FIELD OPERATIONAL TESTS AND NATURALISTIC DRIVING STUDIES

THE ISSUE OF IDENTIFYING CRITICAL INCIDENTS IN NATURALISTIC DRIVING DATA

Experiences from a PROLOGUE small-scale field trial

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ABSTRACT: The methodology of naturalistic driving observation aspires to observe the driver and his environment while driving in his natural driving environment. It is of great importance in research on road safety as this method of observing road users eliminates the disadvantages of traditional methods like simulator studies or interviews. However, it produces vast data amounts and challenges data reduction and data analysis. Therefore, automatic methods based on thresholds for numerical data for filtering critical incidents are often applied to reduce the data. This paper reports a small-scale field trial in Valencia, Spain, which was conducted within the PROLOGUE project. The numerical data analysis using thresholds resulted in a great number of false alarms and did not identify safety-critical sequences. In contrast, video analysis revealed a number of critical events that had not been detected using the numerical parameters. The study conveyed the importance of continuous video recording in these kinds of studies and showed that the methodology of data reduction for naturalistic driving studies requires further development in order to be able to capture incidents automatically.

1. NATURALISTIC DRIVING OBSERVATION

Naturalistic driving investigates driving behaviour in on-road measurement studies, that is, to observe driving behaviour while driving in a natural driving environment. In addition to road behaviour, the interaction with other road users is observed as well as the driver's behaviour behind the steering wheel or the handlebars. The PROLOGUE project (PROmoting real Life Observation for Gaining Understanding of road user behaviour in Europe) which was co-funded by the European Commission, aimed "to demonstrate the usefulness, value, and feasibility of conducting naturalistic driving observation studies in a European context in order to investigate traffic safety of road users, as well as other traffic related issues such as eco-driving and traffic flow/traffic management" [1, p5].

By equipping cars with data logger and cameras, drivers are unobtrusively observed in their everyday driving. The realistic context eliminates many disadvantages of other rather subjective or artificial investigation methods. It enables researchers to “objectively observe various driver- and crash-related behaviour“ [1, p9]. Naturalistic driving observation provides a lot of information about real driving behaviour and helps answer questions we have regarding road safety.

1.1. Data gathering

Driving data can be collected through in-car technological devices gathering kinematic measures [1]. The data is captured with data loggers that dispose of certain sensors or are connected to vehicle based sensors (for a detailed listing of sensor specifications see Welsh et al. [2, p19ff]. Installed cameras capture the driver and his environment [1]. Different perspectives of the in-vehicle cameras installed give comprehensive information about what is going on in the car and in its environment. In other approach, site-based cameras, which have been used in the Dutch field trial of PROLOGUE, give a good insight at certain locations in traffic [3].

1.2. Data reduction and analysis

Driving data in naturalistic driving studies are usually captured continuously while the vehicle is moving. Consequently, short trials already result in vast amounts of data. Naturalistic observations are optimally long-term measurements [1]. As they last several months, vast data amounts are gathered. The studies’ research questions define which parts of these data are of interest for further analysis. Therefore, certain identification aids are required for filtering out the respective sequences from the data [2].

The research questions determine the difficulty and extent of this filtering process. If, for example, analysing speeding sequences, all data where drivers drive under the mandatory speed is easily excluded. The latter parameter works as a threshold in the filtering process. There are various driving parameters that can be measured and allow mathematical selection of certain events. However, some require a more individual threshold depending on car type and data logging system, like for example acceleration or brake pressure. Badly selected thresholds could lead to high analysis time, due to the high number of filtered events or, conversely, to miss important events [2].

1.3. Event triggering

An alternative that facilitates data collection is to pull the filtering process one step forward. By defining thresholds for certain driving parameters some data loggers are able to log data and video recording just for some defined time before and after the parameters reach the predefined value [2]. Thus data collection and video recording is limited to events that reach some conspicuous driving values and are therefore likely to be safety relevant. Some devices collect basic data like travel time and GPS-signals on every trip. This method has been used in the Austrian field trial of PROLOGUE [4], the Israeli one [5] and the Dutch one [3]. Data can also be triggered to certain predefined geographical locations. That is, if the instrumented car reaches a predefined GPS-position, data collection (and/or video recording) is activated for some time. The Dutch field trial included such a location event in their data logging [3].

The amount of captured data is clearly reduced by this methodology. However, this method has certain disadvantages. Welsh et al. [2] name as the most significant issues that the calibration can be affected over time or refuses to work at all without noticing the researcher. Similar to the previously named issue of bad selected thresholds, important events could be missed by not reaching that predefined value. However, with the difference that, in this case, missed events are not even captured in the data and one is limited to the data that has been gathered [2].

2. EXPERIENCES FROM A SPANISH FIELD TRIAL

2.1. The Spanish field trial of the PROLOGUE project

Within the PROLOGUE project a small-scale field trial was conducted in Spain by the University of Valencia. Five experienced drivers drove a highly instrumented car for four days each. While driving, their driving performance and behaviour were recorded continuously. Sensors captured car dynamics and five cameras recorded the driver's face, the scenery in the front and in the back. On two of the four driving days participants used a navigator to find their destinations and could choose whether to make use of any in-vehicle information systems (IVIS). On the other two days they were asked not to use any IVIS while driving. These two days per driver have been the control group. Participants picked up the car at 8am and drove about 2 hours to different destinations in and around Valencia (Spain). They could choose by themselves which route to take in order to reach the destinations.

Approximately 40 hours of driving have been collected with the four drivers. Data analysis aimed to identify safety-critical incidents during the two conditions (WITH/WITHOUT the use of in-vehicle information systems) [6].

2.2. Safety-critical incidents

In-depth analysis of safety-critical events with analysing not just the event itself but also the time before and after the event is of special interest in road safety. Analysing the driver's behavior while driving as well as his road behaviour and the road behavior of other included road users during these critical moments of driving is of special value. It supplies information about causes, sequences of events and driver reactions in case of critical incidents. It is of great value in accident research but also to investigate what leads to successful avoidance of impending crashes. It also helps to evaluate the role of driving assistance systems in critical incidents.

