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Toward Vehicle Content Accessibility Guidelines

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ABSTRACT

This study entails the current status of the accessibility in vehicle. With the movement of Software-Defined-Vehicle (SDV), automobiles transform into a digital device with larger screen and connected content service including map. However, it is questionable if the contents in vehicle is accessible to all. We often experience a feeling of "disabled" when we cannot 1) perceive the content on screen 2) operate the function with interactive components, or 3) understand the messages from the vehicle that we are driving with. How can we diagnose the current in-vehicle accessibility to find the direction to improve? The current issue on vehicle content accessibility is related to the missing of vehicle content accessibility guideline. This study reviews current guidelines and regulation in the USA and introduce the draft of vehicle content accessibility guideline (VCAG) that can contribute to enhanced accessibility of in-vehicle digital content and app. Recognizing the unique challenges posed by the driving context, the research explores methods to test interface design, content presentation, and interactive features to ensure universal design and content accessibility while minimizing cognitive overload for drivers.

Keywords: In-vehicle content accessibility, Human factor guideline, Testing methods, Accessibility success criteria

INTRODUCTION

Our lifestyle changes rapidly with mobility technology. The changes involve in-vehicle user experience design, how easy or difficult to use what the vehicle can offer. When the vehicle opens its functions and contents to the internet connection by real-time access, download, and update by user's interaction, the critical matter of user experience is whether users are able to find how to start and initiate the interaction – in other word, content accessibility. The in-vehicle content in this context refers to what vehicle can communicate with the users including visual and audible information especially though the dashboard (e.g., cluster, head-up-display, and infotainment system). The accessibility of content determines the user experience from the first impression to overall usability.

More and more contents flow into the vehicle and demand user's attention, (inter-)action, and control. Especially when every part of the vehicle can be controlled by software, or Software-Defined-Vehicle (SDV), the interaction with the vehicle turns more virtual and mediated though the interface. Bringing the traditional interface design for the vehicle system or web

design for the in-vehicle reveal the potential safety issues – as controlling in-vehicle interface adds burdens on the users with multi-tasking, which conveys heavy cognitive load due to consistent changes in the road condition (environmental factors) and interactions with other vehicles and pedestrians. With this overloaded situation, the assignment of controlling the vehicle interface timely and precisely while driving is challenging. This make us feel "disabled", because the content is not, at least easily, accessible (Rak, 2024).

The motivation of the current study is to call the needs for the vehicle content accessibility guideline with which designers and engineers can check what elements to be taken care of and how the in-vehicle content accessibility to be measured. It doesn't mean to be a complete guideline but agenda setting toward a work-in-progress sharing, as the complexity of content ecology and vehicle development process evolves. In what follows, this article will present 1) the accessibility challenges in the in-vehicle user experience; 2) the review of the current related guidelines; and 3) the principles and metrics of vehicle content accessibility guidelines.

Across automobile industries and related areas, vehicle content accessibility entails physical, perceptual, and operational quality in user experience (ISO, 2014; Caldwell et al., 2008) to ensure drivers can use the system without mistakes. 1) ISO IEC (the International Organization for Standardization, the International Electrotechnical Commission; ISO, 2014) approaches accessibility as a broader inclusive perspective as a universal design that benefits everyone. 2) W3C WAI WCAG (World Wide Web Committee, Web Accessibility Initiative, Web Content Accessibility Guidelines; Caldwell et al., 2008) covers the principles and recommendations for web content, such as web pages or mobile apps in the form of (coded) text/markup, images, and sounds, to be more accessible to people with disabilities. 3) NHTSA FMVSS (National Highway Transportation Safety Administration, Federal Motor Vehicle Safety Standards) Standard 101 (NHTSA, 2009) covers in-vehicle controls and display items, such as telltales and indicators, to be more physically accessible, visible, and recognizable under various mobile contexts. 4) SAE (J2364_201506; SAE, 2015) defines the accessibility of the feature as a condition that a driver can reach the controller to complete the tasks without any issues in perception and operation under the driver's seat position.

