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Geospatial analysis of residential parking behaviors using a semantic modeling approach

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ABSTRACT

Pedal misapplications by drivers have received attention as being an underlying factor for the phenomenon known as sudden unintended acceleration (SUA) in vehicles. This research investigates behaviors during a common task for drivers, namely residential parking. Parking has been identified as a maneuver that is often linked with SUA mishaps. Using driving trajectories data from a set of four couples collected as part of a naturalistic driving study, we investigate whether consistent behaviors can be detected when parking at home from a geospatial perspective, i.e., whether deceleration and braking occur in a characteristic way at the end of a driving trajectory, and whether these behaviors vary when the geospatial context of parking changes. An ontology-based approach is used to frame the key behaviors of the naturalistic driving, and big data techniques are applied to extract parking-specific behaviors from driving trajectories. Results show that individuals showed relatively consistent parking behaviors under the same geospatial context and the standard deviation of the deceleration threshold has a larger discrepancy between couples parking at different residences than within couples where parking occurs at the same place.

1. Introduction

Modern vehicles contain multiple safety systems that monitor the vehicle, the interaction with the roadway, and can even warn of a collision or begin braking to mitigate the severity of a crash. For example, adaptive cruise control systems have cameras or radar sensors that can sense the presence of a vehicle or object directly ahead and adjust the speed or even apply the brakes when traffic slows ahead (Lerner et al., 2011). The increasing use of automation in new vehicles brings with it even more sensors, more control and more intelligence that can be applied to a variety of situations (Schwarz et al., 2013). There are many opportunities to use this technology to help prevent fatalities and injuries. In 2014, 32,675 people lost their lives in crashes on US roadways (NHTSA, 2016). It is estimated that over 90% of fatal crashes are caused by some kind of driver error (NHTSA, 2008). The more common types of driver error (e.g., distraction, drowsiness) receive much attention and funding; however, less common instances of driver error have been more difficult to address. Pedal misapplications are one example of a type of driver error, and they have received some attention as being one cause for the phenomenon known as *sudden unintended acceleration* (SUA).

Explanations for SUA events range from pedals stuck on car mats to electromagnetic interference (Kane et al., 2010). It appears, however, that a large portion of SUA events are simply caused by pedal misapplication (Schmidt and Young, 2010).

In this paper, we conducted geospatial analysis of driving behaviors where the insights revealed from this research contribute to an improved understanding of human-vehicle interactions and contribute to future safety system designs leading to possible decreases in common driver errors such as pedal misapplications and SUA events. The primary goal of our analysis is to understand driving behaviors, with a particular focus on parking behaviors. We investigate whether individuals have a consistent parking behavior with respect to residential parking from a geospatial perspective, i.e., whether drivers decelerate and brake in a characteristic way over space and time at the end of a driving trajectory when parking at home (e.g., on a driveway or in a garage) and get insights into the range of behaviors during residential parking. Our analysis focuses on the parking behaviors of couples who live in the same residence, and thus share the same geospatial parking context.

In this study, we propose a semantic modeling approach that models the driving behaviors of individuals and provides a conceptual basis for the application of geospatial analytical methods that retrieve driving behaviors, in this case residential parking behaviors, from naturalistic

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driving trajectories. An ontology design pattern of naturalistic driving is proposed. The design pattern can be extended to accommodate additional parking and driving applications. Using this design pattern, we have developed a geospatial semantic model of residential parking, and we apply this model to investigate what a geospatial analysis of vehicle movements can teach us about the driving behaviors of individuals while parking at their residence.

2. Background and related works

With growing awareness of SUA events, the National Highway Transportation Safety Administration (NHTSA) mandated that all vehicles include brake-to-shift interlocks by 2010. A comprehensive investigation on pedal errors was conducted for the NHTSA in 2012 (Lococo et al., 2012). Several findings were consistent across multiple data sources. More females than males were affected, possibly due to their shorter stature. Very young and very old drivers were disproportionally susceptible to pedal errors. Inattention due to distraction or drowsiness and lack of familiarity with the vehicle were all cited as causal factors. Situational factors that caused a startle response in drivers were suspected as causal factors, as noted in previous research (Schmidt and Young, 2010). A survey of media reports of crashes involving pedal errors yielded breakdowns by crash location (Table 1) and pre-crash maneuver (Table 2).

The variations by age and gender make a strong case that a major piece of the SUA puzzle is pedal misapplication by the driver. With demographics leaning towards an aging population, recent research has been investigating driver errors in an aging population (Vemulapalli et al., 2016; Duncan et al., 2015). We also see from both these tables, that many SUA events occurred during parking. Other research has also found that drivers engaged in parking generally produced more significant pedal misapplication errors than while driving on the road (e.g., missing the brake entirely (Young et al., 2011)).

