To Walk or Not to Walk: Crowdsourced Assessment of External Vehicle-to-Pedestrian Displays

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ABSTRACT
Researchers, technology reviewers, and governmental agencies have expressed concern that automation may necessitate the introduction of added displays to indicate vehicle intent in vehicle-to-pedestrian interactions. An automated online methodology for obtaining communication intent perceptions for 30 external vehicle-to-pedestrian display concepts was implemented and tested using Amazon Mechanic Turk. Data from 200 qualified participants was quickly obtained and processed. In addition to producing a useful early-stage evaluation of these specific design concepts, the test demonstrated that the methodology is scalable so that a large number of design elements or minor variations can be assessed through a series of runs even on much larger samples in a matter of hours. Using this approach, designers should be able to refine concepts both more quickly and in more depth than available development resources typically allow. Some concerns and questions about common assumptions related to the implementation of vehicle-to-pedestrian displays are posed.

Author Keywords
Vehicle-to-pedestrian communication, external HMI, autonomous vehicles, crowdsourced design, shared road users, vulnerable road users, pedestrian communication, communication displays.

INTRODUCTION
The introduction of semi-automated and automated driving technologies into the vehicle fleet is often seen as having the potential to decrease the overall frequency and severity of crashes and bodily injury [1]. At the same time, there is some concern that the transition from manually controlled to technology controlled vehicles could have unintended consequences. One such concern is in the area of communication of intent between automated vehicles and shared road users, particularly pedestrians [7, 10, 11, 12, 13]. One perspective asserts that human driven vehicle-pedestrian communication often involves hand and body gestures, as well as eye contact (or avoidance of), when vehicles and pedestrians come together in interactions such as those occurring at crosswalks where miscommunication can easily elevate risk. The question is then posed as to what will replace these forms of communication when a human is no longer actively driving the vehicle?

One approach might be to explore technologies such as the Wi-Fi application proposed in [2] or other Vehicle-to-Entity (V2X) communications that alert pedestrians of potential conflict situations. However, most proposed solutions focus on external vehicle displays as replacements for human-to-human visual engagement. Google drew attention to this approach by filing a patent for messaging displays for a self-driving vehicle that included the concept of electronic screens mounted on the outside of the vehicle using images such as a stop sign or text saying “SAFE TO CROSS” [18]. Drive.ai, a self-driving technology start-up, released an illustration of a roof-mounted display screen concept that combined an image of a pedestrian on a crosswalk and the words “Safe to Cross” [8]. Matthews and Chowdhary [12] describe an LED display for an autonomous vehicle that might display messages such as “STOP” or “PLEASE CROSS” when a pedestrian is encountered. Mirnig and colleagues [13] briefly describe several visual display strategies that they describe as being informed from human-robot interaction principles. Automotive manufacturers have also proposed design visions such as the Mercedes F015 concept car using lighted displays on the front grill and a laser projection of an image of a crosswalk on the roadway in front of car [7]. A Swedish engineering company has proposed a lighted grill design that “smiles” at pedestrians to indicate they have been detected and it is safe to cross in front of the vehicle [15].

Early Stage Design Assessment
Careful and extensive testing vehicle-to-pedestrian communication concepts under real-world conditions and with a broad demographic sampling would seem to be indicated before a design is put into general use due the potentially safety critical implications of miscommunication. Given the inherent costs of real-world validation testing, efficient methods for early stage concept assessment are highly desirable for narrowing in on designs that are promising and setting aside those less likely to prove out. Further, early stage methods that make it practical to test a large number of minor design variations increase the probability of elucidating subtle considerations that may lead to optimized implementations.

Wizard of Oz approaches to assessing how pedestrians might interact with automated vehicles and various external design concepts have been reported [6, 10] and [5] have described a virtual reality based pedestrian simulator. While these methods are less intensive than full scale field testing, they still re-
quire significant effort and strategic choices need to be made in selecting concepts to test at this level.

