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What Road Elements are More Important than Others for Safe Driving on Urban Roads?

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ABSTRACT

Road elements are increasingly digitalized to provide drivers advanced assistance especially in the emergent or adverse conditions. It is challenging and expensive to accurately digitalize all the road elements especially on the urban roads with many infrastructures and complex designs, where we may focus on the most important ones at the first stage. This research designs a questionnaire to ask the drivers to rank the importance of the road elements in various driving conditions. Driver characteristics are also collected, including age, driving style, accident experience, and accumulated driving distance, to explore their effect on drivers' cognition of road elements importance. It is found that driving is a complex activity, and the moving elements (e.g. surrounding cars) are more important than the non-moving ones. Attention should be paid to the road elements even distant from the ego car, to get prepared to the potential driving risk or penalty. Statistical difference between the experienced and non-experienced drivers recommends that driver assistance system should be sufficiently trained in various conditions, to build up autonomous driving tactics and skills. This research promotes the understanding of driving cognition pattern to provide insights into the development of road digitalization.

KEYWORDS

urban road digitalization; road elements; importance ranking; driver heterogeneity; statistical difference.

1. INTRODUCTION

Car driving is a complex task where close attention should be paid to vehicle state and vehicle control to adapt to the uncertain road conditions for driving safety and efficiency [1, 2]. Road conditions can be better captured with road digitalization and advanced road information service, which is also quite challenging especially for the urban roads vary both temporally and spatially. In this endeavour, emphasis and priority can be laid to the most important road elements (e.g. signal light, and road alignment), which are suggested to be first digitalized to avoid the most driving risks in the typical road scenarios [3, 4]. Hence it is necessary to explore the importance ranking of various road elements to safe driving in different conditions, based on which the critical road factors can be prioritized for digitalization to help drivers observe and handle traffic risks [5]. That also provides insights into the development of autonomous driving and driver assistance system in the real world with brain-inspired cognitive and driving intelligence [6].

Road conditions can be categorized into two types, either being static or dynamic. The former refers to the road infrastructures including road layout, lane lines, road edges, road signs, and road access, etc. The latter refers to the moving elements, such as pedestrians, bicycles, and cars. Road conditions can be extracted but generally to a less accurate degree. For example, road information can be extracted with the PostGIS topology engine [7] or InfraBIM Open paradigm [8], with the libraries of typical road elements such as reinforced concrete structures, metal structures, road signs, fences, and lights on the roadside, etc. Note such methods generally return offline and static road information, updating of which requires manual operation.

2. LITERATURE REVIEW

The collection of accurate and real-time road conditions can be much more difficult and open to more challenges as vehicles drive onto open roads, instead in the closed test field. For example, highway digitalization includes a multiple of components namely smart lighting system, smart traffic and emergency management system, smart display, the internet of things, and artificial intelligence in highways embedded with deep learning techniques in the vision node at the traffic junction, to deliver an intelligent system and to predict the cause of traffic events such as accidents or delay [9]. Real-time road centerline extraction, assisting in vehicle lane keeping, has evolved from experience-based to optimization-based with skewness balancing, rotating neighbourhood, and hierarchical fusion [10].

2.1 Road element sensing and communication

Various methods have been developed to address the accurate sensing of various road elements. With the advancement of road sensing, we may provide timely road information service with wireless communication network, to better assist drivers or train autonomous driving agents. For example, robust location-aware service allows drivers to adjust their route dynamically according to nearby traffic conditions and roadside services against sensor noises and biases [11–13]. Crowd-based Road condition monitoring service is proposed to provide customers with accurate and updated road condition information, including longitudinal and lateral roughness, friction, cracking of road surface, and vehicle location, speed, as well as direction [14].

2.2 Effect of road information against driver characteristics

The rapid development of road information has contributed to transport activities in various ways, including transport planning, routing, control, service, infrastructure utilization, as well as time and cost saving. In this endeavour, accurate vehicle control can be the most fundamental and difficult one. For example, collision avoidance is a critical problem, where vehicle lateral and longitudinal acceleration can be optimized with risk anticipation [15]. Actually, hazard quantification can be closely related to driver characteristics and traffic situations [16]. For example, driver's subjective belief and perceptions about driving risks may vary greatly, even among quite a few respondents, 8 for example [17].

In the literature, various factors may influence driver cognition and behaviour [18], such as age [19], gender [20, 21], and driving experience [22]. For example, younger drivers could be less aware of driving risk and unable to perceive hazards quickly [22]. Moreover, a negative correlation is observed between driving experience (i.e. the years of driving) and aggressiveness, where the most experienced ones tend to take the least risks [22]. But illuminating results of human factors are seldom explored against different urban road conditions either in the cases of car-following or lane changing [23]. In the few relevant research, driver personality is categorized into three types, i.e. conservative, situation dependent, and aggressive, respectively, with increasing probability of taking risky actions [24]. Still, more details should be explored for driver heterogeneity.

2.3 Road element importance ranking

Faced with the complex effect of road information that is interacted with driver characteristics, we are motivated to focus with priority on the road elements with higher importance, to which road information service system can be pertinently developed. Importance ranking of road elements can be determined in various aspects. For example, flood exposure analysis can be conducted to evaluate the possibility of urban roads being flooded, so as to get theses those roads prepared to emergency evacuation [25]. Similarly, considering the effect of road information pertinent to different road elements on driving safety and efficiency, the importance of road elements can be identified and discriminated.

With the study area divided into 1113 Traffic Analysis zones, macro-level factors of road networks and socioeconomics are found to be the most important two factors on traffic crash frequency and injury levels [26]. With random forest, You et al. (2017) find it is found that traffic flow on the urban roads poses the most significant influence on traffic safety, which is exacerbated by weather condition [27]. In addition, Dong et al. (2018) investigate the relationship between the examined factors and the traffic crashes is investigated, finding that traffic, geometric, pavement, and environmental factors have direct effects on traffic crashes across injury severities [28]. With gradient boosting model, it is concluded that, though the factors are the same on different severity levels of road crash, their relative importance and marginal effect can be different in various situations, where scenario-based analyses are called for [29]. Moreover, the impact of driver behaviours and attitudes or cognization are also acknowledged to affect driving safety and efficiency [30].

