**	**Width (m)**
Cross section ID – Approach at spiral transition curve	1	5.38	9	5.55
Cross section ID – Circular curve (midpoint)	2	6.26 (5.38[1])	10	6.35 (5.59[1])
Cross section ID – Departure from spiral transition curve	3	5.30	11	5.59
Radius of curvature (m)	47		93	
Length of the curve (m)	32		23	
Approach spiral length (m)	19.20		20.19	
Departure spiral length (m)	28.83		40.45	
Longitudinal slope (m/m)	< 0.03		< 0.03	
Cross slope (m/m)	< 0.03		< 0.03	

[1] Road width excluding the widening in correspondence of the curve.

In order to obtain a synthetic measure able to represent the behaviour of drivers at curves, the radius of the curve trajectory followed by the drivers was chosen. Since a value of the lateral position was available for each of the cross sections used for this elaboration, the points representing position of vehicles' geometric centerline along the considered cross sections for both the two curves and for both the two directions of travel, were fitted for each driver, each day of testing and each test driving condition (free, low, medium and high speed laps). The radius of curvature of the trajectory computed in correspondence with the circular curve was employed as a measurement representative of the trajectory selected.

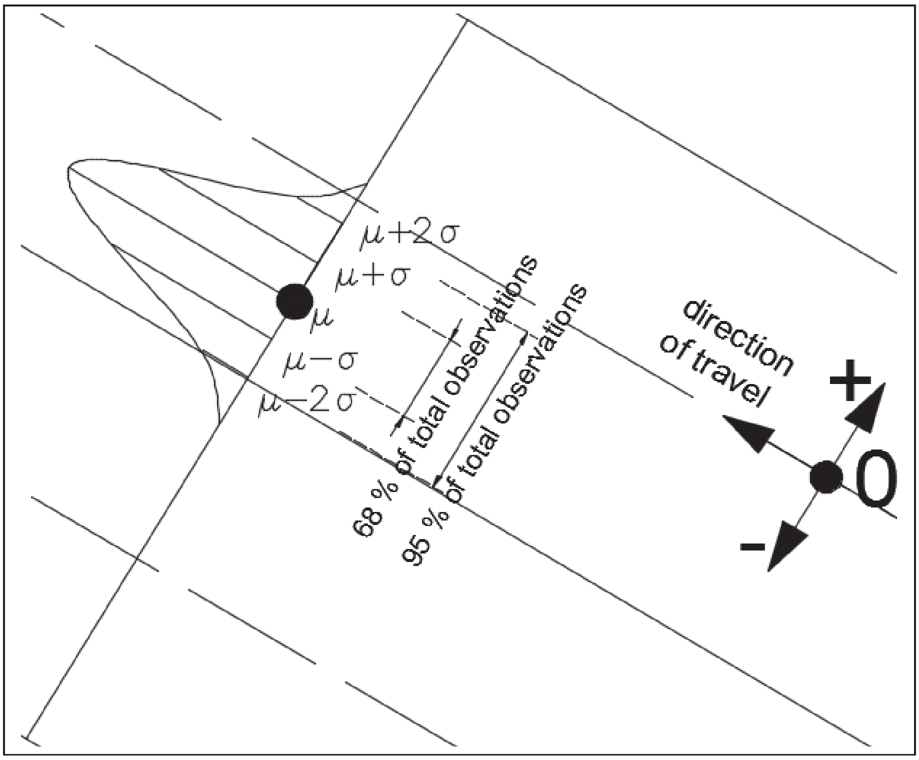
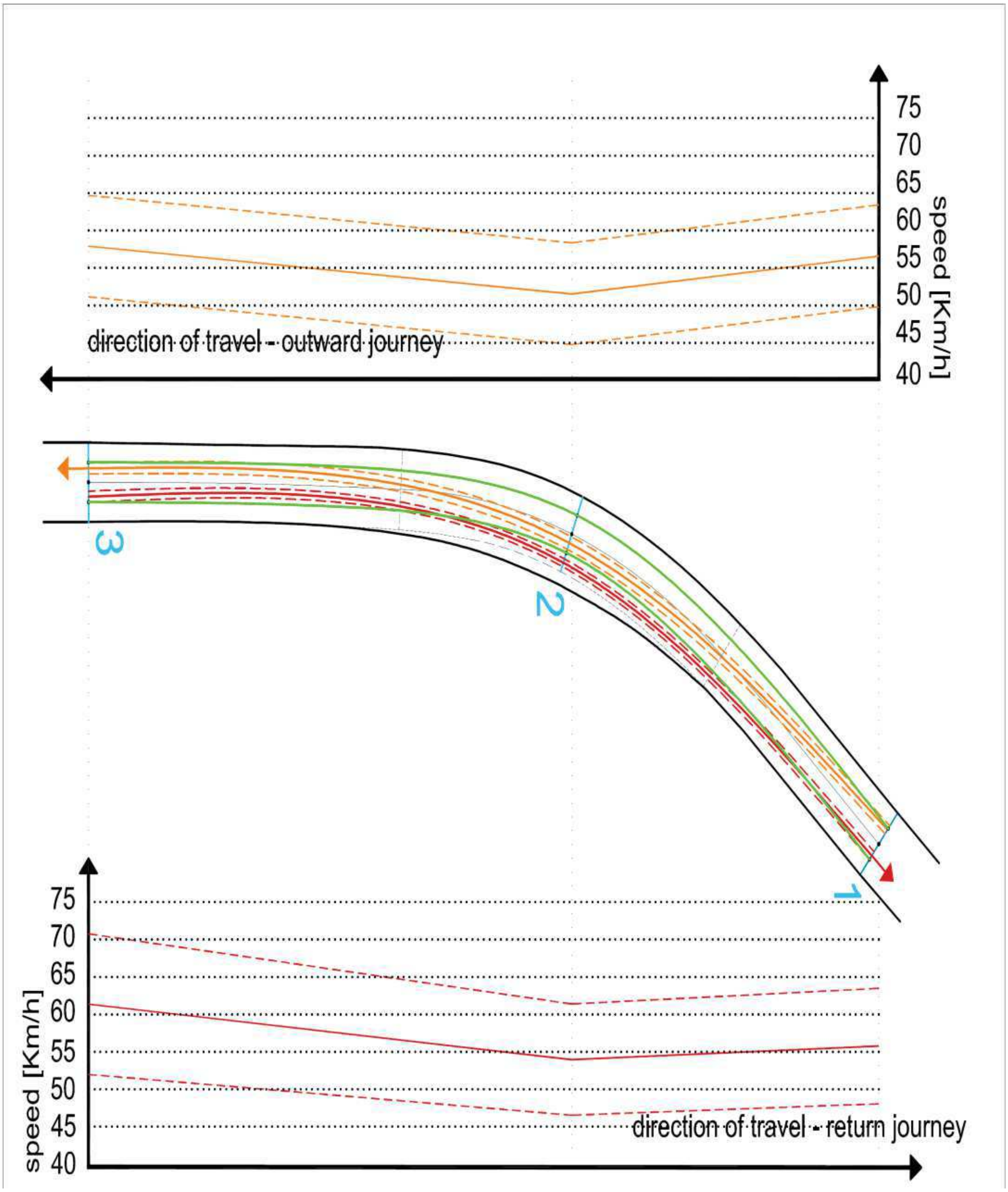


Fig. 22 – Ideal representation of the distribution of the vehicle positions in the cross section and sign convention adopted for the postion with respect to the lane centerline, taken from Colonna et al., 2016c.

In order to show the global behaviour of drivers in terms of speeds and trajectories at the two inquired curves, the mean trajectories and the profiles of mean speed are reported as follows. Moreover, in the pictures, the trajectories fitting the points representing the mean plus/minus the standard deviation of the lateral position of the observations are reported, together with the profiles of the standard deviation of speed.



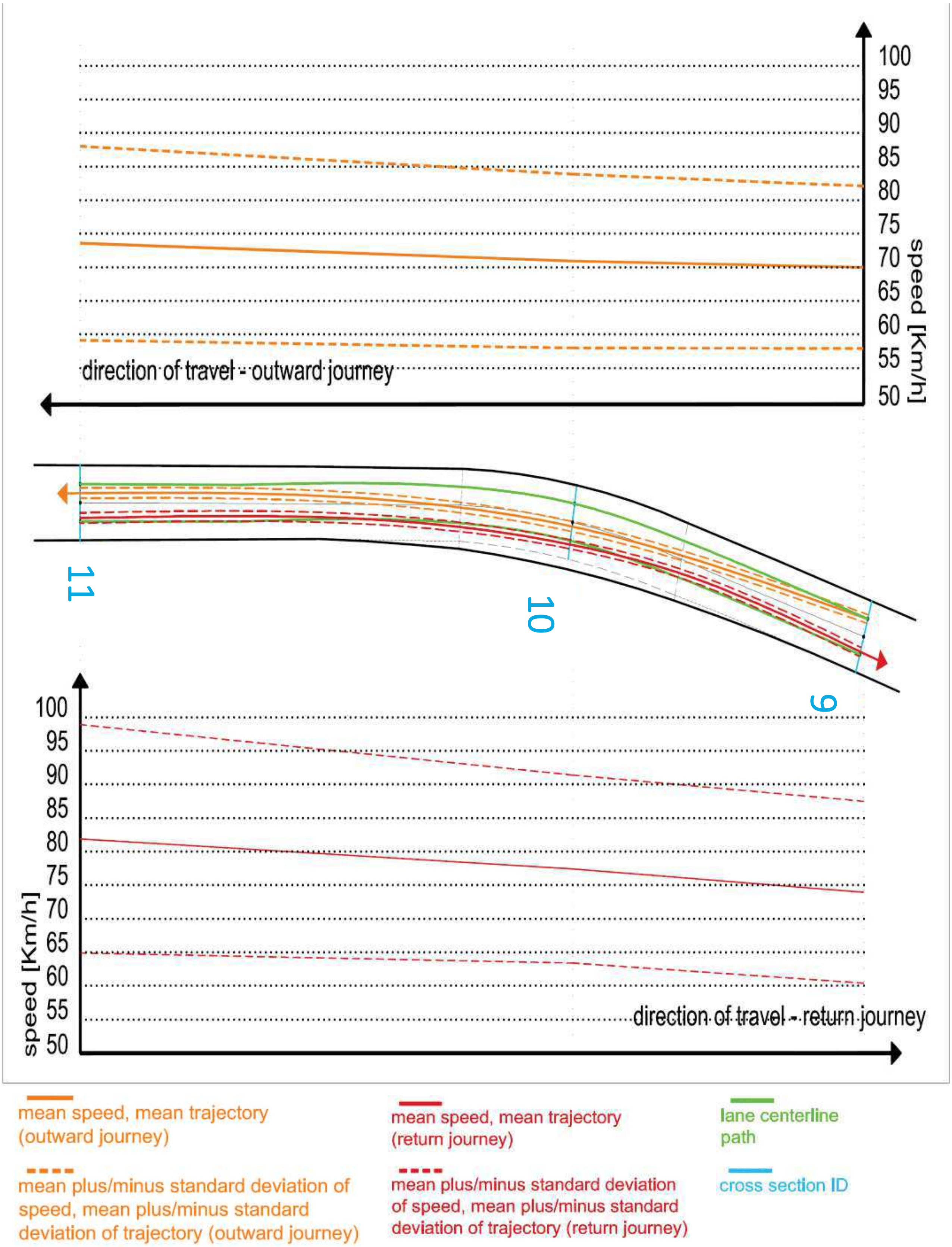


Fig. 23 – Recontruction of speeds and trajectories at curve 1 (in the other page) and curve 3 (in this page), adapted from Colonna et al., 2016c.

As a general tendency (consistent with Bittner et al., 2002; Spacek, 2005; Said et al., 2007), drivers tended to cut curves to the left by showing encroachments on the inside lane (mostly in the sharper curve 1, where in the 84 percent of observations, vehicle centerlines are beyond the carriageway centerline). Furthermore, drivers tended to cut curves to the right in the sharper curve 1 (in about the 95 percent of the observations vehicle centerlines were beyond the inside lane centerline), while at curve 3, mean trajectories are close to the lane centerline.

Considering speed profiles, the presence of deceleration and acceleration along the spiral transition curves at curve 1 can be noted and the speed reaches its minimum at the midpoint. At curve 3, two different driving behaviours can be noted with respect to the direction of the travel: when the curve is on the left, the drivers are likely to decelerate before approaching it and after they accelerate during the curve; while when the curve is on the right, drivers decelerate during the curve. The different behaviour at curve 3 can be explained by considering speeds and trajectories in combination: in the outward journey the approaching speeds are lower, acceleration are allowed by the high radius and the drivers cut the curve also due to a greater sight distance in the external lane; while in the return journey they likely decelerate because the approaching speeds are high and they do not cut curves also likely due to smaller sight distances in the internal lane.

These general mean trends (over time and over the different test conditions) are useful for the remainder of the discussion, but the main focus is on the evolution over days of the speeds and trajectories so computed. In next table, the data about speeds and radii of curve trajectories (obtained by rounding the trajectories with arcs in correspondence of the circular curves) are shown for each day of testing, each considered section and each driving test condition (free, low, medium and high speed laps, as defined in Chapter 2). Therefore, the observed variables were two: speed and radius of the curve trajectories; while the considered independent variables are three: day of testing (representing the degree of drivers' familiarity), road cross section (for taking into account the road geometry) and test driving condition (for considering drivers' perception).

Table 12 – Mean speeds and radii data in the different test conditions, days of testing and cross sections.

Driving test condition	Curve	Measures[1]		Day of Testing					
				1	2	3	4	5	6
Free speed (F)	1 (O)	Radius (m)		68.0	67.9	67.7	68.8	68.1	68.5
		Speed (km/h)	1	55.6	52.2	56.0	57.6	59.4	54.9
			2	52.4	49.1	52.1	55.6	54.2	53.0
			3	58.7	57.6	60.9	61.3	62.2	60.5
	1 (R)	Radius (m)		157.4	156.2	155.9	159.7	158.9	155.6
		Speed (km/h)	3	61.4	63.5	64.2	66.4	69.0	67.7
			2	53.7	56.0	56.6	57.6	57.8	58.1
			1	56.3	58.7	58.1	57.8	61.2	58.7
	3 (O)	Radius (m)		60.3	59.4	60.2	59.3	60.2	60.4
		Speed (km/h)	9	71.2	71.2	76.7	77.1	80.2	76.2
			10	73.1	74.4	79.3	81.0	79.4	77.5
			11	72.2	77.0	83.1	81.0	85.9	81.0
	3 (R)	Radius (m)		124.4	119.8	120.7	124.2	125.5	121.7
		Speed (km/h)	11	82.1	88.7	89.4	90.4	93.0	93.7
			10	76.5	82.7	86.2	86.7	88.0	88.1
			9	71.9	74.9	79.0	81.7	82.6	83.5
Low speed (L)	1 (O)	Radius (m)		68.1	67.9	67.9	68.4	67.8	68.4
		Speed (km/h)	1	50.0	50.9	51.7	53.4	52.1	52.6
			2	46.5	47.6	48.6	51.5	50.7	48.8
			3	49.4	51.8	52.2	55.0	52.7	53.0
	1 (R)	Radius (m)		155.0	153.5	153.8	158.3	152.0	151.7
		Speed (km/h)	3	53.8	53.3	53.5	54.2	55.1	52.4
			2	49.9	48.1	49.2	49.8	48.6	50.1
			1	49.1	49.0	50.0	50.1	49.5	52.4
	3 (O)	Radius (m)		58.9	59.0	58.8	59.5	59.0	59.1
		Speed (km/h)	9	56.2	56.5	58.5	59.0	57.1	58.3
			10	57.2	55.9	57.8	58.6	56.6	57.2
			11	57.9	57.4	59.7	60.5	58.3	59.9
	3 (R)	Radius (m)		122.1	119.7	122.5	124.5	127.6	125.1
		Speed (km/h)	11	61.7	60.5	61.6	61.7	62.9	62.7
			10	60.3	59.3	60.9	61.1	61.3	61.1

			9	59.5	58.0	60.4	61.3	62.6	58.5
Medium speed (M)	**1 (O)**	**Radius (m)**		68.5	68.9	68.4	69.1	68.3	68.4
		Speed (km/h)	**1**	55.9	57.6	58.4	59.3	59.2	57.6
			2	50.3	51.3	52.2	54.2	55.0	51.6
			3	58.0	58.8	59.2	59.6	60.2	59.6
	1 (R)	**Radius (m)**		159.0	160.7	158.7	159.8	159.6	160.2
		Speed (km/h)	**3**	61.4	60.5	62.3	63.4	63.8	62.1
			2	53.5	53.0	55.6	56.1	54.9	56.3
			1	54.7	55.4	57.8	58.3	57.5	57.9
	3 (O)	**Radius (m)**		58.9	59.4	60.1	59.6	59.7	59.5
		Speed (km/h)	**9**	69.4	70.0	72.1	71.9	72.5	72.7
			10	70.7	71.4	73.5	74.6	73.0	72.7
			11	75.6	74.8	76.7	76.1	76.4	77.5
	3 (R)	**Radius (m)**		124.0	125.6	126.7	128.7	129.6	128.8
		Speed (km/h)	**11**	79.8	80.2	84.0	81.5	84.4	84.9
			10	77.0	76.5	79.2	80.5	78.9	81.1
			9	72.5	73.1	75.9	75.4	76.2	78.5
High speed (H)	**1 (O)**	**Radius (m)**		68.4	68.3	68.9	68.5	68.1	68.9
		Speed (km/h)	**1**	57.9	59.9	63.3	63.7	63.9	64.7
			2	51.1	51.4	55.0	55.3	57.6	55.7
			3	60.2	60.9	64.5	64.1	63.7	63.0
	1 (R)	**Radius (m)**		159.6	159.4	161.0	162.4	160.3	161.3
		Speed (km/h)	**3**	65.4	66.7	68.7	67.7	69.0	73.6
			2	57.3	58.1	59.8	59.1	59.6	63.4
			1	60.2	61.7	63.5	61.1	63.2	63.6
	3 (O)	**Radius (m)**		59.9	59.7	60.3	60.3	59.5	60.1
		Speed (km/h)	**9**	75.3	76.9	80.9	76.3	82.9	79.5
			10	77.9	78.3	83.7	82.7	85.4	81.2
			11	83.7	84.8	90.2	84.1	90.6	86.9
	3 (R)	**Radius (m)**		12.05	125.5	127.3	132.0	129.9	131.3
		Speed (km/h)	**11**	92.3	96.3	98.1	100.3	102.7	101.9
			10	85.3	87.4	90.5	95.1	94.4	95.8
			9	78.3	81.8	82.9	85.6	89.5	90.0

[1] The radius is a unique measure for each curve in each direction of travel, while there are three measures of speed, one for each cross section. The notation for cross sections is the same as in Figure 23.

Statistical analyses were carried out in order to test if those variables related to the drivers' perception, the route familiarity and the road geometry are able to affect the speeds and the radii of the curve trajectories.

A mixed ANOVA test was performed to test if there is a difference in mean speed over time, considering the following fixed factors:

- Time (six days of testing: 1, 2, 3, 4, 5, 6),
- Test driving conditions (four speed conditions: low, medium, high, free)
- Road sections (four cross sections: curve 1, outward direction; curve 1, return direction; curve 3, outward direction; curve 3, return direction).

The 19 drivers[3] were considered as random factors instead.

A mixed ANOVA was chosen since data belonging to the same driver could not be considered as independent, because they can be affected by the perception of the same subject who is repeating the test in different conditions. Hence, it allows to consider the measures from the same subject as not independent.

The same analysis was repeated by considering the mean radius of curve trajectory as dependent variable.

Furthermore, in order to individuate where the significant differences lie between the different modalities of the variable, a Bonferroni post-hoc test was carried out for each variable representing a fixed factor.

The results from the application of the mixed ANOVA test are reported as follows, together with the results from the post-hoc tests. Significant differences (p-values smaller than 0.05) were reported in boldface. In order to study the interactions between the variables, the model was built by considering all the main effects and all the two-way interactions between the factors, as reported in next table.

Results from statistical analyses performed were further discussed in order to draw conclusions about the relationships between familiarity, speeds and trajectories (considering the different test conditions). The analyses were performed through the use of the SPSS software[4].

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[3] Data from one driver were discharged from the analysis due to a large number of missing observations in the dataset.

[4] The analyses were conducted considering the online guidelines provided by Laerd Statistics (2016).

Table 13 - Summary of the results of the two mixed one-way ANOVAs performed for both measurements of speed and radius of the trajectory, based on Intini et al., 2016b.

Dependent Variable	**Effect**	**Test**	**p[1]**
Speed	Time	F(5,80.018) = 7.829	**< 0.001**
	Test Condition	F(3,48.003) = 89.351	**< 0.001**
	Cross Section	F(3,48.006) = 493.348	**< 0.001**
	Driver	F(16,100.169) = 2.904	**0.001**
	Time x Test Condition	F(15,1380) = 2.924	**< 0.001**
	Time x Cross Section	F(15,1380) = 2.368	**0.002**
	Test Condition x Cross Section	F(9,1380) = 88.534	**< 0.001**
	Driver x Time	F(80,1380) = 5.147	**< 0.001**
	Driver x Test Condition	F(48,1380) = 13.392	**< 0.001**
	Driver x Cross Section	F(48,1380) = 4.822	**< 0.001**
Radius of the Trajectory	Time	F(5,105.041) = 3.832	**0.003**
	Test Condition	F(3,55.749) = 4.464	**0.007**
	Cross Section	F(3,55.636) = 3834.152	**< 0.001**
	Driver	F(18,90.222) = 1.166	0.306
	Time x Test Condition	F(15,1094) = 0.363	0.987
	Time x Cross Section	F(15,1094) = 2.806	**< 0.001**
	Test Condition x Cross Section	F(9,1094) = 6.860	**< 0.001**
	Driver x Time	F(73,1094) = 1.027	0.419
	Driver x Test Condition	F(54,1094) = 5.288	**< 0.001**
	Driver x Cross Section	F(54,1094) = 5.940	**< 0.001**

[1] Boldface indicates statistically significant values with 5 % level of significance.

As can be noted, significant effects are revelead for both speeds and radii of curve trajectories.

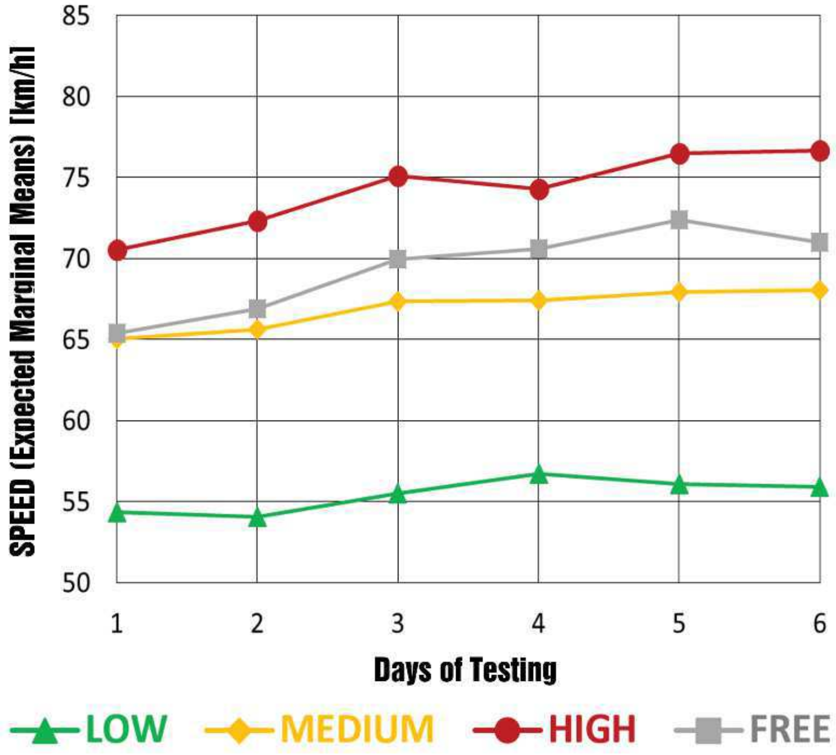
Indeed, a significant effect of time on speed at the $p < 0.05$ level was found [F (5, 80.018) = 7.829, $p < 0.001$]. In this case, the main differences lie between the first two days of testing and the others (from the 3rd to the 6th), as revealed from post-hoc tests. Instead, no significant differences can be noted between the latter days (4th, 5th and 6th). The different cross sections and the different test conditions clearly affect speeds as can be noted in Table 13. In this case, all the pairwise comparisons from post-hoc tests indicate significant differences. Furtermore, statistically significant interactions between test conditions and time on speed [F(15,1380) = 2.924, $p < 0.001$] and between time and road cross sections on speed, [F(15, 1380) = 2.368, p = 0.002] can be noted.

For what about the radius of trajectory chosen at curves, a significant effect of time on radius of trajectory at the $p < 0.05$ level was found [F (5, 105.041) = 3.832, p = 0.003]. The most noticeable differences lie between the second day and all other days of testing for the variable time as revealed by post hoc-tests. Also in this case, the different cross sections and the different test conditions affect the radius and post-hoc tests indicate significant differences from all the pairwise comparisons (except for the differences between the medium and the high speeds laps and between the free and the low speeds laps). However, there was no statistically significant interaction between driving test conditions and time on the radius of trajectory chosen, [F(15,1094) = 0.363, p = 0.987]. Instead, a significant interaction can be noted between time and curve road sections on radius, [F(15, 1094) = 2.806, $p < 0.001$]. Moreover, it must be remarked that for the radius, the factor “driver” was found as not significant.