ISO IEC 71:2024E and Related Universal Design Principles

This accessibility guideline covers the usability (ISO, 9241; 2018), assistive tech/product (ISO 9999, 2022), software interface & ergonomics (ISO, 20282; 2006; ISO, 22411; 2006; ISO, 26800; 2006; ISO, 29136; 2006; ITU-T F.790; 2007), safety (ISO/IEC Guide 50, 2014; ISO/IEC Guide 51, 2014), and the general universal design principles (Story, 1998). The items related to vehicle content accessibility are: Approachability (4 items); Perceivability (4 items); Understandability (8 items); Controllability (4 items); Usability (8 items); Error Tolerance (6 items); and Equitable Use (3 items). Notably, this guideline focuses on the diversity of human abilities and characteristics with details of limitations by sensory functions and physical activities. The

guideline items, however, need proper interpretation to develop the testing metrics for in-vehicle context.

W3C WAI WCAG and Mobile Accessibility

WCAG 2.0 (ISO/IEC 40500:2012, Caldwell, 2008), while the latest version 2.2 is still under the ISO process (expected by June 2025), provides 13 guidelines and 26 success criteria. Four principles of perceivable(4), operable(5), understandable(3), and robust(1) are framed with the specific requirements, success criteria, and accessing techniques by three conformance levels. (Level A for every web page for the general public to Level AAA for the special contents required assistive technology). WCAG has been a powerful accessibility training material for web designers/developers, especially for automated testing by code/ markup inspection. However, it is limited in context with static and indoor/office computer systems. To overcome this limitation, the mobile accessibility extension (WAI, 2024) is under development with additional guidelines(4) for non-traditional computing devices including mobile phones with a small screen and in-vehicle infotainment (IVI).

NHTSA: FMVSS Standard 101 and Related Human Factor Design Guidelines

NHTSA Standard No. 101 (NHTSA, 2003) covers the scope and purpose of controls and displays for the vehicles including passenger cars, trucks, and buses. The focus of this standard is safety communication for the drivers such as the specific performance requirements of the telltales and the indicators about their location, identification, color, and illumination. For example, it describes how visual signs need to be displayed in critical malfunction scenarios of the brake system, airbag, or low tire pressure – the icons in red on the cluster for a certain second with blinks. However, due to the regulatory characteristics, the descriptions are loosely defined in general to accommodate diverse contexts (e.g., Red can be yellow-orange). The complementary resources are available such as Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (Hooey, Kantowitz, & Simsek, 1998), Visual-Manual NHTSA Driver Distraction Guideline for In-Vehicle Electronic Devices (NHTSA, 2014), Human Factor Design Guidance for Driver-Vehicle Interfaces (Campbell et al., 2016), and Human Factor Design Guidance for Level 2 & 3 Automated Driving Concepts (Campbell et al., 2018) - They are nonbinding and voluntary guidelines based on evidence and scientific literature. The limitation is, though, not a few studies in reference are outdated as technology in society changes rapidly therefore user's mental models, behaviors, and expectations are dramatically different from before.

SAE (J2364_201506) and Normative References (J287, 1050, 2396, 2365)

The accessible interface in SAE means the driver can complete the task by the controls within reach (SAE J287, 2015); the driver can perceive the visual

information with head movement (e.g., view angles, SAE J1050, 2009); and the driver can operate the system. The SAE guidelines contain technical details and design recommendations accompanying the testing methods, such as how many participants with which characteristics are needed and how to measure and calculate the performance time to access the interface is accessible. For the example of the navigation and route guidance system (SAE J2364, 2015), the navigation task is required to be performed within 15 seconds under the static test condition: such that 10 participants with active driving experience and a valid driving license, aged 45–56 years old evenly distributed in gender needed to perform three trials and the performance time will be calculated in logarithmic mean for all subjects and all trials to determine whether or not the criterion has been exceeded. Though a great advantage can be found in the details of quantitative methods that help to draw a clear line of success (effectiveness), this guideline can be improved by the qualitative measurement of the accessibility quality (i.e., efficiency and satisfaction). For accessibility, as extended usability in the universal design framework, qualitative data will help to analyse the root causes for the driver's errors or performance delay.

