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Route familiarity in road safety: a literature review and an identification proposal

By Paolo Intini^a, Pasquale Colonna^a, Eirin Ryeng^b

1 ^aDepartment of Civil, Environmental, Building, Land Engineering and Chemistry(Department of
2 Civil, Environmental, Land, Building Engineering and Chemistry), Polytechnic University of Bari, 4
3 via Orabona, Bari 70126, Italy

4 ^bDepartment of Civil and Environmental Engineering, NTNU The Norwegian University of Science
5 and Technology, Høgskoleringen 7, 7491 Trondheim, Norway

6

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13

14 **Abstract.** Route familiarity can be an important safety-related variable, which is often neglected. A
15 review of previous works highlighting the relationships between route familiarity and road safety in
16 behavioural studies and engineering standards/frameworks has been conducted.
17 Theoretical frameworks supported by experimental results have revealed that driving behaviour can
18 be affected by route familiarity. The latter may lead to distraction and self-confidence; and in turn to
19 more dangerous behaviours after repeated journeys. From an economic perspective, the possible
20 worsening of driving safety performance may be explained by trade-offs with mobility benefits.
21 Route familiarity is also considered in engineering practice. Road design guidelines assuming a
22 “design driver” were suggested as implicitly preserving the safety of familiar/unfamiliar drivers. The
23 mix of familiar and unfamiliar drivers in traffic flow is explicitly considered when computing the
24 design traffic. The safety implications of these matters find only partial confirmation in previous
25 studies focused on involvement in crashes. However, comparing those findings was difficult due to
26 the high variability in measuring the route familiarity itself.
27 An attempt to harmonize the possible identifications of familiarity for future studies, based on
28 previous findings, is proposed. The proposal considers two different scales used for measuring route
29 familiarity: one based on travelling frequency, the other on distance from residence.

30

Keywords: route familiarity; road safety; driving behaviour; review; familiarity identification.

1. Introduction

31 Road safety is closely related to human factors, which play a crucial role in about 90 % of crashes
32 (Treat et al., 1979; Singh, 2015). Among all driver-related crash variables, this article is specifically
33 focused on drivers' route familiarity, and its multiple relationships with road safety.

34 "Route familiarity" can be defined as the specific drivers' familiarity with routes (see e.g. Yanko and
35 Spalek, 2013) repeatedly travelled and thus, with the road elements they consist of. The adjective
36 "familiar" is basically defined as: "*well-known from long or close association*" (Oxford University
37 Press, 2016). Early studies associate the word "familiarity" with the frequency of having experienced
38 a given stimulus in the past (see e.g. Mass, 1956; Lewis et al., 1967; Witherspoon and Allan, 1985).
39 Hence, by applying these preliminary concepts, a route familiar driver is a driver who is travelling on
40 a route well-known from long or close association, and the travelling on that specific route composed
41 of different road elements has been the stimulus repeatedly experienced.

42 Drivers may also travel in different vehicles and under many personal, environmental, traffic
43 conditions, with which they may be familiar or unfamiliar. All these factors could be influential: for
44 example a driver can be suggested to be route familiar only at specific hours or in given conditions
45 (Lotan, 1997). However, this article is specifically focused on the effects of drivers'
46 familiarity/unfamiliarity with given routes, not considering in detail other familiarity aspects of the
47 system human-vehicle-environment.

48 The route familiar condition can be easily associated to the recurrent driving task undertaken while
49 going almost every day to the same work place (such as commuters), school, shop, etc.. Hence, route
50 familiarity can be a very common condition for drivers worldwide. Some examples of the significant
51 number of route familiar drivers in the traffic flow are reported as follows. About one third of the
52 vehicle-miles travelled by American private vehicles are for commuting (AASHTO, 2013). More
53 than 60 % of a surveyed Italian sample repeat a given trip at least 3 days a week and more than 60 %

54 of the average daily trips (average: 2000-2014) are made by car (ISFORT, 2014).

55 The topic of route familiarity is considered because of its influence on driving behaviour. However,
56 by affecting driving behaviour, route familiarity can influence road and traffic behavioural-based
57 safety aspects. These relationships between route familiarity, driving behaviour and road/traffic
58 safety aspects have often only been implicitly considered in previous research and technical
59 documents. However, the explanation of these relationships may be of interest for road safety
60 researchers and practitioners, given their potential impact.

61 Moreover, while it is possible to provide a basic definition of route familiarity, and some
62 exemplifications of familiar drivers such as commuters, it is rather hard to precisely categorize
63 different levels of route familiarity. This means that finding a clear threshold for determining when
64 an unfamiliar driver starts becoming familiar after a given frequency of travelling on the same route
65 is difficult. This ambiguity is reflected in experimental research, as further discussed. The related
66 major issue is the difficulty in comparing results from studies which have used different criteria for
67 identifying the drivers' route familiarity and unfamiliarity.

68 Hence, thorough explanations of how route familiarity can be related to road safety aspects, and
69 systematically identified dedicated studies are lacking. Given this, the article has a two-fold aim:

- 70 • Highlighting the relationships between route familiarity and road safety, through a detailed
71 review of research studies and road and traffic engineering technical documents.
- 72 • Proposing a criterion for identifying route familiarity potentially useful for future studies, by
73 attempting to harmonize previous criteria.

74 In the remainder of the paper, the possible influence of route familiarity on driving behaviour with
75 implications for road safety, is described. The methods used for the review of research studies and
76 technical documents are then presented. After that, the results from the review conducted are reported

77 and discussed, revealing relationships between route familiarity and road safety. The proposal for a
78 harmonized familiarity identification criterion, based on previous studies, is further presented.
79 Finally, the main conclusions from the study are drawn.

2. Background

80 This background section has the aim of providing a theoretical basis for the subsequent review of
81 research studies and technical documents, since several concepts presented here are further recalled.
82 The influence of route familiarity on road safety is explored from different, but inter-related,
83 perspectives.

84

2.1 Route familiarity and driving behaviour

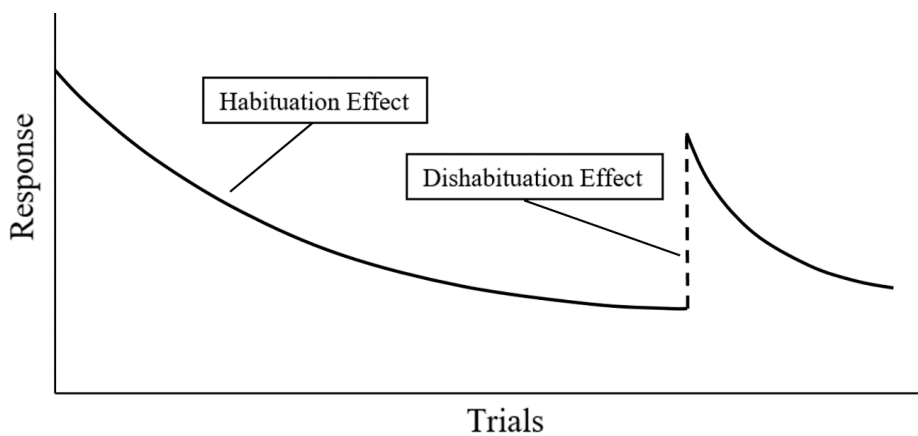
85 Drivers' route familiarity has consequences for road safety because it affects the driving task itself.
86 The driving task is often defined as complex, organized in different hierarchical levels (Michon,
87 1985) and described through different levels of performance (Rasmussen, 1983). Moreover, driving
88 tasks can both require attention, or being partly/totally automatic in given conditions (see also Reason,
89 1990; Embrey, 2005). By combining driving task levels and performances having the focus on
90 familiarity (see Aasman and Michon, 1992; Hale et al., 1990), the following dichotomous relationship
91 arises:

- 92 • Familiarity can be related to skill-based task automation, requiring less attention (such as in a
93 commuting travel, while negotiating familiar road elements or operating short-term driving
94 patterns). The switch to automation is possible in the case of familiarity with one or more
95 factors of the road system (i.e. with the road, the vehicle, the environment). However, drivers
96 familiar with these factors can also shift to rule-based behaviours (for example in unfamiliar

97 cars, by applying well-known rules to other vehicles).

- 98 • Unfamiliarity can be related to the knowledge-based driving task consciousness, requiring
99 attention to address the unknown situation (such as being a first-time driver, or while
100 navigating in unfamiliar environments or operating unfamiliar manoeuvres, as skilled
101 drivers).

102 This discrepancy between familiar and unfamiliar drivers in respect to the task automation implies
103 the familiarization process leading unfamiliar drivers to become route familiar, which is then worth
104 being analysed. The habituation process (Fig. 1) is described in the early dual-process theory (Groves
105 and Thompson, 1970, revised by Rankin et al., 2009). People exposed to the same repeated stimulus
106 over time, progressively decrease their response to that stimulus until an asymptotic value is reached.
107 This habituation effect can last for short or long-term periods (even weeks: long-term habituation, see
108 Rankin et al., 2009). However, in the case of a novel stimulus some responses can be recovered: in
109 the so-called dishabituation effect. The response further decays, whether or not the stimulus is
110 maintained.



