From big data to speed and safety: A review of surrogate safety measures based on speeds from floating car data

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Abstract

In order to overcome biases of crash-based safety analyses, research is looking for surrogate safety measures. A candidate are speeds derived from floating car data (FCD, or probe vehicle data). The goal of the review is to identify challenges and opportunities regarding using FCD speeds to develop surrogate safety measures. Specific points focused on the questions of sampling rate, study size, free-flow speed determination, reliability and validity. The review indicated several remaining knowledge gaps in relation to reliability of different FCD speed sources, sampling design, or estimation of free-flow speeds. Many of these gaps are likely to be quickly resolved at the current rate of research. The main conclusion is that benefits, limitations and nature of different FCD sources need to be carefully understood and considered before adopting FCD speeds as a surrogate safety measure. Further research and development opportunities exist in the subject area.

Introduction

Traffic speeds are one of the most significant factors in road safety performance. With increasing speed on roads both the likelihood and severity of crashes increase. These basic facts have been demonstrated within and across a number of methodological paradigms (Johnston, 2004; Jurewicz, Tofler, & Makwasha, 2015); however, speed-related crashes still occur. This calls for specific measurement and deeper understanding of various aspects of traffic speed in safety context. Such understanding will assist in development and implementation of effective road safety strategies and countermeasures.

Traditional crash-based safety analyses have several limitations, including their reactive nature, and statistically low occurrence of crashes. Surrogate safety measures provide a valuable alternative. For example, the Power Model (Nilsson, 2004) relates the effects of mean speed changes to the number of crashes of different severity, and was validated in various road environments (Elvik, 2009, 2013). However, not all surrogate safety measures proved to have reliable relationship with crashes; Tarko, Davis, Saunier, Sayed, & Washington (2009) noted that using speed as a standalone surrogate measure may be difficult due to the complexity of the speed-safety relationship.

In this context, speeds derived from emerging sources of floating car data (FCD, also known as probe vehicle data) provide an interesting alternative. This approach to speed measurement is based on big data, sampled from vehicle fleets (data "collected by the vehicles themselves"; Bessler & Paulin, 2013).

The goal of this paper is to identify opportunities and challenges regarding using FCD speeds to develop surrogate safety measures. This new use of FCD data could enhance research on speed and safety. Some examples of recent and emerging research explored in the paper include:

a. using speed or speeding as a safety performance indicator, collected in a representative network of sites, for example to evaluate measures (national speed limit changes, campaigns, enforcement, etc.) and observe long-term national safety trends
b. using speeding or harsh braking to identify dangerous events or assess driving behaviour
c. using speed (or derived indicators) to identify and assess high-risk sites, as well as safety variations, for example due to the impact of curve radii on driving behaviour, effect of

changing road width, or traffic calming measures (both before-after and cross-sectional studies), for example to provide background for revision of local speed limits.

Note that in this review, speeding is understood as driving in excess of posted speed limit.

Compared to the previous reviews, which focused mainly on uses of on GSM (Global System for Mobile Communications) and FCD for traffic monitoring (e.g. Bessler & Paulin, 2013; Leduc, 2008; Rose, 2006), the presented review focuses primarily on the safety perspective.

Background

Traditionally data for speed studies have been collected using a mix of methods: hand-held radar guns, roadside traffic counters, or fixed loops or tube counters. The common characteristic of these approaches is their spot character: the obtained speeds come from fixed points, which may not be representative of the rest of the entire studied road segment or location. Therefore, using conventional approaches to collect network-wide data is not likely to be feasible.

Compared to traditional speed measurement techniques, FCD has two main benefits:

- Coverage is not limited in space (suitable for network-wide speed surveys)
- Availability of historical FCD data (ideal source for before-after studies)

The vehicles (probes) are located through:

- mobile phone triangulation (so called GSM data or cellular FCD), or
- GPS navigation devices, registering GPS position and time of a vehicle along a known route enables calculation of average vehicle speed (this being the more accurate of the two; Bessler & Paulin, 2013)

GPS signals may be registered by a portable device (smartphone or satellite navigation), or an in-vehicle data recorder (IVDR). Both may also contain additional sensors (e.g. accelerometer, gyroscope) or a connection to a Controller Area Network (CAN bus), which enables recording data from other car sensors (odometer, fuel consumption, engine performance, etc. – such enhanced data are also called extended floating car data, xFCD; Bessler & Paulin, 2013). In the review, the term FCD will cover subset of data, mainly speed (from GPS) and acceleration (from accelerometer), which are clearly related to safety.