2.4 Research gap and contributions

Research gap is identified in driver's difference in the perception and cognition of complex road elements for safe driving against real-world urban scenarios, to identify the road elements that should be prioritized for digitalization and incorporation into driving assistance system. To this end, the research is proposed to explore the importance ranking of road elements (e.g. signal light and road markings) based on the video collected on urban roads. Importance ranking of road elements is collected via questionnaire, either on road segments or at signalized intersections. Driver characteristics are also recorded such as age, driving style, experience of driving accidents, and accumulated driving distance, which are widely believed to affect driving behaviours. Given the complexity and diversity of road elements, pre-survey is carried out twice to improve the questionnaire before finalizing the survey to secure data quality. Then a method is proposed to rank the importance of road elements for safe driving under driver heterogeneity, i.e. the uncertainty in the importance ranking of road factors across hundreds of respondents. Statistic difference in the importance ranking of road elements follows to decode the effect of driver characteristics on the cognition of road elements.

Contribution of the research is three-fold to promote a comprehensive understanding of drivers' perception of road elements. First, typical real-world scenarios are extracted from urban roads, with all the road elements analysed that drivers may find important to safe driving, based on which questionnaire is designed and carried out. Second, the importance of these elements is ranked by the respondents to identify their contribution to safe driving in the specified conditions. The importance ranking of the road elements is analysed in each scenario to explore driver's perception of traffic environment, where the heterogeneity and uncertainty in the survey among respondents are addressed. Third, statistical difference is tested in the importance ranking of the road elements against respondent characteristics to locate their effect on road environment sensing, helping to develop personalized road information service and driving assistance system.

The remaining of the paper is organized as follows. Section 2 illustrates the design of trial survey and formal survey in different scenarios, followed by statistic description of respondent socio-demographics. Section 3 analyses the importance ranking of various road elements, followed by Section 4 to identify the statistical difference in the importance ranking of the road elements against driver characteristics. Section 5 briefly concludes the research.

3. SURVEY DESIGN AND METHODS

3.1 Questionnaire framework

Urban road changes in many aspects and driving there requires close attention to the complex road factors. To explore the importance of road elements on safe driving, a questionnaire is conducted for varying real-world scenarios. That is, driving video is collected on different road sections and is incorporated into the questionnaire to ask the respondent which road element is most important, which is second important, etc. in each scenario. The smaller the importance ranking, the more important the element. Ethics statement of the research were documented and submitted to the ethics committee of Soochow University for the approval (NO. SUDA20230428H12), where the form of participant consent is obtained orally, after which the questionnaire is showed to the respondents for anonymous data and analyses.

Figure 1 shows the framework of the questionnaire at the selected sites. At the start of the survey, the respondent may decide to take or reject the questionnaire. If they say yes, they will be asked whether they have a driving license. If yes, they are then asked the two parts of questions. The first part is about the importance ranking of road elements, by showing the video of each scenario. The respondents are asked to select the road elements in sequence based on their importance to safe driving. That is, they first select the most important road element, followed by the second important, until the one of least importance. Note if one element is considered not relevant to driving safety, one should not select it. The second part of questions is about respondent socio-demographics, including age, driving style, experience of driving accidents, and accumulated driving distance. Actually, we have also surveyed the factors of driver gender, with which no significant difference is found in the importance ranking of road elements, and is not included in the following analyses.

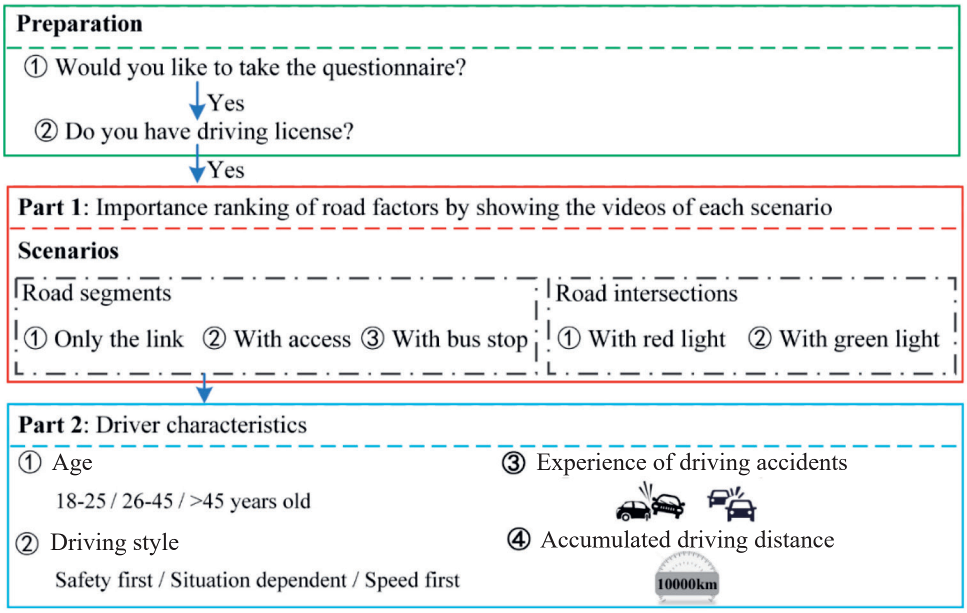


Figure 1 – Questionnaire framework

Specifically, three scenarios of road segments and two scenarios of road intersections are targeted at in the research. *Table 1* summarizes the features of each scenario. The road segments can be featured with an access, or with a bus stop. In contrast, the intersection may have red light or green light on for the ego car. It is observed that all the scenarios are for the urban road with 3 or more lanes. The ego vehicle is operating on the curb, second curb, or inner lane, and can be following a car, or making lane changes. To allow the respondent to focus on one specific road condition, the length of each video is no more than 3 seconds. *Figure 2* follows to show the details and elements of each scenario. For example, Scenario 1 includes a total of 7 road elements, i.e. dotted lane line, car stopping on the right, neighbouring cars, solid lane line, access, curb stone, and road green divider.