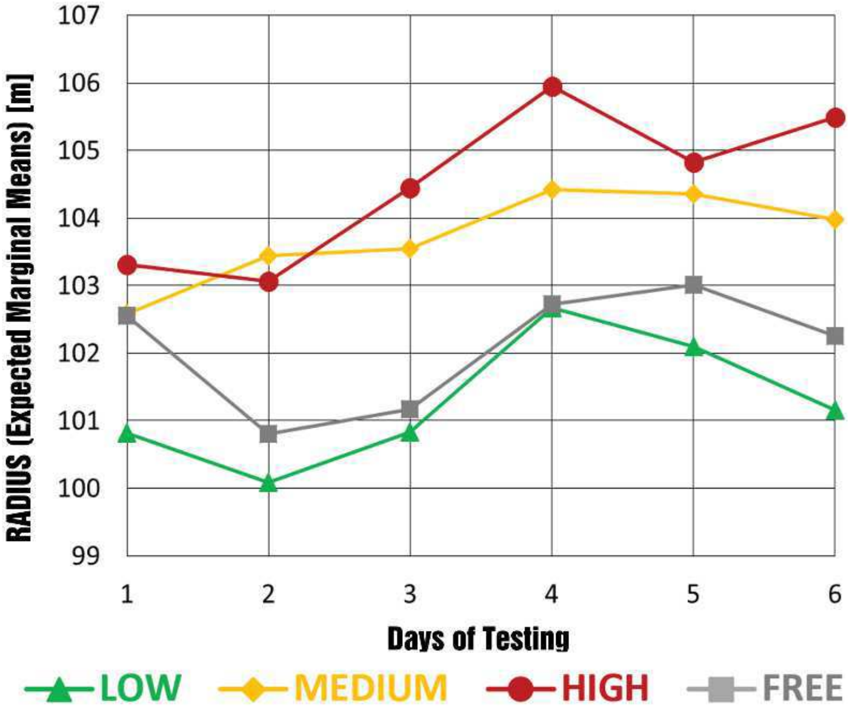
The mean speeds and radii of trajectories estimated through the chosen model (estimated marginal means) are graphically depicted in the next diagrams (included in Figure 24, from a to d), in which the two output variables are plotted against the days of testing by dividing trends for the different test conditions and the different cross sections.

Fig. 24 - Changes in speed (a, c) and radius of the curve trajectory (b, d) over time by considering both the different test conditions and the different road sections inquired, taken from Intini et al., 2016b.

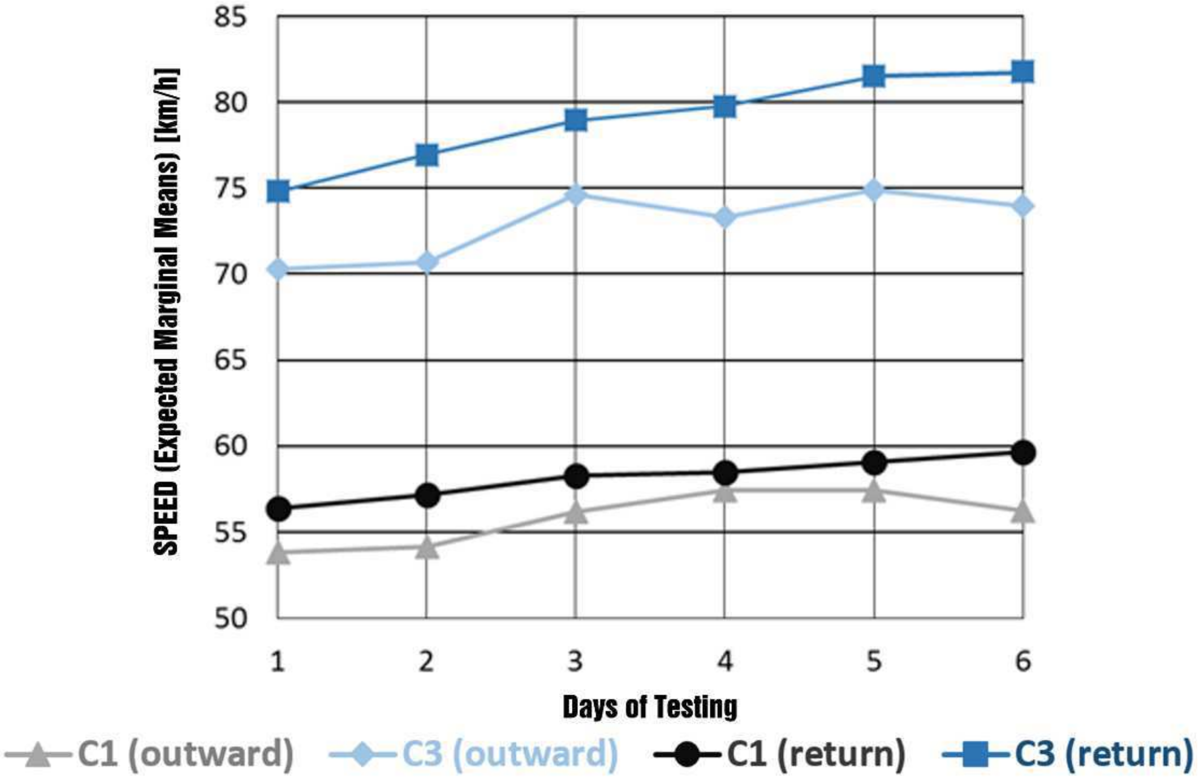
a)



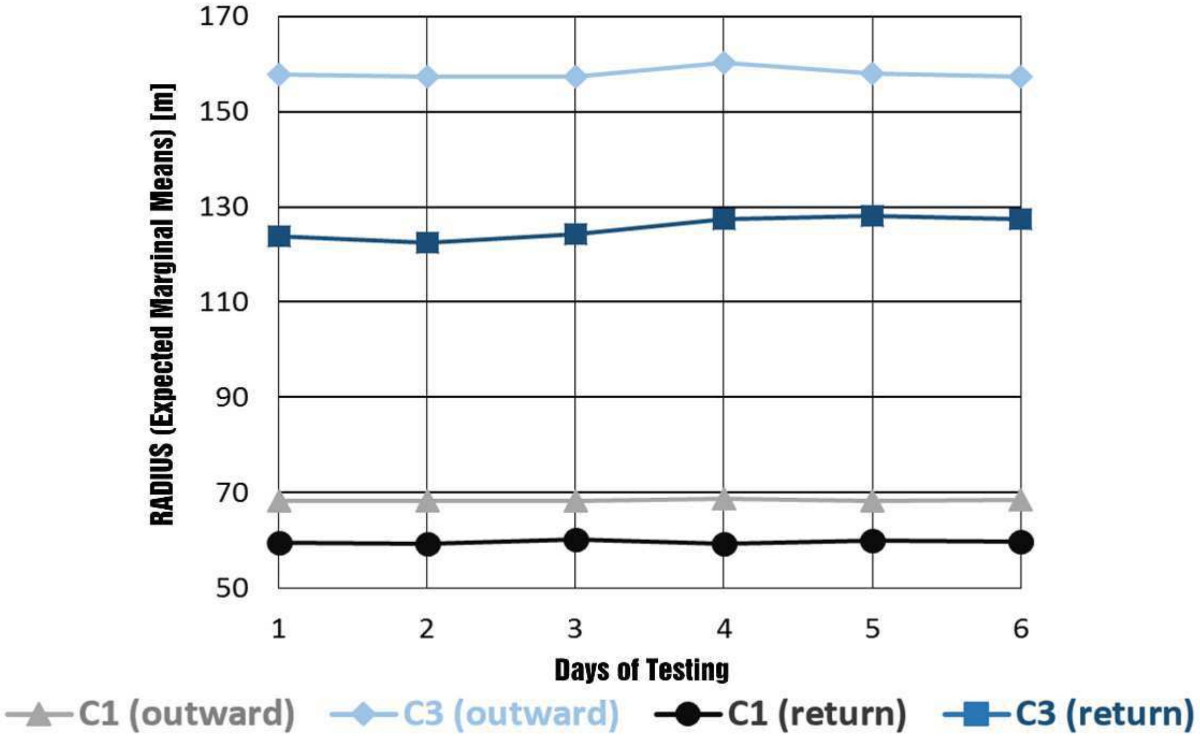
b)



c)


SPEED (Expected Marginal Means) [km/h]
85
80
75
70
65
60
55
50
1
2
3
4
5
6
Days of Testing
C1 (outward)
C3 (outward)
C1 (return)
C3 (return)

d)


RADIUS (Expected Marginal Means) [m]
170
150
130
110
90
70
50
1
2
3
4
5
6
Days of Testing
C1 (outward)
C3 (outward)
C1 (return)
C3 (return)

Some considerations can be made by looking at diagrams in Figure 24 and at the results from the statistical analyses.

As expected from the overview presented in the previous section, drivers seem to tend to increase their speed over time with the acquired familiarity of the road. As it emerges from the statistical analyses, even in more demanding road sections (such as the curves inquired in this analysis) the increasing tendency can be noted in the first four days of testing in a row. Instead, no differences were found between the speeds in the 5th and 6th day and the speeds in the 4th day; confirming the trends shown for the only free speed lap in the previous section. As expected, different curves are related to different speeds but, the increase in speed is more evident at the curve 3 because of its higher radius of curvature, allowing a choice of speeds less conditioned by geometry. The different test driving conditions influence the speed changes over time: the increase in speed over the first four days is higher in both the high and the free speed laps than in the other two test conditions. When drivers were free to choose their speed, they were probably less focused on the task of choosing speed, likely facilitating the switching from conscious to unconscious while acquiring route familiarity. In this case, a speed increase over the first four days was noted. Perhaps, for the reason explained above, in the conditioned speed laps, the increase is less evident (apart from high speed lap). Also the radius of curvature of the trajectories chosen by the drivers was found to increase over days, even if this tendency is less evident. In particular, an increasing tendency can be noted while comparing the days from the second to the fourth. Therefore, drivers can increase the radius of the trajectories over time (that is likely related to an increase in the curve-cutting tendency) even if it was already remarkably high with respect to the radius of the curve (as can be easily detected by comparing radii values in Fig. 24d with the radii of the curves: 47 m for curve 1 and 93 m for curve 3). The increasing tendency over the first four consecutive days is similar to the speed tendency (even if an irregular decreasing tendency from day 1 to day 2 can be noted especially in the free speed lap). In addition, in all driving test conditions, the values of the radius in the fifth and the sixth days of testing, after the two test interruptions, decreased again. Therefore, it seems that in the long term period (after the interruption of the stimulus and its new presentation), the memory of drivers is not able to recall the last trajectory chosen (connected to an increased curve-cutting tendency). This tendency is different from the similar one noted for speeds, which was found roughly constant in the long term, even with the same test interruptions. Therefore, based on the observed data belonging to these two curves, it seems that the curve cutting tendency could be more demanding that the high speeding behaviour if the drivers are not continuously exposed to the same travel on a given road. However, as happens for speeds, the differences in radius of trajectories can be noted at curve 3, while the very small radius of curvature of curve 1 likely prevents a clear increasing tendency in the radius of the trajectories over days. Moreover, even if the radius of curvature is affected individually by time and test conditions, changes in radius of trajectories over days seem to be not influenced by the different driving test conditions (no significant interaction was found between those two factors). This can be explained considering that the driving tests were modeled on speeds and so, drivers were focused on abiding by those rules about speeds. However, even if the evolution of trajectories seems to be independent from different test conditions, higher speeds can be related to higher radii of chosen trajectories. This is confirmed by the results from a Pearson product-moment correlation: there is a strong, positive correlation between speed and radius of curvature of the trajectories, which is statistically significant ($r^2 = 0.613$, $n = 1243$, $p < 0.001$). In conclusion, both the driving performance measures available from the experimental test, that are speed and radius of the curve trajectories, seem to be influenced by the increased road familiarity. The road familiarization process connected to the repetitions of the travel on the same road over time was found to be related to an increase in speed and in the radius of the curve trajectories (even if less evident). If the behavioural theories and studies presented in the general background section are recalled, one should expect that familiarity is related to greater inattention, distraction and changes in perception. However, a shift to more dangerous behaviours, that is speeding and the increase of curve cutting tendencies, was noted from the analyses in this section (coherently with similar results from other studies presented in the introductory section). This dual interacting process is summarized in next figure.

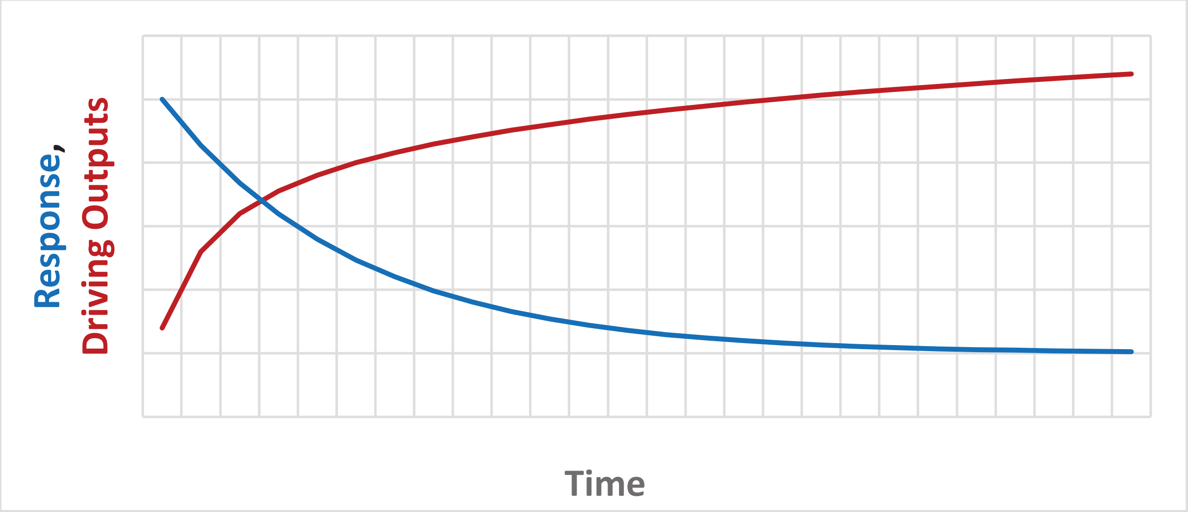


Fig. 25 – Scheme of the drivers' route familiarization process with respect to response (coherently with Groves and Thompson, 1970) and driving measurable outputs, in this case speed and radius.

Considering the perspective of drivers, the tendency to more dangerous behaviours could be not necessarily related to a conscious risk-taking attitude, as the acquired familiarity with the road could lead the familiar drivers to speeds and trajectories still acceptable by themselves, even if likely unsafe for an unfamiliar driver. However, the familiarization process could be partly unconscious, it depends on subjective perceptions and indeed, at least for the speed selection, the factor "driver" was found as significantly infuencing. In fact, in the previous section, it was shown that the speed behaviour of prudent familiar drivers can be different from the behaviour of aggressive familiar drivers, indicating a likely different perception of risk. This can influence the level of performance which can be reached at the end of the familiarization process. When this process can be considered as completed, drivers could be habituated to a given level of driving performance, previously determined while acquiring the information, which remains constant over time. Thus, drivers can adapt to the road environment and reduce their mental workload because they feel confident with the road layout, while having reached a given performance level, depending on their subjective features.

2.3.2 Relationships between route familiarity and drivers' perception changes

In the previous section, the research conducted about the relationships between the familiarity and the driving performances was shown, by highlighting changes in speeds and trajectories with the acquired route familiarity. In this section, the part of research looking in detail into drivers' perception changes due to familiarity and related to the driving performances measured through the experiment (section 2.2.1), is presented.

The four test conditons (free speed, low speed, medium speed, high speed laps) were planned in order to obtain an indirect measure of the drivers' risk perception through their free or conditioned speed selection. Comparing the evolution of speeds over days in the different test conditions is useful to note how the perception of drivers can change with the acquired route familiarity.

On average, speeds selected by drivers in the free speed lap (when they were asked to drive completely free) are included between the medium speed and the high speed lap, as shown in next figure, referred to day 3 as an example (but valid for the other days).

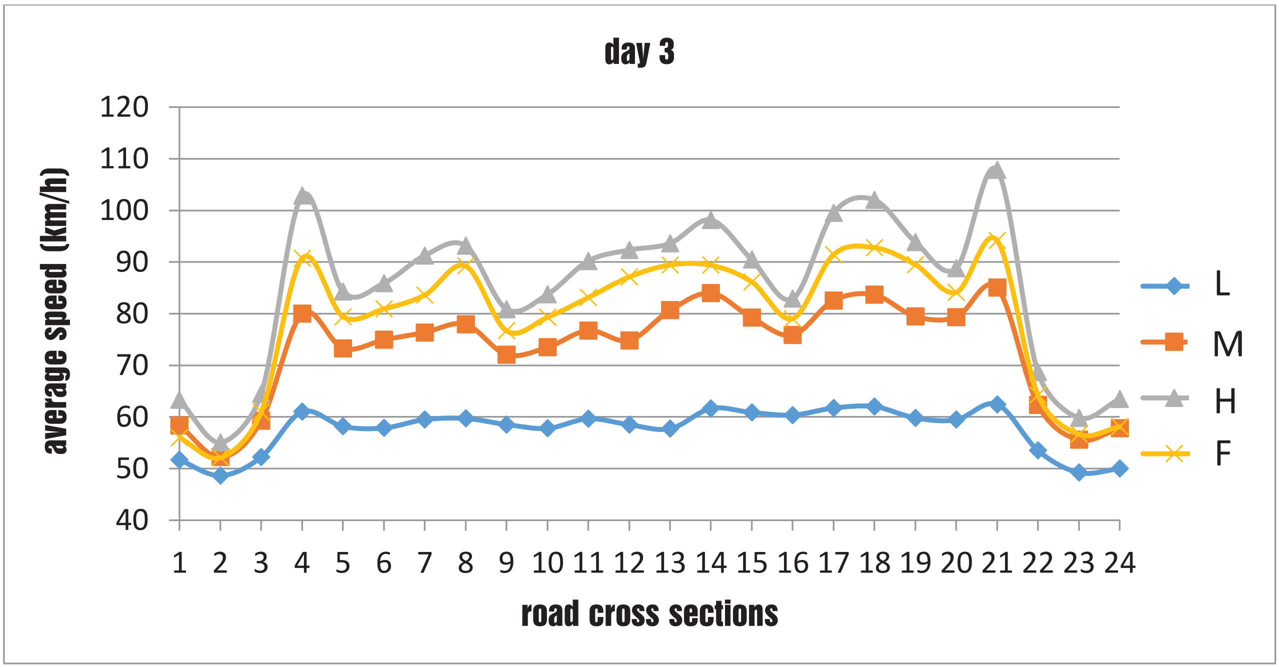


Fig. 26 – Average speed in the different cross sections in the four test driving conditions (sections 1 – 12 are labelled as in Figure 13, considering the outward direction of travel, while sections 13 – 24 are the same sections traveled in the return journey), taken from Colonna et al., 2015.

Therefore, it seems that drivers, when asked to drive freely, select a speed included between speeds considered medium and high by themselves. However, the relative distances between speeds in the medium, high and free laps are not constant over days and they depend on the road cross sections. Indeed, as can be noted from Fig. 26, in the first three sections (1, 2, 3 in the outward direction; 22, 23, 24 in the return direction) belonging to the first sharp curve in Fig. 13, the speeds, as expected from the demanding geometry, are generally lower than in the other sections, making the differences between test conditions less evident. Moreover, the evolution of the relative differences between test driving conditions is highlighted in next Figure.

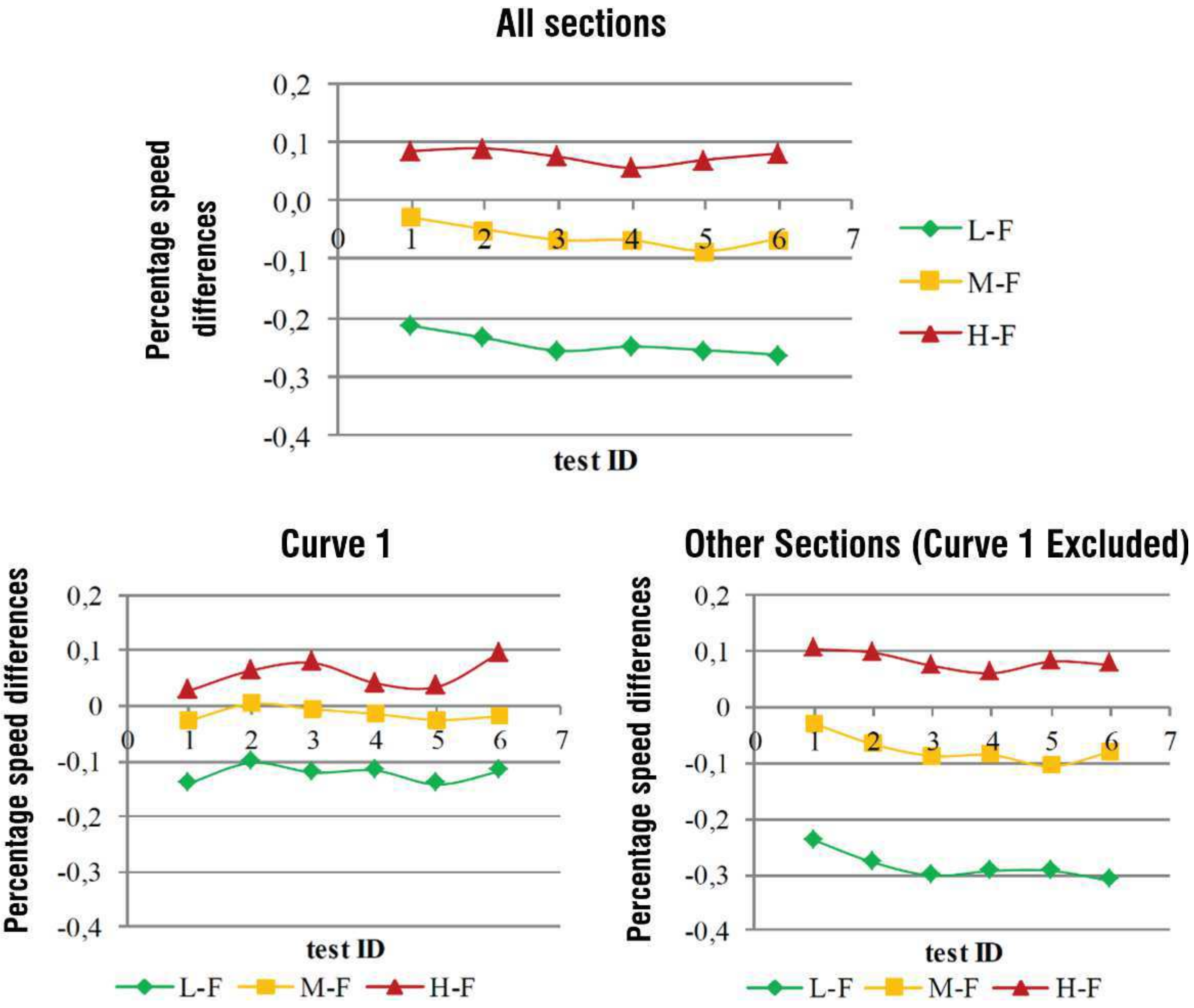


Fig. 27 – Percentage speed differences between different test driving conditions over days, dividing for the different cross sections (Y = 0: free speeds taken as reference), taken from Colonna et al., 2015.

As can be noted from previous Figure, there is an evolution of the speed differences between test conditions over days. In detail, the speed in the free test condition is almost equal to the medium speed condtion in the first day of testing, while it gets much closer to the high speed condition over days. By looking at the first four consecutive days of testing, not interested by the stimuli interruption of the last two tests (making the interpretation of these concepts more difficult), the following tendency can be noted. The speed difference between the high speed lap and the free speed lap progressively decreases over time in the four days, while the opposite can be stated for the difference between the medium speed lap and the free speed lap. From the point of view of risk perception, this could be interpreted as an underestimation of risk while becoming familiar with the road: more familiar users choosing speeds freely, select speeds closer to the speeds considered high by themselves.

If the sections are divided into sections belonging to curve 1 and all other sections, the previous explained tendency is noted in the sections different from curve 1, in which instead the free speeds are about always close to the medium speeds. This could indicate that the risk underestimation is higher in sections in which more degrees of freedom in the speed choice are present (due to the less demanding road geometry). This is coherent with previous findings about the increase of speeds over time by dividing sections into visibility classes (see Fig. 19): the speed increasing tendency in low visibility sections is lower than in the other sections.

Hence, changes in drivers’ perception due to the acquired road familiarity were noted and possible risk underestimation connected to familiarity was highlighted. Since in the previous section familiarity was related to an average speed increase, one should say that familiarity can be responsible for trade-offs between risk and mobility: familiar drivers would take higher risks for the aim of obtaining higher benefits in terms of mobility (reduction of travel times), with the final output of increasing the utility of their travel. In the remainder of this section, these possible trade-offs will be assessed based on the experimental speed data by using the framework of the travel utility presented by Noland (2013) as a basis.

The utility is defined by the cited author as in the Equation 1, previously reported and here recalled:

$$U = f(P, T, C, A, R) \quad (1)$$

Where:
U = Utility of the travel;
P = Price;
T = Travel Time;
C = Capability;
A = In-Vehicle Activities (such as those leading to distraction);
R = Risk.

According to the previous equation, the utility of the travel depends on the mobility-related variables (price of the travel, travel time) and safety related-variables (driver capabilities, activities possibly leading to distraction while driving, risk related to the travel). Drivers tend to maximize the utility of the travel (that is minimizing its general cost) by acting on the independent variables in the equations, making trade-offs between them.

