THE IMPACT OF AFTERMARKET DEVICES ON DISTANCE KEEPING AND TRAFFIC EFFICIENCY

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ABSTRACT

Objective: Traffic conditions significantly affect both the quality of life and the national economies and are considerably onerous as people cannot plan it ahead. In this study, the interest is shifted towards exploring the potential effect of already used nomadic devices for either alleviating or burdening the driver. Exponential growth of in-vehicle driving systems and their interaction with the driver and other infrastructure elements makes it imminent to focus on the effect and impact of aftermarket devices to driving behaviour. Detailed Field Operational Tests (DFOTs) were conducted within the framework of the European Project TeleFOT in order to shed light to the effect of these devices and their integrated functionalities to driving behaviour. This paper focuses on the effect of aftermarket devices to vehicle headway and its potential effect to traffic and driver efficiency.
Methods: A within participants' design was implemented with 8 experienced and frequent drivers, following preset routes in four separate DFOT studies with different combinations of functionalities integrated in the aftermarket device (e.g. speed limit and alert). In addition, two control conditions were added (pure control and control with Advanced Assistance Systems - ADAS). Each driving session -with a highly instrumented vehicle- lasted approximately one hour. The interaction of in-vehicle assistive systems with Forward Collision and Lane Departure Warning System was investigated. Objective data (vehicle log files and nomadic device) were collected.
Results: The results indicate that drivers tend to slightly increase headway when receiving both ADAS warnings and in-vehicle information. The size of increase is similar for all combinations of functionalities but a bit lower for the control group with ADAS only. Therefore, the effect of lateral control because of ADAS systems is not minimised because of in-vehicle information but within safe limits (i.e. not less than 2 seconds). The combination of speed limit information and navigation support decreased significantly variation (p=.012) by

35% when compared to free driving in pure baseline control condition. Statistical significant decrease ($p<.05$) in percentage of time with dangerous car following behaviour with the combination of ADAS and nomadic device functions was found.
Implications for Research, Policy & Public: The analysis indicates that increase in vehicle headways in the network within safe limits could mean no difference for efficiency. It might be inferred that the combination of ADAS and in-vehicle information systems could have a positive-or not negative-impact to optimisation of headway for the traffic network. In conclusion, existing assistive systems might not be an imminent danger for traffic efficiency. A step further would be to establish a holistic approach towards designing new more complex in-vehicle assistive systems that will be efficient for both the driver and traffic network and adapted in order to optimise their near future market deployment.

Keywords: Nomadic devices, traffic efficiency, time headway, car following behaviour.

INTRODUCTION

Mobility is an important aspect of everyday life. The advances in technology increase the use of devices and complex systems for assisting driving. Increased mobility increases also the problems that are related to it, as well as accidents, congestions, delays, and consequently affects safety. It is estimated that congestion problems occur daily on 10% of major road networks in Europe and the associated costs are estimated to be 50 billion Euros per year in addition to 200 billion Euros safety related accidents costs. In addition, human errors such as misconceptions, drivers' lowered reaction times, little anticipative behaviour and increased gaps in destabilising the traffic flow and creating congestions.

There are high expectations about in-vehicle and driving assistance systems for contributing in solving the aforementioned problems (European Commission, 2010). Many studies have focused on the impact of using in-vehicle systems with simulators and simulation models in order to identify their effect on traffic. In order to meet the expectations for these systems, on the road studies should be conducted in order to provide insight to the potential effects and impacts to driver and traffic efficiency.

A general categorisation for vehicle systems could divide them in driving support systems (e.g. navigation support, traffic information, speed information) and vehicle support systems (e.g. collision avoidance system, lane departure system, speed control, speed alerts, Adaptive Cruise Control) (Golias et al., 2001). These systems, though, would probably be integrated to more complicated hyper-systems for future vehicles.

Mobile phones were one of the first devices used in the vehicle. Since mobile phones became available to people, early studies focused on the effect of talking and messaging while behind the wheel. The primary target was to identify the effect of using mobile phones on safety. Safety is the cornerstone of driving research and efficiency has been a secondary objective until now.
Navigation support has exponentially developed within the last few decades. Increasingly more drivers are using dynamic navigation systems with information about potential delays

and congestion. Yamashita and colleagues (2004) found that the when drivers received accumulated traffic information with a Route Information Sharing (IRS) system, travel time decreased. If the system usage increased, then travel time decreased even more. Their findings were based on multi-agent simulation in a latient network and radial ring network.