The guidelines for vehicle content accessibility are curated based on the existing guidelines above. It is not intended to exclude other guidelines not listed above. Those representative guidelines are established over the critical review of the various literature and other guidelines. Across the guidelines, the accessibility principles emerge in support of perceivable, operable, and understandable interface design for the driver's feeling of safety, therefore, are adapted in the Vehicle Content Accessibility Guideline.

Vehicle Content Accessibility Guideline & Success Criteria

The purpose of the Vehicle Content Accessibility Guideline is to help user experience design researchers be aware of the characteristics of in-vehicle and driving context to access the content accessibility. Here, the in-vehicle content is defined as the content presented and created between the human driver and the vehicle in operation, therefore, technically subsumes vehicle controls. When the controllers are designed in a way that users need to perceive, understand, and operate, it is considered as content that the vehicle provides to the user drivers. On the other hand, if the driver cannot access the control, the vehicle fails to communicate with the driver. This failure reveals the accessibility issue as the user cannot make access to what the vehicle offers.

The perceivable interface design for the vehicle includes the requirement of the following:

1) Accommodation of the limited mobility of the driver: User's natural seating posture and hands on the steering wheel. All the necessary driving and safety information (e.g., vehicle status, surrounding views) needs to be perceivable from the driver's view on the seat without further head or body adjustment (as the driver is expected to put eyes on the road).
2) The feeling of safe driving: Users need to be able to find the controls to adjust the settings (i.e., HVAC, Radio Volume, door/window, driving turn signal/wipers/headlights) for the primary and supplementary tasks.

3) Glanceable interface for users to process the information in peripheral vision: High contrast and sufficient exposure time are required regardless of daylight or night. Prevention of distraction and potential harm (ex. Blinking).
4) Multimodal communication: Users need to be informed by multiple ways of communication together for any urgent notifications and provided with a guide about which actions are needed.

All the necessary driving and safety functions (e.g., gear shift, wiper, hazard/SOS, headlight, door/window, turn signal, or climate/media control) need to be operable from the driver's posture without further body adjustment. The operable interface is optimized to support the driver's physical and mental condition in the limited maneuverability under time pressure.

1) Reachable: Controllers are located within the driver's arm reach for critical safety-related driving tasks.
2) One-hand operable: For the hands-on-wheel condition, avoid any operation that requires two-hand coordination.
3) Time to operate: Manageable within the time limit when urgent and user's actions are needed. In non-emergency, interactive components need to be available as long as the control is valid and users can process (read, control, complete) with confidence.
4) Considering safety issues in driving contexts: The interface needs to help drivers be confident to complete the operation as accurately as intended under various road conditions.

The understandable interface needs to provide the information and instructions (including notification, warning, user feedback and status update) as easy to process. Approachable, readable, and comprehensible writing and wording are important.

1) Easy to process: The interface minimizes the cognitive load by a) optimizing the words/characters, b) being consistent in terminology/punctuation/voice/tone/visual spacing, c) presenting the critical info first, and d) minimizing the steps to complete by breaking down the content and by providing an overview of the system, its components, and functionalities so that users can efficiently skim the content through.
2) Approachable: For messages, provide a clear explanation about the current status, consequence, and user's action required about what they can do. For titles, provide an overview of the system, components, and functionalities. Provide help when needed.

Testing Methods

To complement the limitation of the methods in inspection and user testing (Jeffries & Desurvire, 1992), two-step process is recommended. 1) Accessibility audit by checklist as expert reviews. 2) Testing with a group of selected participants.

In the expert review for accessibility audit, the accessibility specialist will examine the in-vehicle interface for the upper vs. lower bound extreme users' ergonomics (i.e., 1 or 99 percentile of population; Tilley, 2001) with the perception, operation, and comprehension with the audit checklists consolidated from the ISO standard, regulation, and recommendations.

