On Social Interactions and the Emergence of Autonomous Vehicles

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Abstract: Nowadays and in the contemporary age, the reality of an all-autonomous traffic seems closer and closer. However, this transition period casts a lot of cards onto the table. Although technology can be replacing people at the driver seat, it has not as yet gained our full trust in what concerns communication in real time and safety. Humans interact on a daily basis in their various activities, and traffic is no exception. Most actions performed on the road rely on our perception of others' awareness and potential reactions. For instance, pedestrians seek for an eye contact before crossing the road, drivers seek for a gesture before starting a manoeuvre, and so forth. Thus, the question remaining is what happens when someone is seeking such a communication interaction and the car has no driver, nor has it someone who even knows what the car is doing. Moreover, people seating in the car might be performing any other activities but driving. Other questions also arise such whether people will accept the idea of trusting self-driving vehicles, or whether will they feel safe when walking amongst such machines. In this paper we pursue a rather social perspective and will raise questions, covering the literature so as to understand what practitioners, researchers and the industry have been doing to overcome the lack of confidence in self-driving cars and improve their trustworthiness towards more efficient and smarter mobility, as well as to identify trends and approaches to answer these emerging questions.

1 INTRODUCTION

As technology moves forward at an immensely accelerated pace, the old-fashioned utopia of self-driven cars is an ever-closer reality. Bearing this in mind, many questions arise, such as what impacts these autonomous vehicles will have on pedestrians' lives. Undeniably, this subject has been the target of much research, leading to many other still unanswered questions.

Although technology can be replacing people at the driver seat, trustworthiness of such new technologies is still to be proven. People are used to a certain kind of interactions, and this leads to constant and patterned behaviours such as seeking for eye contact before crossing the road. The same happens in crossroads when drivers (or a cyclist and a driver) look at each other before yielding, to give the other assurance that they are safe if they proceed. With a partially autonomous traffic, it is necessary to try and foresee how people trust the car behaviour and what they do when confronted with one. And later on, in an all-autonomous traffic, it is important to state whether people should trust blindly the car sensory and decision system and risk crossing the road. Recent research shows that people feel reticent about crossing the road in front of a car without a driver they can look at so as to get any kind of signal.

In this paper, we aim to evaluate this kind of scenarios, summarizing the current state of the art and reflecting upon what has been done, what will be done and what needs to be done. This literature review may lead to new questions and research ideas, since the most recent research will be analysed and counterweighted with older studies, models and simulations, as well.

The rest of this paper is structured as follows. After giving an insight into the current scenarios in road networks, Section 2 discusses on the pedestrian behaviour as well as the driver behaviour at marked crossings. A brief explanation of the traditional models of traffic dynamics from the perspective of the driver's decision-making processes are also presented. Section 3 focuses on recent studies tackling the problems of partially autonomous traffic interactions and what has been done to address the many issues arising in this context. Finally, we reflect on all the issues stated above and suggest some ideas for future work, as we reach the conclusion of this paper.

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2 SOCIAL INTERACTIONS IN TRAFFIC

Human beings interact by attempting to create a mutual behaviour adaptation process with other individuals through verbal and non-verbal communication. Such non-verbal communication can be reflected in posture, gaze and other kinds of body language (Lehsing et al., 2016b). This section discusses on how social interactions in traffic are an essential communication means that should also be taken into consideration even when autonomous vehicles are to be deployed.

2.1 Current Scenario

Needless to say that interactions between road users (e.g. pedestrians, drivers and cyclists) is not only based on a set of road rules but it is also dependent on a large range of informal social protocols such as eye contact, gestures and other social cues. Therefore, the less the road is signalised with traffic lights and other signs, the more a safe navigation depends on the ability of a person (either a driver or a pedestrian) to perceive and interpret these social cues (Earl et al., 2016). The behaviour of a pedestrian on marked crossings, a cyclist waving to signal his/her willing to turn left and even a driver changing lane are situations that require quick problem-solving thinking based on visual perception. Research in the field of transport engineering and traffic psychology has applied methods to better understand how such interactions occur so that dangerous situations and fatalities can be effectively reduced (Lehsing et al., 2016b).