As a definition for safety-critical incidents we used a five-category system that has been adapted by the Virginia Tech Transportation Institute (VTTI) for a big naturalistic driving study, also known as the "100 car study" distinguishing between crashes, near-crashes, crash-relevant conflicts, unintentional lane deviation and illegal manoeuvres [7] [8]. Definitions of these categories are provided below.

– Crash. Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, and objects on or off of the roadway, pedestrians, cyclists, or animals.

– Near-Crash. Any circumstance requiring a rapid, evasive manoeuvre by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash, OR any circumstance that results in extraordinarily close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance manoeuvre or response. A rapid, evasive manoeuvre is defined as a steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.

– Crash-Relevant Conflict. Any circumstance that requires a crash avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive manoeuvre (as defined above), but greater in severity than a "normal manoeuvre" to avoid a crash OR any circumstance that results in close proximity of the subject vehicle to any other vehicle, pedestrian, cyclist, animal, or fixed object where, due to apparent unawareness on the part of the driver(s), pedestrians, cyclists or animals, there is no avoidance manoeuvre or response. A crash avoidance response can include braking, steering, accelerating, or any combination of control inputs. A "normal manoeuvre" for the subject vehicle is defined as a control input that falls within the 99% confidence limit for control inputs for the initial study data sample. Examples of potential crash-relevant conflicts include hard braking by a driver because of a specific crash threat, or proximity to other vehicles.

– Unintentional Lane Deviation. Any circumstance where the subject vehicle crosses over a solid lane line (e.g., onto the shoulder) where there is not a hazard (guardrail, ditch, vehicle, etc.) present.

– Illegal Manoeuvre. Any circumstance where, either the subject vehicle or the other vehicle, performs an illegal manoeuvre, such as passing another vehicle across the double yellow line or on a shoulder. For many of these cases, neither driver performs an evasive action.

2.3. Event identification

To identify these events we first intended to mathematically discover them in the driving data. First we selected the following parameters that could give us information about the occurrence of critical incidents:

- Frontal distance
- Lateral distance (left and right)

- Brake pressure
- Speed of steering wheel rotation
- Sudden speed changes.

In test drivers, we identified critical values of these parameters for our instrumented car. These values served as thresholds for a filtering process in order to identify the critical events. Results of the filtering process were analysed in-depth by screening the video material [6].

2.4. Results of data filtering

The video analysis of all the filtered driving moments demonstrated that the events identified by the thresholds were false alarms most of the time. In other words, videos showed that nothing critical happened during these time frames. Instead, thresholds were exceeded, for example, while just braking in front of a traffic light. Normal driving in (Spanish) urban traffic was full of these conspicuous data.

In the 100 car study, previously defined trigger variables were continuously tightened in order to reduce the number of false alarms and missed events [8]. However, in our study, many of the safety-critical incidents were not filtered out by thresholds, especially not when they were adapted in order to reduce the number of false alarms. We did not want to blame the limited scale of the study for not finding any incidents and decided to screen the whole video material. The result was a number of 16 safety critical incidents; six crash-relevant conflicts, one unintentional lane deviation and nine illegal manoeuvres. No crash or near-crash happened, however, such an event would probably have been identified with our thresholds. The data of the six crash-relevant conflicts have not been conspicuous at all.

3. SUMMARY

After identifying the safety-critical incidents by watching the entire video material, certain factors have been discovered that complicate incident detection by numerical data analysis:

High number of false alarms:

– urban traffic is full of conspicuous driving values and constantly leads to sharp speed changes or close distances between road users (e.g. at traffic lights);
– cultural driving differences might influence the analysis as, for example, braking pressure seems to be in general high in the Spanish traffic.

Missing incidents in driving data:

– driving in lower urban speed does not always result in extraordinary values for braking, for example;
– the observed driver is not aware of the conflictive incident and does

not perform an evasive manoeuvre;

- if the other participant of a conflictive incident performs (predominantly) an evasive manoeuvre there is no conspicuous data produced by the observed driver.

4. CONCLUSION

Naturalistic driving observation is of great importance for research on traffic safety. However, the vast amount of resulting data challenges data analysis. The use of predefined triggers for reducing the recorded data seems critical as important information gets lost and can not be recaptured.

Data analysis by the use of conspicuous values (thresholds) seems practical as unimportant data can be excluded. Depending on the research question, this procedure is quite suitable if, for example, just driving sequences are of importance which include speeding by the observed driver or that take place on a certain GPS location. However, there are some issues if one is interested in safety critical incidents. During most near-crashes and crashes, the observed driver performs a sharp evasive manoeuvre, which can easily be found in the numerical data later. However, safety-critical events like crash-relevant conflicts, driving errors and illegal manoeuvres may not necessarily lead to conspicuous numerical data. Consequently, they are hard to find by data filtering with critical values.

Highway data with its higher speeds may also result in clearer data and easier event identification. However, naturalistic driving data of urban areas seem to make mathematical data analysis difficult due to the irregularity of traffic and constant braking and accelerating. The resulting high numbers of false alarms and missed events challenge the methodology of data reduction and analysis.

An optimization of thresholds like the one performed in the 100 car study (Neale, et al., 2002) may lead to a better ratio between false alarms and missed incidents. However, there are still safety-critical incidents left which do not at all produce conspicuous data. These cannot be found by a preliminatory selection in numerical data but are of great importance for traffic safety.

The issue of identifying critical incidents in naturalistic driving data makes obvious how important video data is for a valid analysis of naturalistic driving. Video material helps to identify possible events and exclude unimportant ones [9]. It helps to interpret the numerical data, to decide which sequences are of real importance and enables an in-depth analysis of the occurrences during safety-critical events. Cameras should capture at best an extensive view of traffic and of course the driver himself.

As in Europe the number of urban crashes is higher than highway crashes [10], urban naturalistic observation and crash analysis is of special importance and requires further development of the ND-methodology.