To gather data on the extent to which pedestrians might be uncomfortable and uncertain about whether they should cross in front of a vehicle if they were unable to make eye contact with the driver (which was presumed to be more likely in vehicles under autonomous control), Lagström and Lundgren [10] presented participants with a set of five photographs ranging from an image of the person in the driver’s seat holding onto the steering wheel and looking into the camera to one where the individual in the “driver’s” seat appeared to be asleep. Participants were asked to image that:

You are walking through a city center and are just about to cross an unsignalized zebra crossing. A car has just stopped and you look into the car before passing the crossing, you see what is shown on the picture. How do you feel about crossing the road?

Participants then were asked for each to respond for each image whether they would cross immediately and made ratings of their likely emotional reactions. Lagström and Lundgren interpreted the responses as supporting a concern that there may be a risk of misinterpretation on the part of pedestrians that observing a “driver” occupied by activities such as reading or sleeping as indicating that the vehicle was not about to move. They note that this might be a wrong interpretation for an automated vehicle and thus some indication of whether a vehicle is in autonomous mode and what its intentions may be desirable.

The present study employed a data gathering approach that is conceptually similar to Lagström and Lundgren’s in that it presented participants with multiple pictures of a vehicle and asked if it was safe to cross in front of the vehicle. However, there were two key differences. First, the goal of the assessment was to evaluate design concepts for communication from the vehicle to a pedestrian whether the pedestrian should cross or not. Second, an automated online presentation methodology was employed that supported efficient presentation of a large number of images across a larger sample of participants.

**METHODS**

Amazon Mechanical Turk (MTurk) was used for data collection. MTurk is an internet based, integrated task presentation and participant compensation system. It provides access to a large potential participant pool at modest cost per participant. It has been reported that MTurk has good performance, especially on psychology and other social sciences research, since participants are diverse and more representative of a non-college population than traditional samples [3, 14]. Participants who take frequently part in MTurk tasks are commonly referred to as “Turkers”.

One of the challenges of constructing a statistically meaningful MTurk experiment is the ability to filter out any responses by Turkers that were not made with their full attention on the task and representative of a “best effort”. We used two types of filtering: (1) accepted only select Turkers with a proven track record on MTurk (see Participants subsection) and (2) the insertion of “catch” stimuli for which there is a “correct” answer (see Stimuli subsection).

A second challenge of setting up a successful MTurk experiment is making to scalable to hundreds or thousands of participants. To this end we implemented a Python framework that created, configured, and served the stimuli in randomized order on a HTML front-end. An asynchronous Javascript (Ajax) communication channel stored the responses in a PostgreSQL database through a PHP-managed backend. This framework allowed for robust, concurrent collection of the dataset underlying this work in just a few hours. Moreover, it allowed for efficient validation of the result and possible future scaling of the number of Turkers and stimuli.

**Participants**

To take part, participants had to be experienced Turkers with a minimum of 1,000 previous HITs (a measure of previous experience where a HIT represents a single, self-contained task that an individual can work on, submit an answer, and collect a reward for completing) and a 98% or higher positive review rating. Data collection continued until 200 Turkers completed the full experiment by providing a response to each of the 30 stimuli. According to tracking of IP addresses, the majority of participants were from the USA and India, and approximately matched the distribution reported by [16] where 57% of Turkers were from USA and 32% were from India. Compensation was at approximately $15/hour based on a conservative estimate of a pace necessary to complete the full experiment. This rate is above the compensation of $2-3/hour commonly provided on MTurk.

**Stimuli / communication design elements**

The base photograph used to create the stimuli (see Fig. 1) was of a late model passenger sedan on a one-way urban street approaching an uncontrolled intersection/crosswalk (no traffic light). Under the lighting conditions the driver is not visible.

![Figure 1: The driver was not visible in the base image used to create the designs due to lighting and reflection angles.](image)

The stimuli were created by superimposing each of the 30 designs onto the base image. Every design had an animated element in that it was either flashing or playing through a sequence of animation frames. Fig. 2 shows illustrative snapshots of four of the designs. A video of all 30 final stimuli...
is provided as supplementary material. The size of the stimuli presented to each Turker was 1280 pixels wide and 720 pixels tall. Turkers with screen resolutions below this size were automatically detected and could not participate in the experiment.