Despite the mentioned benefits, it should be remembered that FCD was originally serving different purposes (navigation, traffic monitoring). In order to make sure that FCD may be confidently used in road safety research, the differences between the original purposes and mentioned research approaches and their implications will be made clear in the following parts:

- Sampling rate
- Study size
- Free-flow speed determination
- Reliability and validity

Method

This paper undertook a review of available literature from across a range of subjects and different study types pertaining to FCD speeds. Given the exploratory nature of this review, only sources with unclear methodology and FCD data sources were set aside. All other studies were considered in high-level reporting used in this review. Full manuscripts were reviewed to extract qualitative and quantitative information.

The review parameters included:

- Retrieved sources:

  - papers from Web of Science, Scopus and TRID databases, including their references (snowballing)
  - "grey literature": ARRB Knowledge Base, institute reports, naturalistic driving studies/field operational test (NDS/FOT) project deliverables
  - proprietary data specification sources.
- Keywords: floating car data, speed, safety
- Language: English
- Time frame restriction: none

The review findings were organised into logical subject areas pertaining to FCD data, its speed aspects, and its potential use to develop surrogate safety measures. These were then synthesised into general conclusions about opportunities and challenges. These subject areas were as follows:

- Sampling rate
- Study size
- Free-flow speed determination
- Reliability
- Validity
- Relevance to road safety

Review results

Sampling rate

Typical FCD studies are conducted for traffic analyses (providing real-time traffic information, travel time predictions, etc.) based on GPS signals from vehicle fleets (taxis, commercial vehicles, but also private vehicles using mobile phones or satellite navigation). For these purposes, GPS signal sampling rate in order of seconds or minutes is common, see examples in Table 1.

Table 1. FCD studies and their characteristics (sorted by sampling rate)

Reference	Data provider (fleet, location)	Sampling rate
Berntsen, Molnár, & Zděnek (2016)	Telemotix (544 vehicles, Norway)	5 sec
Wang et al. (2015, 2016)	YOOTU (15,000 taxis in Shanghai)	10 – 15 sec
Jurewicz et al. (2017)	HERE and TomTom (Australia)	10 – 30 sec
Bekhor, Lotan, Gitelman, & Morik (2013)	Decell (> 100,000 vehicles in Israel)	30 sec
Hrubeš & Blümelová (2015)	RODOS (> 100,000 vehicles, Czech Republic)	1 min
Pascale et al. (2015)	WAY (13,000 trucks in Italy)	20 sec – 3 min
Aarts, Bijleveld, & Stipdonk (2015)	TomTom (the Netherlands)	5 min

Sampling rates have a direct impact on available level of detail of obtained data. For example, 1 second (i.e. 1 Hz) corresponds to approx. 14 and 25 metres driven, at typical urban/rural speed limits 50 and 90 km/h, respectively. This is why frequencies below 1 Hz (i.e. one or more records per second), are necessary for detailed studies. FESTA Handbook (Barnard, 2017) for FOTs explicitly states that "vehicle speed must be recorded in at least 10 Hz". In addition, not only speed is interesting for safety studies. Acceleration data (or jerk, i.e. derivative of acceleration) is collected from accelerometer, usually at higher frequencies, compared to speed. The question is what frequency should be set.

Current FCD data market offers various sensors, which are capable of providing instant data at rates of up to 1000 Hz – however, the choice influences the sample size, representativeness of the data, the price of purchase, data storage and processing. Ideally, data collection requirements should be planned according to the observed phenomenon. For example, in a naturalistic driving studies of motorcycle riders (Laporte, 2010), based on typical riders' reaction time 0.3 – 0.4 s and requirement of at least 15 signal samples for adequate instrumental description of the reactions, sampling frequency was set at 100 Hz. However, most naturalistic driving studies are not as strict: a review of such studies (Backer-Grøndahl, Phillips, Sagberg, Touliou, & Gatscha, 2009) listed typical values between 10 and 30 Hz; another summary (Welsh, Reed, Talbot, & Morris, 2010) recommended 50 Hz as sufficient acceleration data sampling frequency. In general, 10 Hz seems to be typical sampling rate for large NDS/FOT (e.g. 100-Car NDS, SHRP2 NDS, euroFOT, SeMiFOT).

On the other hand, for routinely collected data (not specifically planned for research), lower rates could suffice. For example, Bärgman (2015) distinguishes research data (often collected at 10 Hz or higher) and commercially collected data (usually with lower sample frequency, such as 4 Hz) – these may involve fleet monitoring or car insurers.