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LESSONS LEARNED FROM A LARGE SCALE FIELD OPERATIONAL TEST OF AFTERMARKET AND NOMADIC DEVICES – TELEFOT PROJECT

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ABSTRACT: This paper describes some lessons learned from the field trials conducted within the TeleFOT European project (Field Operational Tests of Aftermarket and Nomadic Devices in Vehicles), where the impacts of nomadic device functions are being assessed. Two of the eight TeleFOT test sites (namely Valladolid-Spain and UK) are harmonizing their test protocols in order to compare in detail their experiences and results. From this collaboration and considering the reference FESTA framework, this study represents one of the first studies of its kind that is able to fully describe experiences with the new FESTA FOT methodology protocols as well as providing recommendations for effective FOTs in the future.

1. INTRODUCTION

Significant research and development in Europe in recent years has been focused on Intelligent Transport Systems (ITS). Many ITS functions are available on portable navigators and smart phones and their market penetration is increasing considerably. Nevertheless no standards directly related to the use of aftermarket and nomadic devices in vehicles exist and there is little published knowledge about their impact on the driver behaviour and the user acceptance.

A Field Operational Test (FOT) is a relatively new method, especially in Europe, for studying the impacts of functions on transportation, i.e. on driving, traffic and transport. From a technical and methodological perspective, the FESTA Handbook [1] defines an FOT as “a study undertaken to evaluate a function, or functions, under normal operating conditions in environments typically encountered by the participants using quasi-experimental methods”.

2. THE APPROACH OF TELEFOT PROJECT

The TeleFOT project (Field Operational Tests of Aftermarket and Nomadic Devices in Vehicles) [2] involves large scale pan-European field trials to assess the impact of functions provided by nomadic devices on the driving task, as well as on the transportation process as a whole.

The core of the TeleFOT research is based on conducting FOTs involving large numbers of drivers (up to 2,500) using functions provided by nomadic devices in their own vehicles. Drivers’ interaction with functions and services are studied and data are collected and stored in a central database to address research questions related to use of the nomadic devices in specific contexts. The data are collected in different phases related to the testing period. In the pre-test phase, data about the user are collected, such as gender, age, driving experience, etc. During the tests, objective data (position, speed and in some cases acceleration and interaction with the device) are logged and complemented with additional subjective data mainly collected by means of diaries and questionnaires. Finally, the post-test phase involves a subjective evaluation of the system by the user through questionnaires and personal interviews.

The FOTs in TeleFOT are organised in three test communities based in Northern (Finland, Sweden), Central (Germany, UK, France) and Southern (Greece, Italy, Spain) Europe and individual test sites can be found in each of these countries.

2.1. Large scale and Detailed FOTs

The TeleFOT project consists of Large-scale FOTs (LFOTs) and Detailed FOTs (DFOTs). LFOTs are the core of the project and their objective is to investigate normal, everyday use of functions by the driver; which are provided by aftermarket and nomadic devices. The studies involve conditions in which a large number of participants receive, use and react to functions and services provided to them and data are collected over a long period of time. The functions studied include traffic information, speed limit information, speed alert, navigation support (static), navigation support (dynamic), green driving support and eCall.

DFOTs investigate the effects of aftermarket and nomadic devices under a more controlled experimental environment than LFOTs. A limited number of instrumented vehicles are being used which are capable of precise recording of driver behaviour, especially in terms of investigating in-vehicle activities while driving through dedicated Data Acquisition Systems (DAS). DFOTs will be used to improve and widen the interpretation of the test results from the LFOTs.

2.2. FOTs harmonisation

Two of the TeleFOT test sites (namely Valladolid-Spain and UK) are harmonizing their test protocols in order to compare in detail the experiences and results obtained from them. The Valladolid-Spain test site is formed by three entities: CIDAUT, BLOM and RÜCKER LYPSA. Similarly, the UK test site is composed by two different organizations, namely LOUGHBOROUGH UNIVERSITY and MIRA LTD.

In general, the same approach is being used such that both test sites are operating a similar subject recruitment and management policy and are testing more or less the same number of subjects. Furthermore, both test sites are conducting the field tests over a similar time period and are utilizing an almost identical experimental approach. In addition, the tested functions and the DAS being used are identical at both sites meaning that the results are very comparable.

3. EXPERIENCES AND IMPLICATIONS

Overall, the study represents one of the first studies of its kind that is able to fully describe experiences with the FESTA FOT methodology protocols.

The lessons learned are multifold and include issues related to study design, recruitment, field test management and data handling issues. The study describes in detail the major issues that have become evident during the FOTs at both test sites and makes recommendations as to how future FOTs should be organized in order to counteract important matters arising and how to overcome unforeseen difficulties. However, FOTs have revealed many positive methodological aspects that are relevant to future FOTs and these are fully described within the study.

3.1. Methodological aspects

In relatively long tests like the ones performed in TeleFOT, the study design is critical for deriving statistically robust results and a within-subject design is the most common approach to data collection. The test participants are thus driving initially under normal conditions without availability of the function(s) (baseline phase) and then with the function(s) in operation (experimental phase). The baseline condition should be reduced to a minimum to avoid a decrease in motivation. With regards to experimental phase, the types of functions under study should be carefully selected, since daily use of some types of functions is not possible in some cases which could imply a reduced amount of data. On the other hand, when a set of combined functions are studied, the availability of the functions for the users should be cautiously introduced during this phase, since this aspect will have a deep impact on the complexity of the analyses in the final stage of the project. Additionally, as was decided in TeleFOT, harmonisation of test sites, essential to obtain conclusions at a global level, requires prior consideration for the definition of commonalities, so as to have as many comparable aspects as possible.

As was previously explained, an important set of data comes from different questionnaires and travel diaries that complement the information recorded by the data loggers. This material needs to be user friendly so that subjects regularly complete them with a high reliability of response. Furthermore, it is important to avoid ambiguity in the text in order to avoid confusion to the users and thereby minimise risk of misinterpretations.

There are several methods that can be used to request the information from the subjects including web tools, paper versions and dedicated applications embedded in the devices. The selection of the method should be carefully considered, since each of these has different advantages and disadvantages. In this sense, although paper versions have an inconvenience of associated costs (especially for preparing the material and the effort involved in the coding process), they are considered as the best methods for preventing subject drop-outs.

