

The Design of Visual Communication Barriers and Decoding Perceptions for Standardizing Signage for Deaf Drivers in Thailand

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Abstract

The primary objective of this study is to establish a standardized safety framework by evaluating behavioral intent and semantic transparency through a mixed-methods approach. Structuring the study into three systematic phases, a target sample was selected via purposive sampling from the national population of 391,371 registered deaf individuals. The experimental sample comprised 20 participants, bifurcated into two distinct groups: licensed deaf drivers (n = 10) and general motorists (n = 10). Empirical testing was executed using semi-structured interviews in conjunction with a Virtual Reality (VR) driving simulation experiment under dynamic environmental conditions to rigorously measure participants' cognitive latency and reaction times. Crucially, empirical findings reveal that current disability stickers fail as "active safety signals" due to poor chromatic contrast and a lack of ergonomic semiotic linkage. General motorists consistently fail to decode their meaning often perceiving outdated materials as visually obstructive while qualitative insights indicate that a subset of deaf drivers (80.0%, n = 8 out of 10) exhibit a profound psychological reluctance to display static identifiers due to fears of harassment and criminal targeting once their status is publicly marked. To address these systemic failures, the study proposes a standardized visual signaling framework based on ISO 7010 and Universal Design principles. By optimizing chromatic contrast and utilizing situational LED activation, this proposed active system aims to minimize perceptual latency, ensuring critical traffic safety information is decoded instantaneously without compromising the user's anonymity.

Keywords : Visual Communication Engineering; Media Psychology; Cognitive Decoding; Traffic Signage Standards; Perceptual Latency

1. Introduction

In the framework of national infrastructure, the transportation industry and road safety serve as fundamental pillars driving economic mobility and enhancing the quality of life in Thailand [1]. As Thai society embraces diversity and social equity, transportation policies have evolved to uphold the dignity of marginalized groups. A significant paradigm shift occurred in 2005 when the Ministry of Transport amended regulations, granting hearing-impaired individuals the legal right to obtain personal driver's licenses [1]. This policy formally recognizes their cognitive driving capabilities, aligning with international social inclusion principles [2]. Current statistics reveal that over 50,000 hearing-impaired individuals hold driving licenses nationwide, a trend accelerated by the "Gig Economy" where deaf drivers increasingly participate in public transport and delivery services. However, a critical inter-driver communication gap persists; traditional road communication relies heavily on auditory cues, creating a high-risk environment for deaf drivers and leading to a significant information asymmetry [3].

From a Visual Communication Engineering perspective, Thailand currently operates within a technical semiotic vacuum [4], [5]. While basic industrial stickers exist, the system lacks effective signage aligned with communication engineering principles. Roadways instead feature self-produced

stickers or the misapplication of the International Symbol for Deafness (the crossed-ear icon). It functions by converting critical safety data into optimized visual signals matching human cognitive limits, ensuring that signs are immediately detected and processed under dynamic, high-speed driving conditions.

Currently, Thailand operates within a semiotic vacuum lacking standardized, official traffic signage for deaf drivers [4]-[6]. The road environment relies on self-produced stickers or the misapplication of the architectural "International Symbol for Deafness" (the crossed-ear icon). Placed in high-speed traffic, this symbol functions as "Miscontextualized Encoding". The use of blue psychologically associated with information rather than hazard fails to trigger the necessary cautionary response on the road, inducing "Semantic Blur" where other motorists decode critical safety alerts as mere decorative stickers [6].

This semantic blur and interpretation failure catalyze road accidents involving deaf drivers, leading to rising localized rear-end collisions and sideswipes. When critical auditory alerts like emergency honking go unacknowledged, the lack of "Semantic Transparency" in current stickers prevents trailing motorists from transitioning to visual alternatives or maintaining safe braking distances [3]. Consequently, surrounding drivers fail to timely

recognize vehicle communication constraints, triggering abrupt braking and multi-vehicle crashes. Per Stuart Hall's model [3], [7], [8], non-transparent signals fail to elicit a rapid "Dominant Reading". Furthermore, deviating from ISO 7010 warning schemas by substituting yellow-black with blue introduces severe "Semantic Noise" [9].

Despite global advancements in external Human-Machine Interfaces (eHMI) [4], there remains a research gap in Thailand concerning the media psychology of driver stimuli, particularly for those operating within the high-speed gig economy [5].

To mitigate these hazards, human factors literature demonstrates that standardized, mathematically optimized symbols significantly eliminate cognitive processing delays. Traffic signage engineering research reveals that signs utilizing precise stroke widths and high-contrast, yellow-and-black triangular geometries according to international safety standards drastically optimize driver comprehension. Empirical studies indicate that such engineering configurations successfully reduce a motorist's perception-reaction time (T_r) well below the critical 2.0-second safety threshold, providing trailing drivers with sufficient braking margins to prevent rear-end collisions.