111 Figure 1. Habituation/Dishabituation effects (based on Groves and Thompson, 1970).

112

113 When driving on the same route in given boundary conditions is the repeated stimulus, then one

114 should expect drivers to get progressively habituated to it. Thus, drivers' responses should
115 asymptotically approach a low level (Fig. 1), at which the mental workload and the attention capacity
116 can be greatly decreased, as explained through the Malleable Attentional Resources Theory (MART)
117 (Young and Stanton, 2002, see also Mahalel and Szternfeld, 1986). However, in a low attention
118 condition, the mind can be unconsciously occupied by non driving-related thoughts: "mind
119 wandering" (see Yanko and Spalek, 2014). Moreover, the less demanding is the driving scenario, the
120 more time may be spent driving with a wandering mind (Geden et al., 2017). Therefore, the acquired
121 route familiarity can possibly foster drivers' distraction, through mind wandering.

122 This possible relationship between route familiarity and distraction may be influential in road safety.
123 In fact, distraction is a crucial causal factor for crashes (see e.g. Singh, 2015; Sandin, 2009; Staubach,
124 2009) and driving errors (Young and Salmon, 2012; based on a previous taxonomy by Stanton and
125 Salmon, 2009). These findings are coherent with the "law of cognitive capacity" (Elvik, 2006): the
126 more cognitive capacity is reduced (in this case through distraction), the more the accident rates
127 increase. Rosenbloom et al. (2007) suggested a two-fold effect of familiarity: it can induce distraction
128 by deteriorating the response to hazardous events, but also lead to overconfidence and risk
129 underestimation (Thurman, 1986; Hamed, 2001). The overconfidence of familiar drivers could be
130 explained by the optimism bias in perceiving accident risks, which increases with driving experience
131 (DeJoy, 1989), and is potentially transferrable to the route familiarity case. Coherently, the perceived
132 involvement of familiar drivers in accidents may be underestimated with respect to that of unfamiliar
133 drivers compared to actual rates (Sticher, 2005). In addition, route familiarity is often mentioned
134 among the self-perceived safest driving conditions (in responses from older drivers: Sullivan et al.,
135 2011). This may also result in overconfidence.

136 Moreover, habituation can also be noted in the case of "behavioural adaptation" (to road changes):
137 *"the collection of unintended behaviours that follows the introduction of changes to the road*

138 *transport systems*” (Rudin-Brown and Jamson, 2013). Drivers’ adaptation is troubling if road safety
139 measures induce negative behavioural changes (e.g. speeding and less concentration in the case of
140 lighting, Assum et al., 1999; or decreasing compliance to enforced speed limits over time, see
141 Montella et al., 2015). Adaptation is possible only if drivers are repeatedly exposed to the
142 countermeasure, then the measure is easily noticed (Elvik, 2004), likely to exclude cases in which it
143 is aimed at reducing crash outcomes (e.g. restraint systems). Route familiar drivers may be
144 particularly subject to adaptation, since they can repeatedly test the new condition (i.e. the safety
145 countermeasure) and get used to it, following the usual habituation process and modifying their
146 behaviour.

147

2.2 Economic aspects of route familiarity

148 The economic aspect focused on risk assessment can give a complementary perspective (see e.g.
149 Colonna et al., 2016). A very simple equation for quantifying the risk R of an event is:

$$R = P \times I \quad (1)$$

150 where: P = Probability of the event, I = Intensity of consequences. It can be measured in terms of
151 losses (such as the cost to society of traffic accidents, see AASHTO, 2010).

152 Road safety measures can reduce the accident probability (e.g. in the case of lighting, Elvik et al.,
153 2009). Drivers who perceive this improvement, could feel safer and modify their behaviour in order
154 to reduce travel times (by driving faster), or mental workloads (by being less focused on driving, as
155 in the case of lighting, Assum et al., 1999). However, these behavioural tendencies are associated
156 with higher risks, able to partially/totally undermine the risk reduction. This phenomenon represents
157 the downside of behavioural adaptation (previously associated with familiar drivers): so-called “risk
158 compensation”. It has been widely documented after introducing several safety measures (see van der

159 Horst, 2013; Vrolix, 2006; for recent example collections). Several frameworks have tried to
160 conceptualize risk compensation through an economic approach (Peltzman, 1975; O’neill, 1977;
161 Dulisse, 1997; Hedlund, 2000; Tarko, 2009; Noland, 2013). A common trait is that drivers, presumed
162 to be rational, can make trade-offs between safety (i.e. accident risk) and other factors (i.e. mobility
163 benefits), for the sake of increasing travel utility, assumed as the reference variable.

164 The formalisation of the perceived utility by Noland (2013) is given as follows:

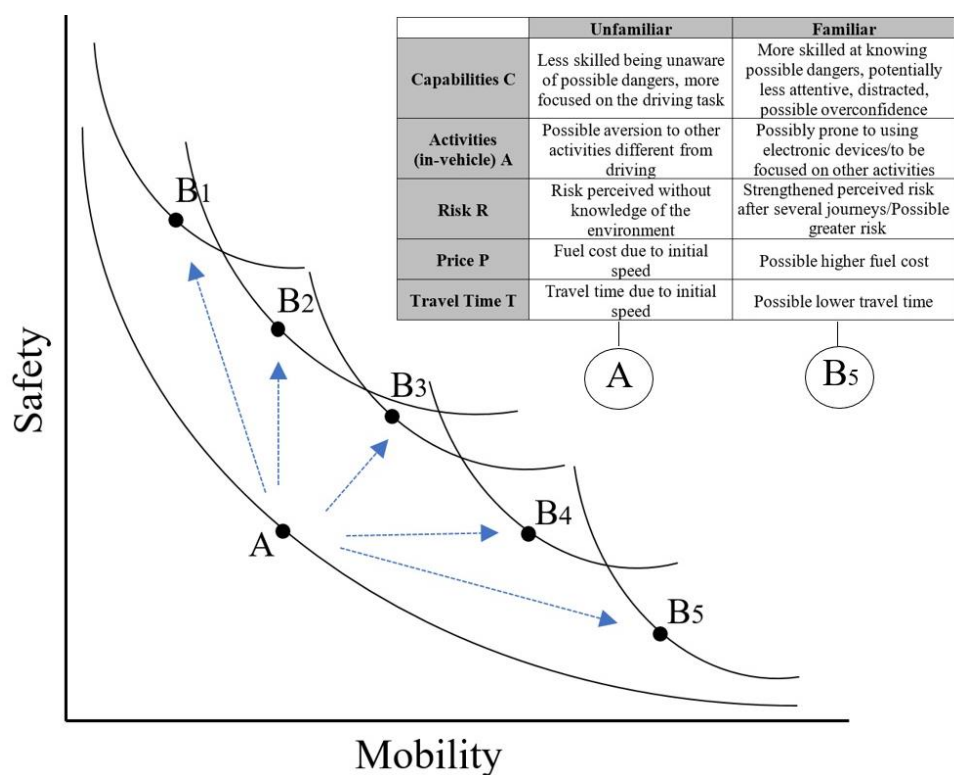
$$165 \quad U = f(P, T, C, A, R) \quad (2)$$

166 where P = Price, T = Travel Time (mobility-related variables); C = driver’s Capability, A = in-vehicle
167 activities, R = Risk (safety-related variables). Drivers seek the maximization of the utility U, by
168 adjusting the variables through their performance.

169 Risk compensation can also be related to the route familiarization process (Intini et al., 2017a), as
170 based on Eq. 2 (see Fig. 2). Drivers could accept more risky behaviours (e.g. speeding, hard braking),
171 to obtain benefits such as decreased travel time (but with a possible fuel cost increase), to increase
172 the perceived travel utility. The process is mainly governed through speed and steering performance.

173 Clearly, the economic perspective should be integrated with behavioural-based theories and not
174 considered as an alternative to them. In fact, models based on rational users searching for utility
175 maximization have been criticized (see e.g. Sen, 1977), and inconsistencies may arise from their
176 application to driving performance. The latter may seem to be rationally determined through defined
177 rules, while the relationships between speed, risk and travel time may be misperceived by drivers
178 (Elvik, 2010). However, learning from experience and subjectivity (e.g. personal differences in
179 perceived utility, see Dulisse, 1997) should also be taken into account. Moreover, drivers may have
180 different target risk levels (Wilde, 1982), as risk perception is influenced by personal factors
181 (Rundmo, 1996; Deery, 2000), emotions and feelings (Damasio, 1994, 2003; Slovic et al., 2004).

182 In fact, the development of driving behaviour is likely to come from trial-and-error stages
 183 (Rasmussen, 1983). For example, by continuously trying and learning from previous experience, the
 184 driver acquires information about the most suitable speed for a given condition, which becomes the
 185 “habitual” speed (Fuller, 2007). Moreover, the “rewarding” speed (allowing the driver to keep control
 186 and avoid collision while pursuing travelling goals) learned for a particular condition can be
 187 potentially transferred to similar situations without trial-and-error (Fuller, 2007). Hence, route
 188 familiar drivers, may feel comfortable in choosing higher speeds (or trade speed for lateral
 189 acceleration at curves, see Herrin and Neuhardt, 1974), which could be perceived as more rewarding,
 190 on road sections similar to familiar sections on which the trial-and-error speed determination stage
 191 has already occurred. This interpretation is coherent with the search for utility goals and the
 192 occurrence of trade-offs, independently from users’ rationality.



193 Figure 2. Trade-offs between safety and mobility (from the driver’s state A on an indifference curve
 194 to different possible states B on other curves), with specific focus on familiarization processes
 195 (possibly from A to e.g. B₅, considering some of the explained theoretical expectations from the
 196 previous section); based on (Noland, 2013)

3. Methods used for the review

197 The methods used for the review of research studies and technical documents which have related
198 route familiarity to road safety are shown in this section.