When possible, the corresponding questionnaires can be filled in during the briefing (e.g. background questionnaire) or during meetings with users to provide clarification and hence avoid misunderstandings. Moreover, if more than one different type of questionnaire is being distributed to users (e.g. questionnaire and diary), it is preferable to combine their application so as to reduce the number of days they have to complete paperwork. This means that the number of dates on which the subjects have to remember to complete the paperwork is kept to a minimum and the number of oversights is correspondingly reduced. Travel diaries are presented as a suitable tool to gather data directly related to mobility. Subjects usually report positively about the tool, but it needs to be well designed to allow enough flexibility in the answers as well as being easy to complete and include clear instructions to prevent oversights. Finally, experience gained from TeleFOT shows that reminders about questionnaires or diary dates are of paramount importance when trying to maximise return rates.

3.2. Data Acquisition System (DAS) and Storage

When setting up the FOT, special attention is required in the definition and development (or adaptation) of the DAS. Different options can be implemented, but the final adoption should be based on a cost-benefit analysis. For example, if the sample is distributed in a wide area, automatic transmission from the corresponding data logger to the database could be the best option. However, in other situations, manual download of stored data is preferable since it allows an opportunity for an informal meeting with users which can provide very valuable feedback regarding their participation in the FOT and their experiences with the function(s) being tested.

In any case, data storage format should be defined in a prior stage of the project and should be harmonised across all of the DAS used in the tests and the database. This will reduce the efforts needed in later stages for post-processing, data checks, data mining, data reduction, etc.

As a consequence, in TeleFOT both the Valladolid-Spain and the UK test sites have used the navigation device itself as a DAS which reduced costs since a second device for data logging was not needed. This provided the added advantage of recording information about the functions activated at each moment, the interaction with the device, the adjustements made by the users, etc. This is information that provides an added value when trying to understand the reasoning behind the driver behaviour during specific segments of the drive.

An essential aspect when performing this type of tests is to ensure protection to personal data provided by users. Data protection laws clearly state that anonymity is essential and a reference to users´ rights (access, correction and objection) should be clearly included in every questionnaire. In addition, a user agreement should be developed and verified according to legal, data protection and administrative points of view. Furthermore, care should be taken not to give a negative impression to participants by overemphasising their responsibilities as subjects.

3.3. Test execution

The first stage of the test execution should involve piloting wherever possible. Pilot tests should be carried out before starting the trials to make a final technical and logistic assessment of the test designs and tools to be used, as well as to ensure good quality dataflow throughout the tests, including collection, transfer, download and analysis. Experience has shown that pilot testing is usually longer than expected, so when defining the final experimental design of an FOT, a suitable time for this phase should be specified.

The real execution of the FOT starts with a briefing session where the overall objectives of the study should be clarified. Aspects directly related to users´ behaviour should be avoided so as not to influence their behaviour during the execution. A reduced number of subjects is suggested (around 20-25 subjects) in each briefing session to give appropriate floor to participants to express their opinions, provide comments or voice doubts or concerns. During the briefing session, a presentation of the project is recommended, especially highlighting the involvement of entities such as the European Commission and any other important stakeholder to emphasise its importance. This is especially important in trying to reduce drop-outs to a minimum. Even so, it is of paramount importance to accept that drop-outs are unavoidable due to several reasons and therefore, the sample should be overestimated to allow for this where possible. Otherwise, there is the risk that an insufficient number of drivers complete the test and as a consequence, significant conclusions cannot be obtained.

During the tests, daily monitoring is necessary to detect potential problems which may jeopardise the experimental design and hence the test results. Therefore, it is important to establish a close rapport with the participants in order to learn from their experiences and preserve their motivation throughout the whole test. As a result, it is useful to set up a management file to include all the relevant information from each participant which should be accurate, up-to-date and accessible such that the personal circumstances of all participants are well understood by the test team. Furthermore, a support service is strongly recommended (by mail and/or telephone) in order to solve problems or doubts. Contact details should be clearly provided to the users and prompt answers will be required. If a solution or reply cannot be given instantaneously, users should be informed that their problems will be resolved as swiftly as possible.

3.4 Analyses and assessment

As was previously mentioned, it is of paramount importance to dedicate an initial effort to decide the study design according to the objectives of the study and the subsequent implications in terms of execution and future analysis. This decision could facilitate or hinder the efforts needed during the assessment phase and thus, it is essential to carefully estimate the likely analysis activities in advance.

Analysts should have all the required information from the test sites, since they have to filter or merge data according to the specific aspects of each test and interpret the results obtained afterwards. Thus, the analysis team should be informed about any change or information that could result in a change in behaviour or that could have an influence on the findings. As an example, during the execution of the Valladolid-Spain LFOT, a change of the speed limit in motorways was legally executed by the Spanish Ministry of Transport which reduced the speed limit down to 110 km/h from 120 km/h over a 4 month period. This type of information should be considered during the analyses; otherwise it could be wrongly assumed that a change in the results could be an effect identified within the study.

Furthermore, to avoid misinterprations and different techniques when analysing the data, the team in charge of the impact assessment should share filtering procedures and/or statistical testing in order to harmonise as much as possible the type of analyses carried out with the different test sites data or executed by various teams.

4. CONCLUSIONS

When undertaking an FOT, different aspects should be carefully planned, from the methodological phase such as defining a study design as simple as possible or trying to harmonise to the maximum, to the assessment stage, as previous decisions will affect the analysis phase. As an example, the appropriate selection of the DAS taking into account the test site needs is presented as a key aspect in terms of subsequent efforts when accessing data. Similarly, questionnaires and other means of data-gathering such as travel diaries are useful tools but the most suitable method should be selected according to test site requirements (users characteristics, availability of resources, etc.) to maximise return rates. Furthermore, the piloting phase is essential to assess the complete process prior to full execution and this phase should be carefully planned, since it usually takes longer than expected. Additionally, motivating briefing sessions, continuous informal meetings and a good support service are aspects of paramount importance to preserve user involvement and to reduce drop-outs to a minimum.

As a conclusion, the present study is of significant relevance to future revisions of the FESTA handbook and will be an important source of reference for future FOTs, particularly those involving nomadic devices.