In general, usefulness of data depends on the purpose of safety research. These may comprise monitoring speed trends, informing strategy and doing evaluations at road segment level, as well as more detailed studies, using acceleration/jerks. For selected examples of research studies, based on both data sources, see Table 2.

Table 2. Research-oriented FCD studies and their characteristics (sorted by rate)

Reference	**Location, fleet**	**Sampling rate**
Naturalistic driving studies with dedicated data collection		
Reinau, Andersen, & Agerholm (2016)	Denmark (ITS Platform)	speed 1 Hz acceleration 10 Hz
Pande et al. (2017)	US (33 drivers)	jerk 3 Hz
Ryder, Gahr, Egolf, Dahlinger, & Wortmann (2017)	Switzerland (57 drivers)	speed 30 Hz
Toledo, Musicant, & Lotan (2008)	Israel (GreenBox)	acceleration 40 Hz
Naude et al. (2017)	France (51 drivers)	acceleration 100 Hz
Studies which used data collected for other purposes		
Ambros et al. (2017)	Czech Republic (Princip)	speed 4 Hz acceleration 32 Hz
Bagdadi & Várhelyi (2011)	Sweden (Lund ISA trial)	jerk 5 Hz
Punzo, Borzacchiello, & Ciuffo (2011)	US (NGSIM program)	jerk 10 Hz
Joubert, de Beer, & de Koker (2016)	South Africa (Digicore)	acceleration 50 Hz

Apart from the mentioned GPS and accelerometers, there are instrumented vehicles, which involve for example cameras, VBOX sensors, Mobileye or LIDAR (see reviews by Carsten, Kircher, & Jamson, 2013; Valero-Mora et al., 2013). While they present excellent data acquisition systems for safety research, they are not likely to be feasible for large fleets due to their high cost. Large FCD fleets are necessary to provide large speed data sources for consideration.

Study size

Conventional sampling theory calculates minimum sample size based on allowable error and sample standard deviation of measured speeds. Traditional recommendation was measuring at least 30, ideally 100 – 200 vehicles (e.g. Kraft, Homburger, & Pline, 2009; Narasimha Murthy & Mohle, 2001; PIARC, 2003). Also TRB synthesis (TRB, 2011) of operating speed studies reports typical requirement "at least 100 per site."

However, Smith, Zhang, Fontaine, & Green (2003) noted that this traditional approach is not fully transferable to FCD studies, where the conditions of sampling theory (data within each measurement interval is stationary, and variance does not change) do not hold. On the contrary, FCD depends on non-constant penetration rate (how large fleet sample should be equipped by FCD sensors, in order to make its data representative of total flow). Reviews summarized that in the highway environment penetration rates up to 3 % are sufficient (Vandenberghe, Vanhauwaert, Verbrugge, Moerman, & Demeester, 2012); in urban areas rates up to 5 % were recommended (Bessler & Paulin, 2013).

In addition, on roads with lower volumes lack of data may be expected. Srinivasan & Jovanis (1996) argued that "probes cannot be used as a stand-alone source of travel time information, especially during off-peak periods and on lightly travelled corridors and low-speed roads, such as local and collector streets and minor arterials". Nevertheless, recent expansion of FCD is changing this situation. Jurewicz et al. (2017) studied FCD on lower-volume roads and provided some guidance on necessary data collection periods (in numbers of months, based on the level of traffic volume).

To produce national/state safety performance indicators, the speed data should come from the widest possible spectrum of locations to make it representative of the entire road network (or from the entire road network). EU SafetyNet project (Hakkert & Gitelman, 2007) developed detailed manual to this process. As a minimum, the sites should be sampled from sub-groups based on different road types, speed limits or number of lanes (approx. 30 sites per group). This could also serve as a minimum requirement for FCD speeds, if necessary.

Free-flow speed determination

In traffic engineering, there is an important concept of free-flow speed, as a standard measure, comparable across different sites and representing speed of vehicles under low volume conditions, unhindered by traffic control devices.

Spot-speed studies are done either collected automatically or manually. In the latter approach, free-flowing vehicles are selected individually by an observer. Another, more objective approach is based on gaps between vehicles – various headway or gap thresholds are used to distinguish between vehicles following others or travelling freely. However, many different values have been used in international guidance, ranging from 3 to 12 s. Other thresholds have been even more pragmatic: for example in terms of hourly number of vehicles (ranging between studies from 200 to 1000 veh/hr) (for a review see Ambros & Kyselý, 2016).