2.1.1 Pedestrian Behaviour at Marked Crossings

In its safety reminders for pedestrians the U.S. Department of Transportation (US DOT) recommends people to make eye contact with drivers as they approach you to make sure you are seen (NHTSA, 2012). With just a look, one can estimate the car speed and the distance of the car from the crossing, highlighting the importance of eye contact in pedestrian-driver interactions. Bearing this in mind, we calculate the time we have to cross without getting hit by a car or another vehicle; finally, we decide whether we can cross the road or need to wait. However, more often than expected, one factor that affects our decision is the various signs given by drivers. Waiting for these signs, which range from eye contact to the waving of a hand or the flashing of headlights, is a consequence of the fact that drivers who give way to pedestrians usually prefer to lower their speed rather than to bring their car to halt. Pedestrians feel the need to ensure their own safety. In fact, as we can see in Fig. 1, 84% of pedestrians wait on the pavement showing their intent to use the crossing sought to establish eye contact with the driver of an approaching car (Sucha et al., 2017).

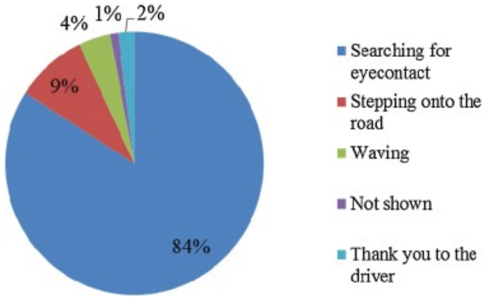

Figure 1: Pedestrian Intention (Sucha et al., 2017).

2.1.2 Driver Behaviour at Marked Crossings

Although the great majority of the pedestrians are proactive in seeking eye contact or trying to establish other forms of explicit communication with the drivers, only 39% of the drivers give them feedback, as shown in Fig. 2. Thus, it makes it hard for a pedestrian to know whether the car will yield the expected reaction. On the other hand, drivers are influenced by the expression of a pedestrian. When pedestrians are engaged in activities such as talking on the phone, texting, reading (e.g. newspapers), talking to another pedestrian or any other non-transport-related activity, a driver might perceive this as a lack of willingness or preparedness by the pedestrian to cross the road.

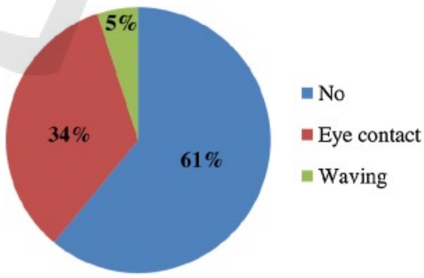

Figure 2: Driver Feedback (Sucha et al., 2017).

2.1.3 Uncontrolled Mid-block Crossings

The interaction during traffic conflicts at mid-block cross walks can be portrayed as a competition for limited resources, mostly time and space. A study shows that game theory is applicable to the analysis of the interaction between vehicles and pedestrians as such theory is based on the rational behaviour exhibited in interpersonal conflicting situations. In order to deal with the limited rationality in virtually most decision-making processes, evolutionary game theory is presented as an extension of the classical paradigm towards bounded rationality in the study by (Chen et al., 2016). In such cases, the developed model is calibrated and validated using real data collected at Jianshe First Road in Wuhan, China. The results show that the proposed model is able to properly simulate the interaction between vehicles and pedestrians (Chen et al., 2016).

2.1.4 Traditional Models in Traffic

Other social interactions worth understanding are the ones that happen in traffic, amongst drivers. Mixed traffic conditions are commonly characterised by the presence of different types of vehicle and behaviours. Different manoeuvring capabilities of different vehicle types lead to vehicle-type-dependent longitudinal and lateral movement driving behaviours. Weak lane discipline allows drivers to simultaneously look for possible lateral movements while progressing longitudinally. All of this gives rise to various driving phenomena and microscopic models — an approach that gives focus onto a finer grained perspective of traffic flow and the inner-workings of its individual particles (Munigety and Mathew, 2016). That being said, it is important to understand how drivers behave in these situations as an attempt at predicting the problems in the interactions between drivers and autonomous vehicles.

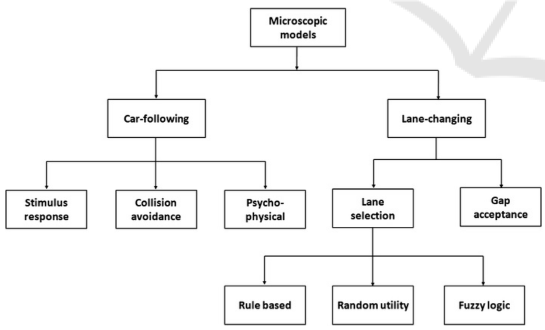

Figure 3: Microscopic Models (Munigety and Mathew, 2016).