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DATA COLLECTION METHODOLOGY FOR STUDYING DRIVER BEHAVIOUR FROM FREE FLOW SPEED PROFILES ON RURAL ROADS

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ABSTRACT: Methodologies based on naturalistic observation provide the most accurate data for studying driver behaviour. This paper presents a new methodology for getting naturalistic data related to drivers' behaviour in a road segment. It is based on the combination of using pocket-size GPS trackers and drivers' surveys. Continuous speed profiles along a road segment and social characteristics for a great number of drivers can be obtained. It has already been successfully used for several studies, such as the development of models to estimate operating speed profile in two-lane rural road segments; or the characterization of driving styles. Those models have been the key for the development of a new geometric design consistency model, making the road safety evaluation easier.

1. INTRODUCTION

Multiple factors typically combine to produce circumstances that lead a vehicle to crash. The main concurrent factors are human factors, roadway environment factors, and vehicle factors. Human factors are the most prevalent contributing factor of crashes, followed by roadway and vehicle factors. However, due to its characteristics, it is also the most complicated factor to study. The best results in this area have been achieved by using methodologies based on naturalistic observation. This kind of methodologies is based on subjects driving the way they usually do, in their own vehicle and without any specific instructions or interventions. Projects such as *100-Cars Naturalistic Driving Study*, *SHRP2-Vehicle-Based Study* and *2 Be Safe* use this data collection methodology.

The main aims of those studies are drivers' behaviour at crash situations and the interaction between drivers and inside car devices. Besides, in most studies, drivers are volunteers who know the scope of the research project, so their behaviour may be biased.

In order to study drivers' behaviour at different road alignment elements (curves, tangents and spiral transitions), it is necessary to collect data from a huge sample of people driving along a sample of elements.

For characterizing drivers' behaviour, the most studied variable is the speed at which they drive. Speed data collection may be based on spot or continuous data.

In most cases, data collection device is a manually radar gun or similar [1]. The use of radar gun has three important problems: human error, cosine error and drivers' behaviour affection. Pavement sensors are also used for collecting speed data [2]. Although they solve those problems, they only collect data in one location, as well.

With those methodologies, the study of acceleration and deceleration phenomenon is not possible. Therefore, several research projects [2] complemented data collection by using lidar guns. This way, speed data is collected in several spots in a road segment location. However, even with lidar guns, starting and ending points of acceleration/deceleration cannot be accurately determined.

These deficiencies in data collection may be avoided by other methods based on continuous speed tracking, such as instrumented test vehicles or different methods based on digital video recording and processing. Last one is only suitable for local studies at short road segments.

Other researchers [3, 4] studied drivers' behaviour from speed data collected using instrumented vehicles. However, the results may be conditioned by the equipment of the vehicle and the number of observations. Moreover, the sample may be biased and it may not be enough representative of the actual driver behaviour because research volunteers know the research objectives and they are not used to drive the instrumented vehicle.

2. OBJECTIVES

Considering the shown deficiencies on speed data collection, the Highway Engineering Research Group of the Universitat Politècnica de València (Spain) has developed a new data collection methodology, as an adaptation of usual naturalistic methodologies.

The main objective is getting naturalistic data in order to study drivers' behaviour in a road segment. The researchers should be able to get enough sample size of drivers along road segments.

Collected data should be both drivers' individual continuous speed profile along a road segment and data related to their social conditions, trip characteristics and vehicle type.

Besides, data collection shouldn't be the cause of drivers' behaviour change, so that it may be considered as naturalistic data collection methodology.

3. METHODOLOGY

This section describes the application of developed data collection methodology on 10 two-lane rural road segments. Data about path and continuous speed profile of actual drivers, their social characteristics, their trip characteristics and type of their vehicles were obtained.

3.1. Data collection

For data collection, two checkpoints were located at the beginning and at the end of each road segment, controlling both directions. Two or three people stayed at each checkpoint. Two members were at the starting lane, while the other one was at the final point. The general diagram of the data collection system is presented in figure 1.

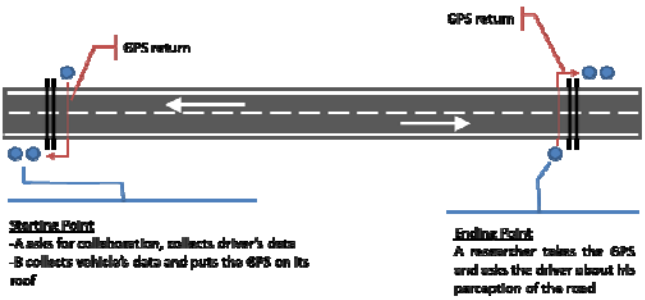

Fig. 1 Data collection diagram

When there was an incoming vehicle, one member of the checkpoint team took care of stopping it and asked the driver about collaboration in the research project, emphasizing that he/she was part of the University. In order to avoid data biasing, the scope of the research was not explained at the beginning. After driver's agreement, he was asked about some general questions about his driving experience, previous knowledge of the road segment and the purpose of the trip. Another member of the group placed the GPS device on the vehicle and wrote down some data, such as the number of passenger or type of vehicle. Driver was also encouraged to not change his usual driving behaviour.

This process took around 1-2 minutes. After this time period, driver was allowed to continue along the road segment.

When the vehicle arrived to the final checkpoint, a member of the team took the GPS device out of the vehicle and asked the driver some questions about his perception of the road segment. At this point, the driver was informed about the research project, by means of a leaflet, in order to be as fast as possible and not slow down the traffic flow.

The average sample size of drivers involved in data collection was 180 drivers by road segment (considering both directions). The total data sample of the research project was 11876.5 vehicles·km.

After described data collection, some recommendations can be made.The sample of drivers who take part in the research will depend on the considered variables for the analysis. Thus, an estimation of the duration of the data collection has to be carried out before it, considering the AADT and the amount of data needed. It is also needed to consider at least one hour before and after the test in order to set and pick up all the equipment placed on the road.

GPS devices provision is always needed at checkpoints. Depending on the traffic flow balance by direction, it may be needed to transport devices from one checkpoint to the other one, in case of lack of devices at one checkpoint.

It is also recommended to select roads with balanced traffic flows for both directions.

Some equipment is needed in order to perform the test, besides of GPS devices. The safety of the people involved in the field data collection is very important. Thus, some traffic guidance elements have to be used for warning drivers about the presence of the checkpoints. A safe area must be created at each checkpoint for allowing their members to work. They also have to wear safety vests.