Van Arem and colleagues (2006) examined the traffic flow effects of Cooperative Adaptive Cruise Control. The ACC system under investigation exchanged information with the vehicle ahead, so that it could follow this vehicle more closely. The results indicated an improvement of traffic flow stability expressed by fewer shockwaves and smaller standard deviations of speed, and a slight increase of traffic efficiency was indicated by higher queue discharge flows.

The use of ACC systems could contribute to reducing head-tail accidents, but it could also reduce the traffic throughput, depending on the system settings (Minderhoud, 1999).
With a 40% ACC equipment rate and one-second headway time, Broqua and colleagues. (1991) estimated throughput gains at 13%. Van Arem et al. (1996) and Minderhoud & Bovy (1999) found a decrease in average speed as a result of a collapse of speed in the fast lane when ACC with headway times of 1.4 seconds and above were used. Minderhoud & Bovy (1999) performed simulations with headway times as low as 0.8 seconds and concluded that current ACC using a one second headway time could achieve capacity gains of 4%.

A combination of ACC and Lane Departure Warning (LDW) was tested in the Alkim, Bootsma & Looman (2007) study. Although LDW was found much less effective than ACC, some of the test drivers reported an interesting positive integration effect. With ACC activated, a slight increase in the variation of lateral position in the driving lane was found. The test drivers, however, claimed that the warning issued by LDW effectively compensated for this, and increased their alertness.

Several simulation studies have investigated the potential impact of ACC on traffic flow. The simulation studies used various ACC algorithms, for instance to get various headway times, and applied them in various environments, at various penetration rates using various behavioural models. All these differences strongly influenced the outcomes on traffic capacity and speed, and therefore they make it very difficult to compare these studies and their results. Communication between vehicles and between vehicle and roadside is considered the technology that will make a whole new generation of ADAS possible.

Intelligent Speed Assistance (ISA) is a promising type of advanced driver support system. From a technical point of view, large scale ISA implementation is possible in the short term. The expectations of the effects of Intelligent Speed Adaptation (ISA) on traffic efficiency are based on the reduction and the homogenization of driving speeds. The results of micro-simulation modeling showed that in high traffic density conditions, ISA would not have a significant effect on network total travel time because driving speeds are already largely limited by congestion in high traffic density conditions. However, in lower traffic density conditions, the travel time would increase due to lower average speeds, especially with increasing ISA penetration rates (Liu et al., 1999).

Moving from simulation to real environments - according to a study carried out in both simulated and real environments- as soon as participants in any of the settings became aware of driving performance deterioration as a consequence of the secondary task, they chose to adapt their behaviour (Brookhuis, De Waard, & Fairclough, 2003). The adoption of lower (i.e., safer) speed, smaller distance to the road shoulder and a longer margin towards vehicles in front was particularly clear in the simulator and field.

Despite the increasing amount of knowledge of driver support systems, it can be concluded that there are no simple, straightforward assumptions on how these systems will influence driving behaviour and traffic flow performance. Many effects are still unknown and more research is required (Van der Heijden & Marchau, 2005).

Advancements in diverse areas of new technologies (such as telematics, telecommunications, sensors, etc.) have made both driving support systems and in-vehicle communications systems more affordable and, subsequently, more frequent in traffic. New technologies already play a key role in traffic safety and their interaction with other-type of systems (e.g. vehicle-infrastructure communication) is an objective set in near future. The evaluation of existing systems in the market as a potentially unified system would ultimately increase their market penetration rates-due to minimised installation costs (i.e. potentially increased cost-effectiveness) - but additional harmonisation among systems and fir their interaction with the driver is required. The impact of these systems to the driver is still uncertain and their investigation is of imminent importance in order to clearly define their interaction and relation. Creating increasingly more complex and sophisticated systems has as a drawback the inherent difficulty of isolating their effect.

In this study, two aspects of car following behaviour were investigated. Time headway based suumary metrics were estimated with different combinations of in-vehicle functions. Violation of safety margins (i.e. small following distances) could be interpreted as deteriorarting driving behaviour with potentially negative safety consquences. Time headway was chosen because it is a reliable index of longitudinal behaviour fitting better an efficiency impact assessment than time to collision which is an index more appropriate for safety analysis.