According to (Munigety and Mathew, 2016), a tree classification of different car-following and lane-changing models are shown in Fig. 3. An extensive review of these driver behavioural models is also described by the authors. Lane changing models are gaining prominence within the scientific research community, since they are one of the most frequent interactions implemented in traffic simulations.

In Fig. 4, vehicle M is the vehicle that wants to make a lane change, vehicle C and vehicle D are the

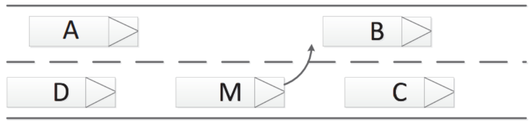

Figure 4: Lane Changing (Nagahama et al., 2017).

leading and the following vehicles in the same lane as vehicle M, respectively; vehicle B and vehicle A are the leading and following vehicles, respectively, in the target lane. Car-following is, as the name says, the action of a car following another. For example, M is following C (Fig. 4) (Nagahama et al., 2017). Most lane-changing models are based on the hypothetical notion that when the vehicle of an adjacent lane changes lane, the following vehicle of the target lane keeps a uniform motion. However, this hypothesis does not reflect the real lane-changing scenario. A paper has already put forward a lane-changing model with the consideration of car following behaviours in mind, focusing on the kinematic behaviour of the lane-changing vehicle in the process of accelerated lane change (Xiaorui and Hongxu, 2013). The vehicle interaction for lane changing is more complex than that of a car-following event because more vehicles are involved in the lane-changing event, which requires a greater workload of the subject vehicle driver. The lane-changing event is associated with a higher crash potential due to complex interactions with neighbouring vehicles (Oh et al., 2017) . According to the usual driver behaviour, when a vehicle wants to run in front of his own vehicle and he accepts this behaviour, then he will speed down to ensure safety for both. Considering the car-following behaviour, and accounting for the real lane-changing scenario, and mainly focusing on the kinematic behaviour of the lane-changing vehicle in the process of accelerated lane change, the study devises a lane-changing model with the consideration of a car-following behaviour (Xiaorui and Hongxu, 2013).

2.1.5 Communication Barrier

As stated above, eye contact plays a very important role on pedestrians' sense of safety. It also avoids danger when the driver, due to distraction or any other reason, is not willing to stop. This kind of communication can be significantly reduced when the driver's car has deeply tinted windows. This situation can be compared to a car with no driver, since both make it very difficult to understand cues. Deeply tinted window glass transmits less light than less deeply tinted glass and therefore reduces driver visibility. The task of looking through the rear window in dangerous situations was stimulated in a laboratory setting with road users such as pedestrians and cyclists. The car was always detected, but detection probability decreased with reduced luminous transmittance for the child and roadway debris targets. The results suggest that the safety of backing manoeuvres is compromised for all drivers at the darkest tinting levels studied (Freedman et al., 1993). Correspondingly, the UK government demands that the front windscreen must let at least 75% of light through and the front side windows must let at least 70% of light through for all vehicles first used on April the 1^{st}, 1985 or later (United Kingdom Government,). The way this scenario affects the behaviour of other road users may lead us to a better understanding of some of the problems on the interaction between humans and driverless cars.

2.2 Simulating Current Scenario

2.2.1 Driver-pedestrian Interactions

In order to analyse this behaviour, in addition to the research in the field of transport engineering and traffic psychology to reveal underlying processes and key factors in traffic that lead to dangerous situations or fatalities, several driving simulators have been implemented. Some use very complex apparatuses in full scale so as to reach full immersion, whereas others are considered low-cost environments resorting to simpler computer environments based on video games (Rossetti et al., 2013).

A pedestrian simulator, based on motion tracking technology, combined with a driving simulator allowed the participants to communicate non-verbally. This approach approximates the study to real-life situations since it creates a communication bridge between both the driver and the pedestrian in pedestrian-crossing situations. The interaction was measured using cross recurrence quantification analysis as described in (Lehsing et al., 2016b).