Table 1 – Basic information of the selected scenarios

No.	Road type	Feature	Lanes	Lane No.	Video length
1	Segment	Just the road segment.	3	1	2.6 s
2	Segment	A car stops right upstream of an access on Lane 3.	3	3→2**	2.0 s
3	Segment	One bus stop is set on the road segment.	3→4*	2	2.3 s
4	Intersection	Red light is on for both left-turning and straight cars.	4	2	2.4 s
5	Intersection	Green light is on for straight cars.	3	2	3.0 s

*Note: * means the lane extension from 3 lanes to 4 lanes, ** means lane changing from Lane 3 to Lane 2.*

3.2 Trail survey

Trial survey was carried out twice off-line with respondents randomly intercepted in the field. The first trial was implemented on September 12, 2022, collecting a total of 77 records. The first trail survey included all the elements observed in each scenario, making the questionnaire difficult to fill, as respondents had to rank the importance of many road elements. To test the stability and credibility of the result, Scenario 2 was repeated at the end of the trial survey. That is, if there was no significant difference in the importance ranking of the road elements of Scenario 2 either at the start or end of the trial survey, the results were believed to be reliable and credible. However, with the method of Wilcoxon Signed Rank Test for non-parametric paired test, there is significant difference in the importance ranking of the solid road line at the confidence level of 99%. Then we try to improve the questionnaire by making it easier to finish for data reliability.

Note the road elements of curb stone and road green divider were ranked least important referring to the average value, no matter if Scenario 2 was placed at the start or at the end of questionnaire, because they were not directly related to the ego car if the car follows the dotted and solid lane lines on the road. That is, these

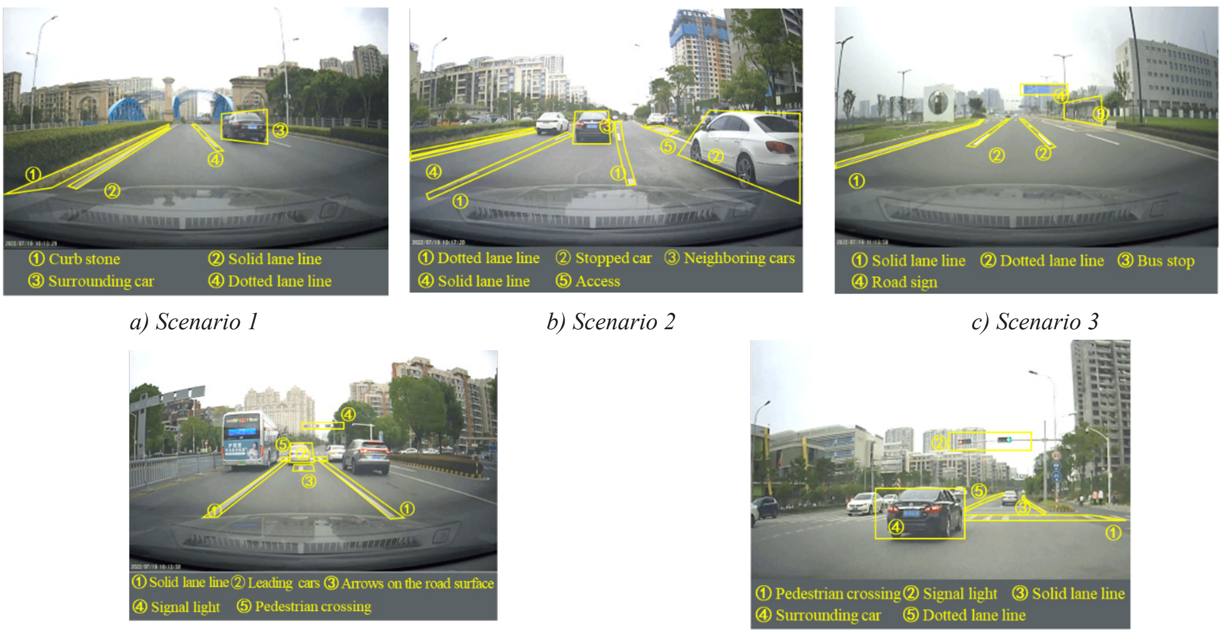
a) Scenario 1 *b) Scenario 2* *c) Scenario 3*

d) Scenario 4 *e) Scenario 5*

Figure 2 – Details of each scenario with road elements (Photos: Hui Xu)

elements do not pose direct constraint on the car movement. Hence we removed the two least important road factors of Scenario 2 in the second trial survey. The least important road elements of other scenarios were also omitted, of road green belt in Scenario 1; of no-stop marking, curb stone, and road green belt in Scenario 3; median divider, curb stone, and road green divider of Scenario 4; and curb stone as well as road green divider of Scenario 5.

Figure 3 shows the selected road elements adopted in the second trial survey, in the order as in the questionnaire. The second trial survey was carried out on September 18, 2022, collecting a total of 116 data. *Figure 4* follows to compare the importance ranking results of the selected elements in Scenario 2 at the start and end of the questionnaire, where no significant difference is found with paired test (p-value >0.1). Thus, the simplified questionnaire is validated to return stable and reliable results, and is adopted in the formal survey.



a) Scenario 1 *b) Scenario 2* *c) Scenario 3*

d) Scenario 4 *e) Scenario 5*

Figure 3 – The selected elements in various scenarios in the second trial survey (Photos: Hui Xu)

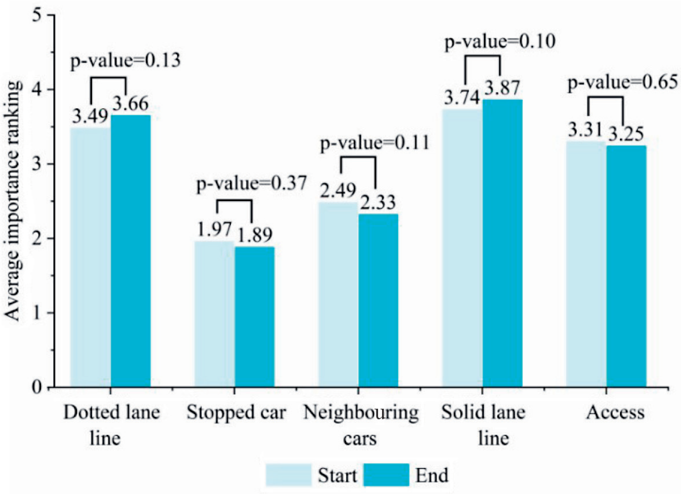


Figure 4 – Comparison of the importance ranking of the elements in Scenario 2 at the start and end of the second trial survey

3.3 Formal survey

Formal survey was implemented at the sites sampled by the layers of transport zones. These transport zones were separated into three types, where large, medium, and small zones total to 56, 791, and 124, respectively. 10% zones of each type were selected based on zone number, i.e. 6 large zones, 79 medium zones, and 12 small zones. In each large zone, 20 questionnaires were collected, while in each medium and small zone, 10 and 5 questionnaires were collected, respectively. Respondents were randomly intercepted in the field (i.e. off-line) from September 20 to 22, 2022. A total of 762 records were completed with response rate being about 20%. The median and average value of survey time length is 2.7 min and 3.1 min, respectively, with standard deviation being 1.8 min. Thus, the survey is of moderate length to the respondents, allowing them to finish the questionnaire patiently without worrying about schedule delay.

