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Naturalistic observation of drivers' interactions while overtaking on an undivided road

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Abstract. Current models of driving behavior and designs of driver support systems are not taking adequately into account the interactions between drivers. Although a driver's intended maneuver may not be physically possible at a specific time point, it may still be safely executed if the driver's intention is successfully communicated to and interpreted by another driver, who alters the own future trajectory so as to enable the maneuver execution. This paper presents some empirical findings relevant to communicative and cooperative interactions between drivers along naturalistic overtaking maneuvers on an undivided road. The cues used by drivers to interpret other drivers' intention and the drivers' interactions were extracted through video observations of the maneuvers together with the frequency of such interactions per level of traffic risk. The findings show that drivers use formal and informal cues to anticipate other drivers' intention. A significant percentage of maneuvers were performed after facilitation by other drivers. Future studies should focus on this phenomenon while future models of driving behavior should incorporate communicative and cooperative interactions among drivers, so as to design adequate cooperative support systems to enhance road safety.

Keywords: Communication, communication signal, cooperation, driver model, design of support systems

1. Introduction

A lot of systems are designed today to enhance traffic safety and avert road accidents by supporting the drivers in several driving tasks [Barnard et al 2011]. These systems try to enhance the drivers' situation awareness, to predict a possible collision and to warn the driver so that he/she may take the appropriate counter-measures and they may even undertake the automatic control of some driving functions, if it is envisaged that the driver will not be capable to take the necessary actions to avoid the accident.

Such systems usually employ algorithms to calculate the future trajectory of the vehicles involved, based on the vehicle dynamics. Normally they employ some assumptions regarding the dynamics of the vehicles, regarding the maximum or preferred accelerations and decelerations, regarding the longitudinal and lateral speed and steering wheel turn velocity, and even regarding the drivers' own needs and preferences [Tideman et al, 2010].

However, the acceptance of such systems by drivers is usually not high. The drivers' opinion on the riskiness of the situations does not often coincide with the system output at a significant percentage [Hegeman, 2007]. Among the main reasons is that the design approach is generally not considering the communicative and cooperative interactions among drivers [Wilde 1976], which may significantly affect the situation evolution. Although a driver's intended maneuver may not be physically possible at a specific time point, it may still be safely executed if the driver's intention is successfully communicated to the other drivers, who may alter their own future trajectory so as to enable the maneuver execution. This is an interaction, which all of us have encountered on several occasions on the road.

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According to [Maturana and Varela, 1998] human beings participate in third-order structural couplings, the social couplings. We consider that driving a car within traffic, as an acquired communicative behavior, is a linguistic behavior and creates a linguistic domain of interactions. In order to develop support systems that fit in the social couplings of drivers, one should certainly study this linguistic domain of interactions created while driving a car within traffic.

In accordance to the above, a driver's communicative act is more than joint coordination of action. It can be considered as the intentional transmission of information by this driver to the others, announcing his/her intended action, the intended maneuver, clearly before this action starts. In this context, a communicative cue is emitted clearly before the start of the intended maneuver. The driver declares his/her intent so that the other drivers get informed about his/her plan and they possibly facilitate the intended maneuver. The driver does not start the maneuver, unless he/she gets certain that the other drivers have perceived his/her intention. This communication of intention may be considered as a "request" by this driver to the others to not interfere with or even to facilitate the intended maneuver. If this intention is perceived and correctly interpreted by the other drivers, then they may react adjusting their trajectories or not. If they react by facilitating the maneuver, which can be considered as theirs acceptance of the request, then this act is a cooperative act. This conceptual model is depicted in Figure 1.

An example of such an interaction is the following. Driver A drives normally on an one-lane per direction road. Driver B is following and wishes to overtake Driver A, but overtaking is impossible due to oncoming traffic. Driver B follows Driver A at a close distance, flashing the headlights, indicating in this way the intention to overtake, but does not initiate the maneuver, waiting for a chance or a change in Driver's A driving behavior. This close following and flashing of headlights is Driver's B request towards Driver A. Driver A perceives the flashing and the close following, understands that Driver B wishes to overtake and decides to facilitate this. Thus, Driver A moves towards the right at the emergency lane, emptying the main driving lane. This movement is Driver's A response, his acceptance, to the request by Driver B. As the main driving lane is now empty, the overtaking can be safely executed. Driver B perceives the movement to the right of Driver A, understands that Driver A has noticed and accepted the request, and therefore initiates the overtaking.