A simulation model for pedestrian-vehicle interactions at unsignalised mid-block cross walks captures the behaviour of both vehicles and pedestrians when approaching unsignalised interactions. The model is based on a cellular-automata ant metaphor that is calibrated with detailed behavioural data collected and extracted from observations of two unsignalised intersections in Nanjing, China. In particular, this simulation model can replicate pedestrian-vehicle interaction and pedestrian delay with high accuracy and reliability (Chen et al., 2016).

The classical and common approach of driving simulation as a tool in traffic research is usually limited to one driving simulator. However, the behaviour of the drivers depends on the traffic environment. Therefore, it is important for the program to gather different scenarios with a higher number of programmed road users. Unfortunately, this is a bottleneck due to programming skills required and software limitations. The proposed method for linking simulators is said to have the potential to create a more human-like behaviour by means of opening interaction channels between road users in a driving simulation (Lehsing et al., 2016a). Nonetheless, other studies succeeded in combining different simulators to represent more complex systems, specially when different model resolutions were combined (Macedo et al., 2013; Perrotta et al., 2014; Perrotta et al., 2012).

Many simulation models have been studied lately to better instil safety to road users, especially pedestrians at cross walks. Nonetheless, these models do not include the non-verbal communication aspects, in which most road users rely on, as discussed in parts 2.1.1 and 2.1.2.

2.2.2 Driver-driver Interactions

Research has also been done in order to model and simulate traditional models (3) in traffic. As stated above, these models focus on the interactions between drivers, such as lane changing and car following. In (Morton et al., 2017), authors also refer methods suitable to learn such driving models from real-world data. This, however, is not within the scope of this work.

3 PARTIALLY AUTONOMOUS TRAFFIC INTERACTIONS

New communication requirements emerge when autonomous vehicles are introduced into the urban context. Certainly they are expected to overcome many of today's traffic limitations; however, the transition between vehicles steered by humans to fully autonomous traffic poses enormous challenges calling for appropriate attention.

3.1 Understanding the Problem

As already stated, people are often dependant on and influenced by other people's behaviour. In (Laznyi and Marczi, 2017) authors state that the level of dispositional trust towards autonomous systems among young adults is low. As when trusting other humans, trusting smart systems depends on those systems sharing the users goals. Moreover, to gain optimal acceptability, goals of the user should be shared by the smart systems, and smart systems should provide information to their user (Verberne et al., 2012). Also, authors argue that experiencing highly automated driving within driving simulators can increase self-reported trust in automation. However, although elsewhere (Choi and Ji, 2015) authors state that perceived usefulness and trust are major important determinants of intention to use autonomous vehicles, and that three constructs (system transparency, technical competence, and situation management) have a positive effect on trust, this study identified that trust has a negative effect on perceived risk.

In order to reach a full autonomous scenario, which will be publicly available in the near future, there will be a time between non-autonomous traffic and full-autonomous traffic, in which we need to cope with the challenges of partially autonomous traffic. It can be assumed that such transition will not be instantaneous. This being said, it cannot be assumed that humans will be completely out of the scene or off the roads during this transitory period (Driggs-Campbell et al., 2017). Instead, finding humans' place in this new scenario and understand how we will react to driverless cars is imperative, not only when we are driving, but also when we are crossing a road or even when travelling as passengers inside these vehicles. In (Driggs-Campbell et al., 2017) authors present a literature review of relevant driver modelling frameworks for cooperative driving and present a non-parametric driver model that can be adapted to many different applications in the so-called human-in-the-loop predictions.

Furthermore, connected cars, which are networked to traffic sensory and on-line information about road conditions, will take the driver's seat, acting in a way that the driver will not always understand or will find counter intuitive. Elsewhere (Koo et al., 2015), authors suggest that autonomous cars need appropriate means to explain their actions to the drivers so as to increase overall safety and become more reliable.

In particular, and we will give special attention to this scenario, pedestrians usually seek interactions such as eye contact, posture, and gestures. Simultaneously, as automation is increasing, people become unable to rely on this crucial factor — i.e. human feedback. Thus, new ways of communicating are necessary in order to warrant safe interactions within autonomous-vehicle settings. For this, pedestrians willingness to cross the street and their emotional state in encounters with a seemingly autonomous vehicle need to be explored. Studies show that pedestrians willingness to cross the street decreases with an inattentive driver. In contrast, eye contact with the driver leads to calmer, more comprehensive and workable interactions (Lundgren et al., 2017). On the other hand, gestures are usually difficult to interpret due to cultural variations. For instance, hand gestures can be used for counting or expressing other messages, varying from culture to culture. Since these elementary gestures are not universal or unambiguous, then a work into the universality of movement gestures is also necessary (Gupta et al., 2016).