199

3.1 Review of research studies

200 This part of the review was focused on highlighting the relationships between route familiarity and
201 road safety based on research studies. Studies showing the influence of route familiarity on safety-
202 related driver performances (i.e.: speed, lateral position, responses), perceptions (i.e.: of speed and
203 enforcement, reaction times), and negative outcomes (accidents, violations) were considered.

204 Those studies were found in main scientific databases such as, but not limited to, “Google Scholar”,
205 “Science Direct”, “Transport Research International Documentation-TRID”, in different time
206 intervals. The main keywords used for the searching process, also in combination with logical
207 connectors, were “familiarity” and: “route”, “road”, “safety”, “accident”, “crash”, “driving”. Studies
208 found in the literature were filtered by considering only those in which it was possible to directly
209 associate the drivers’ route familiarity to road safety-based aspects (such as performances,
210 perceptions and negative outcomes). However, some studies were considered even if the inquiry into
211 route familiarity was not their main objective. In these cases, the review was focused on the aspects
212 which clearly suggested evidence of relationships between drivers’ route familiarity and road safety.

213 Research studies were classified according to the main methodology employed, after having scanned
214 the relevant articles selected for the review. Studies were then classified based on the recurrent
215 methodologies used, explained as follows.

- 216 • Direct observations of driving behaviour (“OBS”), further divided according to the
217 instruments used for the experimental research: driving simulators on recreated road scenarios

218 (simulator-based studies: “OBS-SIM”) or instrumented vehicles on real roads (on-road
219 studies: “OBS-ORS”).

220 • Crash database analyses (“CDA”), used to link accident counts, severities or related features
221 to explanatory variables, or to make comparisons between different groups of accident data.

222 • Surveys (“SUR”), focused on specific questions directly asked to drivers and linked to their
223 previous history of accidents or driving behaviour.

224 • Indirect observations of driving behaviour (“IND”) through analyses of telematic data from
225 car insurance, used to link explanatory variables to actual behaviour and accidents recorded.

226 A further selection of articles was conducted for the first two categories of studies, the most numerous.

227 The following “CDA” studies were not reviewed in detail: those in which detailed statistical analyses

228 regarding drivers’ familiarity were not retrieved (e.g. Baldock, 2008; Mishra et al., 2010; Zheng et

229 al., 2010; Sivak and Shoettle, 2010), those based on specific drivers, such as e.g. young or truck

230 drivers (Chen et al., 2009; Knipling, 2009), and on interaction accidents with specific vehicles (e.g.

231 Zhu and Srinivasan, 2011; Magazzù et al., 2006). The following “OBS” studies were not reviewed in

232 detail: those which are mainly based on unfamiliarity with different road regulations rather than only

233 different road environments (e.g. Thompson and Sabik, 2018; Huang et al., 2018), those in which

234 drivers’ perception (e.g. visual perception of road signs) was related to familiarity, without (or only

235 partial) reference to specific explanatory driving tasks or negative driving outcomes (e.g. Mourant

236 and Rockwell, 1970; Johansson and Backlund, 1970; Beijer et al., 2004; Lehtonen et al., 2012; Babic

237 et al., 2017). However, some of these studies were further referenced, where relevant.

238 This classification into categories of studies was carried out to allow consistent comparison and

239 interpretation of different findings from studies which have used similar methodologies and variables.

240 For the sake of consistent comparisons, the observed, measured or deduced variables considered by

241 the authors of the studies were specifically reported for each of the reviewed studies.

242 Moreover, the criterion used for the identification of drivers' familiarity is a crucial methodological
243 issue. In fact, this was found to vary greatly between the selected studies. Two main criteria based on
244 different scales were used to identify drivers' familiarity:

245 • A frequency-based scale (i.e.: having previously driven a route from more than once a day to
246 never).

247 • A distance-based scale (i.e.: from drivers close to home to foreigners).

248 On both scales, a driver can become route familiar due to repeated exposition. However, the first
249 scale (frequency-based) directly identifies familiarity, by interviewing drivers about their travelling
250 frequency on a given road or by inducing familiarity through repeated driving tests on the same route
251 (and observing behaviours). The second scale (distance-based) indirectly identifies familiarity
252 instead. Information concerning familiarity is typically deduced from specific variables in the
253 database available (e.g. nationality, zip codes), without direct interviews/observations. Given that the
254 main findings of the reviewed studies are evidently based on how drivers' familiarity was identified,
255 the criterion used for the identification was also explicitly reported for each of the reviewed studies.
256 This is useful for the further attempt at defining a harmonized criterion for identifying drivers'
257 familiarity in future studies, as discussed later. However, the conditions of familiarity and
258 unfamiliarity were not always explicitly defined in the reviewed studies. In these cases, the exact
259 definitions were deduced from the methodological assumptions made. For example, in the case of
260 experimental designs requiring several tests on the same drivers on given routes, the basic implicit
261 unfamiliar condition deduced is being a "first time driver" of that route.

3.2 Review of technical documents and related studies

262 The second part of the review focuses on highlighting the relationships between route familiarity and
263 road safety, based on technical documents from road and traffic engineering practice, namely
264 standards, guidelines and technical reports. Hence, some technical documents which explicitly (or
265 implicitly) consider the influence of drivers' route familiarity on road and traffic engineering
266 applications and frameworks, potentially having implications for safety, were considered. The safety
267 implications of the statements and arguments reported from the technical documents are further
268 presented in the discussion section, by referring to studies from the scientific literature. They may
269 also help to explain the recommendations/provisions from the technical documents selected.

270

4 Results from the review

271 The results from the review conducted are reported as follows, by dividing the presentation according
272 to the two main subjects of the review methodology: 1) research studies, 2) technical documents.

273

4.1 Results from the review of research studies

274 The main findings from the review of research studies are summarized in the following Table 1.
275 Since, as previously indicated, the type of study, the variables considered, and the specific criterion
276 used for identifying drivers' familiarity are important for the further comparison of results and related
277 discussion, they are explicitly reported in separate columns, alongside the main findings. In the
278 column including information on the familiarity identification, the criteria used in the reviewed
279 studies are reported in different types, depending on their coherence with the proposed harmonized
280 criteria further presented in Table 3: **bold** if coherent, underlined if partially/potentially coherent.
281 This aspect is discussed in Section 6.

282 As emerges from Table 1, the studies reviewed are from countries in Europe, North America, Asia
 283 and Oceania. It should be noted that studies conducted in the United Kingdom, Japan, Australia and
 284 New Zealand were in the presence of traffic driving on the left (right-hand drive vehicles). However,
 285 familiarity of drivers repeatedly subject to stimuli in the same environment may likely display its
 286 effects independently of left or right-hand traffic.

287 Survey-based studies are rare, potentially depending on the difficulty of collecting familiarity-related
 288 driving aspects (and/or associated to previous crashes) only from surveys. Surveys or questionnaires
 289 have proved to be a powerful complementary tool to reveal familiarity-related aspects of experimental
 290 tests (see e.g. Burdett et al., 2018a). Similarly, only one study based on the analysis of telematic data
 291 from car insurance was found.

292

293 Table 1. Research findings relating drivers' route familiarity to driving performances and negative
 294 outcomes.

Authors (Year) Country)	Type of study (CDA = Crash Database Analysis, OBS-ORS = On- Road Observations, OBS-SIM = Simulator-based Observations, SUR = Survey-based, IND = Indirect Observations)	Variables	Criterion used for identifying Familiarity (F = Familiar, U = Unfamiliar) Bold or underlined if, respectively, coherent or partially/potentially coherent with the criterion further proposed in this study	Main Findings
Donaldson et al. (2006) (USA)	CDA	Crash variables Severity	-distance-based- F: environment of residence (urban/rural) U: environment different than that of the residence	Even if rural residents were found to be over-involved in fatal rural road crashes ¹ , urban residents have the highest fatality risk in rural crashes compared to urban ones.
Wilks et al. (1999) (Australia)	CDA	Crash types	-distance-based- <u>F: country resident</u> U: foreigner	Over-representation of foreigners in angle, sideswipe and head-on crashes, over-representation of resident drivers in crashes with fixed-objects, pedestrians, parked vehicles and animals.