Another example is the following. Driver A wishes to turn left at a junction on an undivided two lane road, being on the right lane. There are multiple oncoming vehicles and turning left is not safe. Driver A turns on the left indicator and waits for an adequate gap, this is Driver's A request towards the oncoming drivers. One of the oncoming drivers, Driver B, notices the turned-on left indicator and decides to facilitate Driver A. Driver B slows down while flashing the headlights, indicating to Driver A that the request to turn left is perceived and accepted, this is Driver's B response. Driver A perceives the flashing of headlights and slowing down of Driver B and starts turning left, since it will now be safe.

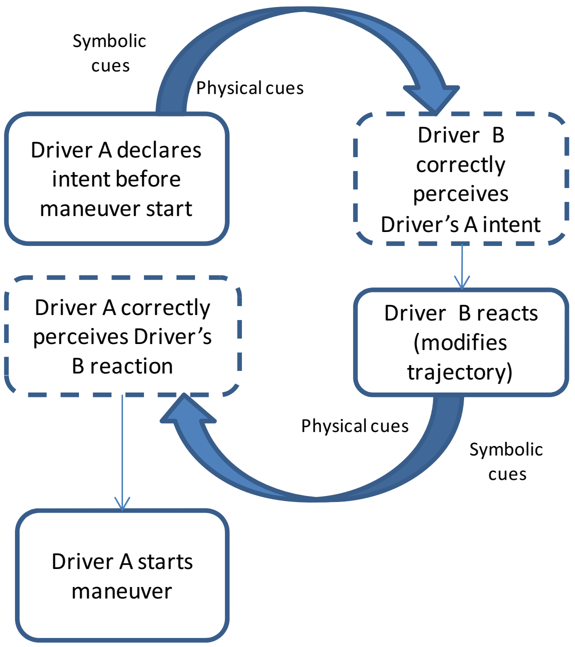

Figure 1 - Conceptual model of a drivers' cooperative interaction

In order to have a preliminary confirmation of the above conceptual model of interactions through empirical data, an analysis of observed communicative and cooperative interactions between drivers through video recordings of naturalistic overtaking maneuvers on an undivided road has been performed. Overtaking is one of the riskiest maneuvers which is greatly based on drivers' estimations [Clarke et al. 1998]. It requires a lot of judgments by the driver, on the time required to overtake, on the gap available for overtaking and a final driver's decision on the adequate time to initiate the overtaking. While overtaking the driver has to continuously monitor the overtaken vehicle and the rest vehicles and either continue the maneuver or abort it. It was expected in this analysis that in many cases the driver wishing to overtake would explicitly express his/her intention in advance, requesting the cooperation of the other drivers, so that they would facilitate the intended overtaking maneuver, especially in cases of high traffic risk. The objectives of the analysis were to estimate the occurrence frequency of the communicative and cooperative interactions among drivers along such overtaking maneuvers, to identify the cues, formal and informal, used by drivers to interpret intention and to analyze whether the riskiness of the traffic circumstances affects the frequency of such communicative and cooperative interactions.

2. Method

Overtaking maneuvers have been observed using an equipped vehicle driven along the intersecting arterial highway of Greece connecting the cities of Korinthos and Patra, a round trip of around 240km. The driver of the equipped vehicle was asked to drive normally at a constant speed of 5km/h below the speed limit and to maintain as far as possible a steady lane position with the right front-wheel near to the right lane marking. These instructions were expected to cause several overtaking attempts by other drivers. Moreover, due to the road design, a driver wishing to overtake the equipped vehicle driving in this lateral position should necessarily enter the opposite lane and therefore would have to possibly interact with oncoming drivers before and during the maneuver. In the following, the wording equipped vehicle stands for the overtaken vehicle

A small city car (Daihatsu Cuore) was used for this experiment, equipped with two CCD cameras, each one with a field of view of 28^o. One camera was mounted on the vehicle dashboard, to record the visual scene of the road ahead, and one camera was mounted on the shelf of the rear window, recording the rear visual scene. The camera recordings were synchronized offline using the clock of each camera and merged into one single video clip, as shown in Figure 2. Two experienced drivers, the observers, watched this video clip in parallel and extracted in common agreement the data used for the analysis.