Two (two-tailed) research hypotheses were investigated:

> H1: Overall time headways will increase with the combination of ADAS and nomadic device functions
>
> H2: Time spent with dangerously low time headways will decrease with the combination of ADAS and nomadic device functions

The effect of 3 specific functions (navigation support, speed limit information and speed alert) to distance headway was investigated in order to indirectly address the potential impact of these functions to traffic efficiency (from the driver's perspective). Aftermarket devices might affect driver's attention and ADAS could decrease driver's arousal and readiness as the driver might rely on the system to warn him/her about a dangerous driving situation (e.g. incidents). On the other hand, the navigation system with the embedded tested functions (speed information and alerts) might support safe driving behaviour by, for example, controlling lateral behaviour and assisting the driver to find the fastest route (both environmentally beneficial and increasing network efficiency).

METHODS

Participants and recruitment

8 participants (5 male and 3 female drivers) drove an instrumented vehicle in each condition. Participants were pre-screened in order to investigate personal characteristics that might affect findings. Participants were all experienced and frequent drivers (>3 years driving experience; average 12,000 km per year; driving on a daily basis). Ages ranged between 30 and 38 years old. They were all healthy volunteers with no eyesight problems or corrected eyesight. Participants gave written consent prior the study onset. All participants were well-acquainted with new technologies, however all blinded to the aims and objectives of the study. The decision to recruit participants familiarised to ADAS was based on the fact that this was a small scale effort with an average sample size and certain routes to drive for about an hour. In other words, learning effects would have an influence on the findings about ADAS and their combination with the functions of the aftermarket device.

It is important to note that familiarisation is not the same as over-exposure. Their private passenger cars do not have ADAS. All participants were well-acquainted with Smart phones. Their ICT literacy was high and most of them have used a navigation system before but none of the participants had such a system installed in their own cars. Participants agreed their data to be available as long as anonymity/confidentiality was protected. Participants did not receive reimbursement for their participation in the trials. In addition, it was decided to carry out the tests at specific hours of day and to avoid traffic volume variations. Testing was carried out on specific time intervals (11:00-12:00 and 13:00-15:00). Although routes included urban sections, they did not include city centre sections avoiding high congestion, extremely low speeds, still recordings (i.e. collection of recording with zero/null values), and vaguely marked or non-existing lanes.

Design and procedure

A Within Subjects' Design was adapted with 3 experimental and 2 control conditions in Detailed Field Operational Tests (DFOTs). Conditions were counterbalanced. The ADAS included were a Lane Departure Warning (LDW) and a Forward Collision Warning (FCW) system.

Table I – Tested conditions

DFOT1: Navigation Support + ADAS
DFOT2: Navigation Support + Speed Limit Information + ADAS
DFOT3: Navigation Support + Speed Limit Information and Speed Alert + ADAS
With two baseline conditions:

$Baseline_0$ = Baseline condition with no warnings (though recorded in CAN bus)
$Baseline_{ADAS}$ = Baseline condition with received warnings (ADAS on)

Four different routes including urban, peri-urban, and motorway segments were selected for all conditions. Based on previous research experience, it was anticipated that both warnings systems (LDW, FCW) will not perform in all parts of the road and this was taken into consideration in both data reduction and statistical analysis. The lane departure warning is active when the lanes are well-defined and marked. In addition, the FCW warning is activated above 30 km/h; hence it might have not optimally performed in urban roads. Participants drove for approximately 40-50 minutes, depending on the traffic volume for approximately 27.2 km. Routes were selected to reflect daily activities for each driver (e.g. shopping, leisure, travelling).

Approximately 70% of testing was conducted during winter and remaining 30% was carried out in spring always with good weather conditions (no rain, snow, or fog) to avoid confounding because of these conditions regardless the fact that warning signals do perform well in light rain conditions. Participants were assigned a unique identification number and gathered data were renamed and allocated to new codes. Access to real names was granted only to chief investigator. Objective data included logfiles from the nomadic device and vehicle data (CAN bus) (Figure 1). Data were stored in safe place and copied in two different password-protected external hard disks.

Figure 1 - In-vehicle data collection

Instrumented vehicle

The Lancia Thesis Emblema is an instrumented vehicle (Figure 2) equipped with basic electrical equipment to manage the power supply to all additional equipment (e.g. auxiliary battery, fuses, relays, switches and lamps to configure and monitor the system). An additional electronic unit (gateway) transfers information from the vehicle (CAN buses) and makes them available to a PC at the boot (among others gas, brake pedals position, longitudinal speed/acceleration, yaw rate, steering angle, lights status, wiper status, external temperature, headway, obstacle distance; sampling rate 100 msecs). The vehicle is equipped with a frontal ACC radar to acquire information about the leading vehicle (distance, relative speed); these data are made available on the CAN bus network. The instrumented vehicle has both Lane Departure Warning and Collision Avoidance Systems with availability of lane and headway data on CAN bus.