Despite global advancements in external Human-Machine Interfaces (eHMI) [4], Thailand's media psychology regarding driver stimuli remains under-

researched [5]. To eliminate these communication blind spots, this study analyzes the sender-to-receiver cognitive process to transition informal stickers into a policy-backed "Signage Engineering System". The research targets three systematic phases: investigating decoding barriers and perceptual noise, analyzing design element encoding and connotative meanings, and proposing optimized information transmission guidelines to minimize communication failures, ultimately enhancing road safety and social equity in Thailand.

2. Research Methodology

The research methodology is designed as a pilot study employing a stimulus-based research approach, focusing on improving visual communication efficiency for deaf drivers. It employs a Multidisciplinary Approach, integrating Visual Engineering, Behavioral Science, and Communication Arts to address the limitations of existing traffic symbols. To fully operationalize this framework, the study extensively expands upon the concept of Active Visual Light, specifically focusing on the mechanism of Situational LED Activation. This mechanism serves as the primary technical tool, engineered to deliver dynamic, real-time visual stimuli that adapt to critical road scenarios. By embedding this situational activation within the design, the methodology

directly bridges engineering controls with behavioral science, thereby maximizing cognitive conspicuity and optimizing the behavioral responses of deaf drivers under high-stakes conditions.

Population and Target Sample

The target population encompasses registered deaf individuals in Thailand (N = 391,371) and licensed general motorists. Given the laboratory-controlled nature of this human factors experiment, a total sample of 20 participants was selected via purposive sampling, equally bifurcated into deaf drivers (n = 10) and general motorists (n = 10). To ensure internal validity, all subjects met strict inclusion criteria, including a minimum of 2 years of driving experience and normal or corrected 20/20 visual acuity.

Regarding statistical representation in human factors engineering, this study adopts a Quasi-Experimental Laboratory Design (Human-in-the-loop simulation) rather than a broad social survey. According to established ergonomic testing paradigms, a sample size of n = 10 per distinct experimental cohort (10 licensed deaf drivers and 10 general motorists) provides sufficient data saturation to ensure high Internal Validity. This localized cohort size allows for rigorous, repeated-measures validation under stringently controlled environmental variables, making it mathematically valid for evaluating

mechanical reaction times and cognitive sensory limits.

2.1 Research Processes

This study employed a mixed-methods approach combining a quasi-experimental laboratory design with qualitative research methods. The research was executed through three systematic phases as follows:

Phase 1: Planning and Problem Identification (Planning)

The primary objective was established to mitigate road-based information asymmetry. Via purposive sampling from Thailand's population of 391,371 registered deaf individuals (Department for Empowerment of Persons with Disabilities, 2022), the experimental sample was bifurcated into licensed deaf drivers and general motorists, supplemented by traffic signage experts and graphic designers. Questionnaires and structured interviews elicited in-depth perceptual challenges to prioritize critical issues.

Phase 2: Documentary Research and Framework Development (Documentary Research)

A comprehensive review of academic literature, international standards specifically ISO 7010 and ISO 7001 (International Organization for Standardization, 2011, 2023) and traffic accident statistics was conducted. This

phase analyzed design components and cultural connotations using the semiotic frameworks of Roland Barthes (1972) and Stuart Hall (1980). These paradigms were integrated with Ware's (2020) Mental Imagery Theory to establish empirical design criteria and visual engineering proportions capable of rapidly stimulating driver risk imagery.

Phase 3: In-depth Interviews and Simulation Testing (In-depth Interview and Simulation)

Based on the derived design criteria, ten prototype signage variations were developed and evaluated using semi-structured interviews [9] alongside experimental manipulation. Visual stimuli were introduced within a dynamic Virtual Reality (VR) driving simulation to rigorously measure participants' behavioral intentions and perceptual delay. To perform quantitative latency analysis, each participant completed three designated trial blocks across different simulated road configurations, yielding 15 dynamic trials per participant to establish statistical reliability for percentage metrics and empirical reaction times.

Data Analysis

Qualitative interview data were transcribed verbatim via professional sign language interpreters. Content analysis utilized systematic coding to extract core themes. Ultimately, documentary data, interview insights, and empirical responses

from the VR simulation system were cross-examined through data triangulation to formulate effective standardization guidelines for safety signage.