Yannis et al. (2007) (Greece)	CDA	At fault driver Crash variables	-distance-based- F: <u>country resident</u> U: <u>foreigner</u>	Foreign drivers are more likely to be at fault in crashes. The road elements associated to greater accident risks for them are junctions. Area types and lighting do not seem influential.
Yan et al. (USA) (2005)	CDA	At-fault driver Crash dynamics (rear-end) Crash variables	-distance-based- Categorical scale variable for drivers' familiarity: from 1 for county residents to 4 for other country residents	Decreasing levels of familiarity (from county residents to foreigners) are associated to higher likelihoods of being involved in rear-end crashes at signaled intersections while both striking and being struck, as emerged from logistic regression models taking into account several variables.
Kim et al. (2012) (USA)	CDA	At-fault driver Crash types	-distance-based- F: <u>country resident</u> U: <u>foreigner</u>	Foreign drivers are more likely to be involved in at-fault crashes. They are associated to accident causation due to improper manoeuvres or wrong way (based on logistic regression).
Yoh et al. (2017) (Japan)	CDA	Crash types Crash variables Traffic violation	-distance-based- F: <u>country resident</u> U: <u>foreigner</u>	Foreign drivers are more likely to commit traffic violations related to comprehension (e.g. of road signs) than resident drivers, who comparatively commit more violations related to speed (and priority to a lesser extent).
Harootunian et al. (2014a,b) (USA)	CDA	At-fault driver Crash types Crash variables	-distance-based- F: <u>state resident</u> U: <u>out-of-state resident</u>	Out-of-state drivers were found to be more likely to be at-fault, especially in single-vehicle crashes. Even with local differences, some crash factors are more associated to out-of-state drivers (e.g. curves, low lighting, wet pavements, etc.).
Burdett et al. (2017, 2018a) (New Zealand)	CDA	Crash variables	-distance-based- continuous scale (distance from residence)	Drivers are more prone to crash close to home when considering both travel and crash data (higher percentage of crashes compared to total journeys in the same radius of 11 km from home). Close to home crashes are over-represented on low-speed urban roads, more associated to inattention (lapses) than violations. Low-speed urban accidents due to lapses of attention occur more at minor and mid-blocks than at major intersections.
Intini et al. (2017b, 2018) (Norway)	CDA	Crash types Crash dynamics Crash variables	-distance-based- F: ≤ 20 km from residence U: ≥ 200 km from residence	Familiar drivers are more involved in rear-end crashes (more being struck than striking), in crashes at low speed limit rural sections, at minor rural intersections and while commuting rather than working. Unfamiliar drivers are more likely to be found at sites with high seasonal traffic variations in summer, and in crashes involving heavy vehicles (based on statistical tests). After reconstruction of accidents at the micro-scale, crashes involving familiar drivers are mostly rear-end crashes (even if based on a small sample).
Rosenbloom et al. (2007) (Israel)	OBS- ORS	Traffic violation Dangerous behaviours Speeding tendency	-frequency-based- F: <u>familiar with the location</u> U: <u>unfamiliar with the location</u>	Drivers (female) perform more traffic violations (including speeding) and dangerous behaviours while traveling on roads in well-known familiar locations than in unfamiliar ones.

Colonna et al. (2016b) (Italy)	OBS-ORS	Speed Sight Distance Speeding tendency	-frequency-based- F: having driven the test route 4 times in 4 subsequent days U: first day driving	Drivers more familiar with the route travel at higher speeds, especially those showing greater speeding tendency. The speed increases regardless of sight distances. Part of the speed increase was recovered after stimuli interrupted some drivers, and part was also maintained in the long-term.
Colonna et al. (2015, 2016c) (Italy)	OBS-ORS	Curve Trajectories Speed self-perception	-frequency-based- F: having driven the test route 4 times in 4 subsequent days U: first day driving	Drivers who were more route familiar show emphasised curve cutting tendency, even if the trajectory radii are already higher than curve radii in the first test. They freely choose speeds similar to those perceived by themselves as high, rather than medium. The opposite tendency is noted in the first test.
Burdett et al. (2018b)(New Zealand)	OBS-ORS	Self-reported thoughts Difficulty ratings	-frequency-based- F: <u>familiar with the location</u> U: <u>unfamiliar with the location</u>	Eleven female drivers observed during ten trips on their home-work routes reported mind wandering in 63 % of total cases (question asked by experimenters multiple times per trip). More attention was reported in the case of demanding tasks.
Young et al. (2017) (UK)	OBS-ORS	Eye fixation	-frequency-based- F: having driven 28 times over several weeks U: first day driving	Off-road dwell time generally increases with road familiarity and dwell time on safety-related aspects on the road ahead generally decreases with road familiarity (except in the open suburban scenario). These results are based on one professional driver who drove on five types of roads.
Wu and Xu (2018) (USA)	OBS-ORS ²	In-vehicle activities Speed Deceleration distance	-frequency-based- F: intersection travelled > 52 times per year U: intersection travelled only once a year	Distracted driving activities and duration of these activities were found to be higher on familiar than on unfamiliar roads. Drivers were more likely to be speeding and decelerating at shorter distances from intersections on familiar roads. These results are based on naturalistic data of drivers crossing a high-risk intersection with different yearly frequencies.
Martens and Fox (2007) (Netherlands)	OBS-SIM	Glance duration Response to Speed changes	-frequency-based- F: having driven 23 times in 5 subsequent days U: first time driving	Duration of glances at road signs decreases while drivers are becoming route familiar, while speed increases. Most drivers fail to notice a change of an intersection priority on the fifth test day.
Bertola et al. (2012) (USA)	OBS-SIM	Speed Lateral Position	-frequency-based- F: having driven 7 times more than unfamiliar drivers U: having driven 7 times in the same day	Speeds and standard deviations of lateral position higher for familiar drivers than the group of “unfamiliar” drivers.
Charlton and Starkey (2013) (New Zealand)	OBS-SIM	Difficulty ratings Detection tasks Speed Lateral position Response to changes	-frequency-based- F: 20 journeys over 3 months U: first time driving	Difficulty ratings, items reported as unusual, speed and lateral position variance generally decreased, and average speeds increased, while becoming route familiar (and compared with a control group of unfamiliar drivers). Detection tasks were more successful for guidance-related items (markings or vehicles). These effects were generally lost when unfamiliar road scenarios were presented in the 8 th test ³ .
Yanko and Spalek (2013, 2014) (Canada)	OBS-SIM	Reaction time Peripheral response Self-reported thoughts	-frequency-based- F: having driven 4 times in the same day U: first time driving	The group of familiar drivers show longer reaction times both for braking and for noting lateral obstacles, and shorter headways than the unfamiliar group.

				When controlling for the influence of mind wandering, drivers who reported mind wandering were found to show longer response times, higher speeds and shorter headways than drivers who reported being focused on the driving task.
Harms and Brookhuis (2016) (Netherlands)	OBS-SIM	Speed Response to changes Detection tasks	-frequency-based- F: having driven 18 times in 5 days U: first time driving	Most of drivers familiar with a simulated motorway section failed to respond to a road change (increased variable speed limit), the latter drivers showing average speeds higher than drivers who have noticed the change. Speed increased with familiarity and then stabilized. Verbal reports concerning events which caught drivers' attention decrease with familiarity, except for the specific task of detecting a truck, the score for which increases instead.
Martens (2017) (Netherlands)	OBS-SIM	Speed Response to changes	-frequency-based- F: having driven 18 times in the same day U: first time driving	Most of drivers failed to respond to a road change (conversion of a road into a no-entry road), in both conditions of exactly the same road and of similar roads repeatedly travelled before the change. This result is based on drivers divided into different test scenarios, considering also the base no-change condition. A general auditory in-vehicle warning was found to reduce the failure to respond, while speeds increase over the consecutive drives tested in a short time period.
Baldock et al. (2005) (Australia)	SUR	Crash dynamics (Rear-end)	-frequency-based- F: daily travelling U: not applicable	Over-representation of drivers travelling daily on a road being struck on that road; in comparison with daily-frequency drivers striking (based on few interviews).
Liu and Ye (2011) (USA)	SUR	Crash types	-frequency-based- F: at least monthly travelling <u>U: rarer than monthly travelling</u>	Drivers travelling on familiar roadways are more likely to be involved in run-off road crashes (64 % of single-vehicle crashes of familiar drivers are run-off road, compared to 54 % of the unfamiliar ones).
Ryeng (2012) (Norway)	SUR	Enforcement perception	-frequency-based- F: at least biannual travelling U: less than biannual travelling	Drivers more familiar with the investigated sections make slightly better estimates on the actual enforcement on the sections with high enforcement levels.
Jin et al. (2018) (China/USA)	IND	Driver and vehicle variables Telematic data (e.g. speed, acceleration, road familiarity)	-frequency-based- Continuous scale, resulting in two predictor variables: percentage of roads travelled by 1-2 times or between 3 and 8 times in one month	Drivers who are more familiar with their driving routes are less likely to report accidents, as a result of logistic regression models. Familiarity is a significant factor for both high and low-risk drivers, based on latent class models.

295 ¹see Blatt and Furman (1998), who found over-involvement of rural/small town residents and urban residents in rural and urban fatal
296 road crashes, respectively.

297 ²Naturalistic data were used in this study, it not being a typical experimentally designed on-road study.

298 ³Results from a pilot study conducted with a similar study design were shown in Charlton and Starkey (2011).

299

4.2 Results from the review of technical documents

300 The main aspects highlighted from the review of technical documents are summarized in the
301 following Table 2.

302 In particular, the main retrieved statements/arguments documenting the consideration of the drivers’
 303 route familiarity in safety-related aspects of the road and traffic engineering practice, or which may
 304 be related to this relationship, are reported. Apart from this information, the table includes the
 305 following variables (reported in separate columns): information about the authors of the documents,
 306 reference area of the engineering practice (road or traffic), type of document (standards, guidelines,
 307 technical reports), type of reference to drivers’ route familiarity (explicit or implicit).

308

309 Table 2. Main road safety-based statements/arguments in some road and traffic engineering technical
 310 documents which may be explicitly or implicitly related to drivers’ route familiarity.