Figure 2 – The instrumented vehicle

Description of functions available in the nomadic device

The aftermarket nomadic device used was a Samsung Omnius II with Sigic maps installed for the Navigation Support system. Participants were offered the fastest available route. Navigation support was static. Text files (log files) were directly uploaded and stored to an appointed FTP site. The stored log files included Global Positioning System (GPS) data, certain pre-determined events, and acceleration (x, y, and z) data.

Participants in DFOT 2 received information about the speed limits (Figure 3b). In some occasions, wrong speed limits were presented. Specifically, three occasions were noted; the speed limit shown on the navigator was 40 km/h and the actual speed limit according to the traffic sign was 90 km/h. For the other two occasions, the speed limit showed a delay in changing speed limit from 60 to 90 km/h. These errors and delays (resulting by GPS signal delays) were not random but constant; therefore they were identified and excluded from analysis.

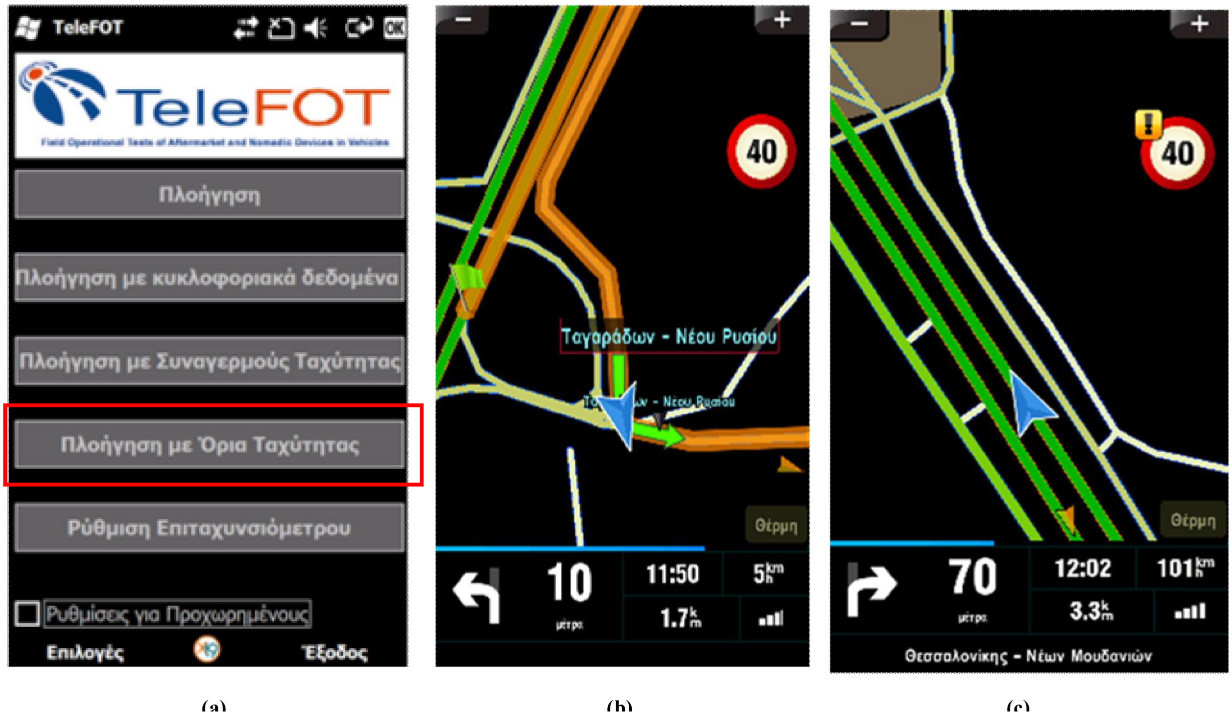

Figure 3 - Nomadic device application main menu: (a) selection of Navigation support wtih Speed Limit Information (DFOT 2), (b) speed limit information, and (c) speed limit information with speed alert (from left to right)

Participants in DFOT 3 received both speed limit information and speed alerts whenever they exceeded the speed limit for the specific road segment. They received auditory warnings (three beeps) and an exclamation mark (visual warning) besides the traffic sign.