![Designs 1, 2, 7, 10](image)

Figure 2: Four of the designs tested (out of 30 total in Fig. 3) shown in cropped, close-up views. Presentation to participants used the entire image shown in Fig. 1 at a 1280 pixels wide and 720 pixels tall resolution. These 4 designs performed significantly better than the other 26 at communicating their intent as shown in Fig. 4.

“Catch” stimuli were created that, instead of a design, showed instructions on what to respond (e.g., Yes, No). Only responses provided by Turkers who passed these catch stimuli were included in the resulting dataset. Given the filtering in the Turker selection, 100% of the Turkers who completed the entire experiment responded to the catch stimuli correctly.

**Procedure**
Participants were presented with introductory text informing them that they would be presented with a series of images of a vehicle approaching a crosswalk. They were to imagine that they were a pedestrian viewing the approaching vehicle and decide if it was safe to cross. Response options were: Yes, No, and Not Sure. The presentation order for the images was randomly shuffled for each participant to control for order effects.

Each of the stimuli was animated on screen indefinitely until the Turker provided a response. Response timing information was recorded, but analysis did not reveal any meaningful patterns or correlation between designs and response dynamics.

**RESULTS**
A few of the concepts showed a high degree of match between the designers’ intent and participants’ interpretation. For the examples shown in Figure 2, designs 1 and 7 received a high percentage of responses that it was safe to walk; designs 2 and 10 received a high percentage of responses that it was not safe to walk. Participants’ interpretation of the communication intent on the part of the vehicle for each of the 30 designs is shown in Figure 3; the proportion of the sample that rated each design as indicating it was safe to walk is colored coded in green, were unsure about the intent in yellow, and interpreted the message as indicating they should not walk is shown in red. It can be observed in Figure 3 that the two designs intended to communicate that pedestrians should not walk (2 and 10; images in Figure 2) match relatively well with participants’ interpretations. The degree of successful communication of designer intent was much more varied for the designs intended to indicate that it was safe to walk; the interpretation ratings of these designs are broken out in Figure 4. The responses for concepts the designers thought would be ambiguous are shown in Figure 5.

**DISCUSSION**
The external vehicle display concepts intended to communicate vehicle intent to pedestrians were developed by a team of graduate design students (Xia, Yang, and Facusse) as part of a course project. As external advisors and collaborators, the remaining authors attempted to guide the students understanding of the potential need for external vehicle displays, while minimize the amount of input on the designs. The advisors, focused on the design of the web based assessment methodology, technical aspects of the MTurk implementation, and empirical data collection to provide the students with a data set that could be used to evaluate assumptions about design elements. The ability to “risk” resources in testing such a large number of design concepts was only practical through the use of a relatively low cost and low time intensive prototyping methodology such as was explored here. A strong focus of this work was allowing the graduate design students flexibility to consider the advantages and disadvantages of various design approach and gain rapid consumer facing feedback on the appropriateness of their decisions.

Twenty of the designs (1, 7, 11-24, 26-30) were created with the intent of communicating that it is safe to walk without explicitly intended ambiguity. Of these, six of the designs obtained an 80% or greater match and none of the designs showed universal agreement. For 8 of the 20 “walk” designs, more than half the participants found the message unclear or misinterpreted the message as “don’t walk”. The 2 “don’t walk” designs fared generally better, although the interpretive match was still not universal – which is of particular concern for a safety critical communication in which nearly, of not 100%, correct interpretation is needed. Clarity and unambiguity will be critical if external communication displays are to achieve the goal of building psychological trust between human and machine [7].