Nevertheless, none of these approaches is feasible for FCD, which is collected from individual vehicles only, without being able to check whether they are influenced by other vehicles or not. Popular approach is thus restricting data collection to off-peak hours (Bekhor et al., 2013; Pline, 1992; Wang et al., 2006), or night time (TomTom, 2016). However, this practice is likely to severely reduce the sample, especially in case of commercial vehicles, which usually travel during daytime.

One could also ask whether night time speeds are representative of typical driver behaviour, as these speeds may be influenced by darkness, fleet composition, presence/absence of street lighting, and potentially increased speeding (Jurewicz et al., 2017). The question could be even more general: if we aim to study 'unsafety', then should we focus on speed data from the times and conditions when crashes happen most? If so, then why do we typically study free-flow conditions, where vehicles are not affected by presence of others?

In general, free-flow speed issues have not been studied much in FCD literature. For example, Diependaele, Riguelle, & Temmerman (2016) attempted modelling the free-flow speeds with probabilistic approach; Ambros et al. (2017) applied cluster analysis to separate free-flow speeds from all-vehicle speed data. For practical purposes, FCD speeds from off-peak periods may be assumed to be an estimate of free-flow speeds. The specific selection of these periods may need to be judgement-based.

In case of FCD speeds it is important to make sure that speeds are:

1. reliable when compared between various providers
2. valid when compared to "ground truth" (traditional speed measurement methods)
3. relevant to road safety

Reliability

Spasovic, Dimitrijevic, & Kim (2013) reported a US validation study for the FCD speeds provided by three commercial traffic data providers (INRIX, NAVTEQ, TrafficCast Dynaflow), using data from 4 roadways in New Jersey and New York. All three technologies were mostly within the acceptance limits for the average absolute speed error (≤ 16 km/h) and the speed error bias (≤ 8 km/h). All of the studied technologies consistently overestimated the speed in the lowest speed bin (0 – 50 km/h), and consistently underestimated the speed in the highest speed bin (> 100 km/h).

Another US study (Rapolu & Kumar, 2015) investigated whether there is a relationship between HERE, INRIX and Bluetooth speed data. Model free-flow speeds were found on an average 10 % higher than the observed Bluetooth speeds; Bluetooth and HERE travel speeds were in general 8 to 16 km/h lower than INRIX speeds during the day.

Validity

Several comparative studies investigated quality of FCD-based travel times and speeds; see Table 3. Due to the wide range of study types, FCD sources, and differences in their robustness, only high-level findings are provided in Table 3 to provide a general overview of validity

Table 3. FCD-based comparative studies and their characteristics (sorted by study date)

Reference	**Data description**	**High-level findings**
	Travel time studies	
Brockfeld, Lorkowski, Mieth, & Wagner (2007)	4 days of data from 500-taxi FCD fleet in Nuremberg (Germany) vs. automated license plate recognition (ALPR)	"travel times calculated by the system deliver valuable data"
de Boer & Krootjes (2012)	9 routes in Eindhoven (the Netherlands), penetration > 2 %, TomTom historic travel times vs. ALPR	"FCD is accurate"
Clergue & Buttignol (2014)	4 routes in France (penetration 0.7 – 4.3 %), TomTom vs. ALPR	"differences are insignificant"
	Speed studies	
Yim (2003)	cellular phone-based speeds vs. loop speeds over 1 month (four French freeways)	cellular data speeds about 10 % *lower* on intercity freeways, higher (24 – 32 %) on an urban freeway
Smith et al. (2003)	cellular FCD (10-minute intervals) vs. point video	FCD on average by 10 – 15 km/h *higher*
Bar-Gera (2007)	cellular FCD vs. dual magnetic loop detectors (Israeli freeway)	"a good match between the two measurement methods"
Lattimer &	INRIX FCD vs. ALPR data on 4	INRIX speeds on average 10 km/h

Glotzbach (2012)	Florida freeways	*higher*
Espada & Bennett (2015)	EastLink in Melbourne, HERE travel speeds every 5 minutes vs. e-tag gate crossings	probe travel speed estimates on average by 9 km/h *lower*
Hrubeš & Blümelová (2015)	Prague ring road (Czech Republic), 2% penetration, FCD vs. loops	"reasonable estimate of speed", shown to be generally *lower*
INRIX (2016)	"The World's Largest Independent Traffic Data Validation" (I-95 VPP)	accurate within 16 km/h of actual traffic speeds on average
Diependaele et al., 2016	Belgian rural roads, FCD vs. loops	FCD-speed almost by 10 km/h *higher* than free-flow loop-speed
Ambros et al. (2017)	Czech rural roads, FCD vs. radar	FCD-speed on average by 2 km/h *higher*