While the statistics present a case that driver error is a contributor to the problem of SUA due to revealed demographic differences, it is not the case that age and/or gender can simply be used as predictors for the occurrence of SUA. Driver behavior is quite individual and depends on many factors, yet it can be predictive of driver impairment and the adverse events that follow (Brown et al., 2014; McDonald et al., 2014, 2012; Schwarz et al., 2015, 2016). If characteristics of parking, for example, can be identified and customized to the individual (e.g., in the form of parking signatures), then unusual patterns might be detected and used to detect increased risk of serious events such as SUA.

As location-enabled devices become more and more common (e.g., GPS loggers, smart phones), collecting and mining spatial trajectories to understand moving objects' behavior patterns has become a research focus (Zheng, 2015). Naturalistic driving trajectories have been used, for example, to examine adolescent high-risk driving behaviors (Shope et al., 2003). Large amount of GPS trajectories of vehicles has also been mined to create road maps and learn optimal routes between two points in a road network based on drivers' historical behaviors (Krumm, 2011).

The utility of ontologies and the need for semantic modeling has been examined for a wide range of application areas including geospatial applications. Semantic data modeling allows for the integration of heterogeneous data types and sources, including authoritative data sources (e.g., The U.S. Geological Survey's National Map[1]) and bottom-up data (e.g., OpenStreetMap[2]), and in the U.S. and elsewhere, there is an active community of practice related to geospatial ontologies, with efforts underway to develop repositories of ontology design patterns (for example, ontologydesignpatterns.org and github.com) including geospatial design patterns. These repositories contain a range of patterns including for example, patterns for terrain features for topographic mapping, aquatic resources, species habitats, watercraft and water areas (capturing the relationships between vessels types and different water areas), and spatial trajectories among others. Calls for more research to support semantic data modeling in GIScience have also been made (Reitsma et al., 2009; Janowicz et al., 2010; Harvey and Raskin, 2011; Jung et al., 2013; Kalbasi et al., 2014). The ontology design pattern developed for this research contributes to further movement-related and driving ontologies.

Table 1
Number and percentage of pedal misapplication crashes by location and driver age group (Media Analysis, n = 565). Reproduced from DOT HS 811 597 (Lococo, Staplin and Martell 2012).

Crash Location	Age Group					
	N	20 or younger	21–35	36–55	56–75	76+
Commercial Parking Lot	416	44 (50%)	33 (47%)	37 (47%)	116 (69%)	186 (74%)
Residential Parking Lot	35	7 (8%)	9 (13%)	4 (5%)	8 (5%)	7 (3%)
Driveway	49	9 (10%)	5 (7%)	7 (9%)	8 (5%)	20 (8%)
On-Road (not intersection)	107	18 (20%)	20 (29%)	19 (24%)	24 (14%)	26 (10%)
Intersection	45	10 (11%)	3 (4%)	10 (13%)	10 (6%)	12 (5%)
Parking Garage	4	0 –	0 –	1 (1%)	1 (1%)	2 (1%)
Total	656	88	70	78	167	253

Table 2
Pre-crash maneuver behaviors (Media Analysis, n = 661). Reproduced from DOT HS 811 597 (Lococo et al., 2012).

Pre-Crash Maneuver/Behavior	Number (Percent) of Crashes
Entering parking space	321 (49%)
Leaving parking space	77 (12%)
Turning	58 (9%)
Startle braking following initial collision	51 (8%)
Startle braking following loss of control of vehicle	45 (7%)
Panic stop to avoid collision	27 (4%)
Slowing/stopping for vehicles	24(4%)
Slowing/stopping for traffic control device	12 (2%)
Slowing/stopping for pedestrians	9 (1%)
Driving in lane	23 (3%)
Parked/still in gear	9 (1%)
Changing lanes	3 (< 1%)
Stopped	2 (< 1%)
Total	661

3. Trajectory data from naturalistic driving study

The data used for this research were collected through a University of Iowa naturalistic driving study centered on understanding driver foot pedal behavior. Data were collected from September 2013 through August 2014, where data collection systems were installed in owners' vehicles for a period of four weeks. An event recorder was developed for the instrumentation and recorded vehicle signals related to position, velocity and acceleration. One third of participants were from the age group of 25–35 years and two thirds were over the age of 65 years. Of the participants, there were five couples living at the same residence. In most cases, these ten drivers shared a vehicle, while in at least one case each partner drove a different vehicle. The project included some coding of metadata, for example, descriptions of the driver's feet to capture any pedal errors. Other collected data included GPS data that was recorded continuously at intervals of 0.1 s (at 10 Hz frequency) while the vehicle is being operated, accelerometer data, and on-board

[1] http://nationalmap.gov.
[2] www.openstreetmap.org.