Author (Year) (Country)	Engineering Area	Type of document	Reference	Relevant statements/arguments ¹
Milliken et al. (1998) (USA)	Road	Technical Report	Explicit	“The designer should assume that motorists are driving on a roadway for the first time and that they have no familiarity with its features”
Wooldridge et al. (2003) (USA); MdE/SETRA (1994) (France); MIT (2001) (Italy); FGSV (2008) (Germany); Lamm et al. (1999) (Germany)	Road	Standards/ Guidelines/ Technical Report	Implicit	Road design consistency. It is defined as the “conformance of a highway’s geometric and operational features with driver expectancy” (Wooldridge et al., 2003). Elements of the road alignment and their associated speeds should be harmonized and not greatly different from the previous ones, in order to possibly avoid surprises (e.g. sudden sharp curves after long tangents; subsequent radii).
MdE/SITRA (1994) (France); MIT (2001) (Italy); CSIR (2000) (South Africa); MdE/SETRA (1994) (France); FGSV (2008) (Germany)	Road	Standards/ Guidelines	Implicit	Element lengths. Maximum and minimum lengths may be set for tangents based on speeds, to avoid: drivers’ misperceptions and inappropriate trajectories (for short tangents between curves), speeding, distraction, and/or fatigue (for long tangents). Minimum curve lengths may be required to avoid misperceptions, incorrect trajectories.
Lamm et al. (1999) (USA); MIT (2001) (Italy)	Road	Standards/ Guidelines	Implicit	Friction. An appropriate level of road friction is required in calculations of road design parameters.
MIT (2011) (Italy); Krammes and Garnham (1998) (USA); Fitzpatrick et al. (2003) (USA); Milliken et al. (1998) (USA); AASHTO (2001) (USA); ITE (2016) (USA); Donnell et al. (2009) (USA); Lamm et al. (1999) (Germany); DTMR (2013) (Australia)	Road/Traffic	Standards/ Guidelines/ Technical Report	Implicit	Speeds. The relationships between design, operating and posted speeds should be controlled. Operating speeds (usually measured through the 85 th percentile speed) should not be substantially different from design speeds, considered as safe for ideal design drivers on each road element. The posted speed should generally be coherent with the 85 th percentile speed.
TRB (2016) (USA)	Traffic	Guidelines	Explicit	In the case of a significant presence of unfamiliar drivers in the traffic flow, both design capacity and free flow speeds may be reduced through appropriate factors accounting for the different

				composition of the driver population. The greater the number of unfamiliar drivers there are in the flow, the more free flow speed and capacity may be reduced, with respect to the “all familiar drivers/regular commuters” condition.
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311 ¹Relevant statements are summarized according to some recurrent topics from the different considered sources, while each of them
312 may contain only part of the summary.
313

314 Possible relationships between route familiarity and safety-based concepts in road/traffic engineering
315 practices are reported in Table 2. Most of the statements/arguments reported for the road design
316 aspects are generally valid in several countries. Hence, examples of standards, guidelines and
317 technical reports which cover them, mainly from North America and Europe are provided.

318 Explicit references to the drivers’ route familiarity were found in documents belonging to both the
319 road and traffic engineering practice. However, most of the possible relationships between the aspects
320 highlighted in Table 2 and the influence of route familiarity in road safety are only implicit. Hence,
321 they are highlighted and discussed in the next section.

322

5 Discussion

323 The findings presented in both Table 1 and Table 2 are discussed in this section. The discussion is
324 structured according to the two aims of this study: the explanation of the relationships between
325 drivers’ route familiarity and road safety, and the attempt at identifying route familiarity by means of
326 the frequency and distance-based criteria. The further proposal for identifying drivers’ route
327 familiarity is mainly based on the discussion of identification criteria used in previous studies.

328

5.1 Discussion on the relationships between route familiarity and road safety

329 The discussion is divided according to the two main categories of documents reviewed: research
330 studies and technical documents. In both cases, the relationships between route familiarity and road
331 safety are explicitly explained, since these are often only implied in the findings highlighted from the

332 review conducted.

333

5.1.1. Discussion based on research findings

334 Research findings reveal some important safety-based aspects related to route familiarity, which were
335 consistently found in the documents reviewed: the proneness of familiar drivers to be less focused on
336 the driving task, their propensity for aggressive driving performances, and the increased likelihood
337 of unfamiliar drivers to be at fault in crashes. Those three aspects are discussed in detail as follows:

338 • Familiar drivers may be less focused on driving tasks, as emerges from studies in which driving
339 behaviour was directly observed (on-road/simulator-based). The decreased attention was
340 associated to mind wandering (Yanko and Spalek, 2014; Burdett et al., 2018a); distracted driving
341 activities (Wu and Xu, 2018); both actual and potential impairment in reacting to environmental
342 inputs, such as increase in dwell times (Young et al., 2017) and reaction times (Yanko and Spalek,
343 2013), decrease in duration of glances at road signs (Martens and Fox, 2007). This tendency is
344 explainable through several psychological frameworks, which associate familiar driving to
345 automatic processes (Rasmussen, 1983; Reason, 1990; Embrey, 2005, Charlton and Starkey,
346 2013. 2018). The familiarization process may lead drivers towards a habituated state, due to the
347 repeated application of the same stimulus (Groves and Thompson, 1970; Rankin et al., 2009),
348 leading to reduced mental workload and attention (Young and Stanton, 2002). The gradual
349 process leading to habituation is documented in studies that monitored key variables during the
350 familiarization process. For example, Charlton and Starkey (2013) found that difficulty ratings
351 associated to each drive and items reported as unusual (see also Harms and Brookhuis, 2016)
352 decreased with route familiarity. Moreover, the acquired familiar drivers' reduced attention was
353 related to failure to respond to changes, such as to road signs (Martens and Fox, 2007), or variable
354 speed limits (Harms and Brookhuis, 2016). In addition, the relationship between familiarity and

355 possible over-involvement in distracted driving activities (Wu and Xu, 2018) is another safety
356 concern, since distraction was consistently related to errors (Young and Salmon, 2012) and
357 crashes (Sandin, 2009; Staubach, 2009). On the other hand, familiar drivers may still focus on
358 demanding tasks (Burdett et al., 2018a) for which “automated” driving may not be adopted, or
359 on specific guidance-related tasks/items, such as detecting vehicles (Charlton and Starkey, 2013,
360 Harms and Brookhuis, 2016). Charlton and Starkey (2013) explain this through two layers
361 present in familiar drivers: one level of inattention blindness due to the automatic process and
362 one level of awareness of some momentary tasks necessary for driving. Another important aspect
363 was suggested by Martens (2017): the effects of familiarity (leading to failure in responding to
364 changes) were noted on roads similar to those on which the familiarization process occurred, but
365 not being strictly limited to them.

366 • Familiar drivers may be more prone to more dangerous driving performances, as another side of
367 the familiarization process. Speeding tendencies (Rosenbloom et al., 2007; Colonna et al., 2016b;
368 Wu and Xu, 2018); traffic violations (Rosenbloom et al., 2007); increase in curve cutting
369 behaviours or higher standard deviations of lateral positions than unfamiliar drivers (Colonna et
370 al., 2016c; Bertola et al., 2012); decelerating at shorter distances from the target point (Wu and
371 Xu, 2018); underestimation of their speeds (Colonna et al., 2015) were all phenomena associated
372 to familiar drivers in studies focused on direct behavioural observations. Moreover,
373 independently of the type of study (i.e. on-road or simulated driving) and the number and interval
374 of test repetitions, speed was consistently found to increase over time with acquired familiarity
375 (Martens and Fox, 2007; Charlton and Starkey, 2013; Harms and Brookhuis, 2016; Colonna et
376 al., 2016b; Martens, 2017). Speeds were found to stabilize after an initial growth in the first test
377 repetitions in at least two studies (Harms and Brookhuis, 2016; Colonna et al., 2016b, even if in
378 the latter study, there were pauses between subsequent tests). The phenomenon of speed increase
379 and further stabilization at a constant value can be equated to the habituation process (Groves

380 and Thompson, 1970; Rankin et al., 2009), which can occur by driving the same route several
381 times. In this case, speed increase does not necessarily mean increasing tendency for speeding:
382 i.e. the increased familiar speed may still be lower than the speed limit. However, higher speeds
383 are associated to higher crash likelihood (Elvik, 2013; Nilsson, 2004). Hence, the familiar speed
384 increase may be related (Intini et al., 2017a) to typical trade-offs (Noland, 2013) between safety
385 (more risks) and mobility (shorter travel time), for the sake of higher utility. Similarly, curve
386 cutting tendencies may also lead to a decrease in travel times but a risk increase. Moreover,
387 familiar drivers were also associated to inattention blindness, distraction, mind-wandering and
388 task automation. These tendencies may seem diametrically opposed to the previously highlighted
389 more dangerous behaviours, but they are connected however. In at least three studies reviewed
390 (Charlton and Starkey, 2013, Yanko and Spalek, 2014; Harms and Brookhuis, 2016), the increase
391 in speed occurred in parallel with a documented decrease in attention capacity. Findings from
392 Yanko and Spalek (2014) demonstrated that drivers were more prone to higher speeds and shorter
393 heading distances when subjected to mind wandering than when driving focused. They suggest
394 that being less aware of the environment; drivers may also be less concerned with applying safety
395 margins while driving. In parallel, the increased speed may result from the familiarization process
396 after subsequent refinements (Harms and Brookhuis, 2016), in a trial-and-error fashion (Fuller,
397 2007), when the attention capacity is still greater than in the case of mind wandering. It should
398 be noted that drivers are generally more prone to crash close to home (Burdett et al., 2017) or in
399 the same rural/urban environment as their residence (Blatt and Furman, 1998; even if Donaldson
400 et al., 2006, point out that urban residents have higher fatality rates in rural compared to urban
401 crashes). Part of these results may also be interpreted in light of the familiar tendency towards
402 more dangerous behaviours. However, data exploration by Burdett et al. (2018b) revealed that
403 most close-to-home crashes (clustering at low-speed urban roads) were more associated to lapses
404 of attention than violations. Based on this, distraction may be more influential than dangerous

405 behaviours on crashes. However, further evidence is needed for this crucial deduction.