Some of the mentioned studies found FCD speeds *higher* than radar speeds; other studies (Aarts et al., 2015; Jurewicz et al., 2017) found an opposite tendency (FCD-speed *lower* than radar-speed). An explanation was given that FCD average speed relates to a whole road segment (i.e. including turning at intersections), while the traditional spot-speed relates to a single spot only (typically collected away from intersections; Aarts et al., 2015). Also, different FCD sources were used in the studies leading to different outcomes. It is thus important to understand the specifications of each FCD source and to sense-check (or calibrate) its speed outputs against a trusted ground truth source.

To sum up, many studies concluded that FCD speed is reliable (not more than by 16 km/h different compared to ground truth or other providers' data). For research purposes, this difference may be too large; if the differences are systematic, calibration may be a solution.

Relevance to road safety

Information, distilled from FCD studies, has a potential to enhance and improve the quality and coverage of speed and safety studies. In terms of the applications, which were outlined in the introduction:

a. FCD-speeds may be used network-wide as a safety performance indicator

This was an idea of a Dutch analysis reported by Aarts et al. (2015). After investigating performance of TomTom data, the source was found feasible for providing information for safety performance indicators (specifically speed levels). The study noted some limitations of FCD, for example that they do not provide information about speed differences between individual vehicles; privacy issues also limit analyses related to vehicle types or driver age/gender.

Recent Australian studies are more positive. Jurewicz et al. (2017) found that FCD can be potentially translated to spot-speed equivalent using calibration models; the authors also provided an example of using FCD speeds for before-after evaluation of a speed limit change. A follow-up study (Jurewicz, Han, & Espada, 2018) used TomTom and HERE data, which can be proportionally split by vehicle type to test matching with actual fleet composition; this would help in estimating speeding and speed percentiles.

b. FCD may be used to derive speeding or harsh braking/accelerating to identify dangerous events and assess driving styles

There is clear evidence that some indicators, for example, related to speed and acceleration, are predictive of crash involvement risk (Sagberg, Selpi, Piccinini, & Engström, 2015). In this regard, FCD, which is linked to specific drivers, is a valuable source for assessing driving performance and driving styles (for example defensive/aggressive/inattentive), as well as driving exposure. This data may then be compiled and used for so called usage-based insurance systems (Tselentis, Yannis, & Vlahogianni, 2017). For example, Feng et al. (2017), using criteria based on jerk metrics, successfully identified aggressive drivers. However, large amounts of collected data need to be analysed; Ellison, Greaves, & Bliemer (2015) mention various approaches, such as using pattern matching algorithms to identify patterns that are of interest and to focus analysis on these portions of the data, including verification through additional video footage. In addition, FCD were found influenced by exogenous factors, such congestion, construction, traffic light timings and other vehicles. The use of video cameras may reduce these influences, but requires a labour intensive manual processing.

Fortunately, there are approaches to recognize conflicts within FCD without manually reviewing all video streams. A common approach is to analyse kinematic vehicle data to detect safety-critical events such as emergency braking or sudden steering. However, critical values (thresholds) of these “event triggers” vary significantly in the literature (Aichinger, Nitsche, Stütz, & Harnisch, 2016), for example:

- longitudinal deceleration range from approx. 0.1 to 0.7 g (Johnson & Trivedi, 2011; Paefgen, Kehr, Zhai, & Michahelles, 2012)
- critical jerks vary between 0.06 and 2 g/sec (Naude et al., 2017; Pande et al., 2017)

Combined criteria were also used (Naude et al., 2017). Alternative approach is analysing all the collected data (so called risk space; Joubert et al., 2016).

Note that smartphones are often used for collecting data for driver assessment. However, studies indicated they may not be fully suitable, compared to in-vehicle data recording. Paefgen et al. (2012) found smartphone FCD as overestimating critical driving events; Händel et al. (2014) reported that they are lacking reliability.

c. FCD may be used to obtain speed and other indicators to identify and assess safety at specific locations

Based on the above-mentioned risk thresholds and frequency of their occurrence on specific locations, high-risk sites may be identified. For some example studies, see Table 4.