For the accessibility user testing, multiple participants are invited to join the in-vehicle setting but in a non-driving context. The target test participant requirement follows the NHTSA guidelines: 24 participants in good general health as a mix of ages between 18–75yr old and gender with a minimum of 7000 miles of drive per year (20 miles/day) with a valid driver's license. This testing requires participants with normal vision/hearing and without mobility issues. This is based on the assumption that if the testing fails with the people without any sensory-motor issue, it will fail with the people in the extreme sensory spectrum or mobility limitations.

The testing setting is in-vehicle or with a testing buck with an adjustable driver seat, a steering wheel, and the in-vehicle content devices - either the structured hardware (e.g., screens or buttons) or the real-life 1:1 scale images of the cluster (ex. speedometer) and infotainment (e.g., navigation), with other controllers (e.g., gear shift) related to the testing scenario. The dedicated external screen for the driving simulation or video is set in front of the driver's front view.

The testing procedure entails 1) introduction and pre-test; 2) the training; 3) trials/practice rounds; 4) testing; and 5) post-test questionnaires.

1. Pre-test/Measurement: Measure the key driver anthropometry and driver's (comfortable).
2. The training: Provide the contextual visuals to simulate the eyes-on-road and hands-on-wheel with the street view. Have a driver to identify and talk aloud the traffic related objects and details (i.e., symbols and colors) in the front view whenever they encounter them.
3. The trials/practice: Demonstrate the sample task (e.g., turn on/off the vehicle) and ask the participants to replicate the task. Allow the participants to practice until they feel it comfortable.
4. Testing: Ask the participant to perform the selected core tasks (e.g., up to six) if the interface is perceivable, operable, and understandable. Per each task, give three trials. Measure the performance time and eye glance time (i.e., away from the road).
5. Post-Test: Questionnaire to check the participant's comprehension and satisfaction (e.g., perceived efficiency).

The detailed measurement and data type and the acceptance/success criteria can be found in Table: Suggested VCAG.

Table 1: Suggested vehicle content accessibility guidelines (VCAG).

Guideline/Recommendation	Testing Procedure/Measurement	Success Criteria
Perceivable		
0.1 [Perceivable accessibility & regulation audit].	Accessibility Audit Checklist	100% passing

Continued

Table 1: Continued

Guideline/Recommendation	Testing Procedure/ Measurement	Success Criteria
1.0 [General Principle] All the necessary driving and safety information (vehicle status, surrounding views) need to be perceivable from the driver's view in the seat without further head or body adjustment.	Have a test participant to identify and talk aloud the traffic related objects and details (symbols, colors) in the front view whenever they encountered.	Passing when answering 100%, if missed warn to pay attention/eyes on road verbal & visual warning.
[Within the view] Have all interaction options clearly presented from the perspective of the driver in their natural driving posture with eyes on road and hands on the steering wheel.	Have the test participant seated in their comfortable posture to be ready for driving. Measure the side, top, front distance and angles from the centre of the two eyes to visual components.	Check the required view field/angle* (within 30deg) cover the major visual items.
[Access points] Have the access/control point of core tasks be well communicated to users as expected.	Ask the test participant to describe how to do the core tasks* by accessing which area and by doing what: • How they expect to start • What they expect to see next to proceed.	[Core in-vehicle tasks* analysis] Match user's mental model with the task analysis and grouping.
[Feeling of safe operation] Have the expected operation sequence with interface/controllers be perceived as safe.	How much does the test participant feel it easy/ comfortable to try the core tasks* (while safe driving under the eyes on road condition)?	Perceive ease of use – Likert scale (1–7), pass if the score is over 6.
[Quick to process] The interface is required to be glanceable within the driver's peripheral vision – enough exposure time and high-contrasted elements regardless of the lighting condition (daytime vs. nighttime).	Overlay the vehicle status messages in context and check if the test participants recognize and verbalize the status changes under the eyes on road condition.	[Effectiveness] Verbal acknowledgement if they spot the changes. 90% accuracy for passing. [Efficiency] Perceived Timing with 7-scale Likert as expected (4) as passing.
Operable		
2.1 [Reach] Have the interactive components (physical, capacitive, or touch screen buttons) located within arm reach.	Have a test participant seated in their comfortable posture for the driving-ready; measure the arm reach to major interactive component groups.	Check the required arm range in the driver's seat position* to touch all the major interactive items (ex. Hard key buttons).
Have the interface operable within the limited manoeuvrability and time pressure. [One hand operation] Avoid any secondary-task situation that requires operation with both hands at the same time.	[Reachable] Test with the test participant to reach the controller from the hand-on-wheel position upon the request. Have the test participant to touch the core controllers by keeping one hand on the steering wheel.	Check the performance time to reach and touch the target within 2se.; To complete the tasks within 15sec.
[Alternative access/Digital twin] Have the interactive components be controllable remotely/virtually (i.e., mobile app) as well as directly (i.e., in-cabin).	Ask the test-participant how they would conduct the non-driving/secondary tasks below by accessing which area and by doing what – climate control, media volume.	Match user's mental model with the task analysis (optimal steps) and grouping.