406 • Unfamiliar drivers were found to be more likely to be at fault when involved in crashes. Improper
407 manoeuvres, wrong way (Kim et al., 2012) or junction-related crashes (Yannis et al., 2007) were
408 specifically related to foreigners, typically unfamiliar with foreign roads. Similarly, out-of-state
409 (Vermont, USA) drivers (Harootunian et al., 2014), were found to be over-involved in at-fault
410 crashes, especially for single-vehicle accidents and in winter. Unfamiliar drivers may suffer from
411 orientating in foreign environments (see also Leviäkangas, 1998), possibly resulting in improper
412 manoeuvres leading to crashes. In Yoh et al. (2017), foreign drivers in Japan were associated to
413 more violations related to comprehension (e.g. of road signs) than residents. If the foreign
414 environment has unfamiliar way of traffic (e.g. left-hand), this may be an additional factor (see
415 e.g. Thompson and Sabik, 2018; Malhotra et al., 2018), such as while interpreting results from
416 Wilks et al. (1999), related to accidents to foreign drivers in Australia. These findings are
417 coherent with common sense expectations, but unfamiliar drivers could have similar problems
418 only in some environments. Yannis et al. (2007) found e.g. that foreign drivers are over-exposed
419 to at-fault crashes especially at junctions (see also Wilks et al., 1999 for angle crashes and Yan
420 et al., 2005, for rear-end crashes at signaled intersections), which may be demanding road
421 elements, leading unfamiliar drivers to errors. Foreigners were also found to be over-represented
422 in angle, sideswipe, head-on crashes (Wilks et al., 1999), and unfamiliarity may then have been
423 a contributory factor. An inverse relationship between familiarity and accident reporting was
424 found by Jin et al. (2018) as well, even it is hardly comparable with previously cited results.

425 Whereas, when it comes to the involvement of familiar and unfamiliar drivers in specific types of
426 crashes, it is hard to find common traits among the reviewed studies. Familiar and unfamiliar drivers
427 were associated to different crash types (Wilks et al., 1999; Baldock et al., 2005; Liu and Ye, 2011;
428 Yan et al., 2005; Intini et al., 2017b, 2018). However, the design of these studies and the familiarity

429 identification criteria were different. It is worth noting that at least two studies (Baldock et al., 2005;
430 Intini et al., 2018) revealed an over-involvement of familiar drivers in rear-end accidents, (being
431 struck more than striking). The over-involvement of familiar drivers in rear-end accidents may be
432 explainable through their possible greater tendency to shorter headways (see e.g. Yanko and Spalek,
433 2013), or to brake at shorter distances from the target point (i.e. an intersection in: Wu and Xu, 2018).
434 Conversely, Yan et al. (2005) related rear-end accidents to unfamiliarity in case of signalized
435 intersections. Other similarities concern the lower tendency of unfamiliar drivers to run-off accidents
436 with respect to familiar drivers (Liu and Ye, 2011, Intini et al., 2018). However, these studies differ
437 in the familiarity scales adopted. Hence, investigation into relationships between route familiarity and
438 crash types should be surely deepened.

439

5.1.2 Discussion based on the review of technical documents

440 As a result of the review of technical documents (see Table 2), some important safety-based aspects
441 emerge in considering the influence of route familiarity. However, except for some specific cases
442 (e.g. Milliken et al., 1998; TRB, 2010), the influence of route familiarity in engineering standards,
443 guidelines and reports is not explicitly stated. Hence, these possible relationships are suggested in
444 this section, especially from the road engineering side, through using findings from relevant research
445 studies.

446 As emerges from Table 2, several road geometric design rules are essentially driver-based and some
447 of them may be associated to route familiarity. The road layout should ideally induce safe behaviours
448 through its own features by meeting drivers' expectations: the concept of "self-explaining road"
449 (Theeuwes and Godthelp, 1995; see Charlton et al., 2010; Mackie et al., 2013; for some applications).
450 Following from this, road design consistency (see Wooldridge et al., 2003) is a strictly user-based
451 crucial safety aspect (Gibreel et al., 1999; Ng and Sayed, 2004; Dell'Acqua et al., 2013), considered

452 in several road design standards and guidelines. The requirements of road design guidelines, ensuring
453 that the road geometry should be consistent and not surprising for design drivers, imply assuming
454 that they are road unfamiliar, as explicitly stated by Milliken et al. (1998). This is clearly
455 understandable, since a familiar driver might know the pitfalls of a road layout very well due to long
456 previous association (except for rapid changes in boundary conditions). On the other hand, unfamiliar
457 drivers can be surprised by demanding and not self-explaining layouts (such as sharp curves after a
458 sequence of smooth curves) possibly leading to improper manoeuvres with crash outcomes (Kim et
459 al., 2012). This may imply that drivers' familiarity could prevent accidents on particularly non self-
460 explaining road sections. Familiar drivers may be able to keep road geometric elements in their
461 memory even after long periods (Colonna et al., 2016b) and provide higher perceived risk ratings in
462 some instances of demanding road curves (Kanellaidis et al., 2000). Moreover, they may be
463 particularly attentive to guidance-related items (Charlton and Starkey, 2018), and form specific
464 mental schemes of different road types and associated speeds (Charlton and Starkey, 2017a,b).
465 However, the greater road knowledge with respect to unfamiliar drivers may be compensated by other
466 behavioural tendencies previously discussed, such as mind wandering (Yanko and Spalek, 2013)
467 distracted driving and more dangerous behaviours (e.g. Wu and Xu, 2018). Liu and Ye (2011) found
468 that familiar drivers were more prone than unfamiliar drivers to run-off-road crashes, of which a large
469 share usually occurs at curves. With no additional information about road layouts and other boundary
470 conditions at which crashes occurred, it is difficult to state whether being familiar was a preventive
471 or contributory crash factor. Moreover, familiar drivers were more associated to crashes on roads
472 (Burdett et al., 2017) and environments (Blatt and Furman, 1998; Ryan et al., 1992; Lu et al., 2000)
473 they are likely to know best.

474 Some road design standards/guidelines set minimum tangent and curve lengths to prevent steering
475 errors. This is referred to a design driver, assumed to be unfamiliar, the most exposed to
476 misperceptions due to ignorance of the road. Conversely, setting maximum tangent lengths could

477 help prevent monotony, fatigue (Lamm et al., 1999), and distraction. Both familiar and unfamiliar
478 drivers could benefit from this setting. However, since familiarity is related to both speeding and
479 distraction, preventing high speeds and/or possible distraction by limiting tangents could be
480 specifically helpful for them. Design guidelines usually impede excessive acceleration/braking
481 between subsequent elements, based on design speeds (see e.g. MIT, 2001). High speed differences
482 (e.g. between a tangent and the sharp curve ahead) could be specific issues for unfamiliar drivers who
483 cannot expect the required speed change. They could suddenly brake or not match the appropriate
484 curve speed. The same remark is valid for intersections or driveways (i.e. unexpected or poorly
485 visible). The latter suggestion is supported by the over-involvement of foreign drivers in angle (Wilks
486 et al., 1999, mostly related to intersections) and junction crashes (Yannis et al., 2007).

487 Features of road elements are internationally designed based on design speeds. However, if operating
488 speeds are significantly higher than design and posted speeds, this could be a safety concern
489 (Fitzpatrick et al., 2003). Considering the driving behaviour, the speed is determined through trial-
490 and-error based on experience (Rasmussen, 1983), and familiar drivers may travel at their subjective
491 maximum “safe” speed. This speed can be higher than speed limits because of trade-offs between
492 risks (e.g. perceived crash and speed ticket risks, Tarko, 2009) and mobility benefits (Noland, 2013).
493 Conversely, unfamiliar drivers could still not have a clear perception of road risks, by not travelling
494 at the optimum safe perceived speed. This means that consistency criteria for design, operating and
495 posted speeds can be considered as mainly focused on increasing familiar drivers’ safety. They are
496 indeed related to speeding and crashes at more familiar locations (Rosenbloom et al., 2007; Blatt and
497 Furman, 1998).

498 Concerning friction, drivers normally notice skidding when it is happening (Colonna et al., 2016d,
499 2018b), potentially being a problem regardless of familiarity. However, on one hand, familiar drivers
500 may have knowledge of specific road sites where the road usually become slippery; on the other hand,

501 skidding could occur to unfamiliar drivers because of speed errors while approaching unexpected
502 curves. The previously determined safe speed of familiar drivers may prevent skidding, except when
503 boundary conditions suddenly change and they do not react accordingly. This latter suggestion is
504 related to the higher proneness of familiar drivers to run-off crashes than those classified as unfamiliar
505 (Liu and Ye, 2011).