The presence of uncertainty and misinterpretation with all of the designs tested suggests some potential concern around the concept of “needing” to employ external communication signals in automated vehicles intended for public roadways beyond those already used in non-automated vehicles (e.g., turn
Figure 3: Frames from each of the 30 animated designs presented to participants, shown here in cropped, close-up views.
signals, brake lights, and vehicle kinematic cues). Lagström and Lundgren ([14]; see also [11] present a substantive series of small studies that document pedestrians’ desire to understand a driver / vehicle’s intent, and explore a creative design concept involving a row “movable” light bar elements at the top of the front windshield to communicate several messages (e.g. ‘I’m about to yield,’ ‘I’m about to start.’). After training in the intended meaning of the messages, all 9 participants in the final test phase were able to correctly report the intention of all of the messages except for the message intended to indicate that the vehicle was in automated mode. What is not clear is how an untrained population would interpret the messaging and whether the net result over time would be greater comfort with automated vehicles and an overall safety benefit for pedestrians.

In another very detailed study, Clamann and colleagues [4] tested a variety of designs including a mock automated van with a prominently mounted, large LCD display employing what would appear to be relatively apparent walk/don’t walk graphics (walking figure with and without a diagonal line across the image). It was concluded that while a large number of participants felt that additional displays will be needed on automated vehicles, most appeared to ignore the displays and rely on legacy behaviors such as gap estimation and inferring vehicles’ approaching speed (collectively kinematics) in making decisions on whether or not to cross the road. In an interview [9], Clamann observed that the displays tested were “as effective as the current status quo of having no display at all.”

The senior researchers on this paper have, as part of a different project, been involved in extensive observation of pedestrian-vehicle interactions [17]. During these observations, we have increasingly developed the impression that pedestrians may take their primary communication cues from overt vehicle kinematics more often than actually depending on eye-contact or body gestures to make judgements about vehicle intent and that multiple attributes may be used to predict intent. As such, vehicle systems may be developed to be responsive to pedestrian movements. Thus, we see it as still an open research question as to whether new external displays are necessarily a priori answer to improving communication of intent. We are in full agreement with Clamann [9] that careful, detailed evaluations need to be carried out to make sure that displays and signals work as intended before they are standardized, mandated or released in any production fashion.

It is clear, that unanticipated consequences can easily occur if a pedestrian in the dilemma zone (stepping off the curb into the flow of traffic) pauses for even a moment to perceive, read or interoperates the intent of external communication devices. As such, while benefits of external vehicle displays could easily improve the communication of intent in a “trained” or “habituated” population, without nearly ubiquitous understanding risks could easily increase. Furthermore, a transition period during which a mixed population of vehicles with and without communication devices, and a mixed set of educated and non-educated pedestrians could be detrimental to short term safety making the societal hurdles to successful adoption of a new technology more difficult.

CONCLUSION
Experience implementing the assessment methodology described here in MTurk demonstrates that this approach can be applied in a cost effective manner for identify design concepts that may be appropriate for more detailed development and testing. Since a relatively large number of elements or minor variations can be tested through a series of MTurk runs in a matter of hours (as opposed to weeks or months for focus groups or experimental simulation or field testing), designers should be able to refine concepts both more quickly and in more depth than available development resources typically allow. Factors that are often difficult to explore during design...
phases (e.g. culture, demographic, prior mental model, etc.) can be factored in early in the process. It is worth noting that there is nothing in this method of early stage design development that is limited to the messaging application explored in this study; it should be equally applicable to work on other design elements such as interior interface icons, graphics, gages, and other forms of information presentation in automotive, consumer electronics, advertising and other domains.

LIMITATIONS
As noted, the majority of participants were from the USA and India, so it is unknown the extent to which the findings for specific design elements generalize to other regions. A single vehicle type and setting were assessed. The Turker sample was motivated to pay attention to details of the images and presumably not distracted (e.g., talking on a phone, etc.), thus correct detection of communication intent may have been greater than might be obtained under real-world conditions and may represent something approximating best case evaluations. With these considerations in mind, the methodology explored here is likely to be most useful for rapidly identifying designs or design elements that are promising for further investigation as opposed to use for late stage validation.

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