Continued

Table 1: Continued

Guideline/Recommendation	Testing Procedure/ Measurement	Success Criteria
[Enough Time to operate] Have the interactive components available as long as the control is valid and users can process (read, control, complete) the content with confidence.	How much does the participant feel it easy/comfortable to try (while safe driving)?	Simple Likert scale (1-7 positive) – pass if the score is over 6.
Understandable		
[Simple: Easy to process] Provide information that is easy to process – be readable & understandable within 2sec while driving. Minimize the cognitive load by 1) optimizing the words/characters, 2) using consistent terminology/punctuation/voice/tone/visual spacing, 3) presenting critical information first, and 4) simplifying the steps needed to complete an action.	• [Readable] Test with the participant by asking to read out loud the full message/icon labels in the given exposure time • [Comprehensible] Test with the participant by asking to elaborate the message/icon/controllers about what it means.	[Readable] Completion of reading out loud, higher than 80%. [Comprehensible] Accuracy of interpretation, higher than 80%. [Accessibility audit checklist 3.1] Passing 100%.
[Content structure & strategy] 1. Message: Provide a clear explanation of the current status, consequence, and user's action required. 2. Title: Provide an overview of the system, its components, functionalities. 3. Provide help when needed	• How much does the participant feel it easy/ comfortable to access the help? • How much does the participant feel the help/ instruction provided is satisfactory?	Simple Likert scale (1-7 positive) – pass if the score is over 6.

CONCLUSION

Vehicle UX needs to support universal design for diverse driving users with the most accessible interface as user interactions involve critical safety concerns in complicated multitasking driving contexts. With a more accessible interface, drivers will less easily feel as if they are "disabled" to perceive, operate, and understand the content provided in vehicles. This consolidated vehicle guideline can help designers and engineers to be aware and be able to test the vehicle content and design and ensure the satisfactory implementation of universal design. However, the study should be considered as a draft and work-in-progress that calls for collaboration toward vehicle content accessibility guidelines. Hardly it will be completed without more concrete behavioral and biometric data to capture the perceptual, operative, and cognitive human factors for a better social contextual awareness.

REFERENCES

Caldwell, B., Cooper, M., Reid, L. G., Vanderheiden, G., Chisholm, W., Slatin, J., & White, J. 2008. Web content accessibility guidelines (WCAG) 2.0. *WWW Consortium (W3C), 290*(1–34), 5–12. http://www.w3.org/TR/2008/REC-WCAG20-20081211/

Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Bacon, L. P.,... & Sanquist, T. 2018. Human factors design guidance for level 2 and level 3 automated driving concepts. *Report No. DOT HS 812*(555). Washington, DC: National Highway Traffic Safety Administration.

Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Sanquist, T., & Morgan, J. 2016. Human factors design guidance for driver-vehicle interfaces. *Report No. DOT HS, 812*(360), 252. Washington, DC: National Highway Traffic Safety Administration.