506 A significant presence of unfamiliar (recreational) drivers in the traffic flow is deemed to possibly
507 reduce both the free flow speed and the capacity of multi-lane highways and freeways (TRB, 2016).
508 This is coherent with the expectations for unfamiliar drivers: they may select lower speeds than
509 familiar drivers (possibly leading to an average speed decrease but a speed variance increase) and can
510 be less prone to close car-following through longer headways (hypothesis reported e.g. by Seeherman
511 and Skabardonis, 2013, who however highlight that further research is needed) than familiar drivers,
512 leading to capacity reduction. The presence of various traffic components (i.e. familiar and unfamiliar
513 drivers) in the flow may be implicitly influential on safety, as well as capacity. In fact, they may show
514 different behaviours in terms of speed, lateral position, acceleration, braking, etc., as previously
515 discussed. A mix of familiar and unfamiliar drivers was associated to a higher speed variance, which
516 in turn could be related to a higher accident risk (Garber and Gadirau, 1988). Moreover, a higher
517 variance of gaps (unfamiliar drivers may select greater gaps) between vehicles could induce following
518 drivers to overtake, leading to more potential conflicts. This in turn could possibly lead to more
519 accidents at different road sites (Fazio et al., 1993; Dijkstra et al., 2010; Lu et al., 2011). However,
520 the possible factors involved are various and they are interdependent. For example, an average flow
521 speed reduction could instead result in a crash reduction (Nilsson, 2004; Elvik, 2013). Nevertheless,
522 the interaction between familiar and unfamiliar drivers may represent a safety concern, as indicated
523 above. However, this topic has scarcely been addressed. Some previous findings (Baldock et al.,
524 2005; Intini et al., 2017b, 2018) reveal an over-involvement of familiar drivers in accidents in which
525 interactions with other vehicles occurred. However, no significant specific interactions between

526 familiar and unfamiliar drivers were noted by analysing a sample of two-lane rural road crashes (Intini
527 et al., 2018). Hence, further specific studies are needed, especially for multi-lane roads, where
528 interactions are greater.

529

5.2 Discussion of the criteria used for identifying drivers' familiarity

530 The criteria used for identifying drivers' familiarity in the studies reviewed were classified into
531 frequency-based and distance-based criteria.

532 In "OBS" studies (direct observations), the behaviour of familiar drivers is necessarily compared with
533 unfamiliar drivers' behaviour, or the possible changes during/after the familiarization process are
534 observed. This is addressed in four basic ways:

- 535 1) by comparing the condition of acquired familiarity with the initial unfamiliarity condition for
536 the same drivers (e.g. in Colonna et al., 2016b; Young et al., 2017; Martens and Fox, 2007)
537 or by observing the behaviour of drivers who have become familiar in the tests (e.g. in
538 response to changes, see Martens and Fox, 2007; Harms and Brookhuis, 2016);
- 539 2) by comparing drivers who acquired familiarity after test repetitions with drivers who only
540 drove once or less than familiar (e.g. in Bertola et al., 2012; Yanko and Spalek, 2013; Charlton
541 and Starkey, 2013);
- 542 3) by comparing drivers already familiar with a given condition (e.g. given locations, as in
543 Rosenbloom et al., 2007; Wu and Xu, 2018) with the same drivers in unfamiliar conditions
544 (e.g. Rosenbloom et al., 2007); or
- 545 4) with drivers unfamiliar with the same condition (e.g. Wu and Xu, 2018).

546 Moreover, in the first two cases of the above-reported list, the number of repetitions to observe
547 potential behavioural changes varies from four tests in a day (Yanko and Spalek, 2013) to 20 times
548 over 3 months (Charlton and Starkey, 2013) or 28 times over several weeks (Young et al., 2017).
549 However, some changes in the same drivers or differences with a control group of unfamiliar drivers
550 (e.g. on their first drive) were observed regardless of the number of repetitions, even if related to
551 different measures (i.e. speed, position, eye fixations, response to changes, etc.).

552 Survey-based studies (Baldock et al., 2005; Liu and Ye, 2011; Ryeng, 2012) also use a frequency-
553 based scale and relate it with crash-related and other variables. Interviewed drivers were asked about
554 their familiarity with the road on which crashes occurred or to which the other variables investigated
555 are referred (i.e. enforcement in Ryeng, 2012). Choosing a frequency-based scale may be explained
556 by the preference for a direct measure, since interviews were possible. However, the studies reviewed
557 have set different minimum traveling frequencies for identifying familiarity of drivers from daily
558 (Baldock et al., 2005), to at least monthly (Liu and Ye, 2011) or even at least biannually (Ryeng,
559 2012).

560 Moreover, in one instance (Jin et al., 2018), telematic data from car insurance were used to reveal
561 relationships between accidents and predictor variables, including route familiarity. In this case, route
562 travel repetitions are directly measurable. Hence, frequency scales may be the best choice as well.

563 Whereas, most crash databases lack information concerning the frequency of travelling on the road
564 on which the accident occurred, this being usually limited to the travel purpose only. However, more
565 frequently collected information concerns nationalities and zip codes of drivers involved in accidents
566 (in Zhu and Srinivasan, 2011, frequency-based variables were also available, derived from a
567 nationwide data collection project). Hence, for these studies, the distance-based scale is a necessary
568 choice. The studies were conducted by comparing accidents to drivers beyond and within given

569 distances from home (the first deemed as “unfamiliar”, the second deemed as “familiar”). In this
570 regard, there are three main strategies:

- 571 1) comparing variables (i.e. likelihood, severity, type, characteristics, location) associated to
572 accidents which occurred involving foreign drivers with those related to resident drivers (e.g.
573 in Wilks et al., 1999; Yannis et al., 2007; Kim et al., 2012);
- 574 2) using urban boundaries to compare crash-related variables (i.e. involvement of urban residents
575 in urban versus rural accidents and vice versa, as in Donaldson, 2006);
- 576 3) using the absolute distance in kilometers from their residence as a variable for relating crash
577 likelihood and features to familiarity (based on travel surveys, Burdett et al., 2017; or on zip
578 codes, Intini et al., 2018).

579 It is worth noting that some findings relating crash-related variables to familiarity were highlighted
580 in the reviewed studies regardless of the specific measures considered (i.e. foreign vs residents, rural
581 vs urban residents, far from home vs close to home drivers). Hence, it is evident that, even if a
582 frequency-based scale was deemed to be directly related to familiarity (because it was self-reported
583 by drivers, measured or controlled through repeated tests in controlled environments), a certain
584 arbitrariness still remains. In fact, the number of tests required or the minimum traveling frequency
585 on a given road to acquire a familiar condition, are hard to define and they actually vary among the
586 reviewed studies indeed. The same is valid for distance-based measures, indirectly derived from a
587 database.

588

6. Proposal for a harmonized method for identifying familiarity

589 Defining standards for identifying a driver’s route familiarity is rather complex. Several measures
590 and different criteria for identifying the drivers’ route familiarity have been used in research studies,

591 depending on the type of study design and the specific methodology. The main issue is that the
592 identification of familiarity should be based on personal subjective features, since drivers may
593 experience different familiarization processes (see Li et al., 2018) or provide different answers about
594 the relationships between travelling frequency and self-reported familiarity (see Baldock et al., 2008).
595 Hence, predefined limits dividing familiarity and unfamiliarity conditions (familiarization as a binary
596 process) should be avoided. Setting universal thresholds beyond which considering a driver as
597 familiar (or unfamiliar), is most likely to be affected by biases.

598 However, for research purposes, some measurable indicators able to reveal the relationships between
599 familiarity and safety-related variables have to be considered. Moreover, a standardized procedure
600 that may at least ensure the comparability between results from different studies (otherwise impaired)
601 should be the optimum goal, even if potentially affected by biases due to the implicit uncertainties
602 discussed. In this sense, a criterion for the identification of drivers' familiarity, which attempts to
603 harmonize the methodologies used in previous studies and theoretical frameworks, is suggested here.
604 The specific identification criteria are shown in Table 3 for both frequency and distance-based scales.
605 For the reasons explained above, they should not be intended as strict deterministic boundaries, but
606 rather as a possible rational harmonized basis deriving from previous studies, an alternative to *a-*
607 *priori* values and potentially useful for future research. The coherence of methodologies used in
608 previous studies with the identification criterion proposed here is documented in Table 1. Most
609 previous studies are entirely or partially coherent with this proposal.

610

611 Table 3. Proposed frequency and distance-based identification criteria for drivers' route familiarity.

Scale	Familiarity	Unfamiliarity
Frequency -based	<ul style="list-style-type: none"> • Survey-based: Frequency \geq Weekly • Observational studies (on-road/simulator-based): Test repetitions \geq 4 	<ul style="list-style-type: none"> • Survey-based: Frequency \leq Yearly • Observational studies: First time driving (excluding practice)

Distance-based	Distance from residence \leq locally calibrated average commuting trip distance	Distance from residence \geq locally calibrated minimum long-trip distance (foreigners considered as unfamiliar)
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612 For the reasons previously explained, different types of studies may necessarily rely on different
613 scales. Hence, the criterion (frequency or distance-based) to be fulfilled depends on the study designs
614 and methodologies used. If both measures are available, frequency-based scales should be preferred
615 since they are self-reported or controlled in repeated tests on the same experimental layouts.

616 The reasons for assuming those measures are outlined as follows.

617 For the frequency-based definition:

- 618 • Commuters (almost daily-frequent drivers) were previously used as a typical example of familiar
619 drivers. However, drivers can be familiar with a route even if they do not strictly travel it daily.
620 Some behavioural changes were actually observed after a number between four and five
621 subsequent travelling days (Martens and Fox, 2007; Colonna et al., 2016b; Harms and Brookhuis,
622 2016). However, these studies differ in their experimental designs: in some of them (Martens and
623 Fox, 2007; Harms and Brookhuis, 2016) there were more drives per day. However, evidence of
624 significant changes was noted even for 4 test repetitions in the same day (Yanko and Spalek,
625 2013). Hence, this is the minimum number of test repetitions proposed for future studies. Clearly,
626 the more test repetitions there are, the more the simulated familiar condition is likely to be
627 reliable. However, a huge number of repetitions may not be necessary, since driving parameters
628 seem to become stable after several drives (see Harms and Brookhuis, 2016). Coherently, Li et
629 al. (2018) estimated that the steady time (time to get a steady memory of road scenes observed
630 on seven drives over subsequent days, based on memory scores) is 7.6 days, through
631 experimental data modelling. Hence, more than 7 test repetitions over different days could be
632 redundant when observing behavioural changes due to familiarity. However, some drivers were

633 found to fail in repeating the same driving performance (speeds and trajectories) if they interrupt
634 the route driving for about one week (Colonna et al., 2016b,c). This is coherent with the
635 possibility of a response recovery after stimuli interruption (Groves and Thompson, 1970;
636 Charlton and Starkey, 2013). Hence, in survey-based studies (self-reported familiarity related to
637 extended time periods), the familiar threshold should be at least weekly-based, to have a higher
638 likelihood of keeping enough road memories. All the reviewed studies are coherent with this
639 identification proposal, except for survey-based studies by Liu and Ye (2011) and Ryeng (2012),
640 which set a very low threshold frequency, monthly and bi-annually respectively. Studies by
641 Rosenbloom et al. (2007) and Burdett et al. (2018a) are formally not coherent with this proposal,
642 but no identification was needed in their studies indeed, since they directly asked drivers to travel
643 on familiar roads.