3.2. Naturalistic data test

GPS devices contain the information about position and speed of all drivers along the road segment under study. The main goal of this field data collection is to obtain accurate, naturalistic and disaggregated data from actual drivers. Thus, it is important to ensure that drivers perform their driving task without being influenced by the presence of GPS devices, by means of a naturalistic data test.

The test was carried out during the first two field data collections, comparing data obtained from drivers who were driving the day of the experiment and drivers who were driving the day before of the experiment. Speed data from both types of drivers was obtained at the same spots.

Some video cameras were set at some spots along the road segment, hidden from driver’s vision. They were recording the traffic flow, for calculating the operating speed of individual drivers. Operating speeds of drivers involved and not involved in the field data collection was compared, for checking if they were influenced by the presence of GPS devices. The analysis was performed by means of LSD intervals, finding no statistical difference between people with and without GPS devices [5].

Recorded traffic was also used for determining the operating speed at those spots. By comparing speeds obtained from video cameras and GPS devices, data obtained from last ones was validated.

3.3. Free-flow condictions test

In order to analyze the influence of the infrastructure on drivers’ behaviour, involved vehicles are supposed to drive at free-flow conditions. Different vehicles are released from the initial point of the road segment at free-flow conditions, but they may be disturbed by other vehicles along the road segment. In this case, there is no an easy option to determine if the registered data is under free or non-free flow conditions. A methodology was developed in order to determine the road segment where a driver drove under non-free flow conditions.

Each driver behaves in a particular way, approaching to certain operating speed percentiles. This behaviour is similar under free-flow conditions, but should be different when the driver is disturbed due to traffic flow. By means of comparing different aggregate operating speed percentiles and individual operating speed profiles, it is possible to determine when drivers' speed is constrained.

4. APPLICATIONS

Described data collection methodology allows obtaining data on several road segments about vehicle paths, individual continuous speed profiles, social characteristics of drivers, of their trip and the type of their vehicles.

Those data allows performing new and more accurate research.

4.1. Operating speed profile models for geometric design consistency evaluation

Previous operating speed determination methodologies were based on spot speed data collection. Some hypotheses had to be made in order to develop operating speed profiles construction rules, such as considering constant speed at curves. Other example is the determination of acceleration and deceleration rates. Spot speed data collection is only able to determine the speed at two previously located spots. Thus, deceleration length is unknown and the hypothesis of considering it constant for all drivers has to be assumed.

With this new methodology both problems are fixed. The continuous operating speed profiles help the researchers to check the behaviour of all drivers at different alignment elements, so the previous hypotheses can be considered or rejected based on naturalistic data. Also, deceleration length is known for all individual drivers, so more accurate analysis can be done.

Taking into account these considerations, it can be concluded that operating speed and acceleration/deceleration rates models calibrated from continuous naturalistic speed data fit better drivers' behaviour than those based on spot data do.

According to this assumption, operating speed models for tangent and curve sections have been developed based on operating speed profiles. Besides, other models have been calibrated for estimating the 85th percentile of acceleration/deceleration rates, instead of the acceleration/deceleration rate of 85th percentile speed profile [5].

Those models have been the key for the development of a new geometric design consistency model [6]. It allows the estimation of the crash rate of a road segment. Thus, this data collection methodology has turn into a tool for road safety evaluation on both road design phase and operation phase.

4.2. Human factors analysis

As a result of data collection and treatment, individual continuous speed profile is available for each single vehicle and for each road segment. Besides, the different questions asked to drivers before and after the test allow the characterization of some variables, such as: driver's characteristics (age, gender, driving experience); characteristics of the trip (distance, regular or not, number and type of passengers); and vehicle type.

Therefore, it is possible to study the relationship between both types of variables, instead of performing aggregate analysis. The obtained results may be used for studying: drivers' speed perception; driving styles characterization; and consistency of drivers' behaviour between elements, between roads and along the time. It may also be the base for the validation of driving simulators that have the purpose of drivers' behaviour study.

The analysis about the influence of those variables in the developed speed on curve sections has already performed. The results show that men drive faster than women and that the older driver is, the slower he/she drives. Driver's experience is also a significant variable, so people with less driving experience drive slower. Besides, people drive faster in a regular trip and/or when they are alone in the car.

The knowledge of the influence of those data on driver behaviour may be useful for road safety media campaigns and education programs designers.

5. CONCLUSIONS

An adaptation of previous naturalistic data collection methodology has been developed for studying driver behaviour on rural roads. The obtained data consists on individual continuous speed profile and data related to driver, his/her trip and the type of vehicle he drives. With those data, aggregated and disaggregated analysis may be performed. In fact, it has been successfully used in order to calibrate the models and construction rules for getting operating continuous speed profile of a rural road segment. This model, based on aggregated data, allows road design consistency evaluation and road safety improvement.

Disaggregated data have been used for studying the influence of driver's characteristics and the characteristics of trip and vehicle on chosen speed and acceleration/deceleration rates.

Therefore, this data collection methodology turns into a new tool for drivers' behaviour and road design evaluation.

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USING NATURALISTIC DRIVING DATA TO ESTIMATE SPEED BEHAVIOUR INDICATORS: METHODOLOGICAL ISSUES

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ABSTRACT: Through the observation of driving behaviour in everyday life, without the artificial constraints of experimental approaches, naturalistic driving studies offer interesting possibilities to assess unsafe drivers' behaviour such as speeding, short headway distance, seatbelt use, daytime running light use ... The paper will present and discuss the methodological issues that must be solved to infer meaningful Safety Performance Indicators (SPI) from naturalistic driving data. Excessive speed SPI estimation will be used as an example to highlight these issues. The discussions will focus mainly on the requirements in terms of data collection and processing and on the different factors that can impact the quality of the SPI estimation.

1. INTRODUCTION

Naturalistic driving studies consist in observing driving behaviours in naturalistic settings. Drivers involved in a naturalistic driving observation drive where and when they want to, at the wheel of their own car. Their vehicles are instrumented, in an unobtrusive way, in order to record information about their behaviour, vehicle dynamics and driving context. The characteristics of this data collection method offer the researchers, new possibility to assess unsafe drivers' behaviour such as speeding, short headway distance, seatbelt use, daytime running lights use, in everyday life, out of the classical experiment artificial aspects.