If the conditions of the on-road experiment described in the section 2.2.1 are taken into consideration, then the following hypothesis can be considered:

- Drivers did not care about the price of the travel since they were compensated for the fuel used;
- The characteristics of homogeneity in the selection of the sample of drivers can lead to consider similar capabilities for all the drivers involved;
- The drivers knew that their performances were recorded and so it is most likely that in-vehicle acitivities were not pursued by them during the experiment;
- The drivers were volunteers undergoing to an on-road experiment, they were fuel compensated, and so they had no reason for minimizing the costs related to the travel (utility can be considered as null).

For the assumptions made above, the terms P, C, A and U in the Equation 1 can be set to zero, reducing it to the following derived Equation:

$$f(T, R) = 0 \quad (7)$$

The Equation 7 can be graphically depicted by plotting the risk R on the y-axis against the travel time T on the x-axis (an adaptation of the mobility-safety plan used by Noland, 2013 and Dulisse, 1997).

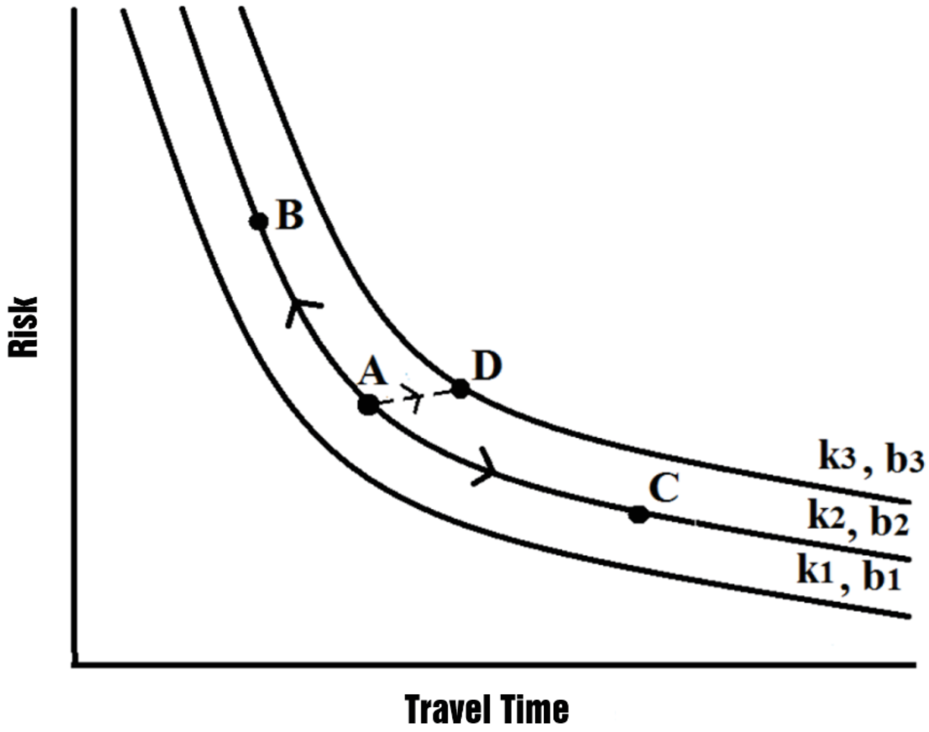


Fig. 28 – Graphical depiction of Trade-offs between Risk and Travel Time, taken from Intini et al., 2016a.

To relate risk to travel time, a negative power function was chosen for this study. It has the following properties matching the travel characteristics on a given road section: a null travel time is related to a theoretical infinite value of speed (and to other dangerous behaviours such as curve-cutting) and so, to a very high risk. Conversely, the more is the travel time for the same road section, the less is the risk (towards the asymptotic condition of null speed). The chosen function is represented by the following equation:

$$R = k\,T^{-b} \tag{8}$$

It is characterized by a set of two parameters (k, b) able to represent a particular road system. The curve characterized by a couple of these parameters (e.g. k_2, b_2) is a drivers' preference curve: it represents the choices of drivers in terms of risk and travel time for that road system. The point A along the curve can represent a particular driver. Other road systems or the same road system which experienced changes in the boundary condtions will be characterized by a different set of the parameters (e.g. k_3, b_3), and a shift of the point A to the point D for the same driver, depending on the new road characteristics. It is also assumed that the same driver can experience changes in his behaviour leading to different perceptions of risk and different choices: the point A could move on the same curve to the points C (safer behaviours, mobility worsening) or B (riskier behaviours, mobility benefit).

This theoretical proposed framework, represented in Fig. 28, is evaluated as follows by considering the speed data belonging to the on-road experiment. The trade-offs between risk and travel time are measured by converting both measures into monetary costs in order to allow the comparison.

Speed data belonging to different drivers in different days of testing were converted into risk measures by considering the relationships found in literature studies between speed and accident risk. Since the experiment was conducted only on some days of testing, it is not possible to use existing relationships between individual speeds of drivers and accidents happened in the past on the specific road section. The model proposed by Elvik (2013a), a re-parametrisation of the power model proposed by Nilsson (2004), allows instead to measure risk in terms of number of accidents with respect to a given level of reference:

$$\text{RAN} = \alpha \times \exp(\beta \times \text{initial speed}) \tag{9}$$

Where:

RAN = Relative Accident Number, number of accidents referred to a value of 100 accidents related to the maximum speed of 115 km/h considered in the study by Elvik;
Initial speed = average traffic speed;
a = 0.072 (for fatal accidents), 1.983 (for injury accidents), 2.928 (for PDO accidents);
b = 0.069 (for fatal accidents); 0.034 (for injury accidents); 0.032 (for PDO accidents).

The study considers average traffic speeds and not individual drivers' free flow speeds. However, since the obtained output is a measure of the relative risk (and not an absolute accident frequency), then it is considered as a qualitative measure of the accident risk related to given speed values.
Hence, drivers' speeds were converted into relative number of accidents (with respect to the value of reference of 100 accidents, corresponding to 115 km/h). Since the model estimates separately fatal, injury and property-damage-only (PDO) accidents, then three different accident values were obtained for each speed. After, each accident estimate related to the three diverse levels of severity is converted into a monetary cost, by applying the Italian general monetary costs (including also health and social costs) published by the Italian Ministry of Transport (2010). Then, for each speed, an unique value of monetary cost is obtained by summing the three computed estimates (through the use of a weighted mean considering the relative proportion of accidents on the total number, based on the Highway Safety Manual default proportions, 2010):

$$Relative\ Cost\ (S) = \frac{(RAN(S)*COST*\%)_{FATAL} + (RAN(S)*COST*\%)_{INJURY} + (RAN(S)*COST*\%)_{PDO}}{100\ (\%)} \quad (10)$$

Where:
S = Speed;
RAN (S) = Relative Accident Number estimated from Equation 9 for each severity level.

Hence, since this monetary cost is computed considering a relative number of accidents, then it is referred to the cost of reference for 100 accidents (average speed = 115 km/h) by evaluating the following index, included in the interval: [0, 1]:

$$Index\ of\ relative\ cost\ of\ risk = \frac{\sum Costs\ of\ accidents\ (S)}{\sum Costs\ of\ accidents\ (115\ km/h)} \tag{11}$$

The same speed data were converted into travel time measures by simply dividing the length of the road sections considered by the average speeds. Since the road layout of the experiment was divided into four visibility classes (see 2.3.1.1), then four travel time measures were computed for each driver and for each day, by considering four road sub-sections (1.3 km characterized by low visibility, 2.7 km by medium-low visibility, 1 km by medium visibility, 1.8 km by high visibility). The obtained travel times were converted into monetary costs considering a conversion factor of 3 €/h (Fiorello and Pasti, 2003) for students who did not earn salaries. Finally, also this measure was referred to the same measure obtained for 115 km/h, in order to be comparable with the risk measure, by defining the following index:

$$Index\ of\ relative\ cost\ of\ travel\ time = 1 - \frac{TT\ (S)}{TT\ (115\frac{km}{h})} \tag{12}$$

The ratio between the travel times is subtracted by the unity in order to obtain another index included between 0 and 1 (no average speed is greater than 115 km/h).

The obtained indexes of accident risk were plotted on the y-axis against the indexes of travel time on the x-axis, as shown in the following diagrams. In the first diagram, drivers were divided into clusters based on their measured speed as explained in section 2.2.1 (prudent drivers: speeds lower than the average; average drivers: speeds consistent with the average and aggressive drivers: speeds higher than the average). Moreover, in the second diagram, drivers were considered all together but, different values of risk and travel time were computed for the different road sections characterized by diverse sight distance values. In both the diagrams, the ordered pairs (travel time, risk) were evaluated for the first four days of testing separately in the different considered conditions.

Based on the framework exemplified in Fig. 28, the points belonging to different drivers' cluster in Fig. 29 were fitted with a unique curve since the overall road section was taken into consideration. Instead, points belonging to diverse sub-sections were fitted by four curves (Fig. 30) because they were thought as related to different road sections.

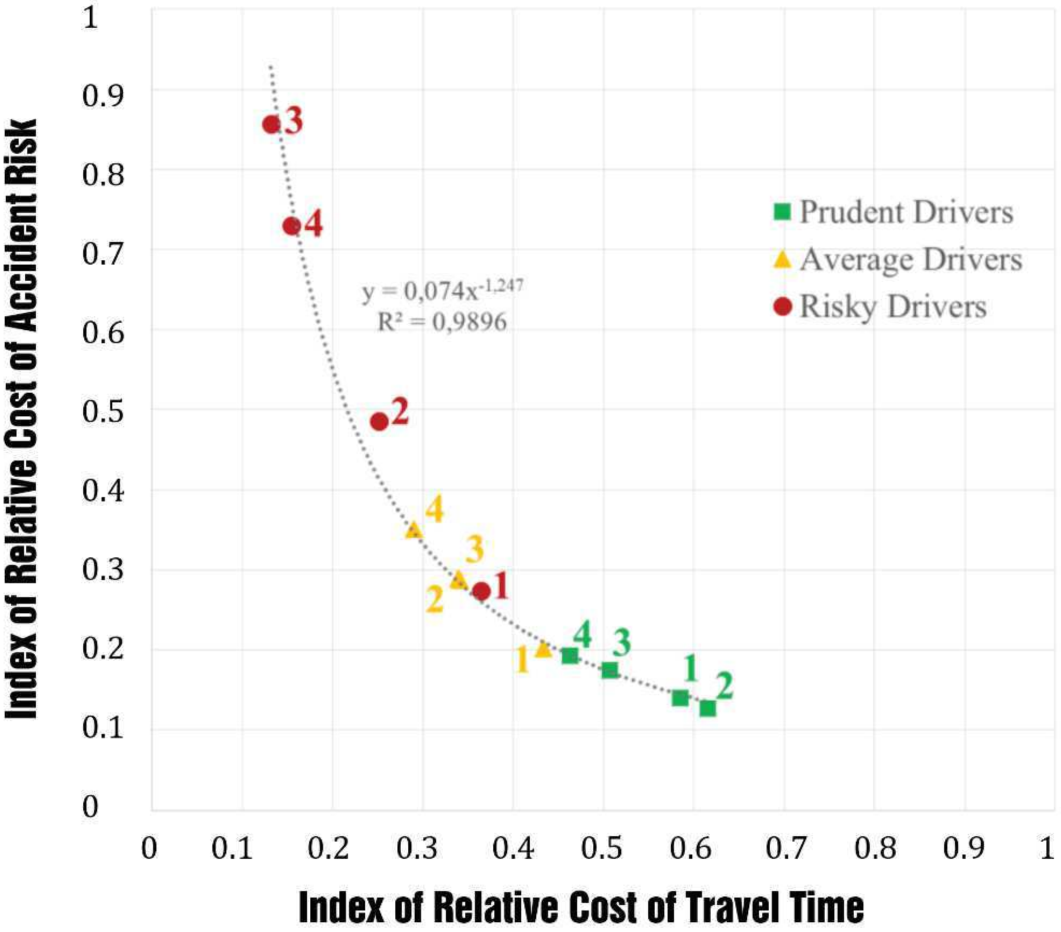


Fig. 29 – Estimated risk-travel time curve for the whole experimental road layout, highlighting the differences between the three drivers' cluster, taken from Intini et al., 2016a.

The Fig. 29 reflects the remark of a unique preference curve for a given road system, even for drivers having different speed inclinations. Trade-offs between risk and travel time due to the increased familiarity, while going from the first days (points 1, 2) to the third and fourth days of testing (points 3, 4) can be noted. The preferences of drivers generally move along the regression curve from the bottom-right to the up-left of the diagram. This phenomenon can be related to the risk inclination of the drivers: for prudent and average drivers, the travel time reduction is associated to a slight increase in risk; while for the more aggressive drivers, a similar reduction of the travel time is associated to a very high increase in the estimated risk. Another important difference can be noted: the risk related to the first day for average and aggressive drivers is very similar, while the level of risk associated to the last days of testing is much higher for the risky drivers than for the average drivers (almost approaching the maximum value 1 for the index of relative accident risk).

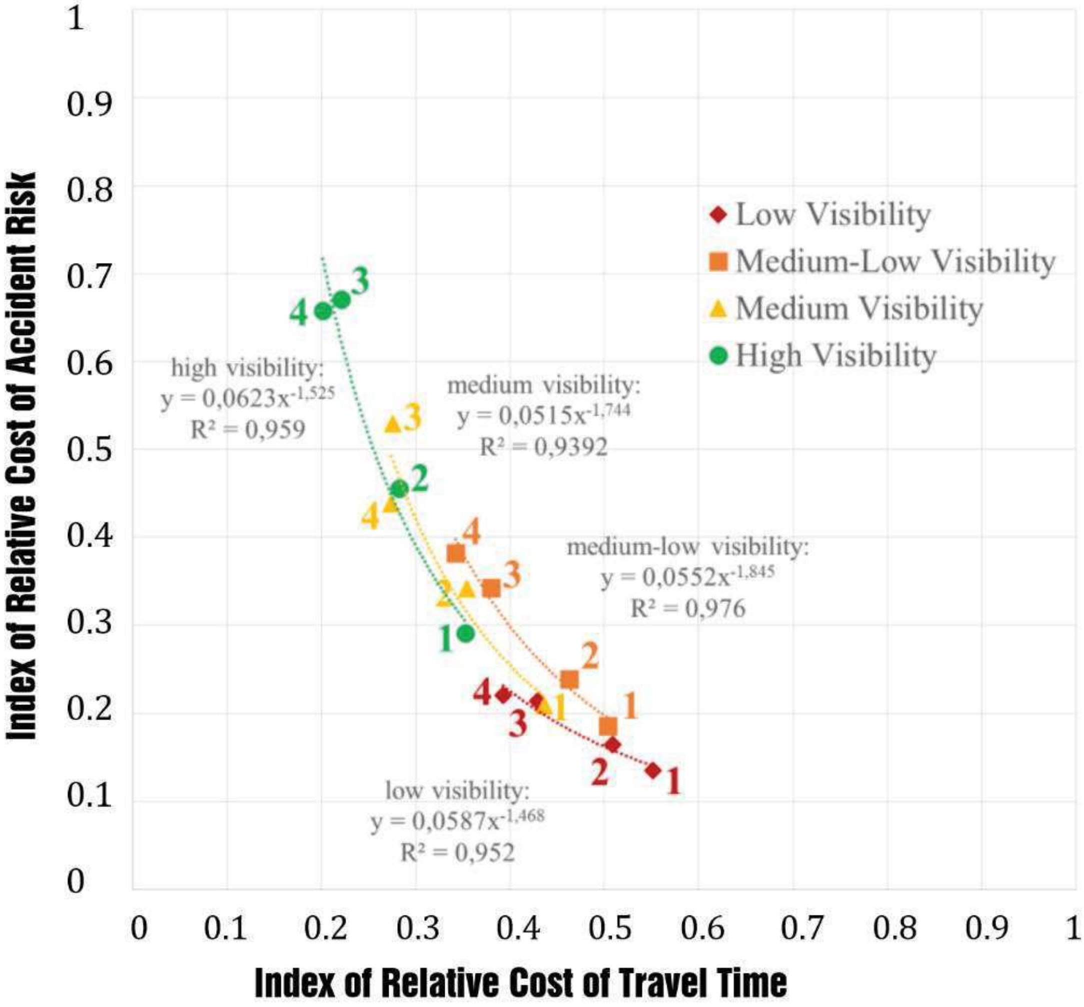


Fig. 30 – Estimated risk-travel time curves for the different road sub-sections characterized by different sight distances, considering the drivers as a whole sample; taken from Intini et al., 2016a.

As it emerges from Fig. 30, small discrepancies between the different preference curves for the four road sub-sections can be noted. This can be explained by the fact that the different sub-sections all belong to the same type of road: low-volume two-way two-lane rural road. A decrease in the travel time and an increase in the risk can be noted for all the visibility conditions. However, while the decrease in the travel time index while going from the first to the fourth day is about constant for the four visibility classes (included between 0.15 and 0.20), the corresponding increase in the accident risk index varies a lot, ranging from about 0.10 for the low visibility sub-section to about 0.4 for the high visibility sub-section. The same tendency about travel time can be noted by looking at Fig. 29, where the different drivers' cluster are considered separately.

This means that, on average, an increased familiarity of the drivers could be related to a constant desired decrement of the travel time which is largely independent from the speeding attitudes of the drivers and from the more or less demanding road geometry. However, the related increase in the risk connected to this reduction of travel-time (since those measures are both based on speed, which was found to increase while becoming more familiar, see previous section) varies according to the different drivers' attitudes and the diverse road geometry. Indeed, a high increase in risk was noted for aggressive drivers and in high visibility conditions, since in these cases the speeds in the first day were lower and the function relating risk to travel time is a power function. However, it must be stated that trade-offs between risk and travel time were measured by using objective measures (accident risk and travel time based on measured speed data). Nevertheless, as explained in the General Background section, the possible changes in driving behaviour due to the familiarity, related to a greater automation of the driving process, could be unconscious and largely subjective. Moreover, the analyzed driving outputs (in this case speeds) are largely influenced by the subjective perception of the drivers (see e.g. Tarko, 2007), who could misperceive risk and the process of speed formation (see e.g. Elvik, 2010). In the on-road experiment, that provided the data on which the elaborations shown in this section are based, the users' perception of risk was indirectly measured by considering four different driving tests (free, low, medium, high speed laps). Furthermore, in the data analysis, the driving attitudes of different individuals were considered through the classification of drivers into classes based on speeding attitudes (prudent, average and aggressive), in order to consider subjective differences in speed choice between drivers (see also Colonna et al, 2016f, for the importance of the different behaviours in explaining speed choices).

In the previous section, route familiarity was related to a general increase in the speeds over time. In parallel to this speed increase, some changes in the perception of drivers were highlighted in this section, partially related to the increase in speeds. Drivers were found to travel at speeds which themselves perceive, on average, as included between "medium" and "high" speeds. An increased familiarity was found to be responsible for a shift of free speeds closer to the high speeds over time, which could be related to a greater confidence of drivers and a higher tendency to underestimate risk. Risks taken by the drivers were estimated by converting speed measures into accident risk measures, showing how the drivers are prone to take more risks while becoming more familiar, in order to achieve travel time benefits (found instead to be about constant for all drivers and for all road sections). This increasing risk tendency is more evident for drivers more prone to speeding ("aggressive" or "risky") and in sections characterized by a less demanding road geometry.

2.3.3 Relationships between route familiarity, traffic flow and expected accidents

As presented in the section 2.1.3.2, the drivers' familiarity with a given road is indirectly considered while estimating the level of service of multilane highways and freeways, in which the differences between regular and recreational drivers are considered through the introduction of the driver population factor fp. In this section, this relationship is deepened by remarking the possible implications for road safety, through a simulation conducted.

The framework of the Highway Capacity Manual for estimating the levels of service of freeways and highways is used as a basis for the development of this application. In this framework, the traffic flow is related to the average speed of the traffic with some equations depending on the free flow speed.

Those equations are structured similarly to the one shown below for given traffic ranges and coefficients varying according to the different free flow speed (FFS):

$$S = FFS - \left[(a\,FFS - \ b)\left(\frac{v_P - c}{dFFS - e}\right)^{f}\right] \qquad (13)$$

Where:
S = average speed of the traffic flow;
FFS = Free-flow speed;
Vp = Equivalent flow rate;

The free-flow speed is computed through the equation (from the HCM):

$$FFS = BFFS - f_{LW} - \mathrm{f}_{LC} - f_M - f_A \tag{14}$$

Where:
FFS = free flow speed [km/h];
BFFS = base free flow speed, depending on the surrounding context of the road [km/h];
f_{LW} = reducing factor related to lane width (minor widths associated to higher factors);
f_{LC} = reducing factor which depends on the distance between the closest road lateral obstacle and the roadway (the less is the distance, the more is the factor).
f_M = factor revealing the presence or not of median widths (zero if median is present);
f_A = factor depending on the number of intersections per kilometer (the more is this number, the more is the factor).

If all the factors are neglected, to a first approximation, the FFS is supposed to be equal to the base free flow speed (BFFS). This speed can be set to the posted speed limit, according to the HCM, increased of 8 km/h, if other experimental data are absent.
Let us suppose now to consider a multilane divided highway with two lanes for each travel direction and to compute the equivalent flow rate per hour per lane, previously shown in the equation 6, here recalled:

$$Vp = \frac{V}{PHF * N * f_{HV} * f_P} \tag{6}$$

Where:

Vp = 15-minute passenger-car equivalent flow rate (passenger cars/hour/lane)
V = hourly volume (passenger cars/hour)
PHF = Peak Hour Factor
N = number of lanes in one direction
fHV = heavy-vehicle adjustment factor
fp = driver population adjustment factor

Considering the values proposed by Sharma (1987, see Table 6), the following relationship between type of road, driver population factor and share of recreational drivers in the traffic flow is supposed. In Table 14, the possibility of high recreational roads mainly traveled by tourists, showing a fp value less than 0.85, is considered, according to the HCM 2010 (in which it is stated that the 0.85 minimum threshold can be lowered if there is a specific necessity proven by specific studies). The reference study is dated, even if those correlations could be considered as still valid nowadays.

Table 14 – Supposed percentages of recreational drivers in the traffic flow corresponding to different values of the driver population factor (based on Sharma, 1987).

Type of road	Type of traffic	fp	share of recreational drivers [%]
Roads used by commuters on Urban scale	Urban commuters	1.00	0
Roads used by commuters on Regional scale	Regional commuters	0.95	10
Roads used by commuters and other users on Regional scale	Regional recreational/ commuters	0.90	20
Roads used on Interregional/long distance scale	Interregional/ Long distance	0.85	30
Roads used for long distance travel and for tourism	Long distance/ recreational	0.80	40
Roads almost exclusively used for tourism	Highly recreational	0.75	50

Then, the equation 6 is applied for different traffic rates and for the different considered values of the driver population factor fp (focusing on the application of this coefficient and therefore considering that the other coefficients present in the equation were already eventually applied previously). The equivalent flow rates obtained by applying different driver population factors related to different shares of recreational drivers in the traffic flow are shown in next Table.

Table 15 – Equivalent flow rates corresponding to different shares of recreational drivers in the traffic flow (example of free flow speed equal to 100 km/h).

V [vehi/h/ln]	fp	Recreational Share [%]	Vp [vehi/h/ln]	Corrected Vp [vehi/h/ln]
1300	1.00	0.0	1300	1300
1300	0.95	0.1	1368	1368
1300	0.90	0.2	1444	1444
1300	0.85	0.3	1529	1529
1300	0.80	0.4	1625	1625
1300	0.75	0.5	1733	1733
1400	1.00	0.0	1400	1400
1400	0.95	0.1	1474	1474
1400	0.90	0.2	1556	1556
1400	0.85	0.3	1647	1647
1400	0.80	0.4	1750	1750
1400	0.75	0.5	1867	1867
1500	1.00	0.0	1500	1500
1500	0.95	0.1	1579	1579
1500	0.90	0.2	1667	1667
1500	0.85	0.3	1765	1765
1500	0.80	0.4	1875	1875
1500	0.75	0.5	2000	2000
1600	1.00	0.0	1600	1600
1600	0.95	0.1	1684	1684
1600	0.90	0.2	1778	1778
1600	0.85	0.3	1882	1882

V [vehi/h/ln]	fp	Recreational Share [%]	Vp [vehi/h/ln]	Corrected Vp [vehi/h/ln]
1600	0.80	0.4	2000	2000
1600	0.75	0.5	2133	2133
1700	1.00	0.0	1700	1700
1700	0.95	0.1	1789	1789
1700	0.90	0.2	1889	1889
1700	0.85	0.3	2000	2000
1700	0.80	0.4	2125	2125
1700	0.75	0.5	2267	2200
1800	1.00	0.0	1800	1800
1800	0.95	0.1	1895	1895
1800	0.9	0.2	2000	2000
1800	0.85	0.3	2118	2118
1800	0.8	0.4	2250	2200
1800	0.75	0.5	2400	2200
1900	1.00	0.0	1900	1900
1900	0.95	0.1	2000	2000
1900	0.90	0.2	2111	2111
1900	0.85	0.3	2235	2200
1900	0.80	0.4	2375	2200
1900	0.75	0.5	2533	2200
2000	1.00	0.0	2000	2000
2000	0.95	0.1	2105	2105
2000	0.90	0.2	2222	2200
2000	0.85	0.3	2353	2200
2000	0.80	0.4	2500	2200
2000	0.75	0.5	2667	2200
2100	1.00	0.0	2100	2100
2100	0.95	0.1	2211	2200
2100	0.90	0.2	2333	2200
2100	0.85	0.3	2471	2200
2100	0.80	0.4	2625	2200
2100	0.75	0.5	2800	2200

V [vehi/h/ln]	fp	Recreational Share [%]	Vp [vehi/h/ln]	Corrected Vp [vehi/h/ln]
2200	1.00	0.0	2200	2200
2200	0.95	0.1	2316	2200
2200	0.90	0.2	2444	2200
2200	0.85	0.3	2588	2200
2200	0.80	0.4	2750	2200
2200	0.75	0.5	2933	2200

In the previous Table, the flow rates shown in the last column are corrected, by rounding the volumes to the capacity, if the capacity was exceeded. The capacity was supposed to be equal to 2200 vehicles/hour/lane, as indicated in the HCM for a free flow speed of 100 km/h. Therefore, the table is referred to a free flow speed of 100 km/h, which is a speed easy to reach on this type of roads. For this reason, in the remainder of this section, all the simulations will be referred to this value of free flow speed.

