# Application of ecological interface design to driver support systems

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**Abstract**

This paper presents the results of two experiments to assess the benefits of using Cognitive Work Analysis (CWA) and Ecological Interface Design (EID) to guide the development of driver support systems. EID suggests novel interface alternatives that have substantial theoretical promise. However, it is not possible to anticipate how drivers will perceive and respond to these displays. Two experiments compared a traditional display with three EID-inspired displays and found complementary results regarding the ability of these displays to support the judgment of safe gaps in a lane change situation. The first experiment showed that participants adapted with a similar speed to the traditional and EID-inspired displays and that one EID-inspired display performed at least as well as the traditional display while promoting more precise calibration between judgment accuracy and confidence in the judgment. The second experiment showed that when participants could only view the situation for a short period, an EID-inspired display substantially outperformed the more traditional display. Importantly, not all the EID-inspired displays outperformed the traditional display. The results are discussed in terms of alternate evaluation venues for emerging in-vehicle technology.

*Keywords: Collision warning systems, Automation, cognitive work analysis, adaptive cruise control, lane change*

## 1. Introduction

Emerging vehicle sensor and control technologies offer great potential for improving driver safety and performance. These technologies, which range from adaptive cruise control to steering assist systems, promise to change the driving task substantially [1]. Without a principled approach to design, it can be quite difficult to develop this new technology in a way that enhances rather than degrades driver performance and satisfaction. The CWA (Cognitive Work Analysis) and EID (Ecological Interface Design) frameworks may provide the underlying structure for such a principled approach to design driver support systems [2, 3].

A focus on identifying domain constraints that govern effective behavior distinguishes EID and CWA from most other human-technology design approaches [2]. Interfaces that represent domain constraints in a way that is compatible with human perceptual and cognitive capabilities have met with success in domains as diverse as neonatal intensive care to nuclear power plants [4]. CWA and EID aim to support an adaptive response to both routine and unanticipated situations. This design philosophy may also benefit the driving domain, where a heterogeneous driver population adapts in various ways to a diverse set of driving situations.

Lane change maneuvers might particularly benefit from EID. EID may help transform radar-based sensor data into a visual representation drivers can use to make better judgments regarding the safety of a potential lane change. In most lane change crashes drivers do not attempt an avoidance maneuver, suggesting the driver is not aware of the impending collision [5, 6]. More specifically, approximately 75% of lane change or merge crashes involve the failure of the driver to recognize the impending collision [7]. Using EID to create a visual representation of the threat posed by an approaching vehicle may help drivers make better judgments regarding whether it is safe to merge into a lane.

The philosophy of EID differs substantially from that of many driver support systems. The focus of many systems is to provide discrete warnings that alert drivers to threatening situations. These warnings are often binary rather than graded and provide little information regarding the type of threat or how it is evolving over time. EID inspires displays that show information at multiple levels of abstraction and leave the determination of what constitutes a threat up to the driver. Traditional driver support systems often use a many-to-one mapping of conditions to a single indicator. This has the advantage of simplicity, but lacks the ability to support the full range of drivers and driving situations. In contrast, EID reveals the full many-to-few mapping of the environment state.

Although theoretically promising, the response of drivers to ecological interfaces is uncertain. A strength of ecological interfaces is their ability to translate low-level data into meaningful information that is made accessible to people through configural graphics. This often inspires relatively complex and unfamiliar displays, which may undermine rather than enhance driver performance. Display complexity may be a particular challenge in applying EID to driving because driving demands decisions that are made in seconds, compared to other domains where decision are made over many minutes.

To address these issues we conducted two experiments. In the first we exposed drivers to many lane change decisions to assess how increasing familiarity influences display effectiveness. In the second experiment, we manipulated the time available to monitor the situation to assess performance when only short glances are possible.