Figure 5 shows the statistical description of respondent characteristics. In *Figure 5a*, most respondents are aged between 18 and 45 years old, while that aged more than 45 years old take a small share of 8%. Thus, the respondents are generally young and probably the users of advanced road information service and automated vehicles in the future. Hence their opinion is illuminating to the development of road digitalization and advanced mobility service. *Figure 5b* shows that, up to 89% respondents are taking safety in the first place, though still 10% and 1% are situation dependent or speed first, respectively. When it comes to driving accidents in *Figure 5c*, it is found that 67% respondents have no experience of accidents. *Figure 5d* demonstrates that 49% respondents have driven no more than 10 thousand kilometres, while 51% have driven more. Driver heterogeneity may be related to different importance rankings of road elements as discussed in the following sections.

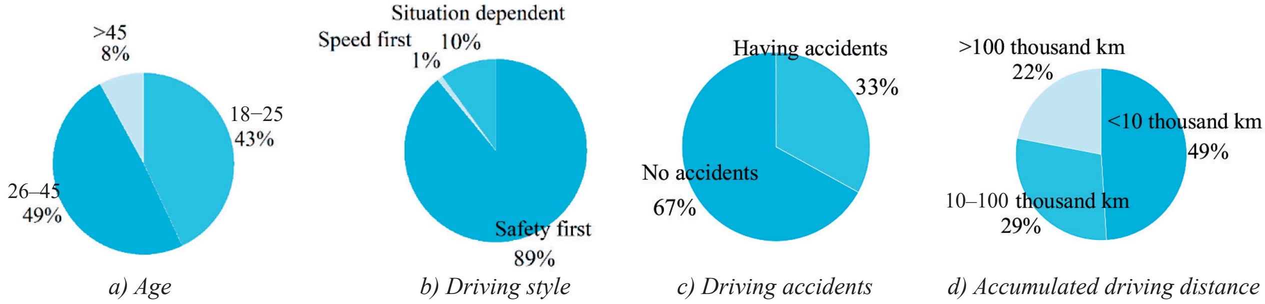


Figure 5 – Statistics of respondent characteristics in the formal survey

4. IMPORTANCE ORDER OF ROAD INFRASTRUCTURES

4.1 Statistical analyses

Figure 6 summarizes the boxplot of the importance ranking of road elements in each scenario. In Scenario 1, the surrounding car is regarded as the most important one, followed by solid lane line, curb stone, and dotted lane line. That is, the car should be aware of the possible risks or penalty, for example, from the neighbouring cars or from the solid lane line, where crossing the solid lane line may cause traffic tickets or colliding with the curb stone, while the dotted lane line is least important as it does not directly affect driving safety. That is consistent to driving experience in the real world, while reflects the gap from the existing research where road lane lines are treated equally important and extracted in a similar way. Instead, the findings suggest that the solid lane lines can be much more important than the dotted lines. Another interesting finding is that solid lane line is more important than curb stone, which can be explained that following the solid lane line secures the distance from the curb stone to avoid hitting it.

When it comes to Scenario 2, the elements of stopping car and leading car are almost equivalently important to respondents, followed by access, solid lane line, and dotted lane line. This result is generally consistent to

