Situation-Aware Risk Assessment for Intersection Driving for Heavy Vehicles

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Abstract

Navigating unregulated intersections with a heavy vehicle is a challenging task harboring significant risks for the vehicle itself and other traffic participants. In this study we introduce a dynamic, evidence-based risk assessment algorithm predicting increased general risk at upcoming intersections based on environmental cues. We qualitatively evaluated two HMI configurations—a standard dashboard versus an adaptive Head-Up Display (HUD)—with professional drivers in a driving simulator. Drivers perceived the predictive risk indicator as highly useful, preferring the HUD layout. Despite physical simulator constraints, the results strongly support the utility of predictive general risk assessment. Future work will integrate real-time driver monitoring of eyes-off-road (EOR) metrics to dynamically adjust risk indicators based on driver attentiveness.

CCS Concepts

• **Human-centered computing** → **User studies**; *Laboratory experiments*; *User interface design*; • **Computing methodologies** → *Probabilistic reasoning*; Reasoning about belief and knowledge; • **Applied computing** → Transportation.

Keywords

Driver assistance systems, risk assessment, Evidence Theory, Dempster-Shafer, human-machine interface, head-up display, driving simulator, heavy vehicles, intersection safety

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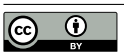

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1 Introduction

Navigating unregulated intersections with a heavy vehicle is a challenging task that includes safety risks for the vehicle itself and its driver, as well as drivers of lighter vehicles and vulnerable road users (VRUs). Due to a longer yielding distance, heavy vehicle drivers need to carefully plan their path and speed through the intersection, as well as being particularly observant of objects or persons that could be hidden within any of the vehicle's large blind spots. Advance Driver Assistance Systems (ADAS) are developed to support drivers, however, the assistance provided may not always coincide with the driver's interpretation of the traffic situation and subsequently annoy the driver. This might be the reason why roughly half of Europe's commercial drivers (trucks and vans) switch off some or all of the provided safety features [8]. In order to mitigate this, we need to overcome the ADAS' limited situation awareness. This means that a future ADAS is supposed to monitor the situation, including the surrounding traffic, traffic infrastructure and the ego driver's state [2]. In this paper, we present the first step towards such a situation aware risk assessment system. Our work is situated at TRL level 4 [1] and includes a driving experiment within a controlled environment (driving simulator) with a small sample size of participants. The objective of this study is to evaluate driver perception of a dynamic risk assessment indicator and to determine user preference between two alternative in-vehicle signage designs. Based on several monitored risk contributors the indicator shows the increased aggregated situational risk at the intersection at the estimated time of the vehicle's arrival (ETA). In an multivariate test we contrasted two HMI variants, one presenting the risk indicator first in the dashboard and moved it at closer distance to the intersections in the HUD, whereas the other kept the indicator in the dashboard. The baseline setup included no risk indicator. Following the laboratory simulation session, qualitative open interviews were conducted to assess aspects of user-centered design, perceived utility, interface ergonomics and cognitive clarity.

Participants were given the chance to provide feedback on indicator effectiveness, display placement and potential sources of user annoyance or misunderstanding.

2 A general risk indicator for the upcoming intersection

Interviews of professional heavy vehicle drivers, conducted at TRATON research and development laboratory, prior to our experiment revealed that drivers find a general risk indication about the upcoming intersection useful. If this information is provided timely while the driver is approaching the intersection the driver will be alerted to the fact that the intersection will need more attention from them. The general risk is thereby based on the argument that the more complicating factors are present the more the general potential risk of some unwanted incident happening increases. Within the considered intersection driving scenarios we will account for the complicating factors of number of traffic participants, roadworks, number of drowsy or intoxicated drivers in the vicinity and presence of approaching emergency transports as well as visibility at the intersection. Furthermore a general risk indicator provides an advantage over a multitude of specific ones. A single indicator does not need to be specifically deciphered to what hazard it refers to and instead allows the driver to allocate their cognitive effort at the traffic situation itself.

We further argue that a general risk indication caters well to professional drivers, since they typically have a lot of experience and may be better equipped to figure out what a general risk probably means in a certain intersection. Several specific indicators instead will risk to annoy the driver because it is likely that they already know about some of them.

3 Situation awareness utilizing evidence theory

Evidence theory [5, 9] also known as Dempster-Shafer theory can be regarded as a generalization of probability theory [4]. It provides a framework for data fusion of uncertain data from multiple sources. It expresses the uncertainty regarding an unknown random variable, X, within a context of a given frame of discernment, Ω_X, through a probability mass function, m. Any subset, A, of elements of the frame of discernment is called a focal element whenever its corresponding mass, $m(A)$, is non-zero. A pignistic transformation [10] will provide an approximation of the probability, the so called betting probability, $BetP$, based on the probability mass distribution, m. When evidence is provided from two independent sources the respective probability mass distributions, m_1 and m_2 can be combined by an evidence combination rule. For our project we will use Dempster's original rule of combination [3, 9] that is both commutative and associative and emphasizes on the agreement of the two sources that it combines.