## 2. Methods

### *2.1. Participants*

Drivers between the ages of 18 and 40 participated in these experiments. Twenty-four drivers ($M$ = 22, $SD$ = 4.6) participated in the first experiment, and 32 drivers ($M$ = 22, $SD$ = 3.3) participated in the second experiment. All were licensed drivers and had normal or corrected to normal vision. Each participant was paid a base rate of $15.00 for their time. To encourage the participants to make correct decisions, performance above 33% was rewarded at $0.15 per 1%. For example, if a participant scored 80%, they received $22.05 ($15 (base rate) + $0.15*(80-33)).

### *2.2. Apparatus*

Data were collected using a part-task simulation that showed only the left side-view mirror of a car. The lane-change display was shown on an image of the mirror as it would appear on a real vehicle. Figure 1 shows the combined image as it appeared on a 19 inch computer monitor at a resolution of 1280 x 1024. Participants did not drive a vehicle, but instead judged whether or not a lane change would be safe by watching the behavior of the display for 2 seconds in the first experiment and between 0.25 and 2.0 seconds in the second experiment.

The scenarios developed for this experiment were chosen from a state space of range and range rate. Range or $R$ is defined as the distance between the participants vehicle and the vehicle approaching from behind. Range rate or $\dot{R}$ is defined as the difference in velocities between the two vehicles. This space describes a range of lane change situations, some of which were defined as safe, others as safe with acceleration, and others as unsafe. These determinations were made using the equations of motion, assuming the approaching vehicle would remain at a constant speed, and the time headway must remain above two seconds.

Figure 2 shows schematic diagrams of the EID-inspired displays. The more traditional Bar display, not included in Figure 2, was simply a horizontal bar that was proportional to a weighted combination of the inverse time-to-collision and time headway.

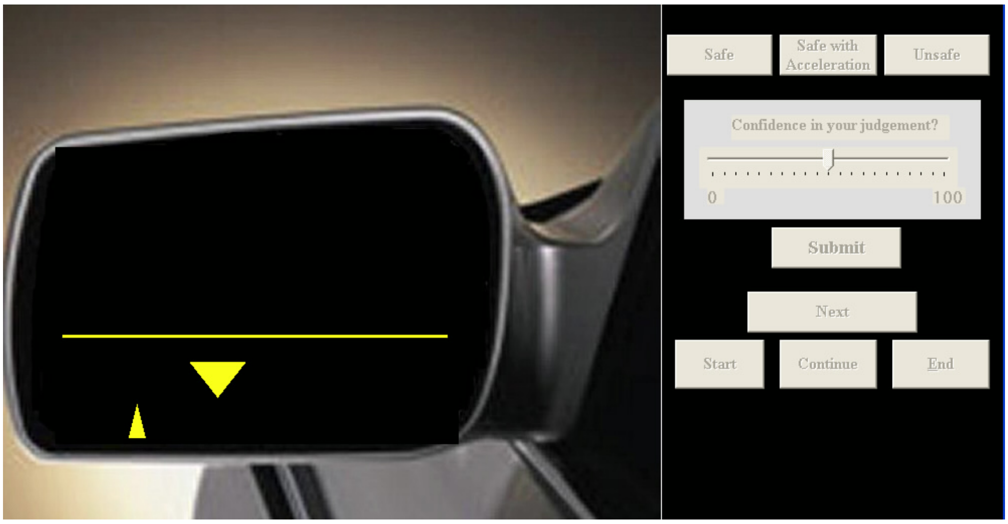


Figure 1. Experimental apparatus showing the EID-Yield display and the image of the car mirror that the participants used to judge whether it was safe to pass or not.