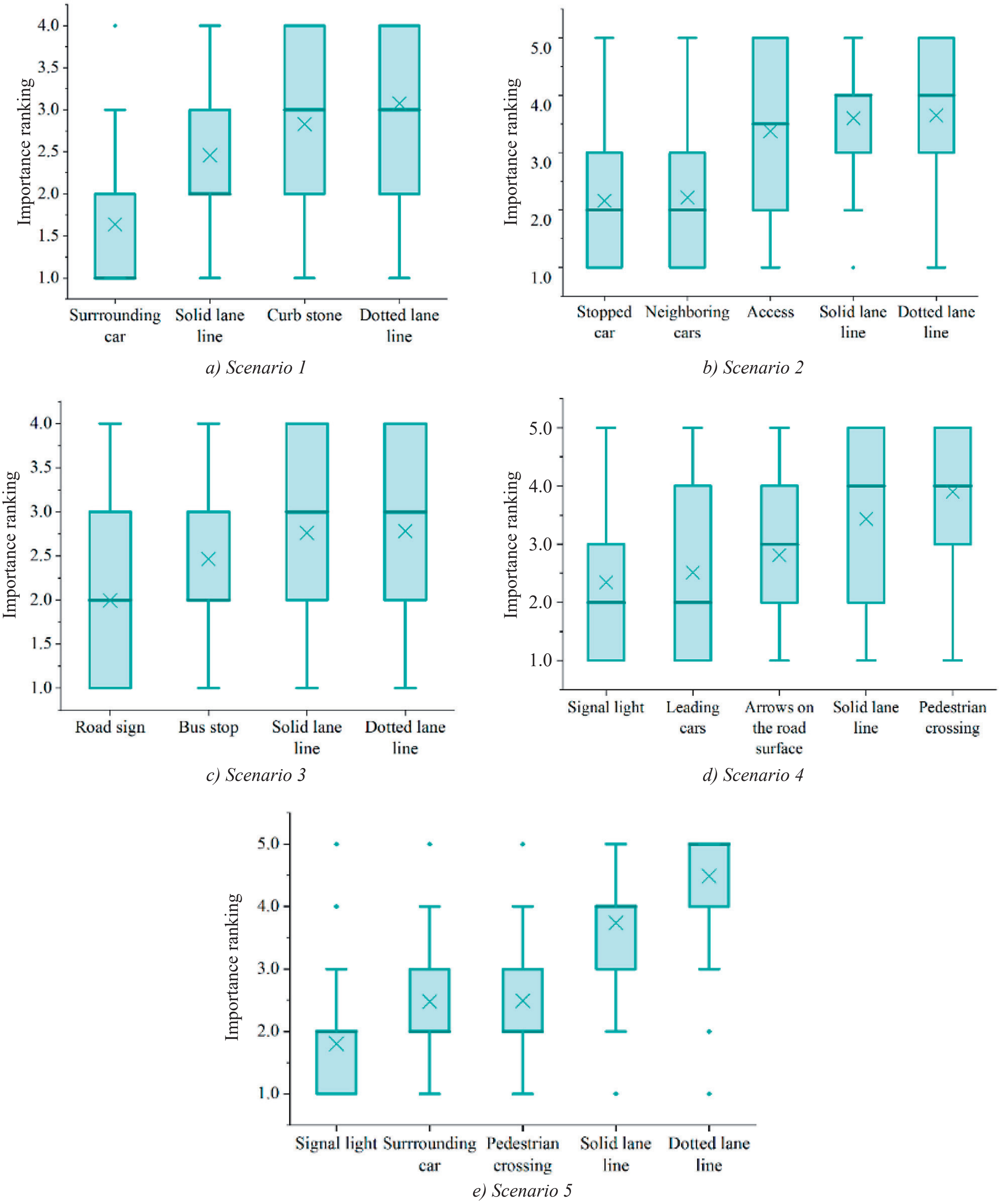


Figure 6 – Boxplot of the importance ranking of the road elements in each scenario

Scenario 1, with the neighbouring cars being the most important, and dotted lane line the least important. Note access, the element of road layout, is more important than solid lane line, as access can be related to more driving risks, such as unexpected and emergent situations of rushing out cars or pedestrians.

Scenario 3 tells that road sign is most important, followed by bus stop, dotted lane line and solid lane line. This emphasizes the value of digitalizing road signs, which provides the rule for safe and efficient driving. Bus stop is also recognized as an important factor to avoid the collision with the pulling-in and pulling-out bus, and the collision with the suddenly walking-out bus riders. Then dotted lane line is noticed to keep the car on the current lane, i.e. the second inner lane, which is meters away from the solid lane line, making it less important compared to that in Scenarios 1 and 2.

Scenarios 4 and 5 focus on the signalized intersection. When the car waits for green light upstream of the stop line, the leading cars that stop downstream are acknowledged to be the most important one, as they are the ones temporally closest to the ego car at its current speed. The second important road element is signal light, because it influences vehicle delay and guides the car manipulation in accelerating or decelerating. The third important element is solid lane line, crossing which can be recorded by video detector at the intersection for traffic tickets. The next important element is arrows on the road surface, failing to follow which, e.g. a straight car on a left-turn lane, can be compensated with turns on the following road segments, which brings no cost other than slight delay [31]. Pedestrian crossing is the last important element, as it is separated from the ego car by the leading cars.

In scenario 5 at green light, when the car moves past the stop line onto the exit lane, signal light turns out to be the most important one, guiding the car to adjust speed to safely move through the intersection. Then pedestrian crossing is noticed by the driver to be alerted to the running-out walkers and bicyclers. In the following, the surrounding cars are noticed to avoid vehicular collision, followed by the solid lane line that is close to the hard separation of road curb stone, and then dotted lane line. Combining the findings of the last two scenarios, we can clearly see that the importance of the same road element can be ranked quite differently in different situations, for example, signal light as the second important in Scenario 4 and the most important in Scenario 5. *Figure 7* summarizes the results from all the scenarios with major insights.

	Cars on the outer/inner lane (Scenario 1&2)	**Cars on the second inner lane** (Scenario 3)	**Cars ahead of the stop line** (Scenario 4)	**Cars past the stop line** (Scenario 5)
Importance ranking of road elements	Surrounding/stopping cars	Stop sign	Leading cars	Signal light
	Access	Bus stop	Signal light	Pedestrian crossing
	Solid lane line	Dotted lane line	Solid lane line	Surrounding cars
	Curb stone	Solid lane line	Arrows on the road surface	Solid lane line
	Dotted lane line		Pedestrian crossing	Dotted lane line
Insights	1. The importance ranking of the same road element can vary greatly, for example the surrounding cars in Scenarios 1/2/4 vs. Scenario 5, and solid lane line in Scenarios 1/2 vs. Scenario 3. 2. The elements implicating serious driving risks are always ranked first, e.g. surrounding cars in Scenarios 1/2 and signal light in Scenario 5. 3. Typical driving scenarios should be specially explored, instead of applying the same sensing pattern.			

Figure 7 – Summary and insights of the road element importance ranking in each scenario

4.2 Analyses against uncertainty of importance ranking

Uncertainties are inevitable in system modelling, which is commonly categorized into two types, being aleatory and epistemic [32]. Aleatory is irreducible, stochastic, and random that is inherent with the system, while the epistemic refers to the subjective and reducible uncertainty, due to the lack of knowledge of system process. The uncertainty in the research is of the latter type because respondents cannot accurately evaluate the risk and consequence of failing to obey the constraint from the road elements. A method is adopted of ranking the importance of road elements against epistemic uncertainty [33]. First, a threshold range $[T_l, T_u]$ is set to compare with the probability r_{ij} of the event that the road element i is more important than element j. *Algorithm 1* summarizes the method.

Algorithm 1 – Importance ranking of the road elements against uncertainty

Step 1: List the road elements in each scenario i={1, 2, 3, ...}

Step 2: Calculate the probability r_{ij} that element i is more important than element j $\left(\forall i \neq j\right)$.

Step 3: Rank the road elements according to the median importance values without considering uncertainties.

Step 4: Compare r_{ij} with T_l and T_u: If $r_{ij} > T_u$, then element i is more important than element j; if $r_{ij} < T_l$, then element j is more important than element i; if $T_u < r_{ij} < T_u$, element i is equally important to element j.

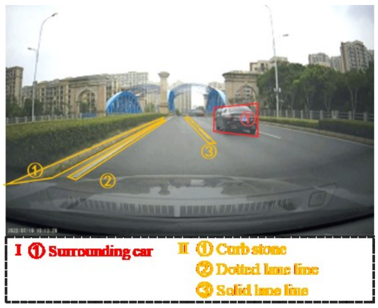
Step 5: Apply the sort step based on r_{ij}.

- ✓ Label the road elements in Step 3 as a list (sublist).
- ✓ Choose the middle element of the list (sublist) as a pivot p.
- ✓ For each in the sublist, compute r_{ij} for each pair of road elements: if $r_{ij} > T_u$, put element j in the sublist of elements less important than i; if $r_{ij} < T_l$, put element j in the sublist of elements more important than i; if $T_u < r_{ij} < T_u$, element i is equally important to element j.
- ✓ Append the sublist of less important elements to the right of p and the sublist of more important elements to the left of p.