Therefore, as shown in Figure 10, these flow corrections (increasing flow) which take into account the presence of recreational drives, could be related to changes in the average speed of the traffic flow, as shown in next Figure. Those expected average speed variations could be related only to the presence of recreational drivers in the traffic flow. The values of speed variations are shown in next Table, in which the free flow speed of 100 km/h and the related capacity of 2200 vehicles/hour/lane are considered as in the previous Table. As it can be noted in next Figure, choosing a free flow speed of 100 km/h means also remarking the most critical situation for speeds at flow rates near to the capacity, which decrease of more than 10 km/h for flow rates approaching the capacity.

For each equivalent flow rate considered, the correspondent equivalent speed is obtained by applying the equation 13 in the case of FFS = 100 km/h (HCM 2000: $a = 9.3/25$, $b = 630/25$, $c = 1400$, $d = 15.7$, $e = 770$, $f = 1.31$), since the FFS and the Vp values are known. Then, the speed variation with respect to the speed in case of driver population factor equal to 1 (i.e. all regular drivers such as commuters in the flow) is computed for each equivalent speed (related to a given recreational share).

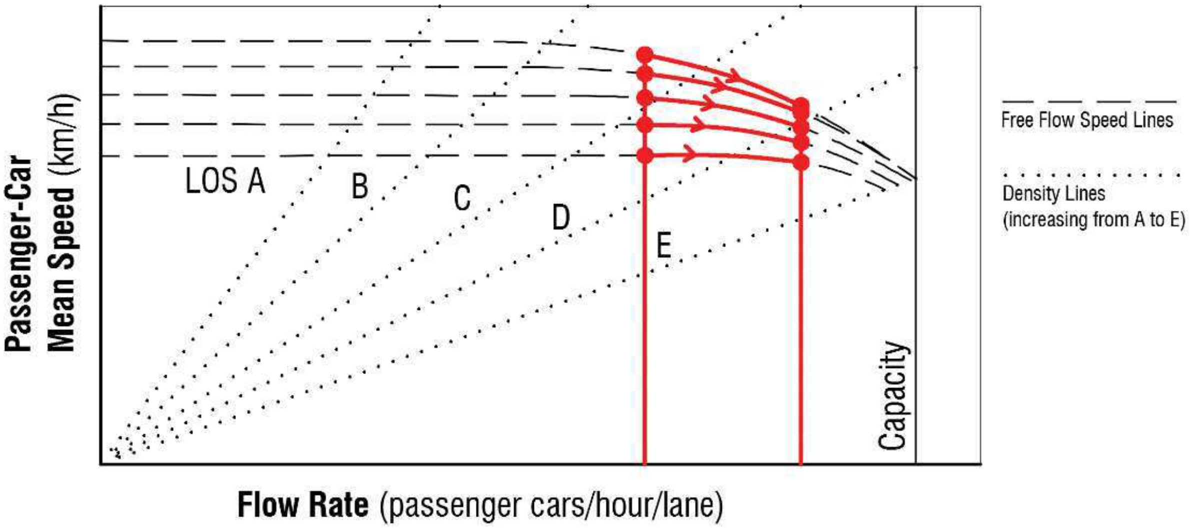


Fig. 31 – Example of influence of the increase in the equivalent flow rate (due to presence of recreational drivers) on the equivalent speed, based on the Highway Capacity Manual.

Table 16 – Estimation of the reduction in average speed of the traffic flow ΔS due to the presence of recreational drivers in the traffic.

V [vehi/h/ln]	fp	Recreational Share [%]	Corrected Vp [vei/h/ln]	S [km/h]	ΔS [km/h]
1300	1.00	0.0	1300	100.0	0.0
1300	0.95	0.1	1368	100.0	0.0
1300	0.90	0.2	1444	99.7	0.3
1300	0.85	0.3	1529	98.9	1.1
1300	0.80	0.4	1625	97.7	2.3
1300	0.75	0.5	1733	96.2	3.8
1400	1.00	0.0	1400	100.0	0.0
1400	0.95	0.1	1474	99.5	0.5
1400	0.90	0.2	1556	98.6	1.4
1400	0.85	0.3	1647	97.4	2.6
1400	0.80	0.4	1750	95.9	4.1
1400	0.75	0.5	1867	94.1	5.9
1500	1.00	0.0	1500	99.2	0.0
1500	0.95	0.1	1579	98.3	0.9
1500	0.90	0.2	1667	97.2	2.1
1500	0.85	0.3	1765	95.7	3.5

V [vehi/h/ln]	fp	Recreational Share [%]	Corrected Vp [vei/h/ln]	S [km/h]	ΔS [km/h]
1500	0.80	0.4	1875	93.9	5.3
1500	0.75	0.5	2000	91.8	7.4
1600	1.00	0.0	1600	98.0	0.0
1600	0.95	0.1	1684	96.9	1.1
1600	0.90	0.2	1778	95.5	2.5
1600	0.85	0.3	1882	93.8	4.2
1600	0.80	0.4	2000	91.8	6.3
1600	0.75	0.5	2133	89.3	8.8
1700	1.00	0.0	1700	96.7	0.0
1700	0.95	0.1	1789	95.3	1.4
1700	0.90	0.2	1889	93.7	3.0
1700	0.85	0.3	2000	91.8	4.9
1700	0.80	0.4	2125	89.5	7.2
1700	0.75	0.5	2200	88.0	8.7
1800	1.00	0.0	1800	95.2	0.0
1800	0.95	0.1	1895	93.6	1.6
1800	0.90	0.2	2000	91.8	3.4
1800	0.85	0.3	2118	89.6	5.6
1800	0.80	0.4	2200	88.0	7.2
1800	0.75	0.5	2200	88.0	7.2
1900	1.00	0.0	1900	93.5	0.0
1900	0.95	0.1	2000	91.8	1.7
1900	0.90	0.2	2111	89.7	3.8
1900	0.85	0.3	2200	88.0	5.5
1900	0.80	0.4	2200	88.0	5.5
1900	0.75	0.5	2200	88.0	5.5
2000	1.00	0.0	2000	91.8	0.0
2000	0.95	0.1	2105	89.8	1.9
2000	0.90	0.2	2200	88.0	3.8
2000	0.85	0.3	2200	88.0	3.8
2000	0.80	0.4	2200	88.0	3.8
2000	0.75	0.5	2200	88.0	3.8

V [vehi/h/ln]	fp	Recreational Share [%]	Corrected Vp [vei/h/ln]	S [km/h]	∆S [km/h]
2100	1.00	0.0	2100	89.9	0.0
2100	0.95	0.1	2200	88.0	1.9
2100	0.90	0.2	2200	88.0	1.9
2100	0.85	0.3	2200	88.0	1.9
2100	0.80	0.4	2200	88.0	1.9
2100	0.75	0.5	2200	88.0	1.9
2200	1.00	0.0	2200	88.0	0.0
2200	0.95	0.1	2200	88.0	0.0
2200	0.90	0.2	2200	88.0	0.0
2200	0.85	0.3	2200	88.0	0.0
2200	0.80	0.4	2200	88.0	0.0
2200	0.75	0.5	2200	88.0	0.0

As can be seen from previous Table and Figure, a high presence of recreational drivers in the traffic flow can be related to a decrease of the average speed of the traffic flow and a possible decrease in the level of service with respect to the condition of a commuting flow (because speeds and flows are related to the density).

However, those speed variations are related to the average speed of the traffic flow. Nevertheless, in this section, the traffic flow is considered as mainly composed of two categories of drivers: the regular drivers and the recreational drivers. A simple proportion could be taken into account for assignign a value of the speed to the two different categories of drivers as follows:

$$S = S_{average,recreational}\ x\ \%_{recreational} + S_{average,regular}\ x\ (1 - \%_{recreational}) \qquad (15)$$

Where:

S = Average speed of the flow adjusted for the presence of recreational drivers (km/h);
$S_{average,recreational}$ = Average speed of the recreational component in the traffic flow (km/h);
$S_{average,regular}$ = Average speed of the regular component in the traffic flow (km/h);
$\%_{recreational}$ = Share of recreational drivers in the traffic flow.

Hence, it can be assumed that the average speed of the regular component in the traffic flow (commuters and regular drivers) is equal to the average speed computed for fp equal to 1 in the equivalent flow rate calculation (no recreational drivers). Then, the average speed of the recreational component of the traffic flow could be obtained by the equation 9, once a given share of recreational drivers is set, and the speeds S and $S_{average,regular}$ (equal to S +ΔS in the previous Table) are known.

Therefore, for each flow rate and for different shares of recreational drivers in the traffic flow, the average speeds of the recreational drivers and the differences between the speeds of recreational and regular drivers can be estimated. They are reported in next table (FFS = 100 km/h, capacity = 2200 vehi/h/ln).

Table 17 – Estimation of the average speed differences between the recreational and the regular component in the traffic flow (ΔS recreational/regular drivers).

V [vei/h/ln]	$\%_{recreational}$	Corrected Vp [vei/h/ln]	S [km/h]	$S_{average, recreational}$ [km/h]	ΔS recreational/ regular drivers [km/h]	$S_{average, regular}$ [km/h]
1300	0.0	1300	100.0	-	-	100.0
1300	0.1	1368	100.0	100.0	0.0	100.0
1300	0.2	1444	99.7	98.6	1.4	100.0
1300	0.3	1529	98.9	96.3	3.7	100.0
1300	0.4	1625	97.7	94.3	5.7	100.0
1300	0.5	1733	96.2	92.4	7.6	100.0
1400	0.0	1400	100.0	-	-	100.0
1400	0.1	1474	99.5	94.7	5.3	100.0
1400	0.2	1556	98.6	93.0	7.0	100.0
1400	0.3	1647	97.4	91.4	8.6	100.0
1400	0.4	1750	95.9	89.8	10.2	100.0
1400	0.5	1867	94.1	88.2	11.8	100.0
1500	0.0	1500	99.2	-	-	99.2
1500	0.1	1579	98.3	90.2	9.0	99.2
1500	0.2	1667	97.2	88.9	10.3	99.2
1500	0.3	1765	95.7	87.5	11.7	99.2

V [vei/h/ln]	$\%_{recreational}$	Corrected Vp [vei/h/ln]	S [km/h]	$S_{average, recreational}$ [km/h]	ΔS recreational/ regular drivers [km/h]	$S_{average, regular}$ [km/h]
1500	0.4	1875	93.9	86.0	13.2	99.2
1500	0.5	2000	91.8	84.3	14.9	99.2
1600	0.0	1600	98.0	-	-	98.0
1600	0.1	1684	96.9	86.6	11.4	98.0
1600	0.2	1778	95.5	85.4	12.7	98.0
1600	0.3	1882	93.8	83.9	14.1	98.0
1600	0.4	2000	91.8	82.3	15.7	98.0
1600	0.5	2133	89.3	80.5	17.5	98.0
1700	0.0	1700	96.7	-	-	96.7
1700	0.1	1789	95.3	83.1	13.5	96.7
1700	0.2	1889	93.7	81.8	14.9	96.7
1700	0.3	2000	91.8	80.3	16.4	96.7
1700	0.4	2125	89.5	78.6	18.1	96.7
1700	0.5	2200	88.0	79.3	17.4	96.7
1800	0.0	1800	95.2	-	-	95.2
1800	0.1	1895	93.6	79.6	15.5	95.2
1800	0.2	2000	91.8	78.2	17.0	95.2
1800	0.3	2118	89.6	76.6	18.6	95.2
1800	0.4	2200	88.0	77.3	17.9	95.2
1800	0.5	2200	88.0	80.8	14.3	95.2
1900	0.0	1900	93.5	-	-	93.5
1900	0.1	2000	91.8	76.0	17.5	93.5
1900	0.2	2111	89.7	74.5	19.0	93.5
1900	0.3	2200	88.0	75.1	18.4	93.5
1900	0.4	2200	88.0	79.7	13.8	93.5
1900	0.5	2200	88.0	82.5	11.0	93.5
2000	0.0	2000	91.8	-	-	91.8
2000	0.1	2105	89.8	72.4	19.4	91.8
2000	0.2	2200	88.0	72.9	18.8	91.8
2000	0.3	2200	88.0	79.2	12.6	91.8
2000	0.4	2200	88.0	82.3	9.4	91.8

V [vei/h/ln]	$\%_{recreational}$	Corrected Vp [vei/h/ln]	S [km/h]	$S_{average, recreational}$ [km/h]	ΔS recreational/ regular drivers [km/h]	$S_{average, regular}$ [km/h]
2000	0.5	2200	88.0	84.2	7.5	91.8
2100	0.0	2100	89.9	-	-	89.9
2100	0.1	2200	88.0	70.7	19.3	89.9
2100	0.2	2200	88.0	80.3	9.6	89.9
2100	0.3	2200	88.0	83.5	6.4	89.9
2100	0.4	2200	88.0	85.1	4.8	89.9
2100	0.5	2200	88.0	86.1	3.9	89.9
2200	0.0	2200	88.0	-	-	88.0
2200	0.1	2200	88.0	88.0	0.0	88.0
2200	0.2	2200	88.0	88.0	0.0	88.0
2200	0.3	2200	88.0	88.0	0.0	88.0
2200	0.4	2200	88.0	88.0	0.0	88.0
2200	0.5	2200	88.0	88.0	0.0	88.0

Since a simple proportion (Equation 15) was used to estimate the theoretical average speed of the recreational component of the traffic, and it was supposed that regular drivers could travel (in case of mixed categories of drivers in the flow) at a speed equal to the average speed of the traffic flow without recreational drivers, some inconsistencies can be noted. Indeed, the estimated speed of regular drivers when the capacity is reached, results to be higher than the same speeds estimated for lower flow rates. This is a condition that cannot seem reasonable. Therefore, in order to overcome this pitfall, if the flow rate is equal to the capacity, then the average speed of the traffic flow could be supposed as equal to the average speed of the recreational component. In this case, the proportion shown in the Equation 15 could be used to estimate the average speed of the regular component, once the recreational speed is already known.

Table 18 – Adjusted estimation of the average speed differences between the recreational and the regular component in the traffic flow (ΔS recreational/regular drivers).

V [vei/h/ln]	$\%_{recreational}$	Corrected Vp [vei/h/ln]	S [km/h]	$S_{average, recreational}$ [km/h]	$S_{average, recreational,}$ adjusted [km/h]	ΔS recreational/ regular users [km/h]	$S_{average, regular}$ [km/h]
1300	0.0	1300	100.0	-	-		100.0
1300	0.1	1368	100.0	100.0	100.0	0.0	100.0
1300	0.2	1444	99.7	98.6	98.6	1.4	100.0
1300	0.3	1529	98.9	96.3	96.3	3.7	100.0
1300	0.4	1625	97.7	94.3	94.3	5.7	100.0
1300	0.5	1733	96.2	92.4	92.4	7.6	100.0
1400	0.0	1400	100.0	-	-	-	100.0
1400	0.1	1474	99.5	94.7	94.7	5.3	100.0
1400	0.2	1556	98.6	93.0	93.0	7.0	100.0
1400	0.3	1647	97.4	91.4	91.4	8.6	100.0
1400	0.4	1750	95.9	89.8	89.8	10.2	100.0
1400	0.5	1867	94.1	88.2	88.2	11.8	100.0
1500	0.0	1500	99.2	-	-	-	99.2
1500	0.1	1579	98.3	90.2	90.2	9.0	99.2
1500	0.2	1667	97.2	88.9	88.9	10.3	99.2
1500	0.3	1765	95.7	87.5	88.0	11.0	99.0
1500	0.4	1875	93.9	86.0	88.0	9.9	97.9
1500	0.5	2000	91.8	84.3	88.0	7.5	95.5
1600	0.0	1600	98.0	-	-	-	98.0
1600	0.1	1684	96.9	86.6	88.0	9.9	97.9
1600	0.2	1778	95.5	85.4	88.0	9.4	97.4
1600	0.3	1882	93.8	83.9	88.0	8.3	96.3
1600	0.4	2000	91.8	82.3	88.0	6.3	94.3
1600	0.5	2133	89.3	80.5	88.0	2.6	90.6
1700	0.0	1700	96.7	-	-	-	96.7
1700	0.1	1789	95.3	83.1	88.0	8.1	96.1
1700	0.2	1889	93.7	81.8	88.0	7.1	95.1
1700	0.3	2000	91.8	80.3	88.0	5.4	93.4
1700	0.4	2125	89.5	78.6	88.0	2.4	90.4
1700	0.5	2200	88.0	79.3	88.0	0.0	88.0

V [vei/h/ln]	$\%_{recreational}$	Corrected Vp [vei/h/ln]	S [km/h]	$S_{average, recreational}$ [km/h]	$S_{average, recreational,}$ adjusted [km/h]	ΔS recreational/ regular users [km/h]	$S_{average, regular}$ [km/h]
1800	0.0	1800	95.2	-	-	-	95.2
1800	0.1	1895	93.6	79.6	88.0	6.2	94.2
1800	0.2	2000	91.8	78.2	88.0	4.7	92.7
1800	0.3	2118	89.6	76.6	88.0	2.3	90.3
1800	0.4	2200	88.0	77.3	88.0	0.0	88.0
1800	0.5	2200	88.0	80.8	88.0	0.0	88.0
1900	0.0	1900	93.5	-	-	-	93.5
1900	0.1	2000	91.8	76.0	88.0	4.2	92.2
1900	0.2	2111	89.7	74.5	88.0	2.1	90.1
1900	0.3	2200	88.0	75.1	88.0	0.0	88.0
1900	0.4	2200	88.0	79.7	88.0	0.0	88.0
1900	0.5	2200	88.0	82.5	88.0	0.0	88.0
2000	0.0	2000	91.8	-	-	-	91.8
2000	0.1	2105	89.8	72.4	88.0	2.0	90.0
2000	0.2	2200	88.0	72.9	88.0	0.0	88.0
2000	0.3	2200	88.0	79.2	88.0	0.0	88.0
2000	0.4	2200	88.0	82.3	88.0	0.0	88.0
2000	0.5	2200	88.0	84.2	88.0	0.0	88.0
2100	0.0	2100	89.9	-	-	-	89.9
2100	0.1	2200	88.0	70.7	88.0	0.0	88.0
2100	0.2	2200	88.0	80.3	88.0	0.0	88.0
2100	0.3	2200	88.0	83.5	88.0	0.0	88.0
2100	0.4	2200	88.0	85.1	88.0	0.0	88.0
2100	0.5	2200	88.0	86.1	88.0	0.0	88.0
2200	0.0	2200	88.0	-	-	-	88.0
2200	0.1	2200	88.0	88.0	88.0	0.0	88.0
2200	0.2	2200	88.0	88.0	88.0	0.0	88.0
2200	0.3	2200	88.0	88.0	88.0	0.0	88.0
2200	0.4	2200	88.0	88.0	88.0	0.0	88.0
2200	0.5	2200	88.0	88.0	88.0	0.0	88.0

Moreover, for each combination of the flow rates and the share of recreational drivers, the speed variance can be computed according to the following equation derived from the study by Wang et al. (2012):

$$\sigma_i^2 = \delta^2\{1 + \alpha S(k_i,\theta)[S_f - S(k_i,\theta)]\} \tag{16}$$

Where:
δ, α =coefficients of the model;
S = generic speed (obtained as a function of k and ϑ, which are namely the traffic density and a vector of parameters describing the speed-density model) [km/h];
S_f = FFS = free flow speed [km/h].

The same authors performed a calibration of the model based on observations along the Georgia State Route 400 for different values of the free flow speeds, providing the values of the coefficients δ, α based on the calibration.
In this way, for each speed, the speed variance can be computed for each average speed of the traffic flow shown in the previous Tables and for the different conditions considered. However, one could argue that, if the traffic flow is composed of different categories of drivers (in this case the regular and the recreational drivers) and different speeds were estimated for the categories, then also variances should be different. Hence, the speed distribution could be considered as composed of two sub-distributions: one for the recreational drivers, characterized by a lower speed than the average global speed and a higher variance; and another for the regular drivers, characterized by a higher speed than the global average speed but a lower variance, as shown below. Since the average speeds of the recreational and regular components were previously computed in different situations (that are the black and blue μ values in the next diagram), then the variances (σ^2) associated to the two sub-distributions can be computed as well, by using the Equation 16. As anticipated before, higher variances are associated to lower speeds and vice versa. This is coherent with what can be theoretically expected for the two different categories of drivers: the behaviour of regular drivers

(which can be considered as familiar with the road environment) is more homogeneous in terms of speed choice, while a greater speed variance can be related to the recreational drivers who do not know the road environment and so, their process of speed selection is less authomatic.

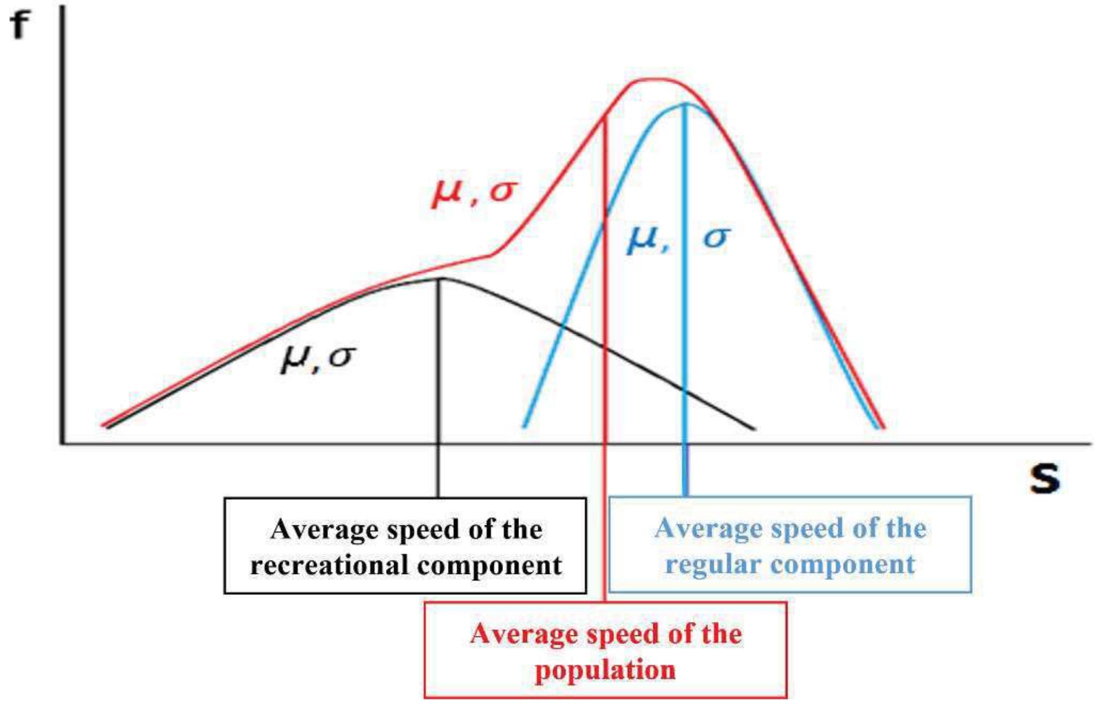


Fig. 32 – Scheme of the differences in the distribution of the frequencies (f) of Speed (S) between different categories of drivers (different means μ and different standard deviations σ).

If the two sub-distributions of speeds (regular and recreational), each of them supposed to be normally distributed, and characterized by a value of mean (μ) and standard deviation (σ) are taken into consideration together; then the global distribution can be obtained by the union of them. The standard deviation of the global distribution (square root of the variance) can be computed as the standard deviation of the distribution obtained by the union of the two sub-distributions.

Hence, an authomatic procedure performed in Matlab environment was used in order to generate two normal distributions characterized by given mean, variance and numerosity and to estimate the standard deviation of the global distribution. The employed sequence of codes is defined below:

- REGU = mean(REGU) + randn(1,x)*std(REGU)
- RECR = mean(RECR) + randn(1,y)*std(RECR)
- GLOBAL = [REGU RECR]
- Std(GLOBAL)

The procedure was repeated for all the values considered for the traffic flow rates in the previous Tables. Estimated mean and standard deviations of the speeds of the two components of drivers (regular and recreational) were used to define the two distributions, considering two different numerosities (x, y) for each distribution, according to the share of recreational drivers in the traffic flow. The numerosity of the simulated sample was set to be enough big to reflect the fixed standard deviation. Then, the union of the two samples, representing the 100 % of the population (x + y), was considered as the global distribution and the adjusted standard deviation was estimated basing on it.

The adjusted value of the standard deviation for taking into account the share of recreational drivers in the traffic flow can be used for making considerations about the accident rates. Indeed, accidents were related to speed variance in previous studies. Using the study by Aarts and van Schagen (2006) as a reference, who wrote a comprehensive review of all the studies about the relationships between accidents and speed (average speed and speed variance), the selected relationships between accidents and speed variance were taken from Garber and Gadiraju (1988). This study was chosen since it was the only one found which considered the relationship between accidents and drivers' speed variance at given road sections for multi-lane highways (and not the variance as the difference between speeds of drivers in different sections). The selected relationships between accident rate and speed variance are the following.

$$AR = 43.2 + 0.00347\,(SV)^2 \tag{17}$$

$$AR = 168 + 0.00273\,(SV)^2 \tag{18}$$

Where:

AR = Accident rate computed as the number of accidents per 100 million vehicle miles traveled [acc/(100mln*veh*mile)];
SV = Speed Variance $[\text{miles/h}]^2$.
(Equation 17 was derived for interstate highways, Equation 18 for arterial highways).