For each overtaking maneuver the observers noted whether they could anticipate the overtaking driver's intention to overtake before the overtaking maneuver start, and if yes, through which cues. According to the Greek traffic code, the flashing of the vehicle headlights can be used to give a warning about the driver's intention to overtake, while the direction lights are used to warn other road users that the driver is going to change direction. According to the US Highway Code, the flashing of headlights warns and informs other road users of the drivers' intended actions, i.e. before changing course or direction. Therefore, the flashing of headlights and the activation of the direction lights were annotated by the observers as formal signals used by the overtaking driver to express intention. Apart from these formal explicit signals, the observers reported any other informal cues which led them to the anticipation of the overtaking drivers' intention to overtake. Such informal cues may sometimes be considered as signals emitted by the drivers to imply their intention. Since the observers were experienced drivers, it is believed that other drivers could also have anticipated the overtaking intention through the same cues.

Figure 2 - Synchronized video clip (left: rear camera view, right: front camera view)

The observers were also noting for each maneuver the sequential actions of the overtaken and oncoming drivers. These were classified as facilitating the overtaking maneuver, if the other vehicle trajectory changed to create more space or provide more time to the overtaking driver, or not facilitating, if the other vehicle trajectory did not seem to change.

Finally, the observers annotated the level of the traffic risk at the time point when the intention was first anticipated, as low, medium or high. For comparison reasons, for maneuvers when intention could not be anticipated, the level of risk was annotated 1.8 s before the overtaking maneuver start. This was done because from the video recordings it was found that the observers could anticipate the overtaking intention as a mean 1.8 s before the maneuver start.

3. Experimental results

A total of 82 overtaking maneuvers were analyzed. In 37 cases (45.12%) the observers could anticipate the overtaking intention before the maneuver start, via either formal or informal cues. In 45 cases (54.88%) the observers could not anticipate in advance the overtaking intention, as no formal or informal cues could be recognized. The cues interpreted by the observers as signals of overtaking intention are shown in Figure 3. In some cases there were multiple cues. They were mainly formal symbolic cues, namely the flashing of headlights (20 cases) and the use of the direction lights before the maneuver (14 cases). There were also cases of implicit cues. In 9 cases the overtaking drivers were following too closely the overtaken vehicle for a long time. The observers reported that this behavior was understood as an attempt by the overtaking drivers to persuade or even force the driver of the equipped vehicle to facilitate the overtaking. In 4 cases there was a lateral displacement of the overtaking vehicle towards the central road marking. The observers reported that this behavior allowed the overtaking driver to enter a state of preparedness to initiate overtaking when the circumstances would allow it.

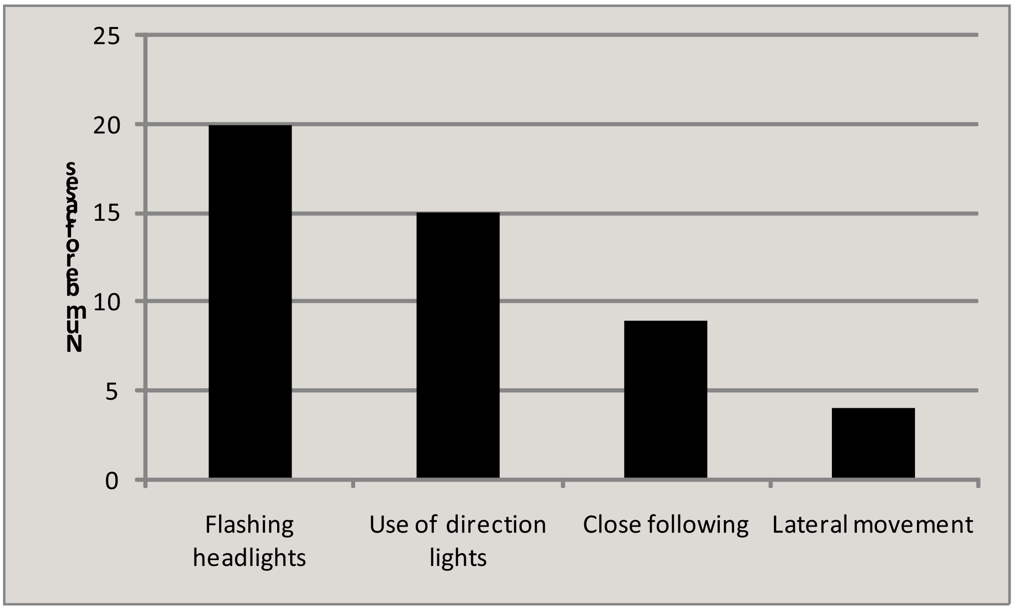

Figure 3 - Cues used by the observers to anticipate overtaking intention

The observed sequences of involved drivers' actions are shown in Figure 4. The Pearson Chi-square test did not reveal a difference between the distribution of cases when the intention could be anticipated and when not. This may mean that the other drivers' responses were not affected by the overtaking driver's communication of intent.