The methodological framework proposed by FESTA FP7 project and widely used in Europe to carry out Field Operational Tests (FOT) and Naturalistic Driving Studies (NDS) and to analyse the huge volume of data collected in this scope, recommends computing Performance Indicators (PI). Performance indicators refer to quantitative or qualitative indicators, derived from one or several measures, agreed on during the initial phases of the NDS or FOT, expressed as a percentage, index, rate or other value, which is monitored at regular or irregular intervals and can be compared to one or more criteria [1]. In a different context, road safety researchers also use the concept of Performances Indicators, but with a slightly different objective.

They compute Safety Performance Indicators (SPIs) that reflects the unsafe operational conditions of the three components of the road traffic system: driver, vehicle, network, which influence the system's safety performance and that can be used to monitor overtime the current safety conditions of the road traffic system [2].

This paper aims to present and discuss the methodological issues that must be solved to infer meaningful SPIs describing unsafe drivers' behaviour from naturalistic driving data. The need of a meaningful description of the driving situations appears to be one of the key issues. To present the different issues, the focus will be set on the drivers' speeding behaviour.

2. SPEED BEHAVIOUR AND ROAD SAFETY: CURRENT SAFETY PERFORMANCE INDICATORS

Speed is one of the main causes of road crash. Speed has been shown as a major contributory factor in 10% of all crashes and in 30% of fatal crashes [3]. Beyond its role in crash occurrence, speed has a direct influence on accident severity. This explains the road authorities' interest in implementing various safety interventions to reduce speeding behaviour. However, to achieve this goal, they need SPIs that give a realistic evaluation of drivers' behaviour related to the compliance with the legal speed limits so that they can correctly assess the current speeding situation, monitor its evolution, measure the impacts of various safety interventions and make comparisons between countries or geographical areas.

Among the various safety performance indicators currently used by road authorities to monitor road safety, indicators related to speed behaviours are common. These speeds SPI estimation currently rely on the instantaneous speed measures of vehicules observed in a restricted set of locations that are selected for their representativity of the road network of a country. The methods commonly used through European countries to collect the data and to estimate the speed SPI have been analysed by SafetyNet consortium and recommendations have been edited based on the best European practices to favour comparisons between European countries [2]. Several SPIs can be estimated from the collected data: the mean speed, the standard deviation, the 85th percentile speed and the percentage of drivers exceeding the speed limit. The estimation of the speed SPI takes into account the road type, the periods of day and week of the speed data collection, and the selected vehicle type. In order to be able to make the link between speed measurements and speeding behaviour, speed data are only collected when traffic can be considered as "free flowing traffic", i.e. when the speed of the vehicle is freely chosen by driver and is not constrained by the driving context. Using this approach, reasonably free flowing traffic conditions are obtained through the thorough selection of the measuring locations and periods. Thus, the following criteria are favoured : selecting straight and flat roads, avoiding proximity with intersection, avoiding proximity with enforcement radar, avoiding proximity with roadwork, excluding morning and evening peak hours (e.g. 7h30->9h30 and 16h00->19h00) and avoiding adverse weather conditions (rain, snow, freezing, fog, strong wind).

3. A SET OF PERFORMANCE INDICATORS TO HIGHLIGHT UNSAFE DRIVERS' BEHAVIOUR FROM NATURALISTIC DRIVING OBSERVATIONS

One of the main challenges of using naturalistic driving observations to provide performance indicators to highlight unsafe drivers' behaviour related to speed is to make the link between the speed measurements and the speeding behaviour. Indeed, in a naturalistic driving setting, data about speed are provided on a continuous basis and the SPI must be inferred from the speed variations over time of a restricted set of drivers. Thus, instead of controlling the location and the period of the data collection, in NDS, it is the sample that is controlled. Thus, to be able to estimate reliable safety performance indicators, it is necessary to select carefully the drivers' sample. This sample can be representative of the country population or of the country's driver population to allow generalization of the results at the level of the country. Furthermore, the observation period must be sufficient to collect driving data in various driving contexts in terms of road type, legal speed limit, period of the day and of the week, traffic conditions and weather conditions.

Lastly, in order to produce safety performance indicator that could be compared to the one computed in Safetynet, the analysis of drivers' speeding behaviours requires the identification, among the huge volume of data, of the driving situations during which the driver is in reasonably free flowing traffic conditions. So the assumption that the vehicle speed is freely chosen by driver and not constrained by the driving context can be verified. This last constraint is a key issue, as it is far from trivial to determine automatically and reliably these specific situations. Once these three requirements are met, the naturalistic driving data can then be processed to produce PI that are close to the SPI described in chapter 2, such as, mean speed, standard deviation and V85 in free flowing traffic conditions.

If naturalistic data can be used to produce standard SPI, it is also important to notice that the naturalistic driving observations offer possibilities to go further and to compute additional interesting SPI to describe drivers' speeding behaviour such as "percentage of driving time over the legal speed limit", "percentage of driving time with speed x km/h over the legal speed limit" or "distribution of the speed around the legal speed limit". The result and interpretation of these indicators while be different wether the data are filtered according to the traffic conditions or not. Indeed, in the first case, the indicators will highlight the propensity of drivers to exceed the legal speed limit when the traffic conditions allow to choose freely their speed. In the second case, the indicators will highlight the exposure of drivers to excessive speeds situations during their everyday mobility.

4. REQUIREMENTS IN TERMS OF DATA COLLECTION AND PROCESSING TO OBTAIN MEANINGFUL PERFORMANCE INDICATORS

As for others PI computation in FOT or NDS, the data requirement depends on the calculation objectives.

Investigating speed behaviour needs firstly to have access to an estimation of the vehicule speed. These measures can be issued from various sources. For example, the CAN bus of the car or a GPS receiver will give respectively the speed displayed by the speedometer and the speed of the vehicle.