Therefore, for each combination of the equivalent flow rates and of the shares of recreational drivers in the traffic flow, the standard deviations adjusted for considering the presence of different categories of drivers were computed as explained above. Then, these values were used to compute the accident rates in the different conditions (considering the roads to be arterial rural multilane highways as an example, Equation 18), which are reported in next table together with the estimated speed standard deviations (FFS = 100 km/h, capacity = 2200 vehi/h/ln).

The column: "ΔAR" (variation of the accident rate), represents the variation of the accident rate estimated for that specific considered share of recreational drivers in the traffic flow compared with the condition in which fp = 1 (no recreational drivers: 0 %).

Table 19 – Estimation of the differences in the accident rates (ΔAR) due to the presence of recreational drivers with respect to the condition of all regular drivers (fp = 1.0).

V [vei/h/ln]	**fp**	**S [km/h]**	**σ [km/h]**	**S_{recr} [km/h]**	**$\sigma_{recr.}$ [km/h]**	**$S_{reg.}$ [km/h]**	**$\sigma_{reg.}$ [km/h]**	**Adjusted global σ [km/h]**	**ΔAR [acc/(mln* vehi*km)]**
1000	1.00	100.0	1.2			100.0	1.2	1.2	0.000
1000	0.95	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1000	0.90	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1000	0.85	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1000	0.80	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1000	0.75	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1100	1.00	100.0	1.2			100.0	1.2	1.2	0.000
1100	0.95	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1100	0.90	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000

V [vei/h/ln]	fp	S [km/h]	σ [km/h]	S_{recr} [km/h]	$\sigma_{recr.}$ [km/h]	$S_{reg.}$ [km/h]	$\sigma_{reg.}$ [km/h]	Adjusted global σ [km/h]	ΔAR [acc/(mln* vehi*km)]
1100	0.85	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1100	0.80	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1100	0.75	99.5	1.4	99.1	1.5	100.0	1.2	1.4	0.000
1200	1.00	100.0	1.2			100.0	1.2	1.2	0.000
1200	0.95	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1200	0.90	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1200	0.85	100.0	1.2	99.8	1.2	100.0	1.2	1.2	0.000
1200	0.80	99.2	1.5	98.0	1.9	100.0	1.2	1.8	0.001
1200	0.75	98.0	1.9	96.1	2.4	100.0	1.2	2.7	0.006
1300	1.00	100.0	1.2			100.0	1.2	1.2	0.000
1300	0.95	100.0	1.2	100.0	1.2	100.0	1.2	1.2	0.000
1300	0.90	99.7	1.3	98.6	1.7	100.0	1.2	1.4	0.000
1300	0.85	98.9	1.6	96.3	2.3	100.0	1.2	2.3	0.003
1300	0.80	97.7	2.0	94.3	2.7	100.0	1.2	3.4	0.015
1300	0.75	96.2	2.3	92.4	3.0	100.0	1.2	4.4	0.044
1400	1.00	100.0	1.2			100.0	1.2	1.2	0.000
1400	0.95	99.5	1.4	94.7	2.6	100.0	1.2	3.0	0.009
1400	0.90	98.6	1.7	93.0	3.0	100.0	1.2	3.3	0.013
1400	0.85	97.4	2.0	91.4	3.2	100.0	1.2	4.4	0.044
1400	0.80	95.9	2.4	89.8	3.4	100.0	1.2	5.5	0.105
1400	0.75	94.1	2.8	88.2	3.6	100.0	1.2	6.5	0.201
1500	1.00	99.2	1.5			99.2	1.5	1.5	0.000
1500	0.95	98.3	1.8	90.2	3.4	99.2	1.5	3.2	0.012
1500	0.90	97.2	2.1	88.9	3.5	99.2	1.5	4.6	0.050
1500	0.85	95.7	2.4	88.0	3.6	99.0	1.6	5.6	0.110
1500	0.80	93.9	2.8	88.0	3.6	97.9	1.9	5.6	0.108
1500	0.75	91.8	3.1	88.0	3.6	95.5	2.5	4.9	0.064
1600	1.00	98.0	1.9			98.0	1.9	1.9	0.000
1600	0.95	96.9	2.2	88.0	3.6	97.9	1.9	3.7	0.019
1600	0.90	95.5	2.5	88.0	3.6	97.4	2.1	4.5	0.045
1600	0.85	93.8	2.8	88.0	3.6	96.3	2.3	4.7	0.054
1600	0.80	91.8	3.1	88.0	3.6	94.3	2.7	4.4	0.040
1600	0.75	89.3	3.5	88.0	3.6	90.6	3.3	3.7	0.019

V [vei/h/ln]	fp	S [km/h]	σ [km/h]	S_{recr} [km/h]	$\sigma_{recr.}$ [km/h]	$S_{reg.}$ [km/h]	$\sigma_{reg.}$ [km/h]	Adjusted global σ [km/h]	ΔAR [acc/(mln* vehi*km)]
1700	1.00	96.7	2.2			96.7	2.2	2.2	0.000
1700	0.95	95.3	2.5	88.0	3.6	96.1	2.4	3.5	0.015
1700	0.90	93.7	2.8	88.0	3.6	95.1	2.6	4.0	0.027
1700	0.85	91.8	3.1	88.0	3.6	93.4	2.9	4.0	0.026
1700	0.80	89.5	3.5	88.0	3.6	90.4	3.3	3.6	0.017
1700	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.016
1800	1.00	95.2	2.6			95.2	2.6	2.6	0.000
1800	0.95	93.6	2.8	88.0	3.6	94.2	2.7	3.4	0.009
1800	0.90	91.8	3.1	88.0	3.6	92.7	3.0	3.7	0.015
1800	0.85	89.6	3.4	88.0	3.6	90.3	3.4	3.6	0.014
1800	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.014
1800	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.014
1900	1.00	93.5	2.9			93.5	2.9	2.9	0.000
1900	0.95	91.8	3.1	88.0	3.6	92.2	3.1	3.4	0.007
1900	0.90	89.7	3.4	88.0	3.6	90.1	3.4	3.5	0.010
1900	0.85	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.011
1900	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.011
1900	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.011
2000	1.00	91.8	3.1			91.8	3.1	3.1	0.000
2000	0.95	89.8	3.4	88.0	3.6	90.0	3.4	3.5	0.006
2000	0.90	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.009
2000	0.85	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.009
2000	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.009
2000	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.009
2100	1.00	89.9	3.4			89.9	3.4	3.4	0.000
2100	0.95	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.004
2100	0.90	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.004
2100	0.85	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.004
2100	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.004
2100	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.004
2200	1.00	88.0	3.6			88.0	3.6	3.6	0.000
2200	0.95	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2200	0.90	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000

V [vei/h/ln]	fp	S [km/h]	σ [km/h]	S_{recr} [km/h]	$\sigma_{recr.}$ [km/h]	$S_{reg.}$ [km/h]	$\sigma_{reg.}$ [km/h]	Adjusted global σ [km/h]	ΔAR [acc/(mln* vehi*km)]
2200	0.85	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2200	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2200	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2300	1.00	88.0	3.6			88.0	3.6	3.6	0.000
2300	0.95	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2300	0.90	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2300	0.85	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2300	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2300	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2400	1.00	88.0	3.6			88.0	3.6	3.6	0.000
2400	0.95	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2400	0.90	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2400	0.85	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2400	0.80	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000
2400	0.75	88.0	3.6	88.0	3.6	88.0	3.6	3.6	0.000

The same procedure could be eventually repeated for different free flow speeds and the related capacity values.

Through this process, a diagram can be drawn, plotting the variation in the accident rate on the y-axis against the flow rates on the x-axis for the different driver population factors (corresponding to different shares of recreational drivers). This variation, that is an increase in the accident rates, could be exclusively related to a variation of the presence of recreational drivers in the traffic flow, all other boundary conditions being equal. The obtained diagram is reported in next Figure.

As it emerges from the diagram, for traffic flow rates far from the capacity, an estimated increase in the accident rate can be noted in correspondence of high shares of recreational drivers in the traffic flow (fp = 0.75 – 0.85). By applying this theoretical model based on the HCM framework, an increase up to 1-2 accidents for 100 thousands vehicle passages per km should be expected for traffic flows included between 1400 and 1500 vehicles per hour per lane (a value far from the capacity set to 2200 vehi/h/ln). This could be explained on considering that this is a critical flow rate in which there are more interactions between regular drivers supposed to keep going at a speed equal to the free flow speed and the recreational drivers going at lower speeds, producing the high speed variance. At lower flow rates less interactions between drivers could be possible instead; while at flow rates near the capacity, speeds are lowered both for the recreational and the regular users due to the increased traffic density.

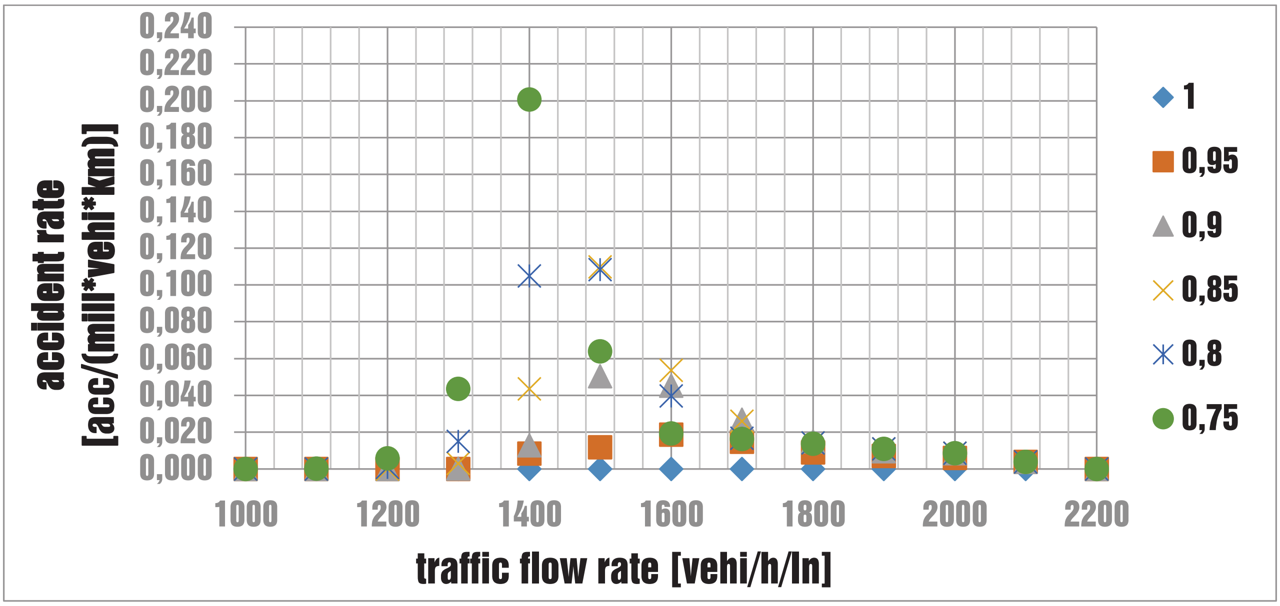


Fig. 33 – Variation of the accident rates for different fp values, free flow speed = 100 km/h.

This situation is particularly evident for a high free flow speed (as the one considered of 100 km/h), while lower variations of the accident rates would be expected for lower free flow speeds since in that case, the speed-flow curve shows a less noticeable decreasing tendency for higher flow rates.

2.3.4 Relationships between route familiarity and observed road accidents

In this section, the relationships between route familiarity and road accidents are explored, by analyzing some results of the analyses conducted on the Norwegian accident database described in 2.2.2.

As introduced in the Section 2.2.2, the main index used for defining the familiarity of drivers with the place where the accident occurred is the distance between the place of the accident (B) and the place of residence (A). This distance was derived by the zip codes present in the accident database and associated to each driver involved in the accident, by finding the fastest path to reach B from A (A was fixed as the center of the city/town associated to the zip code). Hence, two distance thresholds were set for defining the familiarity of drivers (Hjorthol, 2014; Thrane, 2015):

- Familiar drivers: 0 – 20 km;
- Unfamiliar drivers: ≥ 200 km.

The drivers whose residence was placed at a distance included between 20 and 200 km were considered as “transition” drivers, not classifiable neither as familiar nor as unfamiliar drivers.

Three different analyses were conducted on the accident data at different levels of detail. At the first level the accident rates at the 84 road sites individuated were compared by considering traffic seasonal differences between summer and other seasons: this represents a macro-scale analysis of the accident data (sub-section 2.3.4.1). After, since the measure of the familiarity can be associated to the driver (univocally related to each vehicle involved in the accident), a further detailed analysis about the relationships between familiarity and the type of accident was performed (sub-section 2.3.4.2). Finally, an accident micro-scale analysis was conducted, considering specific sites at which high percentages of accidents to familiar drivers and sites at which high percentages of accidents to unfamiliar drivers were recorded (sub-section 2.3.4.3).

2.3.4.1. Results from a Macro-Analysis of the accident data

Accident data can be analyzed at a macro-scale level by considering accident rates at the 84 inquired sites. In detail, by looking at Table 9, it is possible to note that summer traffic volumes (SDT) are considerably higher, on average, than the AADT volumes at the road sites investigated: SDT/AADT ratio = 1.30 (st. dev. = 0.21, minimum value: 0.99, maximum value: 1.91). For the reasons explained in the section devoted to the definition of familiarity (2.1.2.1), since normally the traffic flow can be considered as mainly composed of familiar drivers, then an increase of 30 % in the summer traffic flow (and in some cases much more than this average value), could be related to the presence of recreational drivers or tourists who are, by definition, less familiar with the road environment.

Hence, since the exact share of the unfamiliar drivers in the traffic flow is almost impossible to measure, the SDT/AADT ratio was chosen as a possible surrogate variable. Higher SDT/AADT ratios could be associated to a greater presence of tourists and recreational drivers, supposed to be unfamiliar with the road, and vice versa. To verify the hypothesis of using this variable to represent the familiarity, a preliminary analysis was made by plotting the SDT/AADT ratio related to each road site on the x-axis of a diagram having the mean distances of drivers involved in the accidents at the road site from the place of residence on the y-axis.

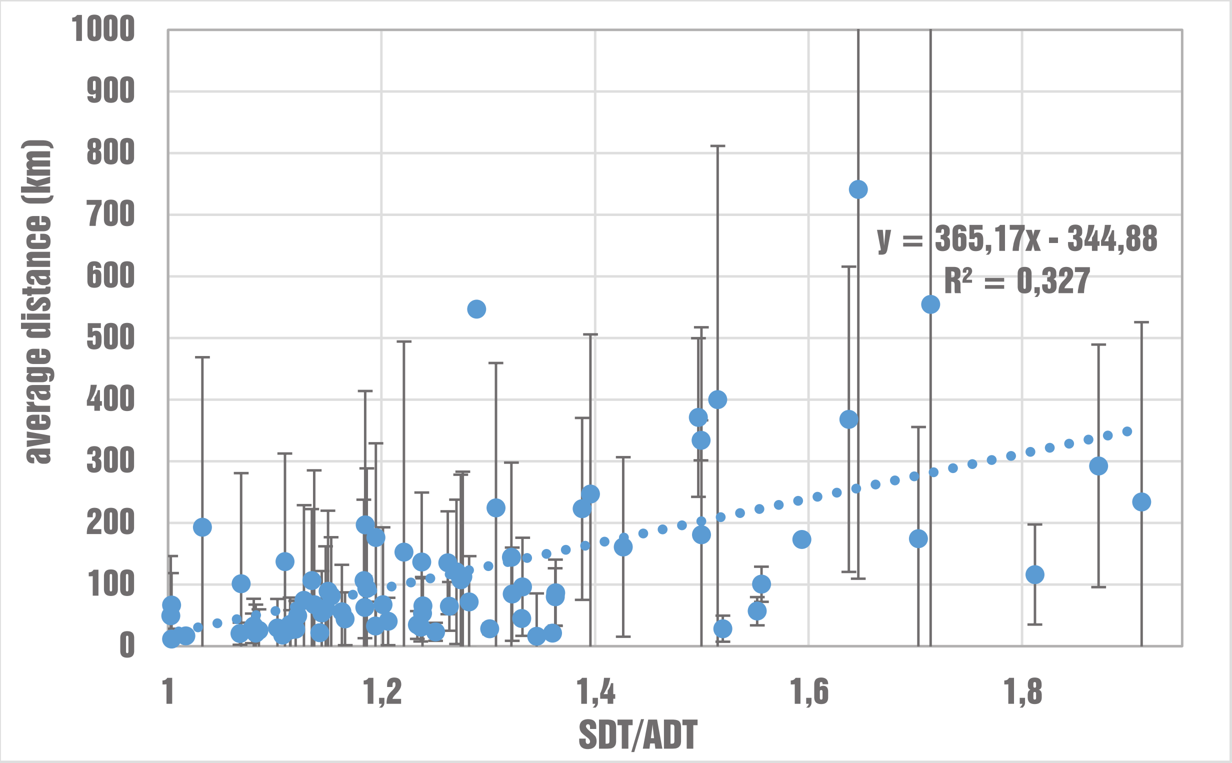


Fig. 34 – Relationship between the SDT/AADT ratio and the average distance between the place of the accident and the place of residence at the inquired road sites.

Based on the linear regression shown in Fig. 34, it is possible to state that the SDT/AADT ratio can statistically significantly predict the average distance [F(1,77[5]) =

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[5] Five road sites were excluded from the regression since no accidents were recorded there on the considered period and so, the average distance cannot be computed.

37.376, $p < 0.001$]. A linear regression was chosen since other non-linear models did not cause significant improvements in the fit. Furthermore, the SDT/AADT ratio is able to explain the 32.7 % of the variation in the average distance (adjusted $R^2 = 0.32$), showing a noticeable effect. Therefore, it can be assumed as expected that, on average, drivers involved in accidents at sites showing higher traffic variations during summer are more likely to be further than home than drivers involved in accidents at sites with lower summer variation. Drivers coming from far distances could be considered as likely unfamiliar and so, since high distances were found to be related to high SDT/AADT ratio, then the latter ratio can be reasonably used as a variable able to predict the share of unfamiliar drivers in the traffic flow.

For the aim of comparing the accident rates between sites characterized by different shares of unfamiliar drivers in the traffic flow, a clustering technique, namely the two-step cluster analysis was used to divide the sites into homogeneous subsets based on their value of the SDT/AADT ratio (traffic volumes are computed for each site as the average over the considered 10 years' period). The two-step algorithm (Chiu et al., 2001) firstly develops a "tree" in which the leaf nodes are a certain number of sub-clusters and after, gathers sub-clusters together if the measure of their reciprocal distance (using log-likehood distance as a measure) is above a fixed threshold. The optimal number of clusters is automatically determined through the application of an estimator based on the Bayesian Information Criterion (BIC). Through this technique, sites are divided into two clusters, described in next Table.

Table 20 - Descriptive statistics about the two clusters identified (Variable: SDT/AADT ratio).

Cluster	No. of items	Min. value	Max. value	Mean	St. Dev.
1 (Low SDT/AADT ratio)	64	0.99	1.40	1.20	0.10
2 (High SDT/AADT ratio)	20	1.42	1.91	1.62	0.14

Since the sites showing a high SDT/AADT ratio were supposed to be related to higher shares of unfamiliar drivers and vice versa, then the accident rates in summer between those two clusters of sites were compared in order to assess the possible influence of the presence of unfamiliar drivers on safety.

Similarly, since the SDT/AADT ratio is a measure of the increase in the traffic volume during the summer months considered in the traffic database (June, July, August), then the accident rates in summer at the sites showing high summer traffic variation were compared with the accident rates in the other seasons at the some sites.

The measures of accident rates were defined as follows, depending on the season:

$$AR_{summer,site\ i} = \frac{N_{accidents,summer\ months,site\ i} * 10^6}{2.5\ years * 365 * mean\ SDT * Length_{(\ section)}} \left[\frac{accidents}{MVKT}\right] \qquad (19)$$

$$AR_{other\ seasons,site\ i} = \frac{N_{accidents,other\ seasons,site\ i} * 10^6}{7.5\ years * 365 * mean\ OSDT * Length_{(section)}} \left[\frac{accidents}{MVKT}\right] (20)$$

Where:

$AR_{summer,\ site\ i}$ = accident rate in summer months (June, July, August) at a given site i;
$AR_{other\ seasons,\ site\ i}$ = accident rate in all the other seasons at a given site i;
$N_{accidents,summer\ months,\ site\ i}$ = number of accidents occurred during summer months over the whole 10 years' period of study at the site i[6];
$N_{accidents,other\ seasons,\ site\ i}$ = number of accidents occurred during all the other seasons different from summer over the whole 10 years' period of study at the site i[7];
mean SDT = mean Summer Daily Traffic (weighted over the 10 years of traffic data);
mean OSDT = mean Other Seasons Daily Traffic (weighted over the 10 years of data);
$Length_{(section)}$ = Length in kilometers of the road section constituting the road site;
MVKT = Million-Vehicle Kilometers Traveled.

The mean OSDT volume was obtained by inverting the simple proportion shown in the Equation 21, since the mean AADT and the mean SDT are known and the SDT volumes

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[6] Since the summer months over the 10 years' period are 30 (3 x 10); then the period of reference in years for the calculation of the accident rate is: 30/12 = 2.5.

[7] Since the months belonging to the other seasons over the 10 years' period are 90 (9 x 10); then the period of reference in years for the calculation of the accident rate is: 90/12 = 7.5.

are supposed to account for 3/12 of the total (the share of summer months) and the OSDT volumes are supposed to account for the remaining 9/12 of the total (the share of months belonging to the other seasons different from summer).

$$AADT\ (mean, 10\ years) = \frac{OSDT\ (mean, 10\ years) * 9 + SDT\ (mean, 10\ years) * 3}{12} \quad (21)$$

The accident rates computed through the equations above reported are shown in next Table for the combinations of periods and clusters of sites considered.

Table 21 – Descriptive statistics about accident rates [accidents/MVKT] for different combinations of the conditions considered (accident rates computed through the use of Equation 19 for summer and of Equation 20 for the other seasons).

Combination of Cluster and Season	No. of items	Mean	St. Dev.	Min. value	Max. value
Low Summer Traffic Variation - Summer	64	0.076	0.078	0.000	0.390
High Summer Traffic Variation - Summer	20	0.106	0.124	0.000	0.459
High Summer Traffic Variation - Other Seasons	20	0.182	0.222	0.000	0.951

Furthermore, statistical tests were performed to compare accident rates between the different conditions considered. Since the data distributions are not normal, as verified through the application of the Kolmogorov-Smirnov and the Shapiro-Wilk tests, that allow to reject the normality assumption at the 5 % significance level for both the clusters; then accident rates data were compared by non-parametric tests. This was expected for data of accident rates, since they are skewed to the zero. Hence, a Mann-Whitney U test, a rank-based nonparametric test was used to establish if there are differences between two groups of sites on the accident rate. The determination of the differences is based on the comparison between the median values if the shapes of the distribution of the two groups are similar, otherwise mean ranks are compared.

The following two Mann-Whitney U tests were performed, by using the software SPSS[8]:

- The first, to test if there is a difference in the distribution of summer accident rates between the two groups of summer traffic variation (low/high);
- The second, to test if there is a difference in the distribution of accident rates at sites showing high summer traffic variation between the two seasonal groups (summer/other seasons).

If significant differences between those groups are revealed, one could argue that the noticeable presence of unfamiliar drivers in the traffic flow can affect road safety, by considering only accident and traffic data. Results of those tests are reported below.

Distributions of the summer accident rates for the two groups of traffic variation (high/low) were similar, so medians were compared. Median summer accident rate for high summer traffic variation sites (0.065) and low summer traffic variation sites (0.065) were not statistically significantly different, U = 596.5, z = -0.462, p = .644. Boxplots of the summer accident rates divided by variation clusters are reported below.

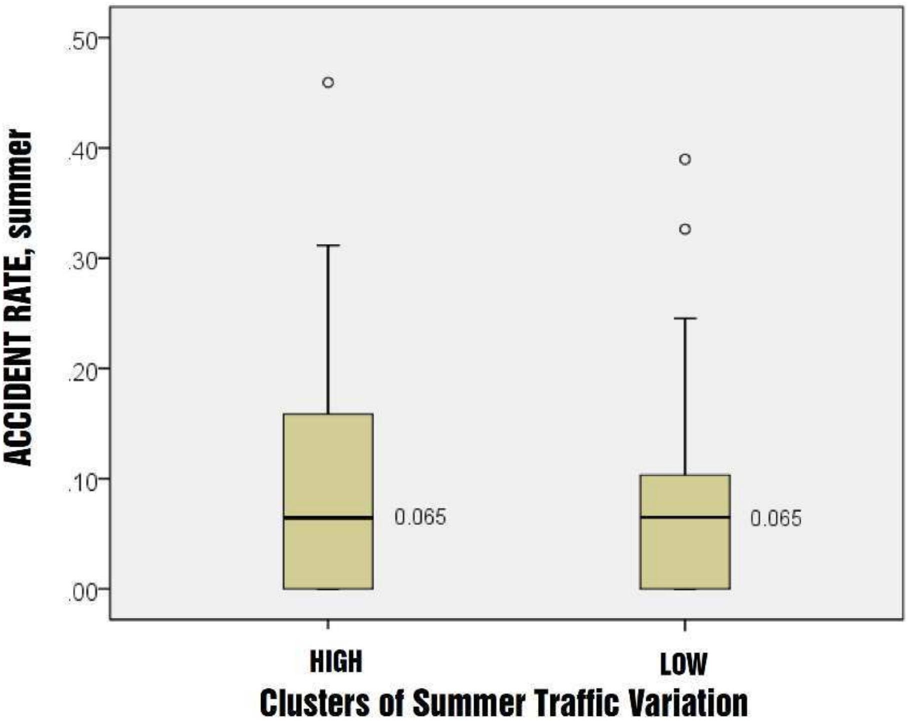

Fig. 35 – Boxplots of summer accident rates (and medians) for the two variation clusters (High/Low).