644 • A driver who has never previously travelled on a given road is surely unfamiliar with it. However,
645 there are several frequency measures included between the familiar definition (weekly), and the
646 zero frequency (e.g. monthly, yearly), representing shades of familiarity/unfamiliarity. Possible
647 long-term memory of previous habitual levels can be expected (Rankin et al., 2009). This has
648 indeed been observed in drivers after almost one month (Colonna et al., 2016b). However, those
649 memory effects are likely to be largely unconscious. In fact, Charlton and Starkey (2018) found
650 that drivers have a generally poor recall accuracy of specific features and events which occur
651 during familiar road driving, even a short time after the drive. Nevertheless, considering monthly
652 drivers as unfamiliar could be unrealistic. A yearly frequency can be suggested as a minimum
653 threshold for defining unfamiliar drivers (see also Ryeng, 2012). All the reviewed studies are
654 coherent with this identification proposal, except for the survey-based study by Liu and Ye
655 (2011), which considered drivers travelling more rarely than monthly as unfamiliar (even if this
656 largely includes the yearly frequency); and the simulator-based study by Bertola et al. (2012),
657 who considered drivers who travelled only seven times on the simulated route as unfamiliar.

658 Whereas, for the distance-based definition:

- 659 • On average, drivers can be reasonably assumed to spend most of their annual mileage on roads
660 near their residence (typically home-work routes), being familiar with them. Hence, a possible
661 definition is based on the drivers' average commuting distance, varying according to private
662 transport patterns of different countries. This distance measure has the advantage of being
663 flexible and less strict than fixed thresholds such as town limits (Rosenbloom et al., 2007). On
664 average, commuting distances are around 20 km. In North-America, Litman (2003) set to 15
665 miles (approximately 24 km) the average home-work trip distances. In countries with lower
666 usage of private transport, such as Norway, average car commuting journeys are 15.8 km
667 (Hjorthol et al., 2014). In New Zealand (Burdett et al., 2017), the mean distance travelled from
668 home is about 39 km, but the median of 11 km is significantly lower, thus being coherent with
669 previous results. These commuting trip distances are coherent with the possible estimate of 1
670 hour/person/day needed for mobility (Colonna, 2009). Significant differences were noted even
671 between in-county and out-of-county (Yan et al., 2005), or between in-state and out-of-state
672 residents (Harootunian et al., 2014a,b) in the United States, coherently suggesting that the
673 “familiarity” distance should be close enough to the residence. Most of the reviewed studies are
674 not explicitly coherent with this distance-based identification proposal for familiar drivers. In
675 fact, most of them were aimed at comparing foreigners with residents. The latter were generally
676 not explicitly defined as “familiar”, but compared with foreigners. However, considering all
677 resident drivers as familiar can lead to biased results in familiarity-based studies since there could
678 be several resident drivers unfamiliar with locations far from their residence but in the same
679 country. A different identification strategy is proposed here.
- 680 • On average, drivers are unfamiliar with roads very far from their residence. Previous studies
681 mainly considered discrepancies between country residents and foreigners (e.g. Yannis et al.,

682 2007). However, even residents may be unfamiliar with state roads far from their residence.
683 Hence, the distinguishing condition could be that long trips are rarer than commuting trips and
684 for them, other modes can be chosen. For this reason, the unfamiliarity distance-based threshold
685 can be set according to the average distance above which other means of transport are typically
686 preferred to the car (e.g. planes), locally derivable. In Intini et al., 2017b, 2018, this distance was
687 set to 200 km, based on Norwegian estimates (Hjorthol et al., 2014; Thrane, 2015). This rule
688 could be potentially violated by professional drivers of long-distance buses/trucks, controllable
689 by introducing variables accounting for heavy vehicles. Moreover, based on previous studies,
690 independently of distance, foreign drivers should be considered as unfamiliar, because of their
691 ignorance of foreign road environments (especially if coming from far away areas, see Yannis et
692 al., 2007), a condition associated to at-fault crashes (Kim et al., 2012), ratings of difficulty of the
693 foreign environment (Thompson and Sabik, 2018) and mistakes associated to different road
694 regulations (Huang et al., 2018). Clearly, there could be cases in which foreign drivers may be
695 familiar with routes in other countries, but this is hardly predictable from a crash database, while
696 most studies using distance-based scales rely on them. Hence, some necessary simplifications
697 are needed for identifying familiarity using this distance scale. Most of the reviewed studies are
698 potentially or fully coherent with this identification proposal, except for Donaldson et al. (2006),
699 who compared urban versus rural residents. In fact, urban resident drivers may be unfamiliar
700 with other urban scenarios in the same country as may rural residents in a similar way. Whereas,
701 Yan et al. (2005) used a four levels categorical scale from county resident to foreigner.

702 Only one “IND” (indirect drivers’ observation) study was found, providing an insufficient basis for
703 linking Table 3 to such studies. However, these studies may potentially rely on the same frequency-
704 based criterion proposed for “SUR” studies, even if Jin et al. (2018) used a continuous scale rather
705 than familiarity thresholds.

706 Values included between those thresholds (frequencies between weekly and yearly and distances
707 between average commuting and long trips) can be considered as representing “transition” drivers,
708 classifiable neither as familiar nor as unfamiliar with a reasonable margin of error. Excluding
709 transition drivers while analysing the relationships between familiarity and driving
710 performances/accidents may result in discarding great amounts of data. In a recent study (Intini et al.,
711 2018), about 50 % of drivers involved in rural segment accidents could be defined neither as familiar
712 nor as unfamiliar based on the criteria in Table 3. Hence, large databases would be needed when
713 conducting studies based on the distance scale, for considering only the extreme cases of familiar and
714 unfamiliar drivers. On the other hand, excluding drivers belonging to the intermediate transition
715 distances, may result in a far greater chance of reliable comparisons between actual familiar and
716 unfamiliar drivers. Finally, it is worth noting that familiarity has also been measured on a continuous
717 scale (see Charlton and Starkey, 2017a). This is a sort of directly self-reported frequency-based scale
718 of familiarity, but transformed into a rating scale, without explicit reference to the frequency of
719 travelling on the road.

7. Conclusions

720 This article was mainly conceived with two aims: 1) a detailed review of research findings and
721 engineering aspects relating drivers’ route familiarity with road safety-based issues, 2) the proposal
722 for an identification criterion, useful for future studies on the topic, which may use different methods.

723 As a result of the review conducted, the common traits that emerged from research findings and
724 technical documents, which found confirmation in the existing theoretical background, are reported
725 as follows:

- 726 • Driver behaviour can be affected by route familiarity. The familiarity driving condition could be
727 a highly automated task, potentially linked to inattention and over-confidence. Higher levels of

728 confidence can also lead to more dangerous behaviours (e.g. speeding) while selecting the
729 subjective safe behaviour during repeated journeys. This possible reduction in safety can be
730 justifiable for trade-offs with mobility benefits (i.e. travel time), which may compensate for the
731 positive effect of increased road knowledge.

732 • Road and traffic engineering practice currently considers familiarity to some extent, with
733 potential links to safety issues. Assumptions for design drivers have been suggested to implicitly
734 preserve the safety of both unfamiliar (e.g. through road consistency) and familiar drivers (e.g.
735 through geometric requirements). The mix of familiar and unfamiliar drivers in traffic has been
736 associated to possible safety-based remarks. However, the highlighted safety implications only
737 partially match results from studies focused on crashes involving familiar/unfamiliar drivers.
738 Nevertheless, comparing these findings was difficult due to the high variability in identifying
739 familiarity, and all the additional contributing factors.

740 The relationships between route familiarity and road safety are often implicit, especially in technical
741 documents. Hence, the review also specifically focused on highlighting those possible hidden
742 relationships, to enlarge the knowledge of researchers and practitioners on this topic. In fact, there
743 are several engineering road-safety based aspects in which drivers' route familiarity should be
744 considered, based on the main findings from the review. For example, it should be taken into account
745 in the assessment of safety countermeasures (by considering familiarization of drivers with them) or
746 while planning safety interventions/new designs for routes mostly travelled by unfamiliar drivers (e.g.
747 tourists).

748 Moreover, since there is currently no standard method for identifying drivers' route familiarity in
749 different types of studies, an attempt was made to present a harmonized proposal, which is mainly
750 based on previous findings and is potentially useful for future studies. Both frequency and distance-
751 based scales have been considered for research purposes according to the study design. The proposed

752 criterion can allow greater comparability between future studies on this topic.

753

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760

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