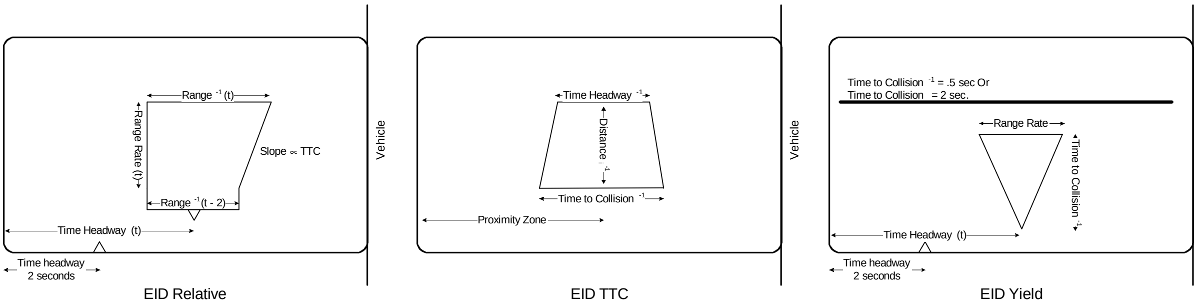


Figure 2. The three EID-inspired displays (EID-Relative motion, EID-TTC, and EID-Yield).

### *2.3. Experimental design*

Experiment 1 was a 4 (display type) x 8 (block) between and within experimental design, with display as a between subjects variable and block as a within-subjects variable. The four levels of display type corresponded to the four displays shown above (Bar, EID-TTC, EID-Relative, EID-Yield). Block had eight levels corresponding to the eight experimental blocks of 50 trials that each participant experienced.

Experiment 2 was a 4 (display type) x 4 (viewing time) between and within experimental design, with display as a between-subjects variable and viewing time as a within subject variable. As in experiment 1, display type had four levels corresponding to the four displays described above. Viewing time had four levels: 0.25, 0.5, 1.0, and 2.0 seconds.

### *2.4. Procedure*

Upon arrival, each participant was randomly assigned to one of the four display groups. The lane change judgment task was explained and participants practiced with a block of 50 trials. Each trial in this block was a unique lane change situation. Following the practice, participants completed eight additional blocks of 50 trials for a total of 450 experimental trials.

Participants initiated each trial by clicking on an on-screen button. After the button press, participants watched the scenario evolve for two seconds in experiment 1, or for viewing times between 0.25 and 2.0 seconds in experiment 2. They were then required to decide whether a lane change was safe, safe if they accelerated during the maneuver, or unsafe, and provide a rating of their confidence in their decision from 0 to 100%. These responses were entered by clicking on the scales and buttons shown on the right of Figure1. Participants were then given feedback that their judgment was “Correct” or “Incorrect”. If the response was “Incorrect”, they received additional feedback explaining why the response was incorrect. At the end of each block of 50 trials, participants rated the workload experienced during the block using the NASA TLX scale.

## 3. Results

Figure 3 shows that the Bar display outperforms most of the other displays in terms of decision time, $F(3,20)= 16.21$, $p<0.0001$, and accuracy, $F(3,20) =15.34$, $p<0.0001$. However, the EID-Yield display performs at essentially the same level after the first few blocks.

As might be expected, the workload, as rated with the NASA TLX subjective workload scale, shows that the simple bar display imposed the least load, $F(3,20)=5.56$, $p=0.0061$. For all measures, there were no interactions between display and block, $F<0.5$. Table 1 shows a higher correlation between confidence and decision accuracy for the EID-Yield display compared to the Bar display, particularly during the unsafe passing situations.

Table 1. Correlations between confidence and accuracy for each type of situation by display.

| | Unsafe | Safe with Acceleration | Safe |
|---|---|---|---|
| Bar | -0.01 | 0.36 | 0.66 |
| EID-TTC | 0.22 | 0.29 | 0.06 |
| EID-Relative | 0.33 | 0.45 | 0.55 |
| EID-Yield | 0.44 | 0.49 | 0.40 |