Hooey, B. L., Kantowitz, B. H., & Simsek, O. 1998. *Advanced Traveler Information Systems and Commercial Vehicle Operations Components of the Intelligent Transportation Systems: On-road Evaluation of ATIS Messages* (No. FHWA-RD-99–132). United States. Federal Highway Administration.

International Organization for Standardization. 2006. *Ease of operation of everyday products - Part 1: Design requirements for context of use and user characteristics* (ISO Standard No. 20282-1:2006). https://www.iso.org/standard/34122.html

International Organization for Standardization. 2006. *Ergonomics — General approach, principles and concepts* (ISO Standard No. 26800:2011). https://www.iso.org/standard/42885.html

International Organization for Standardization. 2006. *Ergonomics data for use in the application of ISO/IEC Guide 71:2014* (ISO Standard No. 22411:2021). https://www.iso.org/standard/78847.html

International Organization for Standardization. 2006. *Information technology — User interfaces — Accessibility of personal computer hardware* (ISO Standard No. 29136:2012). https://www.iso.org/standard/45159.html

International Organization for Standardization. 2014. *Guide for addressing accessibility in standards* (ISO Standard No. 71:2014). https://www.iso.org/standard/57385.html

International Organization for Standardization. 2014. *Safety aspects — Guidelines for child safety in standards and other specifications* (ISO/IEC Guide 50:2014). https://www.iso.org/standard/63937.html

International Organization for Standardization. 2014. *Safety aspects — Guidelines for their inclusion in standards* (ISO/IEC Guide 51:2014). https://www.iso.org/standard/63937.html

International Organization for Standardization. 2018. *Ergonomics of Human System Interaction* (ISO Standard No. 9241-11:2018). https://www.iso.org/standard/63500.html

International Organization for Standardization. 2022. *Assistive products — Classification and terminology* (ISO Standard No. 9999:2022). https://www.iso.org/standard/72464.html

International Telecommunication Union. 2007. *Telecommunications accessibility guidelines for older persons and persons with disabilities* (ITU-T F.790). https://www.itu.int/rec/T-REC-F.790–200701-I/en

Jeffries, R., & Desurvire, H. 1992. Usability testing vs. heuristic evaluation: Was there a contest? *ACM SIGCHI Bulletin, 24*(4), 39–41.

National Highway Traffic Safety Administration. 2009. Federal Motor Vehicle Safety Standards: Controls, Telltales and Indicators (Standard No. 101; Docket No. NHTSA-2009-0145). *Federal Register 74*(155) Retrieved from https://www.govinfo.gov/content/pkg/FR-2009-08-13/pdf/E9-19396.pdf.

National Highway Traffic Safety Administration. 2014. Visual-Manual NHTSA Driver Distraction Guidelines for in-Vehicle Electronic Devices (Docket No. NHTSA- 2014–0088). *Federal Register 79*(179) Retrieved from https://www.govinfo.gov/content/pkg/FR-2014-09-16/pdf/2014-21991.pdf.

Rak, G. 2024, November 3. Touchscreens are out, and tactile controls are back. *Spectrum IEEE*.

Society of Automotive Engineers. 2009. *Describing and Measuring the Driver's Field of View.* (JJ1050) Warrendale, PA: Society of Automotive Engineers. https://www.sae.org/standards/content/j287_202211/

Society of Automotive Engineers. 2015. *Driver hand control reach*. (J287_202211) Warrendale, PA: Society of Automotive Engineers. https://www.sae.org/standards/content/j287_202211/

Society of Automotive Engineers. 2015. *Navigation and Route Guidance Function Accessibility while Driving* (Stabilized Jun 2015). Warrendale, PA: Society of Automotive Engineers. https://doi.org/10.4271/J2364_201506

Story, M. F. 1998. Maximizing usability: The principles of universal design. *Assistive Technology, 10*(1), 4–12.

Tilley, A. R. 2001. *The measure of man and woman: Human factors in design*. John Wiley & Sons.

Web Accessibility Initiative. 2024. Mobile Accessibility at W3C. *WWW Consortium (W3C)*. Retrieved from https://www.w3.org/WAI/standards-guidelines/mobile/.