Table 4. Validation approaches in selected FCD-based studies (sorted by study date)

Reference	Location; indicator type	Validation
Mousavi, Parr, Pande, & Wolshon (2015)	Louisiana highways; jerks	21 jerk value thresholds evaluated in the sensitivity analysis; segment jerk-rates compared to crash rates
Reinau et al. (2016)	Aalborg city (Denmark); speed and jerks	visual comparison of crash location map vs. risk location map
Ambros et al. (2017)	Czech rural roads; speed	speed consistency (i.e. differences between speeds in tangents and following curves) related to a long-term crash frequency
Pande et al. (2017)	California freeways; jerks	relating 10 jerk thresholds (varying from 0.50 to 2.75 ft/s^3, with an increment of 0.25) to crash frequency

Obviously two approaches to validation exist: “theory-based” (confirmatory, testing hypotheses) or “data-based” (exploratory, data mining).

In addition, collecting network-wide FCD also enables studying relationships between speed and driving/environmental characteristics. For example in Denmark, using FCD data from ITS Platform enabled quantifying the influence of road and shoulder width, curve radii, the extent of road markings and the section lengths on speed (Andersen et al., 2016; Rimme et al., 2016). A model, based on Czech FCD data on rural roads, confirmed that increasing road width and enabling overtaking and climbing are associated with an increase of speed (Ambros et al., 2017). An Israeli FCD study (Gitelman et al., 2016) found that changing shoulder width, recovery-zone width (clear zone) or intersection has a potential to affect travel speeds.

Unfortunately, in several studies explanatory power (R^2) of the mentioned FCD-speed models was found relatively low (approx. 30 – 40%; Ambros et al., 2017; Andersen, Reinau, & Agerholm, 2016; Gaca & Kieć, 2016). This finding may be explained by the characteristics of FCD: conventional spot-speed data are based on samples collected in more or less controlled conditions (daytime, season, weather, etc.) and may thus yield homogeneous results with high R^2 values; on the other hand, FCD studies use an "anonymous" sample collected in various days, seasons and weather conditions, leading to heterogeneous results with lower R^2 values. The low explanatory power may lead to insufficient reliability in cases when models are applied in different time and space from the original conditions. Therefore, the models could benefit from the improvement: e.g. adding potential additional explanatory variables, and/or considering vehicle and driver characteristics using random effect models (Bassani, Cirillo, Molinari, & Tremblay, 2016).

Summary, discussion and conclusions

The goal of this review was to identify challenges and opportunities regarding using FCD speeds to develop potential surrogate safety measures.

The review has some limitations. Exploratory nature of the review permitted only cursory critique of the studies. In addition, the reviewed studies were of varied quality and objectives, which limited comparability of beyond the high level findings. Robust studies were given more prominence. In addition, as the reviewed field is quickly evolving, new studies are being published and may change the validity of the reported findings.

Regarding conclusions, firstly it is important to consider benefits and limitations of FCD:

- Compared to traditional spot-speed measurements, FCD has benefits of unlimited spatial coverage, as well as availability of historical data. However, FCD may not be sufficient in case of low traffic volumes.
- Anonymity of FCD may limit distinguishing different vehicle types or driver characteristics. It also complicates determination of free-flow speed.
- In a long run, continuity and quality of FCD measurements is beyond the direct sphere of influence of end users.

Secondly it is important to remember that FCD was originally serving navigation and then traffic monitoring purposes. In order to make sure that FCD may be confidently used in road safety research, the differences from the original purposes need to be considered in context of surrogate safety measures:

1. Sampling rate needs to be planned, based on requirements and type of data collected.
2. Study size also needs to be planned, especially in conditions of low traffic volume.
3. There is not any universal approach to free-flow speed determination, most are estimations only.
4. Reliability and validity: FCD speed reliability and relation to the ground truth is uncertain and is strongly dependent on the compared sources. There are no guidelines for detecting risk thresholds (e.g. rapid braking), nor uniform approach to validating FCD speeds against safety.

Some issues may be inherent to the method: for example, FCD is usually collected out of urban areas, with not-fully-representative vehicle fleet and drivers sample. Both pros and cons of FCD need to be carefully weighed, based on the requirements of specific research tasks. For example, using FCD for network-wide speeding trends may not be as data-hungry as using FCD to assess specific driving styles.

Nevertheless, FCD quality and coverage is continuously increasing. FCD found its way into commercial services, such as PTV Visum (with TomTom FCD) or VIA Traffic Solutions Software and ARRB Aperture tool (with HERE Traffic Analytics). With continuing data collection and investigations, focusing on the mentioned issues, added knowledge will enable developing FCD-speed-based surrogate safety measures.

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