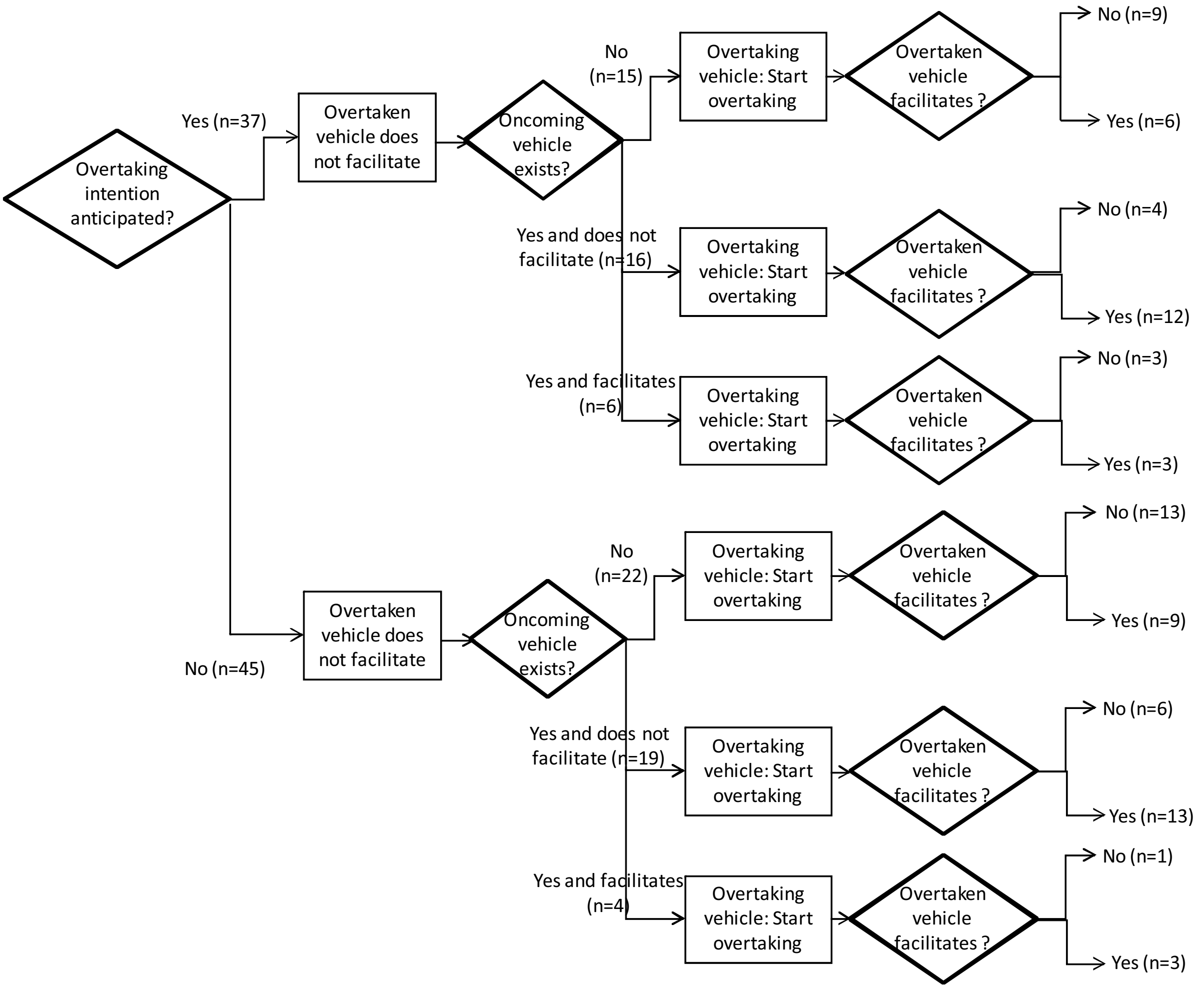

Figure 4 - Observations of drivers' actions per case

The number of maneuvers per level of risk of the traffic situation is shown in Table 1. The Pearson Chi-square test did not reveal a difference between the distribution of cases per level of risk when the intention could be anticipated and when not, however this may be due to the low number of maneuvers per level of risk. A qualitative overview of the results reveals that the existence of multiple oncoming vehicles may be a factor causing the overtaking driver to express the intention to overtake, that is, to intentionally request the facilitation of the maneuver by the other drivers. On the contrary, when there were no oncoming vehicles, there were less cases of expression of intent by the overtaking driver before the maneuver start.

