Criticality Perception in Dynamic Traffic Scenarios: An ACT-R Model

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Keywords: criticality perception; dynamic driving scenario; ACT-R; situation awareness; cognitive modeling

Introduction

Determining the criticality of a traffic situation is a basic task that has to be accomplished in driving. Several theories assume that human drivers' evaluation of the criticality of a dynamic traffic situation is strongly determined by the time-to-collision (TTC) that is the time until two objects will collide if they both maintain speed and course (e.g., Heesen et al., 2012; Tamke et al., 2011). The evaluation of the situation's criticality strongly influences the drivers' action decisions in these situations. One of such dynamic situations where the evaluation of criticality is mainly based on the TTC to other vehicles is a lane change scenario.

Stoll et al. (2018) investigated in a video-based study the following lane change scenario where the criticality of the situation was systematically varied: Participants (Ego) drove on the left lane of a German 2-lane highway. They observed a passenger car (RU1) approaching a slow vehicle (RU2) on the right lane that might cut in to the participants' left lane. They were asked (1) whether they would accelerate, decelerate or maintain speed in this situation and (2) to rate the criticality of the situation on a scale from 1 (not critical) to 5 (very critical). Stoll et al. (2018) varied the criticality of the situation by the TTC between participants and RU1 (TTC_{Ego}, either 2, 4 or 6 s) and TTC between RU1 and RU2 (TTC_{RU1} either 2, 4 or 6 s) at the time participants had to make their decision.

Even though findings suggest a relationship between perceived criticality and selecting the preferred action (maintaining speed was associated with rather low criticality ratings compared to decelerating and accelerating), the TTC values did not reliably trigger typically preferred actions, resulting in a large variance among participants. More importantly, this variance calls for more clarification on exactly how critical vs. non-critical scenarios were perceived in the different TTC conditions.

We are developing a cognitive model using ACT-R (Anderson, 2007) to shed light on the complex cognitive processes of situation awareness (SA: perception, comprehension, projection; Endsley, 1995) in the highly dynamic traffic scenario of Stoll et al. (2018), in order to determine how participants evaluate the different conditions as critical or not.

Most importantly, we argue that not only the TTC, but the combination of perceived elements and the availability of memories containing them and which help build up a situation model (SM) are also part of the resulting perceptual decision (PD[1]) participants make about criticality. We assume that these elements do not merely consist in the perception from the driver's own perspective, but the RU1's viewpoint and intention are taken into account as well. With other words, we suggest that the driver's SM includes the RU1's SM to a certain extent.

Method

ACT-R (Adaptive Control of Thought—Rational, Anderson, 2007) is a cognitive architecture with basic assumptions about human knowledge and about how information in the declarative memory (chunks) are used (production rules) to solve everyday tasks.

We are using ACT-R (Salvucci, 2006[2]) to recreate the driving scenario and to model participants' memory retrieval (MR) to build up SM and that leads to a PD about criticality.

General Assumptions of the Model

The ACT-R model assumes first of all that criticality perception does not mainly stem from perception, but from MR. Accordingly, even if the presented driving scenario was not familiar to participants, a "close enough" memory matching some of the perceived elements is retrieved to

[1] A PD can be considered as an intuitive decision (Thomson et al., 2015; or System 1 decision; Kahneman, 2011)

[2] Since its features are more suitable for driving than the original LISP version, we are using the Java version of ACT-R. (see https://www.cs.drexel.edu/~salvucci/cog/act-r/)

create SM. Further assumptions are listed below and depicted on Figure 1.

1. SM_{Ego} is created through MR.
2. MR takes place regardless, but it is approximative and resulting SM_{Ego} might be incorrect.
3. SM_{Ego} includes $Projection_{Ego}$ (i.e., how the situation is going to develop) and $Intention_{RU1}$ (i.e., RU1's action plan).

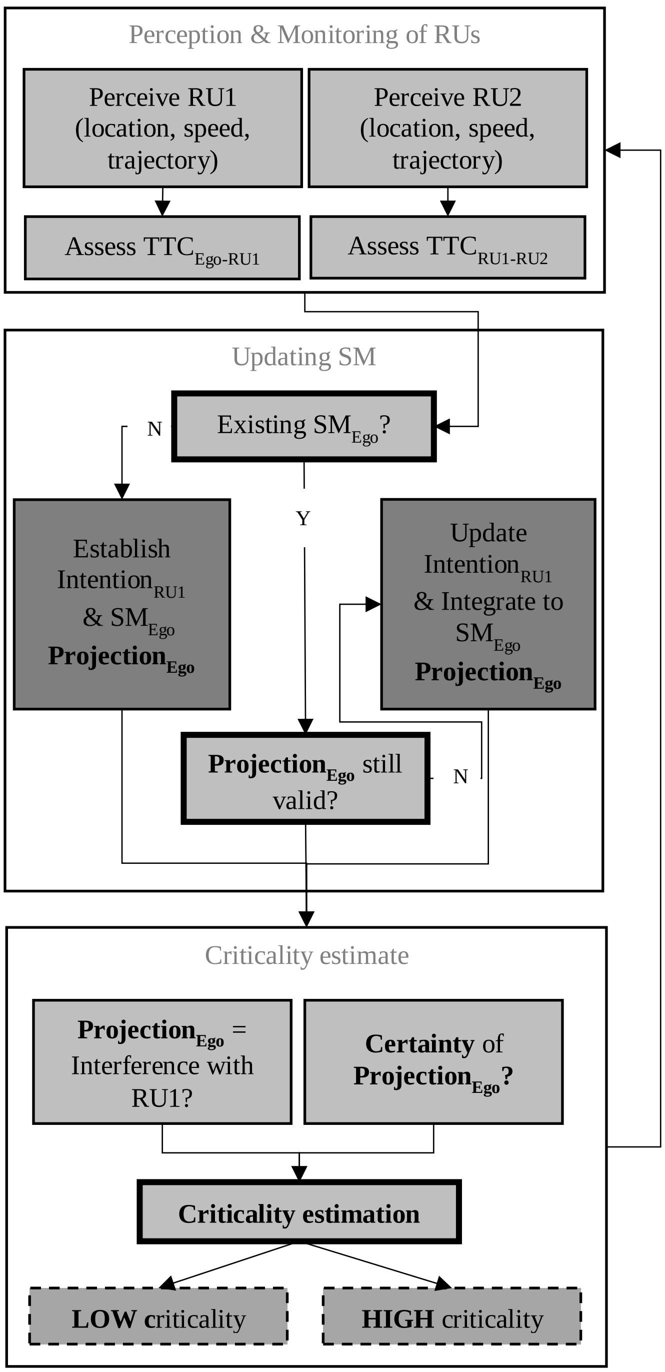

Figure 1: Flowchart representation of the model's main steps

4. $Projection_{Ego}$ gets periodically confirmed by monitoring RUs. As long as $Projection_{Ego}$ is valid, no further MR takes place.
5. If $Projection_{Ego}$ is not valid:
   (1) The model establishes new SM_{Ego} through MR and
   (2) Makes PD (including a criticality decision [whether there interference with RU1 can be expected or not] and a certainty value [i.e., reliability of the SM_{Ego} based on how many times it needed updating]).

We expect the model to reliably reproduce participants' subjective criticality ratings in the different TTC conditions in the study of Stoll et al. (2018).

Acknowledgments

This project was funded within the Priority Programme "CoInCar—Cooperatively Interacting Automobiles" of the German Science Foundation DFG.

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