Each of the identified risk contributors are expressed through mass functions which are updated 30 times per second in accordance with the predicted development of the traffic situation at the upcoming intersection. All mass functions are then combined and the result is transformed into the betting probability, $BetP$, which provides the basis for the risk indicator.

To support counterfactual risk sensitivity analyses and the evaluation of "what-if" scenarios we developed the risk assessment environment SARA shown in Figure 1. Real-time or recorded data from any simulation environment or real vehicle can be displayed and analysed within SARA. The environment allows us to isolate variables in order to find the calibration sweet spot for the transition from *no risk* to *risk* while at the same time accounting for evaluation of the changed parameter settings on the exact same dataset of recorded drives. This eliminates hind-sight bias and at the same time stress tests our model to the exact conditions. Furthermore, SARA acts as a framework for explainability for the risk assessment, by permitting to selectively toggle or scale individual risk factors and to visually and statistically show exactly which factors caused the risk indicator to trigger. With this functionality SARA provides a cost effective, ethically insulated, highly scalable virtual laboratory where a single recorded drive can be used to analyze a multitude of simulated environmental variations.

Figure 1: The graphical user interface of SARA. It shows the current traffic situation at the intersection on the right and the risk evaluation through evidence theory on the left where the bottom half shows a selection of adjustable parameters. A selection of vehicle dynamics and driver monitoring is shown in top right.

4 Spatial zoning framework

In our study we are focusing on unregulated intersections. Based on previous driver simulator tests and drivers' feedback which revealed that drivers' needs may be distinctly different in different phases leading up to the intersection, we consider three different road segments as shown in Figure 2. The road segment from 450 to 250 meters before the intersection is called the pre-planning phase. At approximately 450 meters before the intersection, drivers start gathering information in order to plan how to safely navigate the vehicle through the intersection. A risk indication occurring within this phase would allow the driver ample time to cognitively prepare for a challenging situation, identify upcoming obstacles and to smoothly slow the vehicle, plan for lane changes or even select an alternative route, if available. At 250 meters before the intersection the planning phase starts. Within this phase the driver actively prepares for navigating the intersection. The planning phase ends at approximately 15 meters from the center of the intersection. From that point on we consider the vehicle to be in the intersection

phase and preparations to navigate the intersection are thereby concluded.

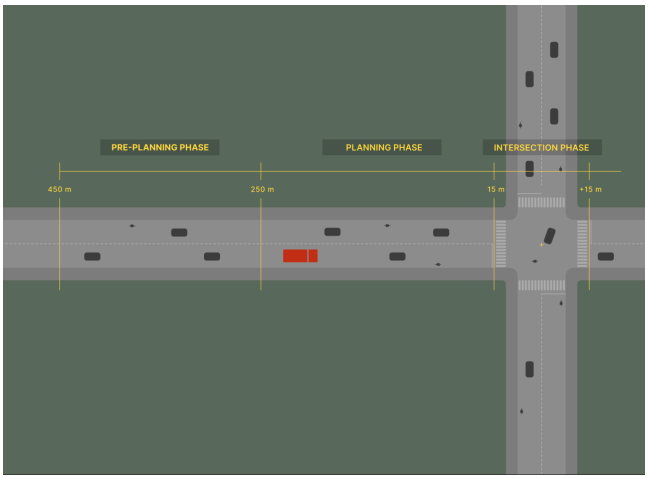

Figure 2: The three phases of intersection driving; pre-planning phase from 450 meters to 250 meters before the intersection, planning phase 250 meters to the zebra crossing, approximately 15 meters from the intersections center point, and the intersection phase starting at the zebra crossing until 15 meters after the intersection.

5 Design of driver-vehicle interaction

Since the layout of the digital cockpit directly impacts on the driver's mental workload, information usability and ultimately driver safety, the placement of all new information elements (icon, text, etc.) is critical and needs to be carefully tested within experiments. One critical aspect is the two-second rule, which dictates that a single glance at an in-vehicle screen should never be longer than 2 seconds. In our experiment we used two different signage approaches and coupled them to the previously introduced spatial zones, the pre-planning and the planning phase and tested them against a baseline with no information about risk at the upcoming intersection.

Concept A displays the indication of an increased general risk in the upcoming intersection in the vehicle's dashboard as shown in Figure 3. The information is provided in a grey, rectangular box with yellow border. The box includes a yellow framed warning triangle with a yellow exclamation mark and the white text reading "Ökad risk i korsning" which is Swedish for "increased risk at intersection". When the driver enters the planning phase at 250 meters before the intersection the same information is moved into the HUD as shown in Figure 4, until the driver has left the intersection phase where the information disappears. Concept B displays the same information in case of increased risk at the upcoming intersection starting as soon as the vehicle reaches the 450-meter mark in the dashboard. Contrary to Concept A the information stays in the dashboard even during the planning phase and until the driver has left the intersection. Within Concept B no information about the increased risk is displayed in the HUD.

Figure 3: The dashboard display for increased risk at the upcoming intersection.

Figure 4: Heads up display for increased risk in upcoming intersections.