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[8] See footnote 4.

Distributions of the accident rates at high summer traffic variation sites for the two groups of time periods (summer/other seasons) were similar, so median were compared. Median accident rate in summer (0.065) and in the other seasons (0.152) were not statistically significantly different, U = 251, z = 1.394, p = .167.

Boxplots of the summer accident rates divided by variation clusters are reported below. Results from the statistical tests reveal that there is no statistical evidence of the influence of a supposed high share of unfamiliar drivers in the traffic flow on the accident rates, chosen as a macro-indicator of the safety performances.

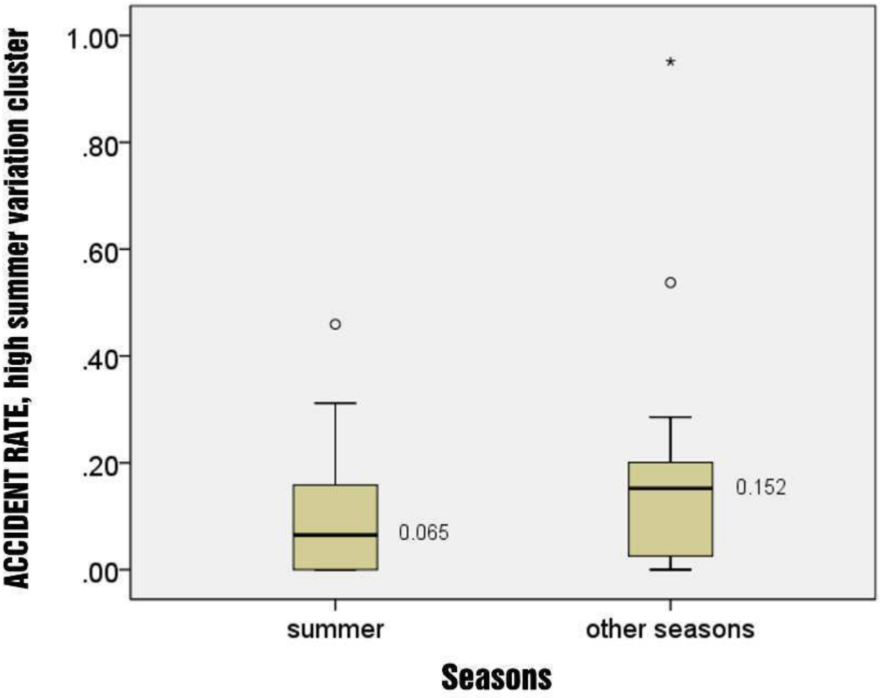


Fig. 36 – Boxplots and medians of accident rates at high traffic variation sites for summer/other seasons.

However, it can be noted that both the median and the mean (see Table 21) accident rates computed for the other seasons different from summer at the high traffic variation cluster are greater than the summer accident rates at the same sites. Therefore, it could be argued that a higher share of unfamiliar drivers in the traffic flow could be positive for safety as long as in summer, at sites experiencing a traffic increase included between 42 % and 91 %, reasonably due to recreational drivers, smaller values of accident rates were found. Nevertheless, those differences were not significant, they are referred to a small number of sites and so, they should be taken only as an indication.

These results could lead to consider that using a macro-indicator as the accident rate for individuating differences between familiar and unfamiliar drivers could be inappropriate, since those differences were described as extremely subjective. The matter could be even perplexed by the differences between road sites (e.g. in the allowed speeds along the sections). Moreover, a possible argument could be that the SDT/AADT ratio is not able to correctly represent the presence of unfamiliar drivers in the traffic flow but, as shown in Fig. 34, this issue can be rejected considering the strong relationship with the average distance between the accident place and the residence.

Clearly, it should be taken into account also that the route familiarity could have no influence on the road accidents. Hence, in the remainder of this section, this hypothesis is further tested by looking at the matter from different perspectives.

2.3.4.2. Results from an in-depth analysis of the accident data

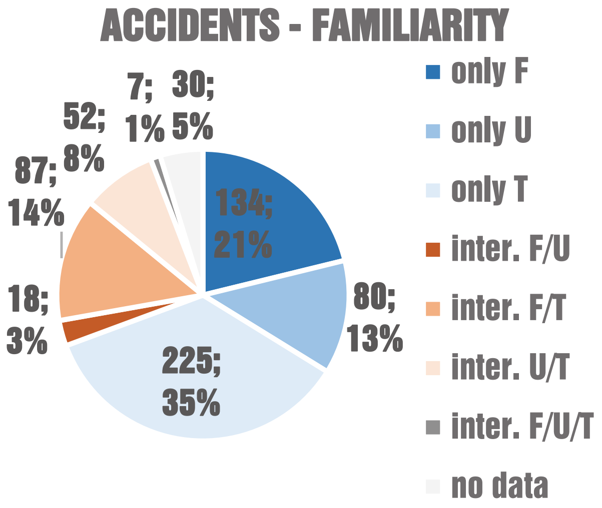
In this sub-section, the focus is on the accident type and on the role played by the driver in the accident, considering the familiarity of drivers involved, through the application of statistical analyses. Firstly, the 633 accidents occurred at the road sites inquired were analyzed as a whole sample; while at a second stage, the 1092 involved vehicles were considered as single items composing the sample of vehicles/drivers to be further inquired for analyzing their specific contribute in the accident dynamics. The following variables were associated to each vehicle according to the information in the database:

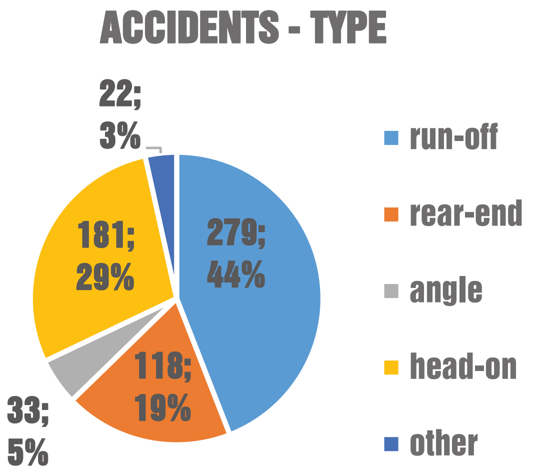
- Distance of the driver from the place of residence (as a continuous variable);
- Distance of the driver from the place of residence (as a categoric variable: familiar, unfamiliar and transition drivers, through previously defined thresholds);
- Type of accident having involved him (run-off, rear-end/angle, head-on, other);
- Code assigned to vehicles for their role in the accident dynamic (vehicle moving: “Moving”, stationary after braking/for turning: “Stationary”, losing control: “Out of Control”, in a turning/overtaking maneuver: “Maneuvering”, “Other”).

Since more than one vehicle can be involved in each accident, then it is necessary to rearrange accident data before applying the statistical analyses. Seven categories of accidents were defined with respect to the familiarity of drivers involved, excluding 30 accidents (4.7 % of the sample) for which no information about familiarity for all the vehicles involved in the accidents were deduced (no zip codes[9]):

- Only FAMILIAR: only familiar drivers involved in the accident (one or more drivers, whose residence is 20 km or less from the place of the accident);
- Only UNFAMILIAR: only unfamiliar drivers involved in the accident (one or more drivers, whose residence is 200 km or more from the place of the accident);
- Only TRANSITION: only transition drivers involved in the accident (one or more drivers, whose residence is from 20 too 200 km from the place of the accident).
- Interaction FAMILIAR/UNFAMILIAR: a combination of at least one familiar driver and at least one unfamiliar driver involved in the accident;
- Interaction FAMILIAR/TRANSITION: a combination of at least one familiar driver and at least one transition driver involved in the accident;
- Interaction UNFAMILIAR/TRANSITION: a combination of at least one unfamiliar driver and at least one transition driver involved in the accident;
- Interaction FAMILIAR/UNFAMILIAR/TRANSITION: a combination of at least one unfamiliar driver, one familiar driver and one transition driver involved.

The percentages of the accidents divided into the familiarity categories and crash types are shown below. Percentages of drivers/vehicles divided into the familiarity categories and accident dynamics associated to the vehicles are shown as well.





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[9] In the 603 remaining crashes (1056 involved vehicles), missing zip codes were present for 59 vehicles (5 %).

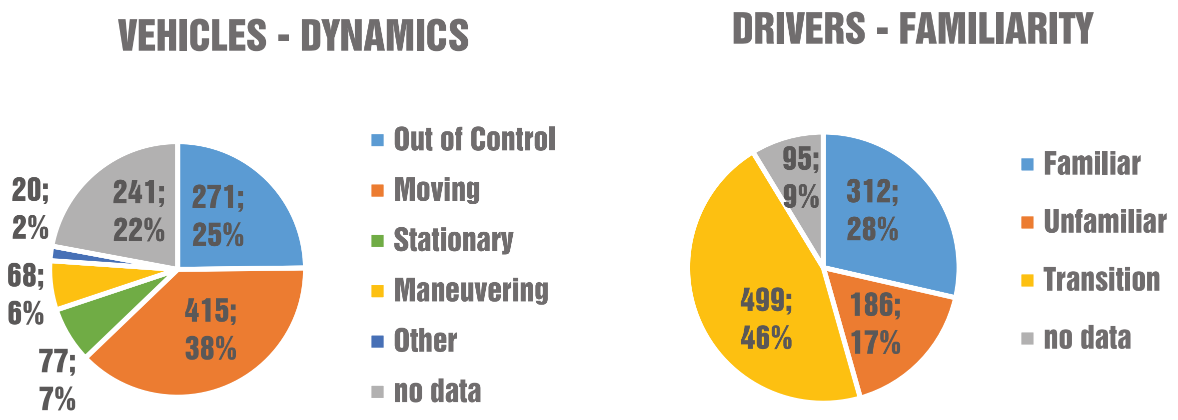

Fig. 37 – Percentages of distribution of the accidents in the different considered familiarity categories (on the upper left) and in the diverse accident types (on the upper right); percentages of distribution of the drivers/vehicles in the different considered familiarity categories (on the lower left) and in the diverse accident dynamics (on the lower right).

Foreign drivers (41 drivers), for whom zip codes were not available, but the nationality different from Norwegian was recorded, were included into the “unfamiliar” category since they can be considered unfamiliar as well with the road environment. Since angle accidents account only for the 5 % of the total and their dynamic in the database was described in certain cases as resulting in a subsequent rear-end accident, they were grouped together in a unique category (rear-end/angle). The category “other accidents” was not considered in the analyses because it is composed of other sub-types of specific accidents (e.g. collision with animals) which account for only some units.

In order to assess the influence of the familiarity on the type of the acccident, a chi-square test of independence was conducted between familiarity class and type of accident occurred. In order to distinguish the different possible influences of the different categories of familiarity of drivers, two tests were performed: one considering the accidents in which all drivers were familiar, unfamiliar or transition (categories 1, 2, 3) and the other considering the accidents in which an interaction occurred between different drivers (categories 4, 5, 6). Indeed, mixing all categories together could have made the results difficult to explain. The category 7 was excluded since it is composed of only 7 items (1 %) and it depends on the interactions of all the categories of drivers.

The results of the first analysis regarding the familiarity classes in which the interactions between the different categories were excluded are reported below.

Table 22 – Crosstabulation Familiarity (in case of no interactions) x Accident Type. Observed counts (adjusted residuals in brackets, highlighted in boldface if greater or equal than 2[10]).

	Type of Accident			**Total**
Familiarity	**Run-off**	**Rear-end/Angle**	**Head-on**	
Only Familiar	78 (0.3)	33 **(3.0)**	16 **(-3.1)**	127
Only Unfamiliar	53 **(2.0)**	9 (-1.4)	13 (-1.1)	75
Only Transition	124 (-1.8)	32 (-1.7)	64 **(3.6)**	220
Total	255	74	93	422

A chi-square test of independence was performed between accident type and familiarity (interactions excluded). There is a statistically significant association between accident type and familiarity, $\chi^2(4) = 20.379$, $p < 0.001$. However, the association is small (Cohen, 1998), Cramer's V = .155.

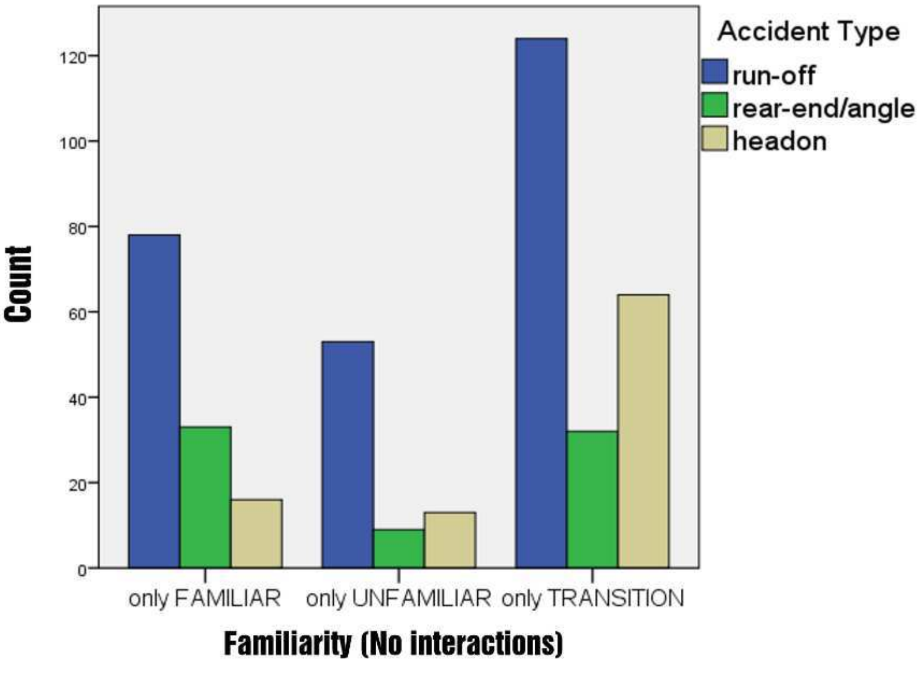

Fig. 38 – Counts of Accident Types in the different familiarity categories considered (no interactions).

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[10] Adjusted standardized residuals are considered significant if they are greater than 2 (absolute value) in case of small tables and greater than 3 in case of larger tables (Agresti, 2007). All the expected frequencies are greater than 5 in all the chi-square tests performed in this sub-section.

More familiar drivers were involved in rear-end or angle accidents and less familiar drivers were involved in head-on accidents than the expected. More unfamiliar drivers were involved in run-off accidents than the expected. More transition drivers were involved in head-on accidents than the expected.

Furthermore, the chi-square test of independence was repeated between accident type and familiarity, considering the interactions between the different categories of drivers. Run-off accidents were excluded from this analysis since in almost all cases, they were described as single-vehicle accidents. In this case, no statistically significant association between accident type and familiarity was found, $\chi^2(2) = 0.558$, $p = 0.757$.

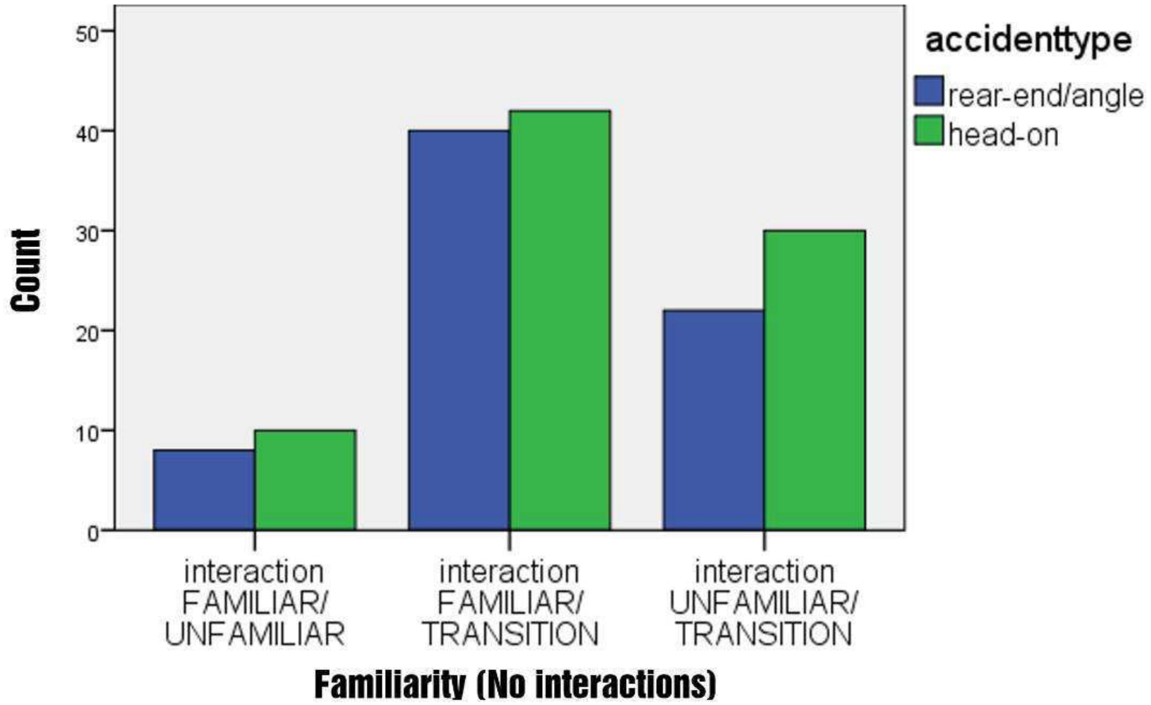

Fig. 39 – Counts of Accident Types in the different familiarity categories considered (with interactions).

Furthermore, a third test was performed in order to assess if there is association between accident type and the interaction (or not) between the different categories of drivers' familiarity. For this reason, the categories 1, 2 and 3 above defined were grouped together, forming the "no interactions" macro-category (in which a given category of drivers had no interactions with the others in the accident). Similarly, the categories 4, 5, 6 and 7 were grouped together, forming the "interactions" macro-category.

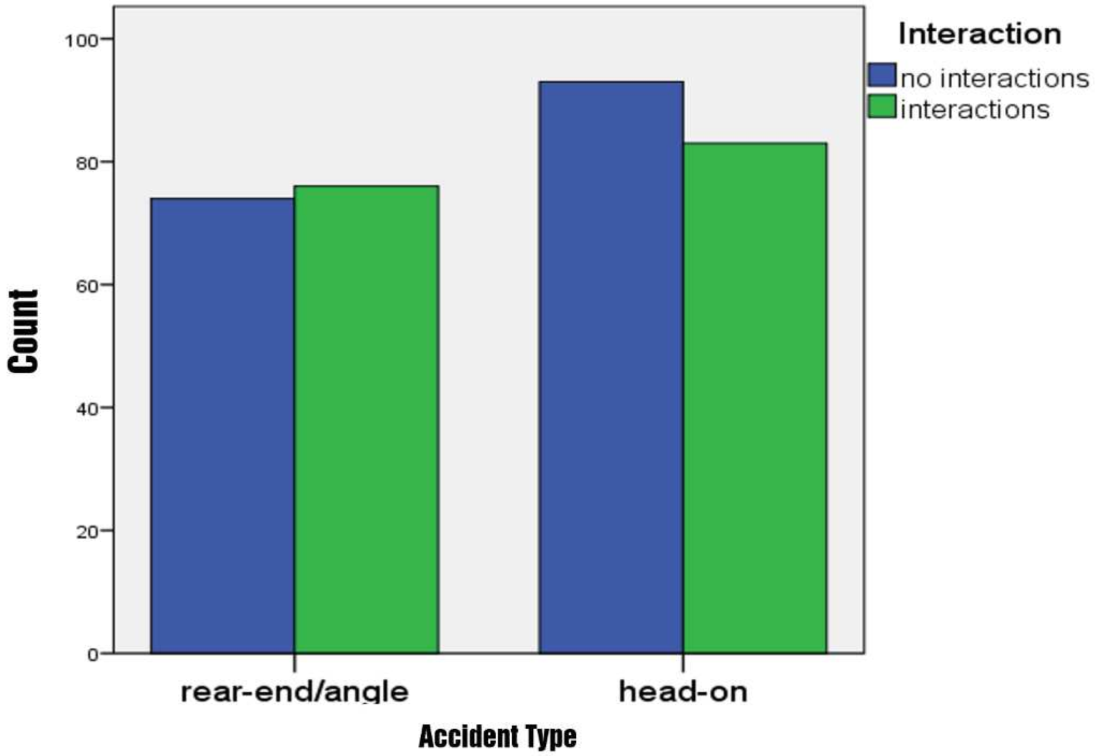

Fig. 40 – Counts of Accident Types in case of interactions or not with other familiarity categories.

However, no statistically significant association between accident type and interaction was found, $\chi^2(1) = 0.399$, $p = 0.528$. (Run-off accidents were not considered for the same reason previously explained).

In order to perform the two chi-square tests above presented, a familiarity code was asssigned to each accident. However, since a description of the role played by each vehicle in the accident dynamics was present in the database for almost all the vehicles and it is related to the individual vehicle, then a last chi-square test of independence was performed to test if there is association between familiarity and accident dynamics. The categories defined for familiarity and accident dynamics are the same introduced in the first part of this sub-section ("other dynamics" were excluded for the same reason of the exclusion of the "other accident" category). Results of the test are reported below.

There is a statistically significant association between accident dynamics and familiarity, $\chi^2(6) = 14.632$, $p = 0.023$. However, the association is small (Cohen, 1998), Cramer's V = .097.

Table 23 – Crosstabulation Familiarity x Accident Dynamics. Observed counts (adjusted residuals in brackets, highlighted in boldface if greater or equal than 2).

	Accident Dynamics				**Total**
Familiarity	**Moving**	**Stationary**	**Out of Control**	**Maneuvering**	
Familiar	103 (-1.4)	29 **(2.3)**	78 (0.9)	13 (-1.4)	223
Transition	195 (0.1)	24 **(-2.9)**	132 (0.9)	36 (1.3)	387
Unfamiliar	91 (1.4)	19 (1.1)	43 **(-2.1)**	13 (-0.1)	166
Total	389	72	253	62	776

More familiar drivers were involved in accidents being stationary after braking or for turning than the expected. Less unfamiliar drivers were the vehicles who lost control in the accident dynamics than the expected. Less transition drivers were involved in accidents being stationary after braking or for turning than the expected.

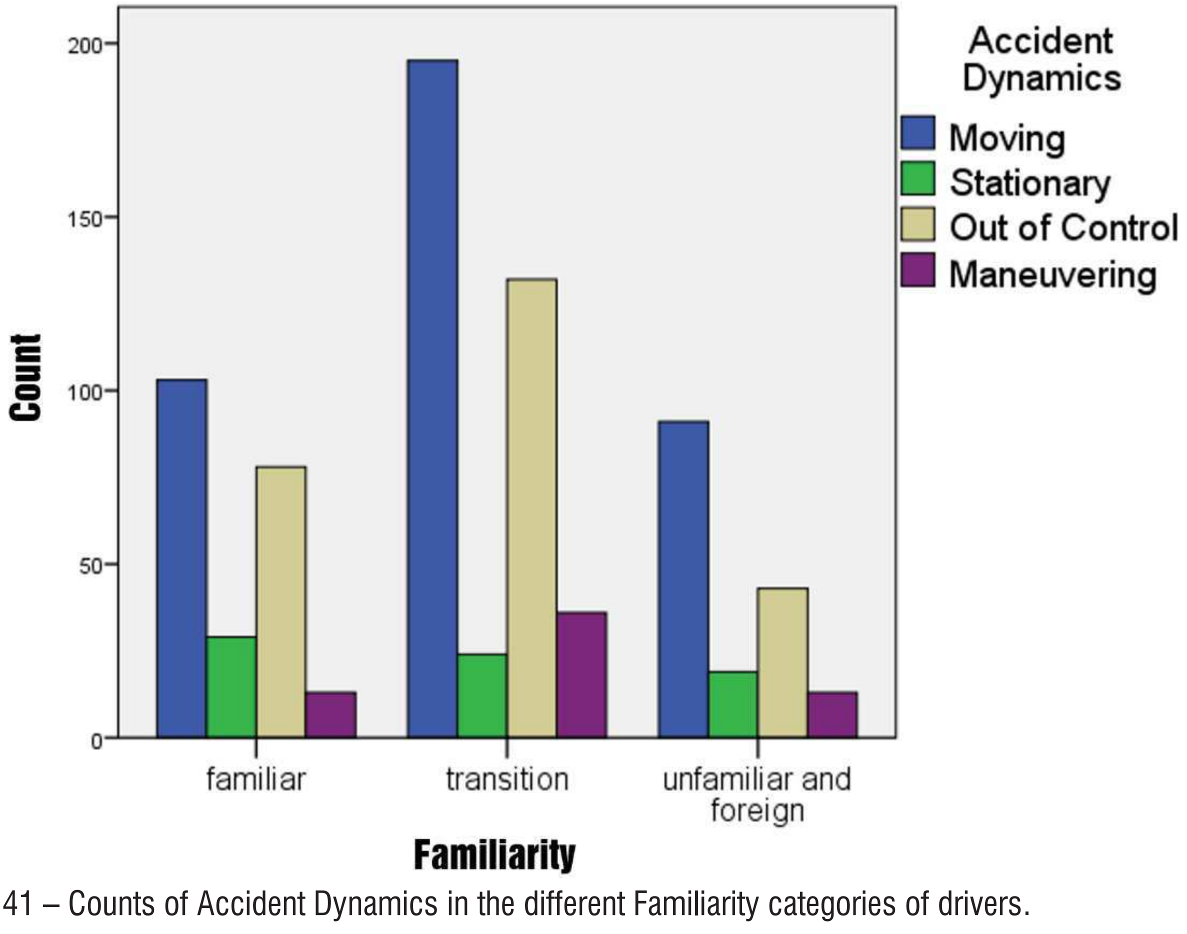

Fig. 41 – Counts of Accident Dynamics in the different Familiarity categories of drivers.