Table 1

External traffic circumstances at the time point when intention was anticipated or 1.8 s prior to the maneuver start

	Intention understood by observer (formal cues only):	
	Yes	No
High risk		
Multiple oncoming vehicles at both the left and right lane	2	3
Oncoming vehicle at the left lane	5	4
Medium risk		
Multiple oncoming vehicles at the right lane	8	3
Oncoming vehicles at the right lane and reduced	2	1

	Intention understood by observer (formal cues only):	
	Yes	No
visibility due to curve		
No oncoming vehicle, reduced visibility due to curve	3	5
Oncoming vehicle at the right lane	8	11
Low risk		
No oncoming vehicle	6	13
Oncoming vehicle very far away (more than 6 s from the overtaken vehicle)	3	5
ALL CASES	37	45

4. Evaluation and Conclusions

The analysis of the video observations by experienced drivers revealed that the overtaking intention could be anticipated before the maneuver start in a 45.12% of observed maneuvers, not only via formal but also via informal cues. Furthermore, the observations revealed that in 6 out of 22 cases in which overtaking intention could be anticipated and an oncoming vehicle existed, the oncoming driver changed his/her trajectory so as to facilitate the maneuver. Even the driver of the overtaken vehicle was sometimes forced to change trajectory after the maneuver start so as to facilitate it, although he was specifically instructed to maintain a steady lateral position. Although the other drivers' reactions were not different when intention could be anticipated or not, these findings seem to confirm the conceptual model of the communicative and cooperative interactions among drivers, as depicted in Figure 1. This phenomenon should be integrated into driver models and should be considered in the design of driver support systems. Indeed, systems which discourage a maneuver based on vehicle dynamics only may not be accepted by drivers, who may be aware that the other drivers have noticed their request and agree to facilitate them.

No effect of the level of traffic risk on the intention anticipation was found, that is, the overtaking drivers did not send requests to other drivers more often with the increase of the level of risk. Furthermore, no effect of intention anticipation on the other drivers' responses was found. These findings may be due to the low number of observed maneuvers per case and should be confirmed with studies with more observations. If they are indeed confirmed, they may indicate that other factors, like for example previous drivers' experiences, play an equally significant role in the driver's decision to request cooperation and in the other drivers' acceptance of this request. The other drivers' responses may also depend on their perception or not of the request, on the correct or erroneous interpretation of this request and on their own interpretation and estimation of the level of traffic risk.

It must be noted, that the findings of this analysis are limited by the design of the study, since the driver of the overtaken vehicle was asked to maintain a steady lateral position, namely to ignore the request by the overtaking driver, even if he could anticipate the intention and interpret it correctly. This instruction was given so as to force the overtaking drivers to enter the opposite lane and thus to have to possibly interact with oncoming drivers. If the instructions to the overtaken driver were different, then there would also be natural reactions by him to the perceived overtaking requests and results of this study would be much richer. Moreover, the findings presented here are based on the interpretations by two observers. Future studies where the drivers themselves will express their own understanding of the situation and own interpretation of cues generated by other drivers are planned in order to obtain stronger confirmation to confirm the conceptual model presented in Figure 1.

Existing models of driving behavior [Hollnagel et al, 2003] employ a single driver perspective and do not consider interaction with other drivers. One attempt to integrate such interactions is proposed in [Renner and Johansson, 2006], who specify that drivers' joint actions are performed with a common goal, which is based on drivers' assumptions and always demands coordination and propose the Joint Action Control Model to explain driver coordination. This model however only refers to drivers' coordination, which does not necessarily employ intentional exchange of information but rather automated and unconscious adjustment of own vehicle movement so as to achieve the common goal of safe driving and reaching of destination.

Future studies of driving interaction should try to decompose this domain of linguistic interactions created while driving a car in real traffic, i.e. the frequency of communicative acts, the sequence of states in this communication, the language used, namely the cues used to transmit and collect information about intention, the drivers' responses to other drivers' requests, the drivers' assumptions stimulating and affecting this communicative sequence and the effect of this phenomenon on the way that maneuvers are performed and on road safety in general. The final objective would be to build a rich model of the interaction among drivers, including phenomena of communication and cooperation, which could be used to design adequate cooperative support systems and enhance traffic safety. Such systems would be able to avert misunderstandings among drivers about each other's intentions, which may be a contributing factor leading to road accidents.

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