The simulator driving experiments took place 14th–29th April 2026. Eighteen commercial heavy vehicle drivers were recruited, two drivers were forced to discontinue the experiment due to simulator sickness and one driver could not proceed due to technical problems. The remaining drivers were making three drives each: the baseline, with no risk information about the upcoming intersection, Concept A and Concept B. The allocated time for each driver was two hours including introduction to the experiment, familiarization with the simulator, the three drives which were randomly assigned, each followed by a questionnaire, and a semi-structured interview at the end.

6 Thematic analysis

Increased situational awareness in demanding situations. The majority of drivers described the risk indicator as valuable because it

helped them anticipate risks earlier. Some participants emphasized that the indicator could be especially valuable when drivers are tired or visibility is limited. Drivers pointed out its potential value when driving long and monotonous roads where attention and vigilance may gradually decrease, and at night time.

HUD supporting eyes on road. Many participants appreciated the information displayed in the HUD which supported the driver's eyes on road. The HUD was often perceived as more natural and less distracting. Several participants specifically highlighted that the HUD partly reduced the need for visual scanning between the road and the dashboard, and that the risk indicator was easier to notice when it was placed in the windshield. When participants were asked which of the two concepts they preferred overall, concept A was selected most frequently with the explanation mainly being its support for eyes on road. Drivers generally preferred having the risk indicator directly in the HUD without it being displayed first in the dashboard.

Appropriate timing. Fifty percent of the participants described the timing of the risk indicator as appropriate and well adapted to the driving situation. Drivers appreciated that the indicator generally appeared early enough to allow them to adjust their speed and plan their actions before entering the intersection. Some participants also highlighted that the indicator disappeared at a suitable point after the intersection. However, even among participants who viewed the timing positively, there was an understanding that the "correct" timing depends on the driving context. Some drivers suggested that timing should adapt dynamically to factors such as the road type, the speed limit, or how heavily the vehicle is loaded.

Some participants felt that the risk indicator appeared too early and before they even saw the intersection, which sometimes made it feel disconnected from the actual driving task. One driver stated that this could make them feel unsafe. Some drivers explained that when the indicator appeared too early, they either forgot about it or accelerated again after initially braking in response to the risk indicator. This created a sense that the indicator did not align well with the natural rhythm of driving and decision-making. Also here, participants suggested that timing should vary depending on the driving environment.

Redundant information. Several participants perceived the risk indicator as redundant because it often communicated information that experienced drivers already monitor themselves. Drivers expressed that city-contexts, and intersections in particular, are inherently risky environments where they already are highly attentive to VRUs and other traffic, meaning that a general indicator did not add meaningful and new information.

Almost half of the participants feared that the risk indicator might activate too often, it would become irritating, stressful, or mentally exhausting.

Appropriate visual HMI-design. Participants generally felt that the HMI contained an appropriate amount of information and that the text was short, clear and easy to understand while driving. Drivers appreciated that the indicator combined both, text and symbols, which helped explain the meaning of the indicator without becoming visually overwhelming. Several participants emphasized that the message was concise enough to be quickly read and interpreted in real traffic situations. The yellow color was also consistently perceived as suitable for the purpose of the indicator. Participants described yellow as attention-grabbing without being overly alarming or stressful, unlike red which several drivers associated with critical danger or emergency braking.

7 Discussion and future work

The primary finding of this research is that a general indicator for increased risk at the upcoming intersection is principally perceived to be useful by heavy vehicle drivers. Most of the drivers preferred the HUD which is backed up by the findings of [7] which identified significant positive effects to driving behavior and traffic safety when a HUD is used. Due to the small number of participants and the qualitative nature of the experiment, significant statistical information about how the general risk indicator actually influenced driving behavior cannot be provided. We also need to point out that driving in a driving simulator is not the same as driving in real traffic. However, while driving simulators possess constraints regarding physical feedback, they also have high relative validity for evaluating driver decision-making profiles and HMI interactions e.g. [12].

As a next step the functionality should be extended to also take the drivers' attention to the road into account. As drivers and literature [11] state, there is no need for risk indicators, if drivers already see and attend to the situation themselves. In fact, over-warning an attentive driver can trigger alarm fatigue, leading drivers to distrust or to entirely deactivate the safety system. However, in cases where the driver is distracted or fatigued, an indicator even for a minor risk might be appropriate. Since heavy vehicle drivers are highly susceptible to monotonous driving fatigue during long-haul routes, a tailored safety net becomes critical. Therefore, our future work will include the drivers' eyes-off-road (EOR) observed by a driver monitoring system, into the dynamic risk assessment.

By blending vehicle-to-infrastructure predictive risk data with real-time gaze-tracking metrics, the system can dynamically suppress redundant indicators when the driver is attentive to the situation, while reducing the threshold for when the indicator is presented only when a lapse in attention is detected.

At the same time, we need to investigate the *black box effect*. Since the risk indicator is dynamic and evidence-based the driver might not always understand why an increased risk is predicted. Hence, we face the challenge of balancing the goal of minimizing information overload and counteracting alarm fatigue with transparency [6].

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