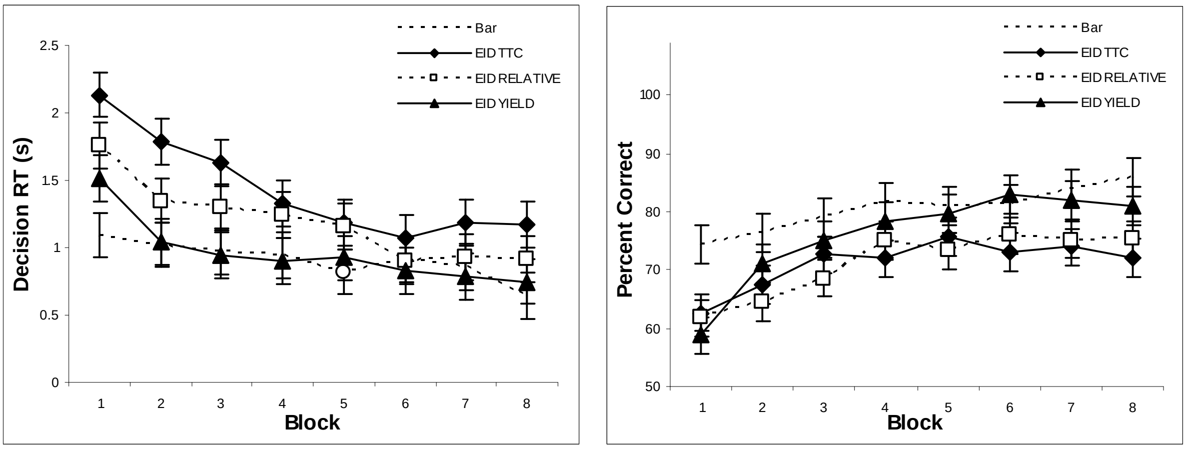


Figure 3. Decision time and accuracy across time.

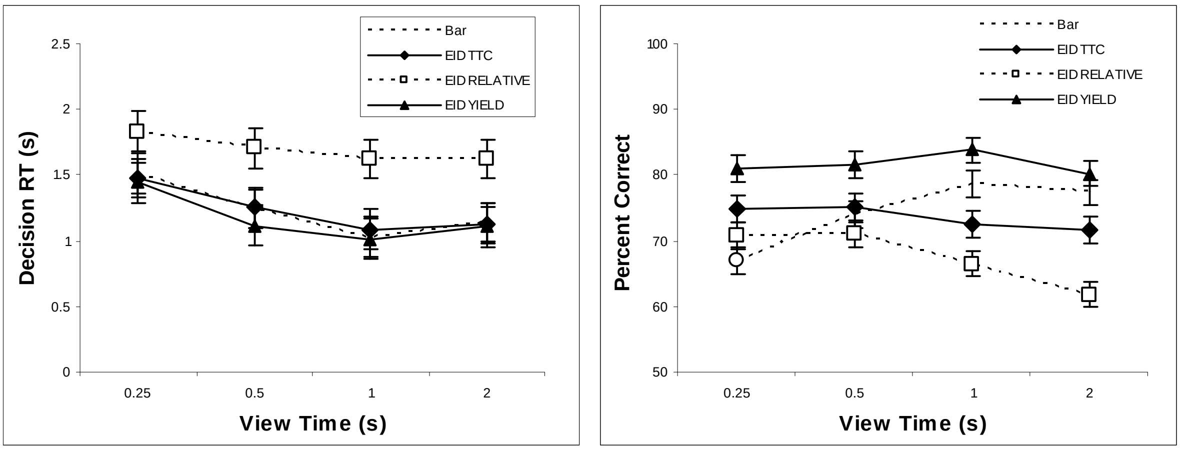


Figure 4. Decision time and accuracy as a function of view times.

Figure 4 shows main effects of display type for both reaction time, $F(3,28)=10.44$, $p<.0001$, and judgment accuracy, $F(3,28)=34.6$, $p<.0001$, when the viewing time was varied. In terms of reaction time, the EID-Relative display had a substantially longer reaction time than the others. In terms of accuracy, the EID-Yield display outperformed the other displays across all viewing times. Longer viewing time resulted in shorter reaction times for all the displays, $F(3,84)=4.82$, $p=0.0038$. In contrast, the decision accuracy depended on an interaction between display type and viewing time, $F(9,84)=3.76$, $p=0.0005$. As the viewing time decreased the performance of the Bar display deteriorated. In contrast, the EID-Yield display was remarkably robust to changes in the viewing time, while performance with the other ecological displays actually declined as the viewing time increased.