Generally, the dashboard speedometer overestimates the speed of the vehicle. Some drivers are aware of this overestimation and take into account this margin of error to choose their speed. Thus, the identification of the speeding situations will have to take into account the accuracy and the specifications of the sensors that will be used to estimate the vehicle speed. In the case of speeding behaviour SPI, in order to be able to classify estimated SPI according to the road type and the driving period, it is necessary to have access to GPS data including time, date and position and to a geographic information system (GIS) in order to be able to access to more detailed information about the road network, through map matching. In the case of “excessive” speeds which can be described as “speed 5% above the legal speed limit”, the “legal speed limit” will be required in the dataset. The access to the GIS data can be done in realtime, during driving, so that the collected data directly contains the relevant information, or can be post processed, using raw GPS coordinate and enriching the data set with required information.

In addition to the requirements in terms of data, a specific processing approach has to be undertaken to process the SPI calculation. The way to filter the data to keep only relatively free flowing traffic condition should first be investigated. Indeed, it is possible to build “hour based” filters, which, for example, automatically remove from the calculation the data collected during the peak hours where traffic is supposed to be dense. It is also possible to use the concept of level of service (LOS), and knowledge of traffic engineer on traffic flow characteristics to filter the data according to the distribution of the vehicle headway or speed. Level of service is “a qualitative measure describing operational conditions within a traffic flow, based on service measures such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort, and convenience” [4]. Six LOS, labelled by a letter, extend from LOS A that refers to the best operational conditions to LOS F that refers to the worst ones. The LOS scale has been used as a measure of traffic density in the 100 car study [5]. The concept of LOS is interesting because it can be used on different driving situations (freeways, highways,signalized or signalized intersections, etc.) and different modes (car, pedestrian, bicycle, buses, etc.). Nevertheless, in the case of naturalistic driving observations, the data analysts do not systematically have at their disposal all the required tools and parameters to determine the LOS as traffic engineers do. Additional researches are necessary to develop a relevant scale to describe traffic conditions in a driver's behaviour perspective based on data available in a NDS. In particular, this new scale might integrate the fact that drivers seem to perceive less than six categories of LOS [6, 7].

5. FACTORS THAT CAN AFFECT THE QUALITY OF THE SAFETY PERFORMANCE INDICATORS

Inferring Safety Performance Indicators describing drivers' speed behaviour from Naturalistic driving observation data raise the question of the precision of the calculation of the indicators. The first issue deals with the clustering of the SPI according to the different driving conditions that are relevant in terms of speeding behaviour. For example, it seems interesting to be able to monitor the speeding behaviour according to the different values of legal speed limits but also according to the period of the day or of the week, or according to the weather conditions .However, the combination of clusters that can be computed has to be considered carefully taking into account the temporal windows used to aggregate the speed data in order to keep a sufficient number of speed values in each clustering class and not to decrease the precision of the indicator estimation. In these conditions, it seems difficult to produce indicators on a time window less that 1 month and even on a monthly period, we cannot combine too many clusters or use clusters that have too many classes. Furthermore, the calculation of the indicators must take into account the variability of time spent driving between participants. We can assume that the more the driver spends time in a given driving context, the more the assessment of his/her behaviour will be reliable because of the mitigation of the impact of specific road context. The number of speed measurements in each of the context will be used to define weighting factors.

Another issue is the availability and the quality of the data from the GPS and the GIS. For example, legal speed limits are not available in all the geographic information system, and if they are available they can be erroneous. The accuracy of the data can greatly vary between different countries or geographic and acording to the road type and the duration of the speed restrictions (for example restriction of short duration like highway entrance and exit might not be indicated at all).

Finally, the sample design of the Naturalistic observation is an additional issue to solve to provide road authorities with accurate and representative SPI. The selected driver sample has to be representative of the population to allow the generalization of the results at the level of the country. The sociodemographics variables used to stratify the sample must be the most relevant in terms of impact on participant mobility and driving behaviour. Gender and age are a first set of relevant variables due to their strong relationship with driving behaviour. Another potential variable deals with the occupation and more precisely with the fact to be part of the working or nonworking population, as the part of professional trips [8] will take a lot of importance within the observed trips. The last candidate variable is the urban density, due to its impacts on the motorization of household and the mobility by car [9]. However, even by controlling these variables, there is still no guarantee that the sample will drive in various driving context and during all the time of the day and it will be interesting to monitor their exposition to learn more about their mobility patterns.

The question of the size of the sample is also very important, as it will affect directly the precision of the SPI estimation. It will be necessary to establish a trade-off between the economic constraints of the naturalistic observation and the expected precision of the results. Indeed, even if naturalistic driving methods allows to collect a big number of speed measurements, as we need to first aggregate data at a driver level to calculate speed behaviour indicators, the issue of the sample size is crucial. As the sample is a stratified one, one cannot use simple random sampling estimators [10]. Despite this restriction, error in sampling can be reduced by increasing the sample size but bias is more elusive. We can only minimize it via a well-planned and well executed design plan [11].

6. CONCLUSIONS

With some methodological constraints, the SPI used by Road authorities to monitor drivers speed can be estimated from naturalistic driving observations. In addition, naturalistic driving observations offer the opportunity to extend existing knowledge on driver’s engagement in excessive speed according to the driving context and to place speeding episodes in the whole driver’s everyday life mobility.

Beyond the question of excessive speeds related to the legal speed limit, naturalistic driving data can also permit to address the question of the inappropriate speeds. Nevertheless, the development of SPI for assessing inappropriate speed is trickier due to the necessity to have a detailed description of the contextual driving situations and to implement specific analysis to highlight the adequacy of drivers’ speed choice to the driving situations or manoeuvres. For example, performance indicators could consist in the distribution of the speed on motorway according to the weather conditions, or the distribution of the speed in entrance of a bend according to the radius of curvature of the bend. This SPI estimation requires to identify, among the set of data, specific driving situations or manoeuvres that are relevant. For that advanced “pattern matching” method can be useful [12-14]. In any case, SPI linked to inappropriate speed choice remain at this stage research investigations in link with the understanding of drivers’ speed behaviour.

As a final conclusion, it is important to highlight that even though the scope of this paper was reduced to the speeding behaviours, the methodological considerations and issues raised in the paper remain true for any other SPI and should be considered when computing SPI from naturalistic driving data.

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