Recursively apply to each sublist steps 5.2 to 5.4 until no sublist with more than one element exists.

Step 6: Rank the road elements according to the median importance values without considering uncertainties. Repeat Steps 4 and 5.

Step 7: If one element is ranked differently in the two cases, take the lower rank.



a) Scenario 1

b) Scenario 2

c) Scenario 3

d) Scenario 4

e) Scenario 5

Figure 8 – Importance ranking of the road elements under uncertainty (Photos: Hui Xu)

Figure 8 shows the results of importance ranking for the road elements under uncertainties, with T_l and T_u being 0.3 and 0.7, respectively [33]. In Scenario 1, the surrounding car is more important than solid lane line, curb stone, dotted lane line. The importance ranking of the elements in Scenario 2 is similar to that in Scenario 1, the moving elements of stopping and leading cars are of equal importance, followed by access, and by equally important solid and dotted lane line. In Scenario 3, it is found that bus stop, solid lane line, and dotted lane line are equally important, but less important than the road sign, which guides the car to follow the rules. Scenario 4 takes signal light, the stopping cars, arrow on the road surface, and solid lane line equally important, followed by the element of pedestrian crossing, which is separated from the ego car with the leading stopping car. Scenario 5 tells that signal light is more important than the leading car and pedestrian crossing, followed by solid lane line and dotted lane line.

5. DRIVER HETEROGENEITY

5.1 Hypotheses statement

To examine the difference in the importance ranking of road elements among heterogeneous drivers, *Figure 9* summarizes the proposed hypotheses as following.

H1: Drivers who are aged between 18- and 25-years old rank the importance of road elements significantly different from those aged between 26 and 45 years old.

H2: Drivers who have driven more than 10 thousand kilometres rank the importance of road elements significantly different from others.

H3: Drivers who have experienced accidents rank the importance of road elements significantly different from others.

H4: Drivers who are aged between 18 and 25 years old, have driven no more than 10 thousand kilometres, and have experienced no accidents rank the importance of road elements significantly different from others.

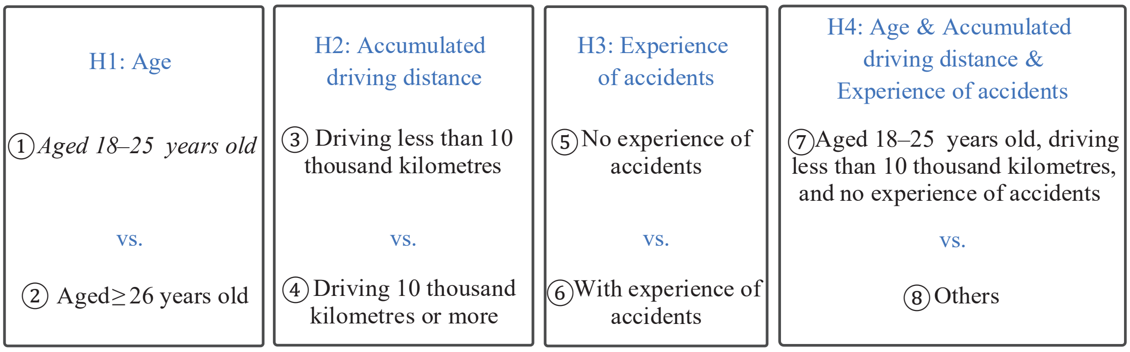


Figure 9 – Summary of the hypotheses on the importance ranking of road elements

Hypotheses examination is completed with two steps. First the pre-test of Kolmogorov-Smimov Test is adopted to examine whether the importance ranking of the road elements in each scenario is of normal distribution [34] against driver characteristics as in each hypothesis. If p-value<0.05, i.e. the data not of normal distribution, the method of independent samples T-test is selected for hypotheses test when data is non-paired [35], otherwise paired T-test is selected for paired data [36]. Considering that the data is not of normal distribution (p-value<0.05) and is not paired, the method of independent samples T-test is adopted.

5.2 Hypotheses test

Figure 10 shows the statistical difference in the importance ranking of all the scenarios against each hypothesis. It is observed that, in *Figure 11a*, the younger ones (aged between 18 and 25 years old) tend to underestimate the importance of dotted lane line and neighbouring cars of Scenario 2. This is consistent to the existing literature that the younger drivers tend to perceive potential hazards less quickly and comprehensively [22], as dotted lane line and neighbouring cars can be closely related to possible collisions to require the ego car to follow a specific lane and be careful with nearby cars. In *Figure 11b*, the ones driving no more than 10 thousand kilometres emphasize the element of curb stone in Scenario 1, while underestimate the importance of signal light in Scenario 5. Such cognition pattern reflects the lack of driving experience. That is, the ones who have driven limited kilometres feel more pressure when getting near the curb stone, to avoid the collision with hard road separation. In contrast, they may feel free from the signal light once the stop line is past, less alerted to the possible danger from signal phase switch.

In *Figure 11c*, the ones who have experienced accidents emphasize the importance of leading cars in Scenario 4 and dotted lane line in Scenario 5, while underestimate the importance of arrows on the road surface in Scenario 4. It is speculated that, the ones with accident experience are cautious of the potential collisions with the leading cars and decelerate the ego car in a more reliable and safer style to avoid rear-end collision, which accounts for nearly 29% accidents [37]. The higher importance of dotted lane line in Scenario 5 shows that these experienced drivers pay attention to their right of lane to prevent emergencies. In contrast, the reduced importance of the arrows on the road surface shows that the experienced drivers are aware that they can easily get back to the planned route, even if they move onto a wrong lane. Further, in *Figure 11d* on Hypothesis 4, for the young and less experienced drivers both in the accumulated driving distance and accidents, curb stone in Scenario 1 is emphasized, while leading cars are underestimated. Note the less experienced drivers take access more seriously to prevent emergent situations.