Furthermore, since a value of the distance between the place of the accident and the place of residence was available for each driver (and then, for each vehicle) and it is a continuous variable, statistical tests were performed to compare the variable distance between the different conditions considered (since the distance was used in this section as a measure of familiarity). This is another strategy to look into the phenomenon, as long as in this way no thresholds are set in order to decide if a driver is familiar or not with the place of the accident, but the exact distance from the place of residence is considered instead.

Since the data distributions are not normal, as verified through the application of the Kolmogorov-Smirnov and the Shapiro-Wilk tests, that allow to reject the normality assumption at the 5 % significance level for both the type of accident and accident dynamics categories; then distances data were compared by non-parametric tests. This was expected for data of distances, since they are skewed to distances close to the place of the accident (confirming that a significant part of the traffic flow comes from close distances, and then this part can be considered likely familiar). Hence, two Kruskal-Wallis tests, a rank-based nonparametric test similar to that used in the previous subsection for the accident rates (but suitable for more than two groups), were performed. They were used to establish if there are differences between the three groups of accident type and the four groups of accident dynamics on the distances.

For what about the differences in distance between type of accidents: “run-off”, “rear-end/angle”, “head-on”, the distributions of distance are similar for all groups, as it can be noted by looking at boxplots (reported in the following Figure 42), therefore medians can be compared. Median distances were statistically significantly different between the different types of accident, $\chi^2(2) = 6.174$, $p = .046$. Pairwise comparisons were performed using the procedure by Dunn (with Bonferroni correction for multiple comparisons).

Median distances for vehicles involved in rear-end accidents (34.0 km) are lower than the median distances for vehicles involved in head-on accidents (46.5 km, confirming the trend found from the chi-square test for familiar drivers). However, when adjusting for multiple comparison due to the presence of more than two groups, this difference results not more significant (p = 0.053).

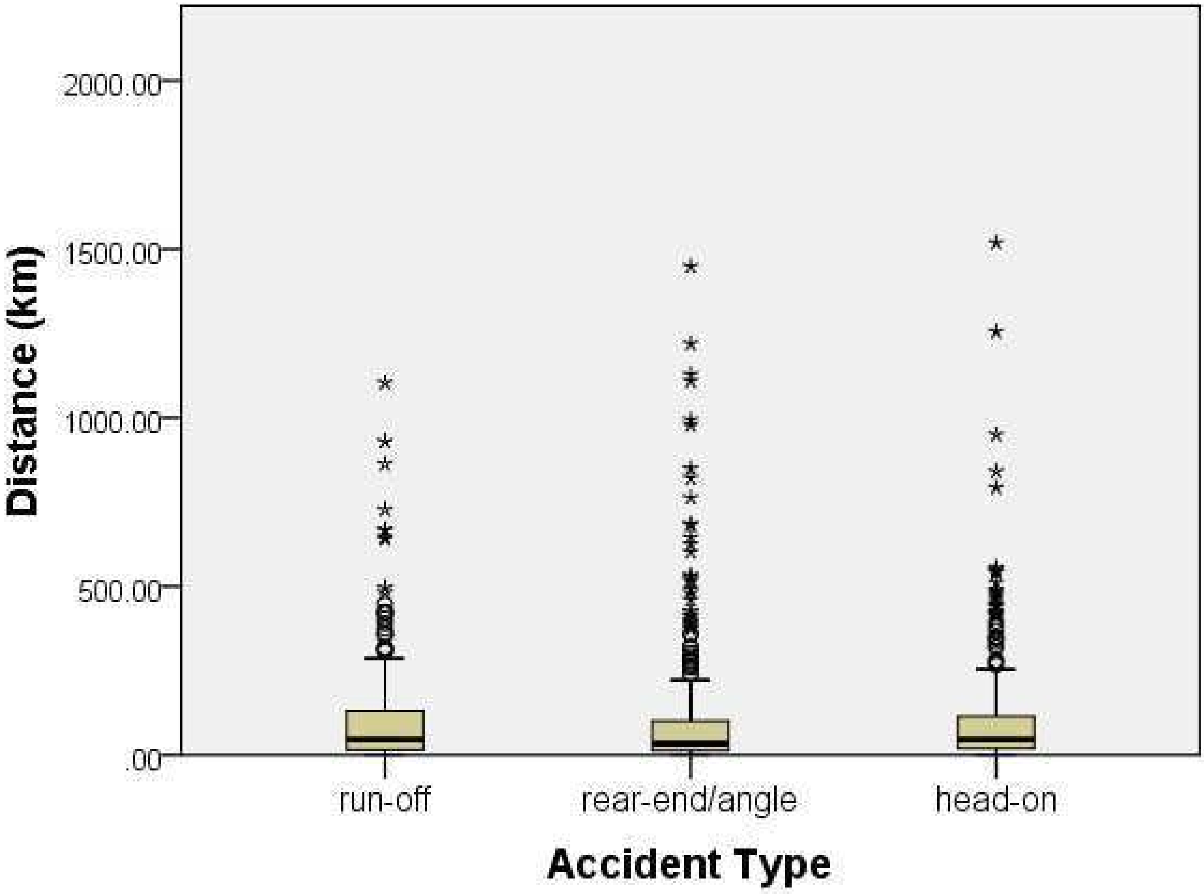

Fig. 42 – Boxplots of distances for the three classes of Accident Type.

The other Kruskal-Wallis test was conducted to state if there were differences in distance between groups of accident dyamics: “moving”, “stationary”, “out of control”, “maneuvering”. Distributions of distance were similar for all groups, as it can be noted by looking at boxplots (reported in the following Figure 42), therefore medians can be compared. Median distances were not statistically significantly different between the different accident dynamics, $\chi^2(3) = 5.140$, $p = .162$.

However, in this case, no association tests were performed between vehicles and accident types because the entire sample could be not considered as a set of independent measures: more than one vehicle/driver can be involved in each crash. Conversely, accident dynamics can be independently associated to each vehicle involved in the accident.

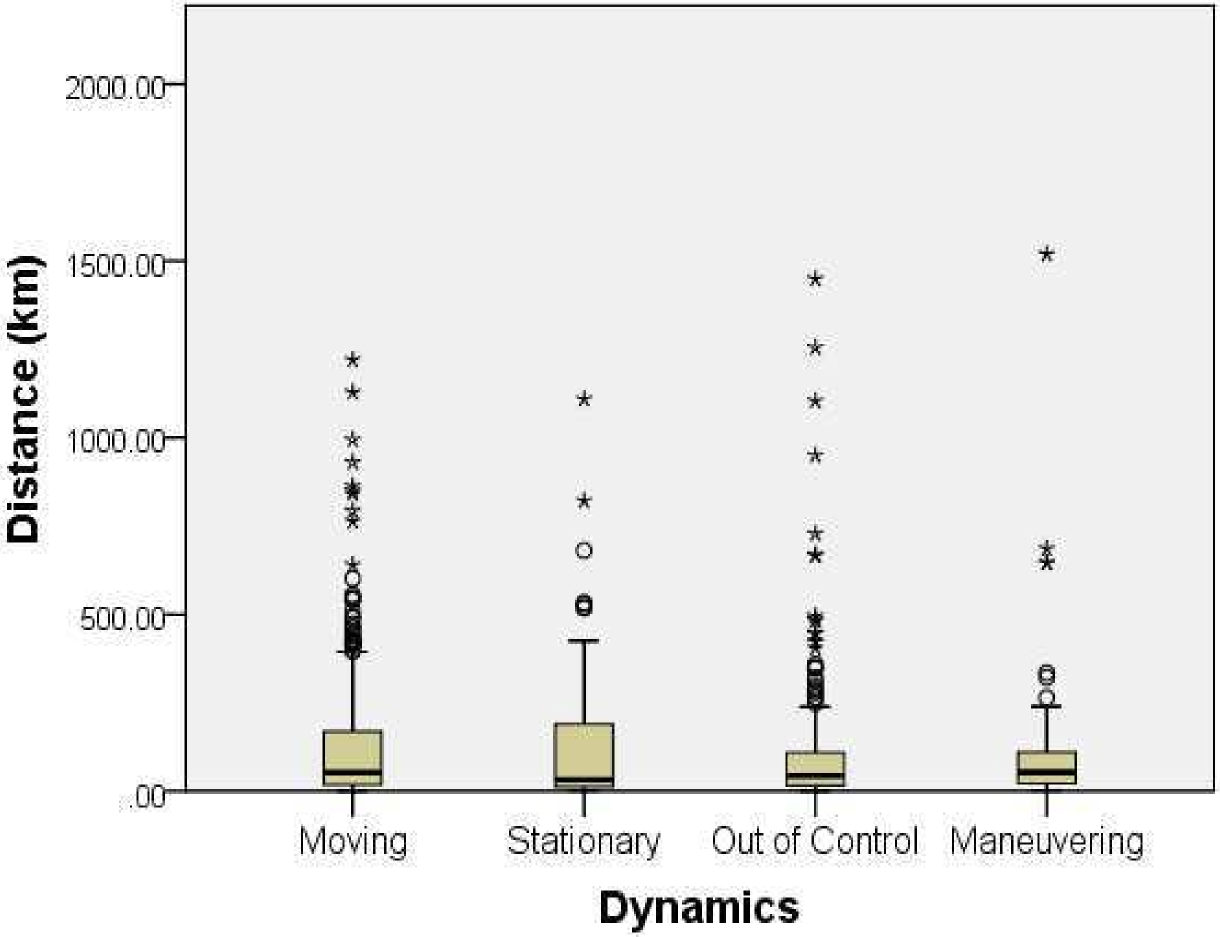

Fig. 43 – Boxplots of distances for the four classes of Accident Dynamics.

Trying to catch the key findings emerging in this sub-section through the statistical analyses conducted, one should argue that some relationships between familiarity and accident characteristics were revealed, when searching for them at a more detailed level. Most of the accidents (69 %) were accidents in which no interactions between different categories of familiarity of drivers occurred, henceforth referred to as "no interactions" accidents. This is largely due to the high share in the sample of run-off accidents, typically involving only one vehicle (44 %). Among these "no interactions" accidents, familiar drivers were more associated to rear-end/angle accidents and less associated to head-on accidents than the expected. This result is confirmed by the analysis of the relationship between accident type and distance as a continuous variable: median distance for vehicles involved in rear-end accidents is lower than median distance for vehicles involved in head-on accidents (even if when adjusting for multiple comparison, this difference results not more significant). Moreover, more unfamiliar drivers were associated to run-off accidents than the expected. No differences between the different types of accidents were found instead for the “interactions” accidents (accidents in which familiar and unfamiliar drivers were both involved). Moreover, no association was noted between being involved in an accident with or without other categories of familiarity and the type of accident (rear-end/angle or head-on).

When considering the accident dynamics, more familiar drivers were involved in accidents being stationary after braking or for turning than the expected. In addition, less unfamiliar drivers were the vehicles who lost control in the accident dynamics than the expected. These differences emerge if different categories of familiarity are considered, while no influence was noted by using the continuous variable “distance” as an input.

Those results can be discussed in light of what shown in the General Background section. The fact that unfamiliar drivers seem more prone to run-off accidents could be related to their absence of knowledge about the road environment, resulting in being surprised by unexpected sudden dangerous road sections. This result is in opposition to what found by Liu and Ye (2011): familiar drivers resulted to be more involved in run-off crashes. However, that study is based on post-crash surveys and familiarity was defined based on the frequency of the travels (daily, weekly and also montly frequencies were considered for the familiar category). When looking at the accident dynamics, unfamiliar drivers seem to be less prone to being the ones to lose control of their vehicles during the accidents. However, most of the run-off road crashes are caused by losing control and unfamiliar drivers were more involved in those accidents. Therefore, one could indirectly argue that in the other types of accidents different from the run-off road, unfamiliar drivers were strongly less associated to being out of control. It is difficult to compare this finding with previous literature since similar studies were more focused on foreign drivers than on unfamiliar drivers in general (Wilks et al., 1999; Yannis et al., 2007; Kim et al., 2012).

For what about familiar drivers, a relationship was found between rear-end accidents and accidents in which all drivers were familiar. This is confirmed by the fact that rear-end crashes show the smallest median drivers’ distance from residence among all the types. This is not surprising, since familiar drivers were previously associated to more dangerous behaviours due to their over-confidence with the road environment. They could be prone to wait until the last possible moment to brake in order to turn (for example into a driveway) but also prone to greater speeds and closer car following, all behaviours related to rear-end crashes (while striking or being struck). However, in the accident dynamics considered, familiar drivers were more often the drivers involved in the accident while stationary after braking or before turning. This is coherent with results from Baldock et al. (2005). They found an over-representation of drivers being struck while driving the road traveled with a daily frequency, in comparison with daily drivers striking (even if based on a small sample of interviews). This could mean that, if “no interactions” accidents are considered, rear-end/angle accidents are more associated to familiar drivers. However, considering all the rear-end accidents (including also interactions with other categories), the familiar drivers seem often the ones being struck, since most of the vehicle being stationary during an accident were involved in rear-end accidents. Moreover, the head-on accidents were less associated to the involvement of only familiar drivers. Head-on accidents can be assimilated to run-off accidents for being caused by a vehicle which initially loses control and eventually invades the opposite lane. Being familiar with a given road seems to prevent this type of accident due to possible errors in choices of speed and steering. Wilks et al. (1999) found for example that international drivers are over-represented in head-on collisions with respect to the local drivers from a crash database analysis. In this case instead, no specific association was found with unfamiliar drivers (but with transition drivers).

A final remark can be made about the possible influence of the interactions between different categories of drivers’ familiarity. As expected from the discussion in the previous section, one should expect that the interaction between familiar and unfamiliar drivers (regular/recreational drivers) would lead to an increase in the accident rate. In this sub-section, accident rates were not analyzed since the focus is on a more detailed level of analysis. However, considering the possible interactions between the familiarity categories, no particular association was found between the different interactions between the various familiarity categories and the accident type (Fig. 38). No influence of being an “interactions” or a “no interactions” accident was highlighted with respect to accident type too (Fig. 39). However, the HCM framework accounting for the presence of recreational drivers is valid for multilane highways and freeways, at which traffic volumes are greater and the interactions are much more numerous than on two-lane rural roads. Therefore, in order to observe clearer effects of familiarity on the road accidents, these other roads should be probably analyzed with techniques similar to those used in this section.

2.3.4.3. Results from a micro-anaysis of the accident data

In this last sub-section, the accident data are inquired at the most detailed level possible by looking at specific road sites characterized by outstanding percentages of accidents occurred to familiar/unfamiliar drivers.

In detail, the selection criteria were the following:

- road sites where at least the 70 % of total accidents involved at least one unfamiliar driver (≥ 200 km from residence) were considered as “unfamiliar sites”;
- road sites where at least the 70 % of total accidents involved all familiar drivers (0 – 20 km from residence) were considered as “familiar sites”;
- road sites where less than 10 accidents occurred were not considered, in order to obtain meaningful percentages.

The percentage of 70 % was chosen because it was the higher percentage allowing to identify at least a road site in each of the two categories (unfamiliar and familiar sites). The “at least one unfamiliar driver” rule was chosen instead of the “all unfamiliar drivers” rule (as for the familiar case), because unfamiliar drivers (being resident more than 200 km from the place of the accident) can be considered as an anomaly in the traffic flow (at least one unfamiliar driver was involved in the accidents in the database in only 25 % of the total sample, see Fig. 37).

Two road sites (one familiar and one unfamiliar) were identiified by applying those criteria. The characteristics of these sites are summarized in next Table, while the detailed analysis of the accidents at the two road sites is reported as follows.

Table 24 – Characteristics of the two road sites selected.

Site	AADT (veh/day)	Road	Length (m)	Crashes	Vehicles	Posted Speed (km/h)	Road Width (m)	Driveway Density (n/km)	Curve Density (n/km)
1 (FAM)	6697	E39	2400	11	23	50-80	6-8.6	2.1	3.3
2 (UNF)	5165	E6	5500	10	19	50-80	6-8.3	1.1	4.4

At the “familiar” site (1) selected, eleven accidents in ten years, with 23 vehicles involved occurred. Among these eleven accidents, eight of them were classified as “familiar”. The information about the accidents, the vehicles and the drivers involved are reported in Table 24. Schemes representing the reconstruction of accidents to unfamiliar drivers are reported in Figure 44.

At the “unfamiliar” site (2) selected, ten accidents in ten years, with 19 vehicles involved occurred. Among these ten accidents, seven of them were classified as “unfamiliar”. The information about the accidents, the vehicles and the drivers involved are reported in Table 25. Schemes representing the reconstruction of accidents to all familiar drivers (except for the case of missing data, about the 15 % in the database) are reported in Figure 44 as well.

Some general remarks about the noted recurrent accident patterns emerge from the results of the accident analyses at both sites.

At the familiar site, most of the accidents were rear-end crashes (7 out of 11, 5 of them involved all familiar drivers). Another recurrent type is the run-off road (3 out of 11, 2 of them involved all familiar drivers). Only one head-on crash was analyzed and it involved a familiar cyclist.

This road site is placed near a residential area (that is likely the reason for the high share of familiar drivers in the traffic flow) and it is therefore characterized by several driveways and minor intersections (in some cases not well signaled or not provided with turning lanes). This fact could be easily associated to the high share of rear-end accidents (7 out of 11, 5 of them in correspondence of a driveway). However, among these familiar rear-end accidents, a recurring pattern can be noted by comparing Table 25 and Fig. 44: familiar drivers hit the cars from behind in the rear-end accidents in 4 out of 5 of the familiar crashes (4 out of 7 of the total rear-end crashes). The presence of missing data for some drivers did not influence this remark, since they were the vehicles hitted except for one case (accident 3).

Table 25 – Details about the "Familiar" site (based on Intini et al., 2017, in press).

#	Type	Road Section	Weather/Road/ Visibility Conditions	Vehicles/Drivers' Familiarity*			
				A	B	C	D
1	Rear-End/ Angle	Straight/ Before Curve	All good	Car (ND)	Car (NC)		
2	Rear-End/ Angle	-	-	Car (ND)	Car (F)		
3	Rear-End/ Angle	Curve/near a driveway	All good	Motorcycle (F)	Unknown (ND)		
4	Head-on	Curve/near a driveway	Wet road/Bad visibility (road lights)	Car (ND)	Bicycle (F)		
5	Run-off	Curve/near a driveway	Wet road/Other Conditions Good	Car (F)			
6	Rear-End/ Angle	Straight road	Wet road/Other Conditions Good	Car (F)	Car (F)	Car (F)	
7	Run-off	Straight road	Icy Road/Other Conditions Good	Truck (F)			
8	Rear-End/ Angle	-	-	Tractor (F)	Tractor (ND)	Car (NC)	
9	Rear-End/ Angle	Curve/near a driveway	All Good	Car (F)	Car (F)		
10	Rear-End/ Angle	Curve/near a driveway	All Good	Car (F)	Camper (ND)	Car (F)	Camper (F)
11	Run-off	-	-	Car (NC)			

* F = Familiar (≤ 20 km), U = Unfamiliar (≥ 200 km), NC = Transition (20 – 200 km), ND = missing data. The definition "camper" includes campers, vans, cars with trailer, light trucks.

The correlation found between accidents involving all familiar drivers and the rear-end crashes was expected by the statistical analyses shown in the previous sub-section. However, the accident patterns at this site seem to be in opposition to the previous suggestions (familiar drivers more being struck than striking). Anyway, as anticipated, both striking and being struck in a rear-end accident could have some traits in common with the familiarity of drivers. Indeed, a rear-end crash can be caused by a car traveling at high speed and failing in braking promptly or to distraction of drivers (potentially related to familiarity). However, given the small number of accidents inquired at this site and the presence of missing data, these remarks should be considered only as indicators, while the interpretation of statistical analyses is more reliable. Furthermore, as other examples, also in the accident 5 (familiar driver fell asleep as reported in the database) and in the accident 7 (familiar driver who likely tried to overtake on icy road), drivers' tendencies to distraction/fatigue and dangerous behaviours are present again.

For what concerns the unfamiliar site, most of the accidents were head-on crashes (5 out of 10, in 4 of them at least one unfamiliar driver was involved). Two run-off crashes (1 of them with the presence of an unfamiliar driver) and two rear-end crashes (1 of them with the presence of an unfamiliar driver) were reported too. Only one crash with an animal (included in the category "other accidents") was found involving an unfamiliar driver.

In this case, the unfamiliar site is a rural rolling/mountainous road section far from relevant cities. This can explain the high share of unfamiliar drivers in the traffic flow and then in the accidents. By considering together head-on and run-off crashes (since as anticipated, both can be related to some speed and steering errors), an unfamiliar driver was involved in 5 of the 7 total grouped accidents and, in 3 out of 5 cases, the unfamiliar driver invaded the opposite lane or ran off the road at a curve section. However, given the small number of crashes investigated, neither this cannot be interpreted as a recurring pattern, nor it can be associated to the findings reported in the previous sub-section.

Table 26 – Details about the “Unfamiliar” site (based on Intini et al., 2017, in press).

#	Type	Road Section	Weather/Road/ Visibility Conditions	Vehicles/Drivers’ Familiarity*			
				A	B	C	D
1	Head-on	Curve Section	Icy road/Rain/ Good visibility	Camper (U)	Camper (U)		
2	Other	Curve Section	All good/Without road lights at night	Car (U)			
3	Run-off	Curve Section	All Good	Camper (U)			
4	Head-on	-	-	Motorcycle (NC)	Truck (NC)		
5	Head-on	Curve Section	All Good	Camper (ND)	Bicycle (U)		
6	Run-off	-	-	Car (NC)			
7	Head-on	Curve Section	Icy Road/Other Conditions Good	Car (NC)	Camper (U)		
8	Head-on	Straight road	All Good	Car (NC)	Camper (NC)	Car (U)	
9	Rear-End/ Angle	Curve/ Driveway	Good weather/Slippery road/Without lights	Car (NC)	Truck (NC)	Camper (U)	
10	Rear-End/ Angle	-	-	Car (NC)	Car (NC)		

* see footnote to Table 25.

As a general remark about findings from this sub-section, it is evident that the micro-analysis seems the less indicated strategy to find general patterns and tendencies about accidents and behavioural variables, given the small number of accidents. However, it could be useful to practically visualize concepts emerging from statistical analyses and to relate them with real road situations. For example, the correlation between the presence of driveways and the accidents to familiar drivers or the correlation between a winding road section characterized by several curves in rolling terrain and the accidents to unfamiliar drivers could be considered for further reflections about road design and safety improvements at similar sites with a similar expected composition of traffic flow.

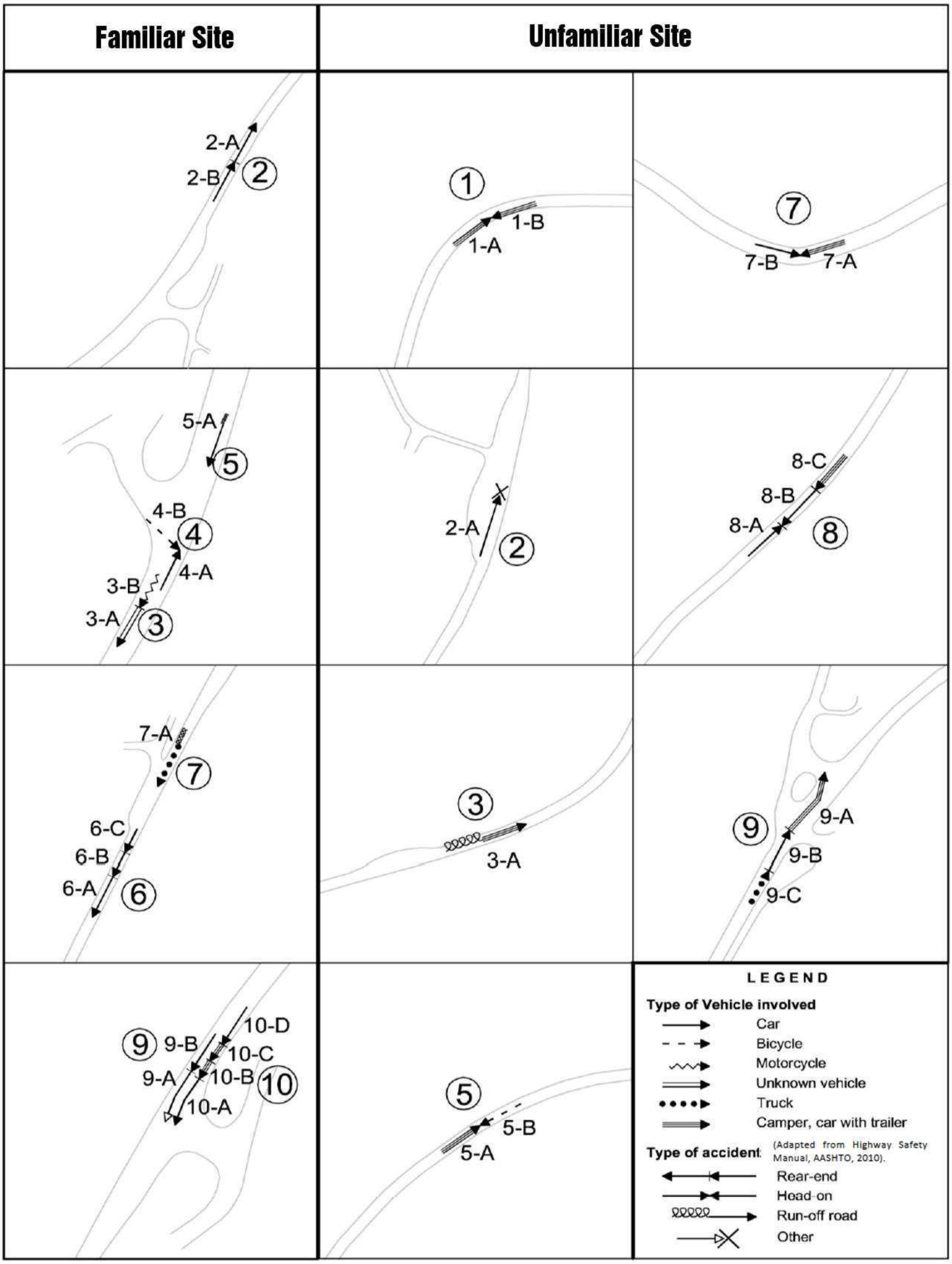

Fig. 44 – Schemes of the crashes occurred at the two road sites (taken from Intini et al. 2017, in press).