Statistical analysis

Firstly, data were checked for correctness, missing values, erroneous recordings (e.g. impossible values for vehicle parameters). Secondly, data were post-processed in Excel files. Data were both graphical and statistically checked for outliers. Data were filtered in order to create required datasets for further analysis steps. Thirdly, data were analysed for the whole trip, for certain threshold values for the indicators (e.g. time headway values < 5 seconds; distance headway values < 50 m), and before and after the activation of warnings (LDW/FCW). Nonparametric tests were used as sample size was quite small and α was adjusted in pair-wise comparisons (Bonferroni adjustment).

RESULTS

Time headway is defined as the distance to the lead vehicle (bumper to bumper) divided by the travel speed of the ego vehicle (i.e. own vehicle) (Östlund et al., 2004) and usually large values are discarded.

The addition of the nomadic device and related functions did increase headway but not significantly (p>.05) in all conditions The average overall increase in time headway when compared to the pure baseline condition (free driving) was 8.85%. For the analysis of central tendency measures, values higher than 5 seconds were excluded. Increase in headway was found for the condition with ADAS and then the difference pertained with the stepwise addition of navigation support, speed information and speed alert.

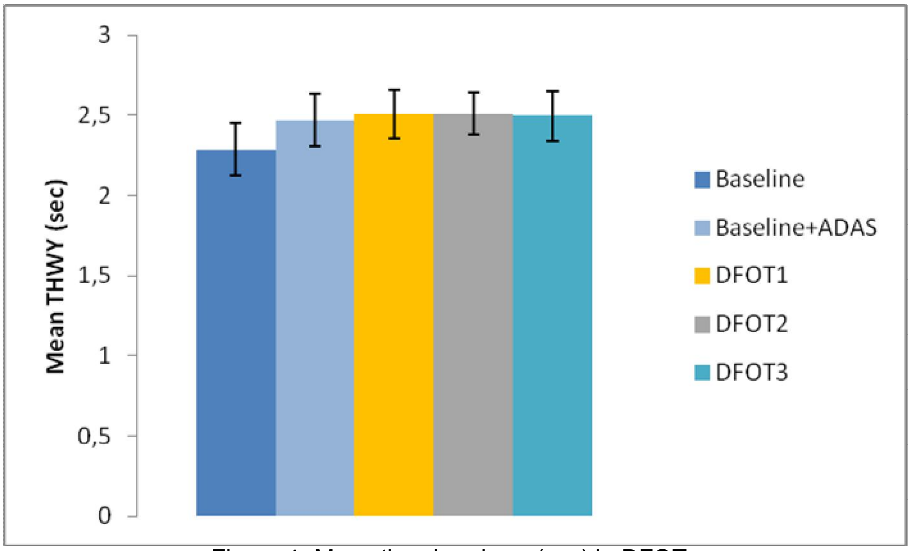

Figure 4 -Mean time headway (sec) in DFOTs

The next step was to investigation the variations in time headway, as these variations could affect the stability of the network and, subsequently, increase or decrease traffic efficency. Standard deviation (SD) of time headway was calculated for all DFOTs data were derived from. Overall related samples Friedman's two-way ANOVA by ranks test was significant ($\chi 2(4)=15.3$, $p=.004$). Pair-wise comparisons were carried out with Wilcoxon signed ranks test (Bonferroni adjustment). As the samples had a mean correlation of r = 0.379, then the Bonferroni correction was adjusted for this correlation from 0.005 to 0.012. The correction to Bonferroni adjustment was made in order to avoid making a Type II when trying to not make a Type I error. Stringent significance α values are retained because the number of pair-wise comparisons is high as variance in within subjects design accounts more for similarities than for differences.