To further explore the consequences of these encounters, a proof-of-concept study was implemented at a cross walk and a traffic circle. In the study, participants encountered a vehicle that appeared to have no driver — the Ghost Driver experience. This vehicle was driven by a human confederate hidden inside a car seat costume. Pedestrians who encountered the car reported that they saw no driver, yet they managed interactions smoothly, except when the car misbehaved by moving into the cross walk just as they were about to cross. In light of the aforementioned, practices such as making eye contact or making hand gestures will no longer be a reliable means of communication. Road users cannot observe any head movements indicating that they have been noticed to advance. This is not only connected to the pedestrians' safety but also to their comfort when walking on the road. Not only can pedestrians increase their own safety by interacting with car drivers through signals and gaze, but also with cyclists, since drivers tend to make decisions about their intentions by looking at the cyclist's face. A driver's gaze goes first onto the face of a cyclist and remains there for longer periods than any gaze directed at the cyclist's hand signs (Rothenbucher et al., 2016). A *Wizard of Oz* (WOZ) methodology for evaluating these interactions with autonomous vehicles has also been implemented more than once (Lundgren et al., 2017; Rothenbucher et al., 2016). The WOZ technique enables unimplemented technology to be evaluated by using a human to simulate the responses of a system. The *wizard* — a person who pretends to act as an autonomous system — is hidden, observing the user's actions. The *wizard* then simulates the system's responses in real time. Since participants do not suspect that a *wizard*, i.e. a human entity, was behind the feedback they were receiving, the method can be said to be successful. Also, this is an easily implemented but nonetheless powerful tool for gathering information at this early stage of the shift to an autonomous traffic, as it requires little software resources to yield a well-presented deception. The WOZ method simulated interaction in realistic traffic situations, although achieving repeatability in such dynamic settings can be challenging sometimes (Rothenbucher et al., 2016). In another experience (Lundgren et al., 2017), all pedestrians (N = 13 of 13) that met the standstill vehicle stated that they would only cross the street once they had established eye contact with the driver. The willingness to cross was reduced when the driver was talking on the phone, (N = 10 of 13). But it was further reduced when the driver was reading a newspaper (N = 5 of 13), or even when there was no driver present in the vehicle (N = 5 of 13). All pedestrians (N = 13 of 13) stated that eye contact with the driver, and the driver behaviour and interaction in general, changed the experience completely. When asked about the safest encounter, all pedestrians (N = 13 of 13) affirmed they felt most safe when they got eye contact with the driver (Lundgren et al., 2017).

3.2 Possible Solutions

To sustain perceived safety when eye contact is discarded due to vehicle automation some solutions have lately been proposed. For instance, a project treated autonomous vehicles as social robots; instead of establishing eye contact, humans could acknowledge vehicles' intentions through audio and visual cues. This could assure other road users of the vehicle's intentions. Without this assurance, road users can easily get scared while walking in shared zones. The pedestrian has no clear way of ensuring that the driver sees him/her moving around the vehicle as there is no driver to interact with. And people inside an autonomous vehicle have no sure way of knowing that the car is noticing the pedestrian and whether has it the intention to move on or slow down and let the pedestrian cross. As a result, the pedestrian may not be the only one not feeling safe with the idea of autonomous vehicles; passengers can feel scared too!

So far a number of researchers have studied ways of turning the vehicle more sociable. This is illustrated by showing motion intentions of the autonomous vehicles, such as the route destination and mission state, through a LED message board. An audio cue, as firstly referred, in the form of music has also been broadcast through the speaker while the vehicle was driving autonomously to capture the attention of the surrounding pedestrians and other road users, who otherwise might not notice that the vehicle did not have a human driver. This LED strip to broadcast obstacle detections from a LiDAR (remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light) was found to be an effective method to acknowledge pedestrian presence (Florentine et al., 2016). A research has been carried out in order to catalogue the gestures of transport authorities of different states. This classification of hand and body movements has not only contributed to understanding the psychology of such gestures, but also to the categorisation of hand rules. This research can provide revelations about the various elements involved in such gestures, which include arm movement, eye behaviour, body posture and head movement (Lundgren et al., 2017).