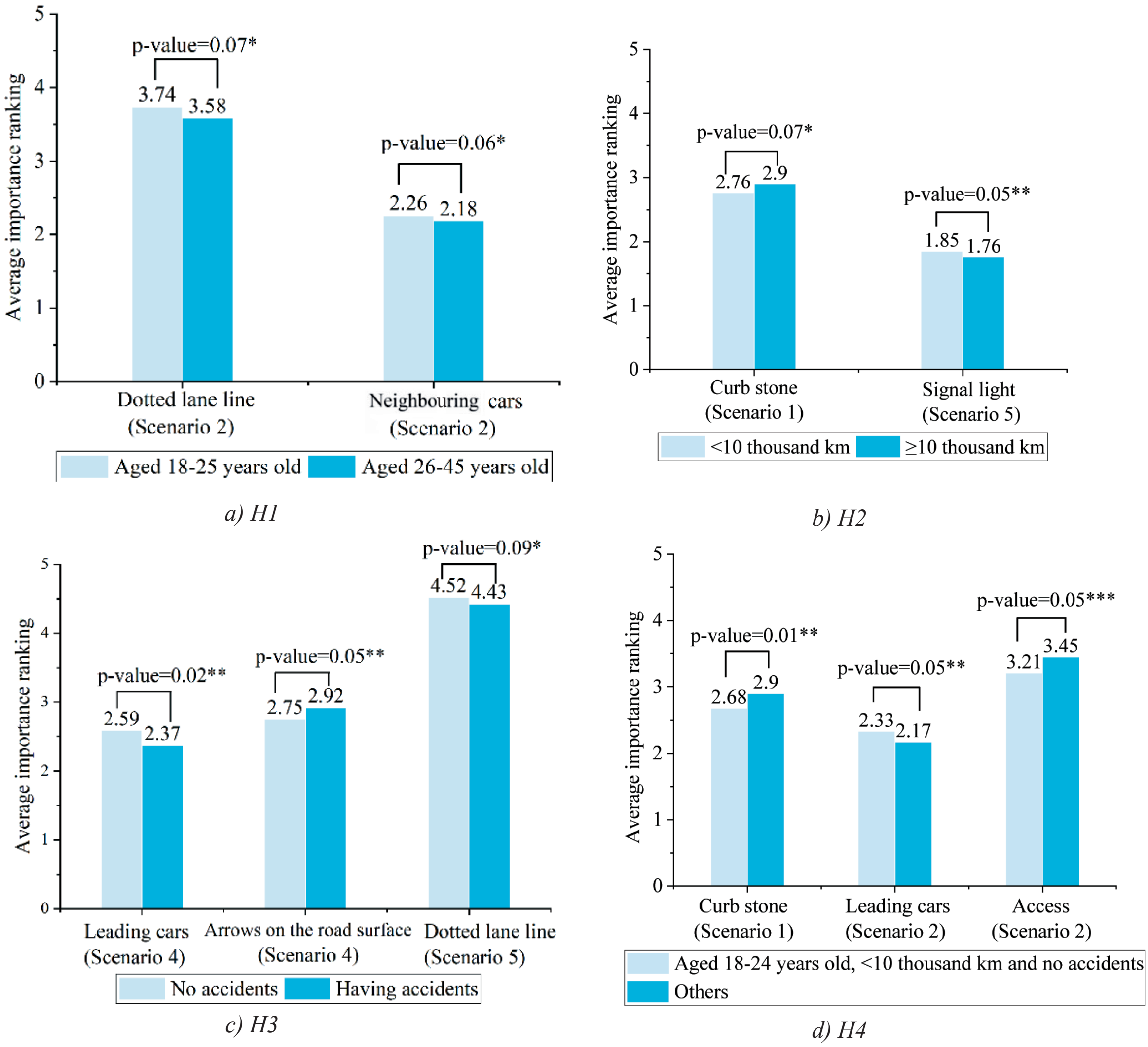


Figure 10 – Statistical difference in the importance ranking of road elements

6. DISCUSSIONS

This research provides a new perspective on the importance ranking of road elements. It does not quantify the driving risk from various road elements based on complex calculation [38, 39]. Instead, the research explores on the road element importance from driver cognization, who are asked to select the specified road elements in the sequence of importance ranking for safe driving in the questionnaire. That provides empirical insights on the prioritization of road elements during the long process of road digitalization, so as to better address the important road infrastructures to promote driving safety in the development process of automated vehicles.

Figure 11 compares the importance ranking of road elements without and with uncertainty. By introducing the importance ranking against uncertainty, the research manages to obscure the absolute difference on road element importance. That helps to strengthen the finding that road elements can share quite similar importance ranking, against the uncertainty caused by different drivers. Thus the stages of road element digitalization can be divided into a few stages, where movable elements are first targeted at, with road layout and critical road signs as following, and other road elements in the last stage.

Implications from the results can be three-fold. (1) Driving is a complex activity to closely trace the dynamics of the surrounding road elements that are posing direct or indirect effect on safe driving. That is, when one drives a car, his attention is not exactly constrained to the specific road elements along the current lane. Instead, he pays attention to the surrounding vehicles, road signs, access, and bus stops etc., getting fully prepared to the situations in the next time step. (2) From the driver perspective, the most important road element for safe driving may be remotely related to the ego car, e.g. the access of Scenario 2 and the road sign of Scenario 3, or may not directly constrain the vehicle movement, e.g. the signal light of Scenario 5 as

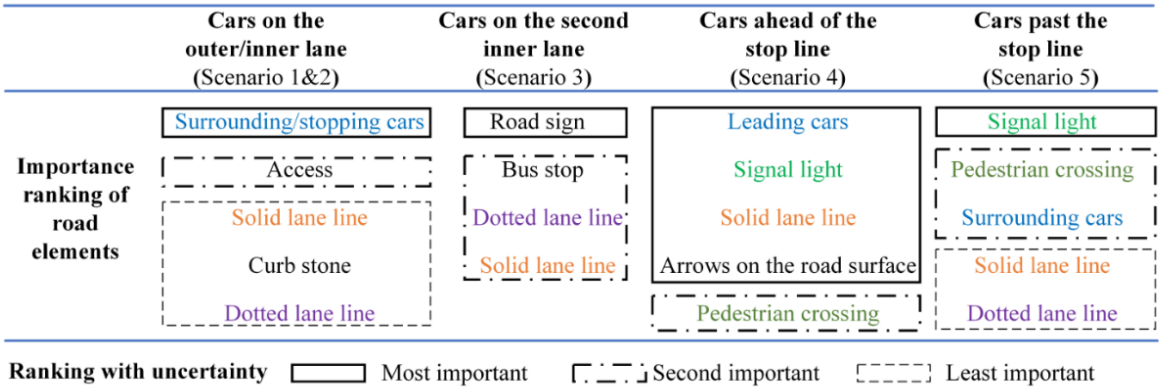


Figure 11 – Comparison in the importance ranking of road elements without and with uncertainty

the car has driven past the stop line. Thus the existing research on the driving risk quantification based on the distance from the road element [40] is suggested to be improved with actual driver sense pattern. That also emphasizes the understanding and simulation of human driver conception and behaviours before digging into road digitalization [40]. (3) Driving assistance system or autonomous driving agents are suggested to be trained in various situations, to be intelligent in cognizing and adapting to the difference in importance ranking of diverse road elements.