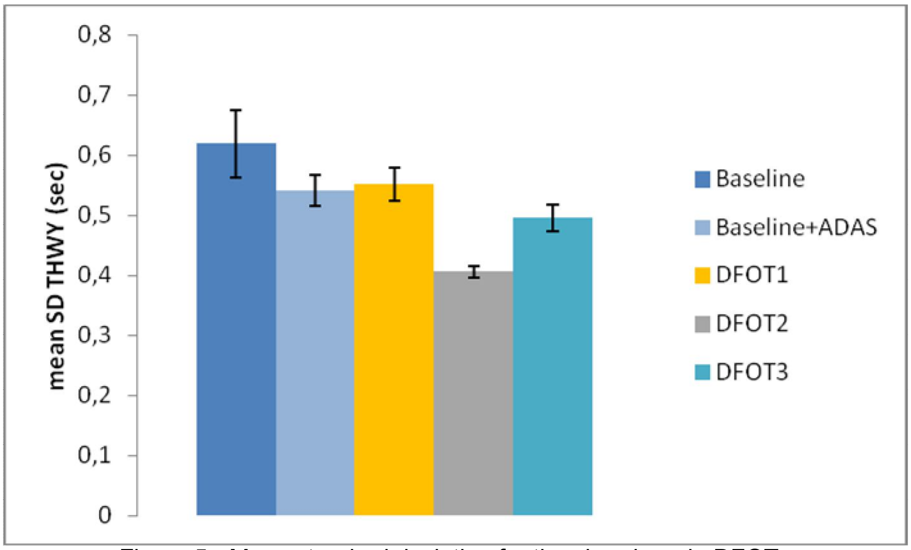

Figure 5 - Mean standard deviation for time headway in DFOTs

Significant differences were found for the following comparisons:

- Significant decrease (34.47%) of Standard Deviation (SD) of time headway in DFOT2 when compared to the pure baseline condition (Baseline 1) ($z = -2.51$, $p=.012$).
- Significant decrease (26.39%) of SD of time headway in DFOT2 when compared to DFOT1 (navigation support) ($z = -2.51$, $p=.012$).
- Similarly, trend to significance was found for the pair-wise comparison between DFOT2 and Baseline 2 (ADAS only with no functions) ($z=-2.38$, $p = .017$). The addition of navigation support and speed limit information decreased the standard deviation of time headway by 25%.

Variation in time headway was lower for DFOT 2. The addition for speed limit information with navigation and ADAS was more effective than the addition of speed alert. An interpretation of this finding could lie to the fact that speed alert warning was either ignored by the users or lost as “noise”. Drivers often asked the investigators for confirmation that the warning they heard was the speed alert. This is an important argument for designing the next generations of nomadic devices.

The minimum time headway metric is directly linked to safety. Extremely low headways increase the probability of accidents that create numerous problems in traffic flow affecting the efficiency of a traffic network. No statistical differences were found for mean minimum time headway among DFOTs ($p>.05$).; however the lowest minimum values were observed in the pure baseline condition (0.47±0.09) and the highest minimum values in DFOT3 with the bundle with all TeleFOT functions and ADAS (0.56±0.15) (Figure 6).

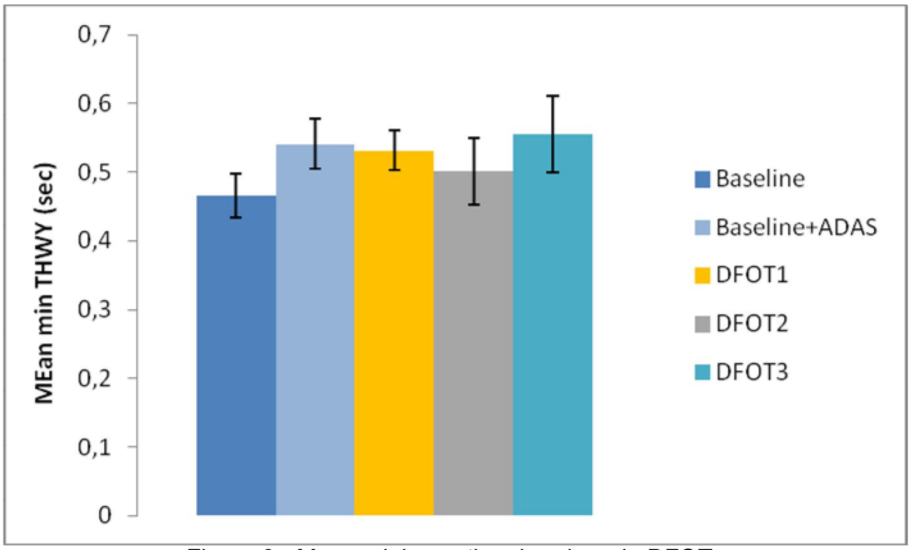

Figure 6 - Mean minimum time headway in DFOTs

Stratification for road types

The second analysis level, included stratification based on different road types. Chosen road types were: urban, peri-urban and rural and motorway.
No differences were found in mean time headway among conditions in DFOTs within city area. The greatest (but not significant) was reported between the pure baseline condition and DFOT3 where a decrease of 6.43% in mean time headway was found. The integrated functions probably slightly decreased time headway values but the differences are small within the city area. In addition, all values are above 2.4 seconds and therefore are within safety limits.