3.3 Future Approaches

Researchers say there is a need to draw conclusions about other traffic situations (e.g. crowded crossings, turning manoeuvres) and other cultural settings, since one of the WOZ tests were carried out in a small Swedish population (Lundgren et al., 2017). Similar methods to the Ghost Driver should be implemented to investigate other types of encounters with an autonomous vehicle. In particular, pedestrians' behaviour when coming across an autonomous car in which the only visible person in the car displays atypical behaviour inside the car. From eating, to reading, applying make-up or any other kind of leisure activity in the autonomous vehicle instead of driving, it should be noted how pedestrians respond to the person in the car and whether they would attempt to communicate back with the pedestrian. Since these people do not necessarily know it is an autonomous vehicle, it might be a cause for concern when the person inside the car is doing an unrelated task. Finally, the research about the gestures could extend the study to peoples interpretation of these gestures. Future work will also address the question whether any of these agreed gestures are also used by pedestrians and human drivers. Therefore, autonomous vehicles need to understand the intentions beyond gesture signs.

4 CONCLUSIONS

Taking all this into account, interaction in traffic will change as the number of autonomous vehicles circulating on the roads increases. Nowadays, pedestrians' feeling of being safe is much dependent on eye contact and other non-verbal forms of communication. In a near future, road users will have to communicate with autonomous vehicles. Not only pedestrians but also cyclists and other drivers will have to interpret signals from a machine to know how to proceed in traffic.

This literature review aims to show how road users interact with each other, approaching vehicles' interactions' traditional models such as car-following and lane-changing, pedestrian-driver behaviour at both marked and unsignalised cross walks.

Current concerns are discussed as well as are the latest research done on social interactions with autonomous vehicles. In our opinion, the future can bring new approaches to address these concerns, which may vary from audio and visual cues on the autonomous vehicle to real-time body language recognition. Finally, some ideas of future work that we considered worth investigating are presented at the end of the recent studies section. These ideas range from new data collections about other traffic situations, different cultural settings and its analysis to new fake encounters that test people's reactions.

We believe this paper helps understanding the biggest concerns that are triggered when we talk about inserting autonomous vehicles in a mostly human-based traffic. In addition, it has highlighted which questions need answers and further investigation. Indeed, as future work, we would like to explore how tinted windows affect the communication between the driver and the other road users (i.e. other drivers, cyclists and pedestrians). Due to such glass characteristics, the light reflected prevents people who are outside the car to easily see the driver's gestures and expressions. We believe that testing the interaction between a driver in a tinted-windowed car and a pedestrian at a cross walk, as well as another driver, can be an easy way of testing people's behaviour in a situation in which it is hard for them to establish eye contact or to get another kind of feedback from other gestures, in order to better manage their own safety.

Also, this can be useful to test the results of using the headlights of an autonomous vehicle as a means to signal pedestrians or any other road user about the vehicle's intentions. Different communication metaphors can be easily tested even with low-cost driving simulators (Gonçalves et al., 2012; Alves et al., 2013; Gonçalves et al., 2014), in which subjects play drivers and pedestrians in virtual environments may give important insights into how such interactions emerge when visual clues are not present. Once we get the data about people's behaviour in a situation in which it is hard for them to establish eye contact or to get another kind of feedback, we aim to build a dataset that we intend to use for a social simulation approach to refine the existing models or even find a more appropriate behavioural mining approach.

Ideally, mining large volumes of recorded data to extract useful information about behaviour patterns of individuals and groups of individuals in the area under study, and monitoring the scene in real-time in order to provide an immediate response would be a desirable outcome. Learning spatio-temporal behaviour patterns from a public space is frequently of intrinsic commercial or security interest for users to gain more knowledge about activity patterns in public spaces they are responsible for (Hospedales et al., 2012). Having said that, we could use behavioural mining to identify typical behaviours in pedestrian-driver social interactions. The nature of behavioural patterns in a given scenario could be defined by a wide variety of factors, affecting the activity of a single object both over space and over time. Building models general and flexible enough to represent all these aspects of behaviour is an open research question needing further investigation (Hospedales et al., 2012). In the next steps of our research, we intend to study these topics and also integrate social simulation tools to vehicle simulators (Pereira and Rossetti, 2012) so as to investigate how autonomous cars can be prepared to communicate with pedestrians and other road users. Furthermore, outcomes of research in this emerging field may yield enormous contributions to improving legislation and traffic regulatory directives in the new age of autonomous vehicles.

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