Figure 12 summarizes the difference of and insights from less experienced drivers, no matter from the aspect of age or driving distance or accidents, compared to the experienced ones. Faced with the significant difference in the cognition of road elements among different types of drivers, it is inspired to develop personalized road information service, especially for the younger and less experienced drivers, to compensate for their driving deficiency. In this way, we may better address the driving challenges and potential dangers in various situations and incorporate the response strategies in the driver navigation or assistance system. That finding extends the existing literature on the difference in experienced and less-experienced driver behaviors [41, 42].

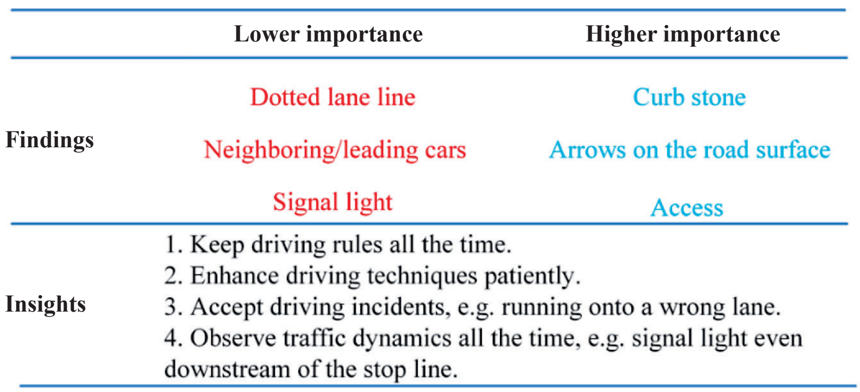


Figure 12 – Difference of and insights from less experienced drivers compared to the experienced ones

7. CONCLUSIONS

With the rapid development of road information service and the long-time challenge to collect accurate and real-time road information for advanced driving assistance system, it becomes increasingly urgent to decode driver's cognitive mechanism of road conditions, especially against different scenarios on urban roads due to the complex driving environment. That will promote our understanding of driver cognition pattern to the surrounding road elements, to identify the key elements of road digitalization and to provide insights into driver warning or driver assistance system, with which we can enhance driving safety. Considering driver heterogeneity, drivers' cognition of road elements can vary greatly. Therefore, this study designs a questionnaire to ask the drivers the importance of the selected road elements in various driving conditions on the urban road segments or at signalized intersections, with or without the changes in road layout (such as access). Driver characteristics are also collected, including age, driving style, accident experience, and accumulated driving distance, to explore their effect on driver cognition of road elements importance.

It is found that driving is a complex activity, and the importance of road elements, such as the surrounding vehicles, road access, road marking, road sign, and signal light, can vary from one case to another. Note the moving elements, such as the surrounding cars, are generally more important than the non-moving ones, which is consistent to our common sense, as the moving ones may bring immediate interruptions to the ego car. The static road elements can be ranked with significant difference in importance, for example, in Scenarios 1 and 2, access is ranked second important, compared to dotted lane line ranked least important, while in Scenario 3 dotted lane line is ranked more important than solid lane line.

Moreover, it is confirmed that driver attention is not exactly constrained to the specific road elements right along the current lane. Instead, he pays attention to the surrounding elements, even the distant ones to be prepared to the possible risk or penalty, which extends the existing literature that models driving risk based on the distance between the ego car and road elements. Note that when considering the uncertainty of importance ranking of road elements, the moving elements tend to share equal importance, so do the non-moving road elements, and that the former is generally more important than the latter. Thus it is unnecessary to divide the digitalization process of road elements into multiple stages. Instead, we may focus on road layout first, and then on road signs and markings.

With respect to driver characteristics, it is validated that there is significant difference in driver cognition of road element importance. When one is less experienced in age, driving kilometres or traffic accidents, he tends to underestimate the importance of dotted lane line, neighbouring and leading cars, as well as signal light, while the importance of curb stone and arrows on the road surface can be overestimated. Thus it is recommended that driver assistance system or autonomous driving system be trained with sufficient driving distance and traffic accidents to extensively learn traffic dynamics, building up their driving tactics and skills in various conditions.

In the future, we plan to extend the research to more situations, with the ego car turning left or right, for example. Another promising avenue is to integrate driver actions into the analyses of driving pattern to explain when drivers honk, slow down, and steer the wheel. On-going research is to digitalize the road elements that are believed to be most important for safe driving, which is combined with the design and evaluation of improved driver warning and assistance system for safer and more efficient driving.

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哪些道路要素对城市道路上安全行驶更重要？

摘要：
道路要素数字化可为驾驶员提供先进的驾驶辅助，尤其在紧急或不利条件下作用突出。精准的、特别是设施多样且设计复杂的城市道路数字化极具挑战性并且成本很高，为此我们在初始阶段可首先聚焦最重要的道路要素。这个研究设计了针对驾驶员的问卷，引导其为各种驾驶条件下的道路要素进行排序。同时也收集了驾驶员特征，包括驾驶员年龄、驾驶风格、事故经验及累计驾驶里程，从而探索这些因素对驾驶员在道路要素重要性认知上的影响。研究发现驾驶是一个复杂活动，移动的道路要素（如周围的车辆）比非移动的要素更重要。注意力应集中在有些甚至距离目标车辆较远的道路要素上，以为潜在的驾驶风险和惩罚做足准备。经验型和非经验型驾驶员的统计差异表明，驾驶辅助系统应该在不同条件下进行充分的训练，从而构建自动驾驶技术与技巧。该研究促进了对驾驶认知模式的理解，从而为道路数字化的发展提供指导。

关键词：
城市道路数字化，道路要素，重要性排序，驾驶员一致性，统计差异。.