2.3.5 Proposal of a more comprehensive definition for measuring familiarity

In light of what shown up in this section about research, a more comprehensive definition of route familiarity can be assumed and it could be proposed for new research on the same topic. In the General Background section it was stated that currently, the definition of route familiarity varies with the different authors and with the aims of the studies. It can be frequency-based or distance-based. However, no clear and widely accepted definition about which is the correct frequency or the correct distance to use for identifying familiarity can be found in previous studies.

The results from the experimental study inquiring into changes into speed and lateral position choices due to the road familiarity (Sections 2.3.1 and 2.3.2) suggested that four consecutive tests on the same road can be considered as a sufficient time in order to observe changes in the drivers' perception due to the familiarity. This could be considered as coherent with similar previous experimental-based studies (Martens and Fox, 2007; Yanko and Spalek, 2013). However, in the Section 2.3.1 it was shown also how some drivers can fail in recalling the last driving performance (in terms of speeds and trajectories) if the driving stimuli are interrupted for some days (in this case the first interruption lasted for six days). Therefore, if the familiarity is defined on a time-based scale by using the frequency of traveling on a given road (daily, weekly, monthly or more rarely), the results from the analyses made in this section can lead to exclude frequencies more rare than weekly. Indeed, while behavioural theories (such as Groves and Thompson, 1970) suggest the possibiity of an asymptotic constant response to continuous repeated stimuli over time, the interruption in the stimuli could lead to a novel increase in the response, as confirmed by some experimental results. Furthermore, normally, the commuters are considered as the familiar drivers per excellence, since they repeat the same travel on the same road almost daily, as previously discussed. Hence, the proposal of a frequency-based definition of familiarity is based on those remarks: it should be at least weekly-based and particularly, the optimum could be a threshold of at least four days a week on the same route, to be considered familiar with it. This definition emerges from the combination of theoretical expectations and experimental results. Nevertheless, the frequency-based definition of "unfamiliarity" is easier to address. A driver who never traveled on a given road can be surely considered unfamiliar with that road. The optimum frequency-based familiarity threshold was set to 4 days a week (or at least once a week). However, between the weekly frequency and the condition of having never traveled on a given road, a wide spectrum of possible frequencies exists, covering different shades of familiarity/unfamiliarity. Since a possible long-term memory effect related to the habituation could be naturally expected (Rankin et al., 2009) and it was indeed experimentally noted on a almost montly basis (see Section 2.3.1), one should exclude that monthly drivers are surely unfamiliar with a given road environment. Therefore, a yearly frequency (order of magnitude likely corresponding to once a year) can be suggested as a minimum threshold for defining a driver as unfamiliar with a given road (see also Ryeng, 2012).

The other evaluation scale for the familiarity is the distance-based definition. In fact, while the time-based frequency is a definition which takes into account the real familiarity of drivers and it is tipically used for post-crash surveys; in studies based on accident databases the information about familiarity should be deduced from the database, without the possibility of interviewing the drivers. Therefore, a measure of familiarity can be based in this case on the distance from the drivers' residence (for example using zip codes, see e.g. Blatt and Furman, 1998, as in this study). Other authors, as explained in the General Background section, used the division foreign/local (e.g. Yannis, 2007) or the definitions rural/urban (e.g. Blatt and Furman, 1998) to consider distance-based familiarity. However, defining town or state limits as default boundaries to determine the familiarity of drivers could be in some cases too constraining (e.g. drivers can be familiar with places close to a small town but out of the town limits) and in other cases too permissive (e.g. non-foreign drivers could be totally unfamiliar with places in the same state but too far from their residence, until the extreme cases of large states like United States, Russia, Canada, Brazil etc.). In this study and particularly in the previous Section 2.3.4, a distance-based definition of familiarity, independent from administrative boundaries, was proposed. It is based on mobility remarks: there are distances which are easily covered on average by drivers for commuting purposes and there are long trip distances above which another mean of transport is generally preferred to the private transport (excluding e.g. professional truck drivers). In that section based on Norwegian data, measures found from Norwegian reports and studies about mobility led to select 20 km in order to define commuting trips and 200 km as a threshold for long-distance trips (Hjorthol et al., 2014; Thrane, 2015). The distance of 20 km is coherent with other international studies (such as Litman, 2003) and with the desired time devoted to mobility per day, estimated in about 1 hour (Colonna, 2009). Average distances of commuting trips and distances at which there is a switch between private transport and other means of transport can vary between different countries, having different driving habits. However, one should expect that they will not vary too much with respect to the values here proposed.

This section about the research discussion ends with a summarizing Table in which the proposed definitions based on both time and distance for measuring familiarity/unfamiliarity are reported. Since currently there is no consensus about these thresholds, they could be used for further research for the aim of guaranteeing a greater uniformity.

Table 27 – Proposed definitions of the maximum thresholds for measuring the familiarity and the minimum thresholds for measuring the unfamiliarity of drivers, with respect to both time and distance.

Type of Definition	**Familiarity**	**Unfamiliarity**
Time(Frequency)-based	Weekly (optimum set to 4 days a week)	Yearly
Distance-based	About 20 km (to be eventually locally calibrated according to average commuting trips)	About 200 km (to be eventually locally calibrated according to minimum long distance trips)

However, it is evident that those definitions can be valid for great amount of data when the necessity of defining the familiarity of drivers with a given road section based on indirect measures arises. This is because, as widely explained throughout all the present work, the familiarity of drivers concerns their subjective sphere and it depends on the psychological processes connected to the human brain. Therefore, each attempt of defining a rational and obejctive indicator to measure familiarity could be affected by some errors due to the large discrepancies between different individual processes. The definitions of thresholds in Table 27 should be taken indeed as probabilistic and not deterministic. Values of distances and frequencies minor than the defined familiarity thresholds could be objective measures representing drivers most likely familiar with the given route. Conversely, values of distances and frequencies greater than the defined unfamiliarity thresholds could be objective measures representing drivers most likely unfamiliar with the given route. It is always possible that, for example, a driver particularly skilled for having memories of roads previously traveled more than one year before could feel familiar and confident with those roads and vice versa for small frequencies; or that a driver make frequent long-trips by private means of transport for distances greater than 200 km on the same roads being familiar with them and vice versa for small distances. However, on large samples of data, the effects of these reasonably rare cases could lead to few mis-classifications of drivers' familiarity and then to acceptable errors.

It should be remarked anyway that, as expected from the General Background Section (2.1) and as it partly emerged from experimental results (especially from Sections 2.3.1 and 2.3.2), the driving performances are affected by famililiarity in different ways according to all the other human individual factors. Therefore, the proposed measures for defining familiarity have to be taken as tools for classifying drivers into categories (indepedent variables) and not to directly predict different driving performances (dependent variables). Hence, Table 27 could be useful for further studies in order to divide drivers into familiarity categories while defining the indepedent variables of the study, based on the objective measure "time" (typically for studies based on post-crash surveys) and the objective measure "distance" (typically for studies based on databases).

It is also clear that further specific psychological studies could help in having a better knowledge about the relationships between objective and indirect measures of familiarity and the self-perceived familiarity with a given road, considering all the other possible influencing factors. At the same time, the “no-man’s land” between the familiarity and the unfamiliarity conditions (that is, while the familiarization process is in progress or it is interrupted), could benefit from further studies as well. Hence, the proposal made in this section is, for the above explained reasons, an attempt to summarize and harmonize the existing knowledge in this field, useful for further researches in road safety, to be improved in future according to other sources and other experimental studies.

3.0 CONCLUSIONS AND PRACTICAL DEVELOPMENTS

In the General Background section (2.1), it was shown how the matter of route familiarity is currently considered in theory and practice of road safety. After being defined (2.1.2.1), familiarity was associated to a more automated and unconscious driving, with a tendency to distraction and inattention (2.1.2.2). This was explained through the application to driving of the habituation theory (2.1.2.3): familiar drivers are expected to show a minor response to the same stimuli (driving on the same route) repeated over time. However, a minor response could be related also to a risk underestimation that, connected to a greater experience about the road layout, could lead to more dangerous behaviours, with the aim of maximizing the utility related to the travel through the driving performance (2.1.2.4). Moreover, familiar drivers could be prone to adapt to road safety measures, reducing their effectiveness (2.1.2.5). However, unfamiliar drivers can show some potential pitfalls as well. For this category of drivers, the problems could come from the road itself: they do not know the route and so, unexpected road elements or situations could result in sudden dangerous surprises for them. This can be theoretically expected and it was indeed remarked by previous studies about differences between international and local drivers with respect to accidents (2.1.2.4). In fact, in the road design stage, great attention is devoted to the unfamiliar drivers: road design guidelines include prescriptions and standards for guaranteeing the consistency, in order to meet the drivers' expectations (2.1.3.1). Moreover, in the traffic engineering practice, the presence of unfamiliar drivers is considered because it can be related to a worsening in the level of service connected to speed and density (2.1.3.2). Therefore, both unfamiliarity and familiarity are considered in matters regarding road safety even if some issues needed to be better explored (2.1.4).

The results from the Discussion Section (2.3), are reported as follows, in order to answer to the research questions highlighted after the literature review.

- A more detailed look into the relationships between route familiarity and driving performances was needed. Repeated measurements over time of speeds and lateral positions of a sample of drivers on a two-lane rural road (2.2.1) were used in order to address this need. Based on these data, analyzed in Section 2.3.1, familiar drivers seem to be prone to increase both the speeds on the test road layout and the radii of the trajectories at curves (related to an increase in the curve-cutting tendency) if the driving tests are repeated in consecutive days (in this case, four). The increasing tendency for speed is more evident than the tendency for radii. The increase is generally noted indepedently from the specific road geometry, even if in very demanding sections (such as the low visibility sections for speed or the sharpest curve for trajectories) it is reduced. When looking at differences between drivers (studied for the speeds, which were found to be highly variable especially in the fifth day of testing), drivers more prone to speeding (aggressive drivers) were found to increase their speed over days much more than the prudent and the average drivers. A long-term memory effect was noted for speeds, which stayed around the same level even after two test interruptions lasted for some days, suggesting a habituation effect (except for prudent drivers, who seemed to need a further re-test of the road layout after the first interruption). If the radius of curve trajectories is taken into consideration, it seems that drivers fail in recalling the last trajectory chosen before the test interruptions. Therefore, based on the observed behaviour, drivers could perceive the curve-cutting tendency as a more demanding task than the speeding, feeling confident with it only with the continuous repetitions of the tests, even if speeds and trajectories seem to be related.

- An experimental-based evidence of the changes in the subjective drivers' perception due to the route familiarity was needed. The same data belonging to the on-road experiment (2.2.1) were used for this aim, focusing in particular on the different speed driving tasks (free, low, medium and high perceived speeds) asked to the drivers and on an utility-based model, trough the analyses presented in Section 2.3.2. As a general remark, drivers travel on average at speeds included between the speeds that themselves perceive as medium and high. However, this tendency is dynamic over time: after four days of testing, drivers tend to travel at speeds going progressively closer to the speeds perceived by themselves as high, especially in sections characterized by a less demanding road geometry. This could be interpreted as a change in the risk perception by the drivers due to the familiarization with the road layout, mostly unconscious, measured through the different speed perceptions. Moreover, this change in perception becomes more evident if the trade-offs between accident risk and travel time are quantified based on the speed data. Drivers who acquired familiarity with the road seem to accept higher risks in order to obtain mobility benefits in terms of travel time. The accepted risk at the end of the familiarization process is evidently higher for more risky drivers than for prudent or average drivers and in less demading road sections (high visibility sections). However, it was noted that the desired reductions in travel time are about constant for all the categories of drivers and for all the different classes of visibility. This leads to different final risks because the initial speeds are different among the diverse drivers and visibility categories and the function relating risk and travel time was a power function. In any case, trade-offs between risk and mobility were observed, even if they can be unconscious, they are largely subjective and they can be probably misperceived.

- Starting from the HCM framework (2.1.3.2), an integration of this framework with the knowledge in the field of road safety was considered as useful. This was made in the Section 2.3.3, starting from the remark that the presence of unfamiliar drivers in the traffic flow can be related to an increase in the equivalent traffic flow and to a decrease of the average flow speed. However, the key concept applied in addition to the HCM framework is that a high share of unfamiliar drivers, which could travel at lower speed than the familiar drivers, could be related to an increase in the speed variance at a cross-sectional level. Hence, the speed variance should be not computed for the average flow speed but for the distribution of speeds obtained considering two sub-distributions of speed: one for the familiar drivers and the other for the unfamiliar drivers (supposed to be two different categories interacting one with each other). This increase in the speed variance was converted into an increase in the accident risk with respect to the condition in which all drivers are familiar. The process can be repeated for different values of the free flow speed conducting to different results in terms of accident increase. However, apart from the magnitude of this effect, the important remark is that, for a given range of flow rates (intermediate between free flows and the capacity), the interactions between a significant share of unfamiliar drivers and the familiar drivers could lead to an increase in the expected accident rates due to the increased speed variance. This effect is not more expected neither for free flows, in which drivers did not influence each other; nor for values near to the capacity, where speeds are conditioned by the traffic, reducing the free choice.

- A more detailed look into the relationships between familiarity and road accidents was needed. This matter was addressed in section 2.3.4, in which it was shown how these relationships should be inquired at a detailed level, because they cannot be easily investigated by looking at macro data of accident rates. Indeed, some influence was revealed through statistical analyses, while no effect of familiarity on accidents was found by comparing accident rates between summer and the other seasons or in summer between sites with different share of traffic variations. Moreover, a micro-analysis could be not meaningful as well, if only few accidents are considered for further analysis as in the subsection 2.3.4.3. In fact, in this case, a high share of specific types of accidents could be explained by other factors different from familiarity. The results from the detailed analysis pointed out that, among the accidents in which no interactions occurred between familiar and unfamiliar drivers, familiar drivers were over-involved in rear-end/angle accidents and less involved in head-on accidents (as confirmed by looking at the distances from residence for different groups of accident types). This could be explained by their tendency to a possible over-confidence with the road environment resulting in dangerous behaviours in braking or turning (for rear-end/angle accidents) and to their simultaneous greater knowledge about the road, possibly preventing errors in speed and steering (for head-on crashes). Instead, unfamiliar drivers were over-involved in run-off accidents, as it was expected since they could be less prepared to sudden changes in the road environment. Moreover, if the entire sample of accidents is considered together with the accident dynamics, results suggest that familiar drivers could be more frequently being struck than striking in rear-end crashes, while no clear tendency was highlighted for unfamiliar drivers (except for the fact of being probably less prone to lose control in accidents different from run-off crashes). Finally, no specific influence of the different interactions between the categories of familiarity on accident types was found, even if this could have been expected from sub-section 2.3.3, since probably the effects of interactions could be visible only for multi-lane highways and freeways. In any case, the associations found from statistical analyses were small, so they can be mainly taken as indications.

In light of these results shown, some conclusions can be drawn. Familiarity and unfamiliarity can be seen as two faces of the same phenomenon connected to the habituation effect, using for them the frequency-based and distance-based definitions proposed in 2.3.5 (see Table 27).

Being familiar with the route is a state of the driver which presents itself at the end of a familiarization process, where the stimulus repeated over time is the act of driving and the response to this stimulus progressively decreases. This reduction in the response could be associated to a progressive shift from the conscious to the unconscious, since the driving task could become easier and it could require less attention. However, in parallel, acquiring a greater confidence in the road environment could lead drivers to change their driving performances (see Fig. 25) since the travel of a generic user is normally governed by the aim of maximizing its utility. Indeed, according to the studies presented here, this was noted in particular for speeds and radius of curve trajectories (even if to a lesser extent). The relation with the utility of the travel is contemplated since the increase in speeds and radii could be interpreted as an attempt to reduce travel times, for the aim of increasing the utility. However, this reduction is necessarily related to an increase in the risk connected to the travel through the increase in speeds and the change in the trajectories. While trade-offs were noted on average for all drivers, these processes are largely dependent from the differences between individuals and they are partly irrational, since they can happen while the driving task is switching into the automation. The partly irrational and unconscious nature of this process could lead to exclude the thought that the familiarization process can support more risk-taking atttudes. Indeed, drivers could accept more risk-taking behaviours, feeling them as still acceptable because their perception is changed and they could have became habituated to a given new level of performance, which instead is felt unacceptable by unfamiliar drivers who do not know the challenges of the road environment.

Therefore, the drivers in the traffic flow can be considered as divided into two components which interact one with each other, showing different potential behaviours in terms of driving performances. This was observed as influencing on the capacity and on the level of service and, it was shown how this can be related to a greater flow speed variance and to an increase in the accident rates for traffic flows far from the capacity. Moreover, when looking at the influence of familiarity on observed accidents, these differences between driver behaviours were indeed associated in some cases to different types of accidents and different accident dynamics. Familiar drivers were found to be over-involved in rear-end accidents being struck by other drivers and unfamiliar drivers were found to be over-involved in run-off accidents, while less prone to lose control in other accident types. The tendency found for unfamiliar drivers is coherent with the possibility of being surprised by unexpected road elements (e.g. sudden sharp curves) if the road design is not adequately related to the driver behaviour. In fact, in the road design stage, currently, great attention is devoted to the unfamiliar drivers while setting standards and guidelines about geometry and consistency, considering to meet the expectations of drivers who do not know the road. Moreover, the suggested fact that they can be less prone to lose control in other accident types could mean that, on average, they show a more conservative behaviour even if, unexpected road elements could influence their loss of control indepedently from their driving style. However, this remark is based on a deduction: it was not directly observed.

Nevertheless, it was shown how also the matter of familiar drivers should be stressed with respect to road safety. As a matter of fact, behaviour of drivers got familiar with the road could be totally different from an ideal behaviour, especially for the type of roads considered in the experiment presented here (very low-volume rural roads), where less constraints are present for drivers. Speed and steering behaviours could be different from the ideal ones used in standards and guidelines for setting limit values or for the design practices. Actually, familiar drivers were found to be over-involved in rear-end accidents but, while inquiring the matter in detail, they were suggested to be the ones being struck rather than striking. This circumstance is not easy to be interpreted since both striking and being struck in a rear-end accident can be associated to some behavioural tendencies like distracted and inattentive driving causing delayed braking (striking), high speed (both striking and being struck) or for example a sudden maneuver for turning (being struck), which could be attributed to familiarity. For this reason, it is not easy to make clear conclusions about familiar drivers in accidents considering also previous literature. Anyway, their different behaviour possibly leading to dangerous situations should be considered for road safety as well as the unfamiliar condition in the road design practice.

Hence, these conclusions can be read from the point of view of the road safety, while thinking about road design and countermeasures and trying to apply this research knowledge in practice. If the two-way two-lane rural roads are particularly considered, because they are the type of roads to which part of the research presented here is mainly devoted, some typical situations about road safety can be highlighted (Colonna et al. 2016a, d). The essential categories of typical black spots which emerge are two: sharp/poorly designed curves after long tangents at which run-off road crashes cluster and tangents in suburban areas characterized by several driveways and/or minor intersections, where rear-end and angle crashes are often present. The first type of crashes was associated through this study more to the unfamiliar drivers (who can be surprised by the unexpected curves), while the second type was related more to the familiar drivers (who can be distracted or be prone to high speeds or e.g. overtaking maneuvers, inaccurate turning into driveways).

Therefore, some general practical considerations could emerge from this study. Geometric adjustments of curves at rural road sites (handling the compliance with design standards and guidelines which are thought for the unfamiliar drivers, see 2.1.3.1), could be specifically prioritized when a significant share of unfamiliar drivers in the traffic flow is expected (e.g. rural road stretches far from big cities or towns, see 2.3.4.3). This could potentially reduce the high concentration of run-off road crashes at curves due to sudden surprises, according to the indications given here. In parallel, the high concentration of driveways and/or minor intersections on long tangents potentially allowing high speeds and overtaking maneuvers should be treated through measures forcing drivers to behave in the most suitable way. If these road sites are placed near urban or sub-urban areas, where significant shares of familiar drivers are present, these measures should not include only road signs or potentially ineffective control devices. In fact, they could not allow drivers to feel certain about being sanctioned if rules are broken and familiar drivers could get easily used to their presence (see Section 2.1.2.5 about adaptation). The best way to avoid adaptation to the countermeasures for familiar drivers could be, as anticipated, to force them to adopt the most suitable behaviours for that condition. This could include for example the introduction of roundabouts in correspondence of minor intersections, the insertion of turning lanes, the prevention of left turns into driveways (i.e. through service roads). Another strategy can be the installation of an efficient traffic speed control which can give to the familiar driver the idea of being really monitored (differently from unfamiliar drivers, who could be worried about a monitoring system independently from its real effectiveness or not). These strategies could represent some countermeasures potentially useful to act on behaviour of drivers according to the variable familiarity, which was considered as influential on the driving process. Apart from road safety measures, some other remarks can be made for further research:

- Experimental studies (both with simulators or instrumented vehicles) should consider that the behaviour of drivers in the first driving test could be different from the same behaviours in subsequent tests for the habituation effect due to the acquired familiarity. Hence, according to the aims of the specific experiment, some preliminary driving tests should be made on the same road before the real measurements to be further elaborated would start. In this way, the possibility of having measures influenced by the unfamiliarity of drivers (not corresponding to the real behaviour that the same drivers could have on that road) could be avoided. If tests in consecutive days are planned, a sufficient level of familiarity could be considered as acquired in at least four days, based on the research presented here.

- When developing crash modification factors to assess the effectiveness of a safety countermeasure (e.g. through before-after study, see Hauer, 1997), the possible effect of adaptation of familiar drivers to the countermeasure should be taken into account. This means that a sufficient period of time after the implementation of the countermeasure should be considered in order to take into account also the possible behavioural compensations for familiar drivers. Elvik (2013)b, for example, provides a very useful guidance about how considering adaptation of drivers for cost-benefit analyses. This could be valid especially if the road safety measure is implemented in urban or sub-urban areas, where a high share of familiar drivers (i.e. commuters) is present in the traffic flow.
- For future studies, the definition of familiarity provided in Section 2.3.5 could be used for defining the familiarity or unfamiliarity of drivers based on the travel frequency and the distance from residence.

The results presented here, together with the conclusions and recommendations arising from them, are based on the experimental and observed data on which the research was conducted. They are generally in harmony with previous studies, except when other contradictory results were mentioned in the text. However, it should be stated that the conclusions drawn are limited by the specific data sources used. More in detail, the data sources were related to two-way two-lane rural roads. Then, a step forward of this research could be the analysis of accidents on multi-lane highways using criteria similar to those used in the Section 2.3.4, since some relationships between the interactions familiar/unfamiliar drivers and the accident rates can be expected (Section 2.3.3). Moreover, the experimental data used for the discussion in Sections 2.3.1 and 2.3.2 come from an on-road test made by a sample of twenty young drivers. Even if the results were discussed considering previous similar studies and expectations from theoretical frameworks, clearly the general conclusions could benefit from other similar experiments (using instrumented vehicles or driving simulators). The influence of other factors (such as for example considering the influence of different drivers' ages or other individual/external characteristics) could be deepened as well. It is also evident that the proposed recommendations for the road safety practice need to be verified through some specific real tests. Some real road interventions in specific areas interested by significant shares of familiar and unfamiliar drivers could be indeed monitored with the aim of quantifying the effect of the specific adaptation caused by familiarity and potentially forecast through the presented work.

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6.0 SHORT CURRICULUM VITAE

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Born in Bari (Italy) on January, 11th, 1988. I obtained a bachelor's degree in Civil Engineering in 2011, from the **Technical University of Bari, Italy**. From the same university, in 2013, I obtained a **master's degree in Civil Engineering** (curriculum: Transportation), after having discussed a **thesis partly developed in Norway (NTNU University, Trondheim)** through the Erasmus+ project (supervisor: Prof. Colonna, co-supervisors: Prof. Ryeng, Eng. Berloco).
I started the **Phd Programme in Environmental, Territorial, Building Risk and Development** in 2014 (**XXIX Cycle**) at the same university (curriculum: Infrastructures, Transport and Territory, Scientific Sector: ICAR/04, Roads, Railways and Airports). **Part of the research was developed abroad also with the support of the NTNU University**, Trondheim (Norway), co-tutor: Prof. Ryeng. Moreover, during the PhD Programme, I supported the **didactic activities for the "Road Safety" course** (Master's Degree in Civil Engineering, 2015 and 2016, chair: Prof. Colonna).
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In this period I was **main author and co-author of some journal and conference papers in the field of road safety**. I also co-authored a **book** (Sicurezza Stradale – Un approccio scientifico a un problema tecnico e comporamentale, P. Colonna, N. Berloco, P. Intini, V. Ranieri, 2016, WIP Edizioni) about road safety, specifically devoted to the safety-based interventions on existing two-way two-lane rural roads.