The EID-TTC display and the EID-Yield display consistently supported more confident judgments, $F(3,28)=22.73$, $p<.0001$, generally with lower workload, $F(3,28)=16.76$, $p<.0001$, compared to the Bar and EID-Relative displays. The Bar display resulted in lower confidence and higher workload, particularly for short viewing times.

## 4. Discussion

The two experiments provide complementary results regarding the assessment of four potential displays to support the judgment of safe gaps in the lane change situation. The first experiment showed that the Bar and EID-Yield displays outperform the others on the basis of performance (judgment accuracy and reaction time) as well as attitudes (confidence and workload). Although performance and attitudes changed with experience these changes did not depend on the display type. People seemed to adapt to all the displays at a similar rate.

Interestingly, the Bar display performed as well as or better than all the EID-inspired displays in the first experiment, suggesting that the EID-inspired displays may be inferior. However, such a conclusion must be tempered by considering the correlation between judgment accuracy and judgment confidence. Both the Bar and the EID-TTC displays showed very poor correspondence between confidence and accuracy for certain decision situations. Specifically, there was little link between confidence and accuracy in unsafe passing situations. Although judgment accuracy is a critical performance metric, the calibration of judgment accuracy and confidence may be just as important. On this metric, the Bar display performed poorly, which may reflect the many-to-one mapping of conditions based on a single level of abstraction included in the display. This metric is particularly important because displays that make it difficult for drivers to calibrate their confidence with their judgment accuracy will leave them unlikely to use the driver support system in safety critical situations.

The second experiment provided an important complement to the first by examining the effect of time pressure on the judgment task. In most lane change situations, drivers will not have two seconds to watch a display. Instead, they may have less than half a second. The second experiment showed that the duration people could view the display had a strong effect on performance. More importantly, this effect depended on display type. The Bar display performed particularly poorly for short viewing times, while the EID-Yield display performed well over a range of viewing times. This effect was also reflected in the attitudes. Workload was higher for the Bar display for short durations compared to longer viewing times and confidence was generally low for judgments with the Bar display. These results show that display quality must be assessed over a range of situations. Robust performance across situations may be a more critical design consideration than relatively high performance in a single situation.

Overall, these results show that drivers may not always be able to extract information efficiently from the relatively complex EID-inspired displays. The complexity of some of the EID images seemed to hinder performance in the longer duration exposures, possibly reflecting an overload of visual working memory due to the amount of information presented in the display. In the case of the traditional Bar display, for long viewing times, it seems drivers were able to extract rate-based information from the Bar display, but this ability was compromised by short viewing times. The robust performance of the EID-Yield display suggests that it enabled drivers to perceive rate-based information in a way that did not depend on viewing time. This finding suggests that the EID-Yield display may represent a novel and particularly promising way of presenting information to drivers regarding the relative motion of vehicles. Moreover, these results show that EID can inspire novel displays that can outperform conventional displays, but that these require empirical evaluation.

These results also point towards part-task simulation as a way of efficiently evaluating potential displays. The part-task simulation made it possible to collect data for tens of thousands of lane change judgments. Collecting similar data in a full-scale simulator or with instrumented vehicles would have cost much more and taken months rather than weeks. The part-task evaluation in this experiment tests the compatibility of a display with basic perceptual and cognitive capabilities of drivers. This compatibility is a necessary, but not sufficient criterion for success [8]. A full evaluation requires full-scale simulator and on-road studies. The simple part-task evaluation demonstrated in this paper is particularly valuable because it provides an efficient means of evaluating a range of display concepts before resources are invested in the more expensive and time-consuming evaluation approaches.


## Acknowledgments

This research was supported by Nissan Motor Co., Ltd., with special thanks to Erwin Boer, project coordinator.


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