In peri-urban and rural roads, significant differences were found between DFOT1 and Baseline 1 ($z = -22.87$) and DFOT3 ($z = -28.2$, $p < .001$). In particular, mean time headway increased by 10.95% with the addition of navigation support but dropped 15.86% with the addition of speed alert. It is hypothesised that users were not so familiarised with these roads and therefore they paid more attention to the navigator resulting in more “loose” following. However, the addition of speed alert, decreased headway because of better marked lines (LDW).

If it is assumed that these roads are unfamiliar roads and navigation systems are more useful and used more for these types of roads, then the addition of speed alert functions increases longitudinal control and therefore it positively affects the stabilisation of traffic flow.
There is a potential conflict between these types of information as speed alert is more closely related to ADAS than In-Vehicle Information Systems (IVIS) and receiving both needs prioritisation by the driver.

Similarly, on motorway segments significant differences were found but in this occasion a significant increase from pure baseline to ADAS condition (14.95%) (Baseline 2) ($z = -19.31$, $p < .001$) and significant decrease (18.2%) from baseline 2 to DFOT3 ($z = -24.49$, $p < .001$). Activation of FCW warnings was more frequent in motorways and probably the increase is the effect of compliance to the warnings. In addition, speed alert decreases time headway by stabilisation speed variations. Therefore, the effect is similar to the previous road types but increase was probably affected by the most prominent function in each road context. Navigation support was most needed in not so familiar roads and ADAS warnings were more frequetly activated on the motorway. The findings are potentially influenced by the need for “shift of focus” in each context. Drivers seem to prefer to prioritise based on context but further research is needed on importance of “shift of focus” per road type.

Percentage of time spent with certain time headway values

Percentage of time (%) spent with low time headway values was estimated because of its importance for its potential impact on both traffic flow and volume. It is evident from Figure that drivers in pure baseline condition spent almost three times more time driving with dangerously low time headways (8.8%). The addition of ADAS significantly decreases (5%) time spent with dangerous time headway values but the addition of the other functions did not significantly affect percentage (%) of time spent with very low headways but did not have a negative effect either.