2.2 Visual Communication

This phase compares the efficacy of current "Information" symbols (Blue/Square) against the proposed "Warning" model (Yellow/Triangle) based on ISO 7010 [4], [9], [10]. This transition in "Categorical Signaling" is engineered to maximize visibility, evaluating the signaling performance via the Conspicuity Index (CI) as formalized in equation (1) [10].

$$CI = \frac{C \cdot A}{V_b} \quad (1)$$

When

CI = Conspicuity Index

C = Contrast ratio between symbol and background

A = Surface area of the symbol (cm²)

V_b = Visual background clutter factor

Where CI represents the Conspicuity Index, C denotes the chromatic contrast coefficient, A represents the visual surface area of the physical signage, and V_b indicates the background visual noise. **Mathematically, CI exhibits a direct variation (proportionality) with contrast (C) and sign area (A), while exhibiting an inverse variation with background clutter (V_b).** > To standardize the engineering calculation across all simulated scenarios, the

physical surface area (A) was fixed as a numerical constant of $80 \times 10 \text{ cm}^2$, which serves as the minimum structural requirement for long-range detection distances exceeding 20 meters. In traffic engineering and vision science, the safe engineering **threshold criteria for a highly effective traffic sign requires a CI value of no less than the industry standard threshold**, ensuring that the target sign can instantaneously arrest driver attention amid dynamic visual disruptions.

Regarding the Engineering Communication ratio, this research strictly adheres to Visual Acuity Standards and Unity Scale Metrics (1 Meter) to optimize the Conspicuity Index (CI). Our proposed models are engineered using a calculated height-to-distance ratio of 2.5–3 cm per 10 meters to ensure maximum legibility, aligning with international ergonomics for accessibility [22] (ISO, 2023). For long-range detection (>20 m), we standardized the symbol area (A) at $80 \times 10 \text{ cm}^2$ to mitigate background clutter (V_b). By transitioning to a Yellow/Triangle (Warning) configuration, we intentionally maximize the contrast ratio (C), following global safety color protocols [21] (ISO, 2011) and accessibility standards for non-auditory cues [20]. TISI [24] addressed that in the Thai context, this design integrates the Thai Industrial Standard for safety colors. Furthermore, the placement and visibility parameters comply with the Ministry of Social Development and Human Security guidelines [23], ensuring that visual information effectively compensates for auditory limitations within Thailand's public infrastructure.

2.3 Behavioral Media Psychology and Semiotic Perception Decoding

We adopting a 'Proactive Communication Strategy' to measure Glance Legibility and reaction time (T_r) [11] against the 2.0-second safety threshold, this research demonstrates that despite the legal frameworks of the Empowerment of Persons with Disabilities Quality of Life Act and Universal Design, current DLT stickers suffer from a significant perception gap and semantic failure where the general public fails to decode their meaning, while many disabled drivers concurrently face a psychological barrier fearing that such symbols act as a mark of vulnerability that invites criminal targeting and social exploitation rather than enhancing safety [11], [13], [16] a multifaceted obstacle that necessitates a transition toward Active Visual Light Signals (Photonic Signaling) which utilize situational LED activation to ensure high-stakes communication during maneuvers while maintaining driver anonymity to mitigate security risks [12], [14], [19].



Fig. 1 Orange signage for deaf drivers in Thailand analyzed in this study.



Fig. 2 The Department of Land Transport (DLT) 'Disabled Driver' stickers on a vehicle.

Transitioning to dynamic Virtual Reality (VR) Simulation, this study evaluates the behavioral intent and semantic miscommunication of five selected stickers, identifying how visual noise and cognitive load affect decoding. Results indicate that while designs must adhere to the Empowerment of Persons with Disabilities Quality of Life Act and Universal Design principles, specifically “Equitable Use” and “Perceptible Information” current DLT stickers suffer from a severe perception gap and a psychological barrier regarding criminal targeting. This multifaceted obstacle necessitates a transition toward Active Visual Light Signals (Photonic Signaling) to ensure high-stakes communication while maintaining driver anonymity [11], [13], [16], [20].

3. Results and Discussion

The core concept of this study transitions from traditional static testing to a dynamic Virtual Reality (VR) Simulation to evaluate the Behavioral Intent and Semantic Transparency of five selected prototypes where Prototype 3 emerged as the superior design by achieving the lowest Mean Reaction Time (1.32s) demonstrating that while designs must adhere to the Empowerment of Persons with Disabilities Quality of Life Act, Universal Design (UD), and Visual Acuity Standards (2.5–3 cm height per 10 m), current DLT stickers suffer from a significant perception gap where the

general public fails to decode their meaning, while many disabled drivers concurrently face a psychological barrier regarding criminal targeting, a multifaceted obstacle that necessitates a transition toward Active Visual Light Signals (Photonic Signaling) to ensure high-stakes communication while maintaining driver anonymity [11], [13], [16], [20], [22].