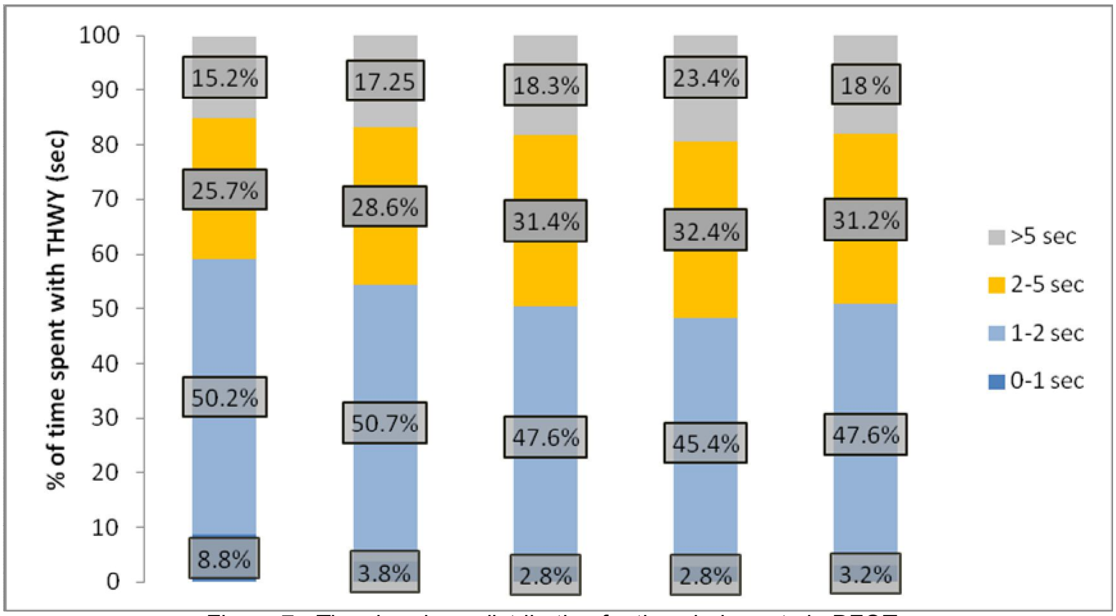

Figure 7 - Time headway distribution for the whole route in DFOTs

DISCUSSION

Longitudinal driving behaviour shows great heterogeneity and therefore affects traffic flow. Differences in car following behaviour affects to some extent the distribution of vehicles in lanes leading to induced lane changes with more disturbances in traffic flow(Kernel and Klenov, 2004). On the other hand, low and stabilised headways increase traffic volume and therefore increase the efficiency for the traffic netwotk. There were several components for headway analysis in this study.

Overall, headway increased as a result of lateral and longitudinal warnings and the addition of navigation support, speed limit information and speed alert. It is not clearly evident if the increase in headway is mainly an outcome of ADAS or functions effect or both. The assumption their effect is somehow additive is erroneous, linear and oversimplistic. It is important, though, that their effect was not counteractive; if for example, increase was evident with the addition of ADAS but vanishes with the addition of functions.
Therefore, hypothesis one was accepted with limitations; accepted for rural, peri-urban roads and motorways. The second hypothesis was also accepted.

Increase in headway within safe limits is not a positive outcome for traffic efficiency as decrease in driving with dangerous distance keeping behaviour is. The latter outcome positively affects traffic efficiency by minimising the possibilities of road accidents that disrupt the stability of the network and create problems in traffic flow.

For a macroscopic investigation of the effect to traffic efficiency, their impact should be further studied with the application of simulation models with different penetration rates for the nomadic devices and bundle of functions (i.e. equipped vs. non equipped cars).

A step even further would be to conduct a very large scale study with one common site for all Europe that would probably solve direct effects evaluation but would create sequences of others. The management of fleets across Europe would be a very high maintenance endeavour but the gains and benefits to all members engaged would be enormous.

Implications for research, policies & public

Navigation support alone was not found to affect traffic efficiency, at least as a primary indicator. It appears to hold tertiary significance. Indirect effects -not possible to investigated in this study- might exist. The choice of other peri-urban roads or rural roads, for example, because of navigation support could potentially affect efficiency because of re-distribution of traffic volume to smaller roads and subsequent avoidance of traffic jams and delays (route choice).

Speed limit information and alert does affect time spent with very low time headways on the network in combination with ADAS. Drivers spent -more than half- less time with very low time headways with both the bundle of functions and ADAS. Decrease of accidents could be attained with secondary benefit the robustness of traffic flow with less accidents. This finding has a potential twofold advantage, it affects both safety and efficiency.

The development of in-vehicle technology is driven by several factors (Van Arem, 2006). On the one hand, public authorities and road operators recognize that driver support systems offer possibilities to alleviate the problems on their roads. On the other hand, car industries and suppliers consider the systems an important product innovation and a competitive advantage.

In spite of their potential, the take-up of driver support systems in the market is very slow. The development of ACC systems started more than 25 years ago, whereas nowadays only a small percentage of (luxury) cars are fitted with this system. The main reasons for this slow take-up are legal barriers, the competitive situation of the automotive sector, the high cost of the technology, the lack of consumer demand, the lack of information about the potential benefits and a clear business case (European Commission, 2010).

The benefits and know-how distilled from the implementation of this methodological framework constitute a valuable and viable approach for other types of Field Operational Tests. The on-site data analysis tools developed will be customised and used for analysing data resulting from similar studies such as the ones performed within the FP7 European project FOTsis (European Field Operational Test on Safe, Intelligent, Sustainable Road Operation). This is a large scale effort aiming to test the road infrastructure management systems needed for the operation of seven close-to-market cooperative technologies (e.g. intelligent congestion control, dynamic route planning). Their potential and effectiveness will be assessed with full deployment in European roads (Spain, Portugal, Germany, and Greece).

It is important to mention that a set of sustainable structural indicators could be set for monitoring the effect of functions to traffic and driver efficiency that could infiltrate the development of next generation of assistive and information systems and would prove useful for strategies within policy making for nomadic device deployment.

A common goal is pertaining in current research efforts for global effects. Drivers must be protected from hazardous traffic situations and a harmonised, stable and efficient network enhances road users' safety. As controlling the vehicle and the traffic environment simultaneously is a hard and often time consuming task, then future hyper systems should primarily support the driving task.

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