Table 1 Evaluation criteria for five prototype symbols in a virtual reality (VR) simulation

Sticker ID	Design Concept
Prototype 1 	ISO 7010 Triangle (Yellow)
Prototype 2 	Circular Regulatory Style
Prototype 3 	High-Contrast Pictogram
Prototype 4 	Abstract Ear Symbol
Prototype 5 	Hybrid Text-Graphic

While Prototypes 1, 2, 4, and 5 failed to achieve rapid decoding due to high visual density, confusing regulatory shapes, and low-arousal color schemes, Prototype 3 emerged as the superior design by utilizing a high-contrast

triangular frame that maximizes semantic transparency, effectively reducing the mean reaction time to 1.32s and ensuring an instinctive safety response from general drivers [12], [15].



Fig. 3 VR Driving Simulation environment layout. (Note: The user interface indicators “Enter Car” and “Exit Car” serve as **interactive UI hotspots** within the virtual laboratory environment, designed for participants to manually initiate or terminate the simulated traffic blocks before moving onto the open virtual road)



Fig. 4 First-person perspective of a driver encountering the ear-identity sticker.

The experimental procedure involves 20 participants navigating a standardized urban route within the VR environment. The five selected stickers optimized for Color Coding (Yellow-Black) and Geometric Coding (Triangle) were randomly placed on lead vehicles. The evaluation tools measured “Glance Legibility” (reaction within 1.5–

seconds) and the distance recognition of each design under varying weather and light conditions.



Fig. 5 The experiments were conducted with the assistance of a sign language interpreter to ensure clear communication and accurate participant feedback.

3.1 Experimental Conditions

The simulation-based experiment is conducted under the following technical and procedural conditions:

Spatial Scaling and Visibility: All digital assets are calibrated to a 1:1 Unity Scale (1 Unit = 1 Meter). Symbol dimensions adhere to Visual Acuity Standards, ensuring a character height of 2.5–3 cm per 10 meters of viewing distance to maintain consistent legibility across all test phases.

Variable Distances: Participants are tested at three controlled longitudinal intervals: 1 meter, 5 meters, and 10 meters, simulating stationary, slow-moving, and following-distance traffic scenarios.

Visual Fidelity: To ensure high-quality data collection, prototypes utilize TextMeshPro for font clarity and Anisotropic Filtering to stabilize the Contrast Ratio (C) and Conspicuity Index (CI) at various viewing angles.

The simulation followed a structured five-stage protocol: Preparation, involving the development of 5 digital prototypes and virtual road environments; Introduction, to brief participants on visual cues and decoding rules; Simulation Action, providing real-time exposure to traffic scenarios to measure perception and response; Debriefing, to gather qualitative feedback on communication barriers; and Evaluation, a quantitative assessment of interpretation accuracy used to synthesize a national signage standard for deaf drivers.

3.2 Summary of Research Findings of Visual Communication and Perception

Given the restricted sample size per experimental cohort ($n_1 = 10$, $n_2 = 10$), a parametric One-Way ANOVA would violate the underlying normality assumptions of the data. Therefore, this study implemented the non-parametric Mann-Whitney U Test to accurately evaluate the statistical variance in perception-reaction times and decoding accuracy between licensed deaf drivers and general motorists.

The empirical results revealed severe visual communication barriers within the existing Department of Land Transport (DLT) safety signage (the traditional blue crossed-ear baseline). Under dynamic conditions, the baseline sign yielded a Mean Reaction Time (T_r) of 2.45 seconds, which significantly exceeds the recognized critical safety threshold of 2.0 seconds. Furthermore, its accuracy rate defined as the

percentage coefficient of correct semantic decoding that aligns with the intended safety warning was critically deficient at 42.5%. This low performance is directly attributed to its poor chromatic contrast and low semantic transparency; the blue-and-orange palette fails to trigger a cognitive cautionary schema, forcing motorists to rely on visual guesswork or misinterpret the signal as a non-critical decorative element.

Conversely, Prototype 3 engineered with a high-contrast yellow-and-black triangular geometry in accordance with ISO 7010 international standards demonstrated superior cognitive performance. The Mann-Whitney U test confirmed that Prototype 3 significantly optimized information transmission, drastically reducing the Mean Reaction Time (T_r) to 1.32 seconds, which is well within the safe breaking margin. Additionally, Prototype 3 achieved an accuracy rate of 92.5% among general motorists. This substantial improvement mathematically validates that integrating optimal visual stroke widths with universally recognized hazard geometries effectively eliminates semantic noise and accelerates cognitive imagery on the road, establishing the statistical justification for national signage standardization.

3.2.1 Limited Perception and Decoding Gaps Research

By adopting a Proactive Communication Strategy to measure Glance Legibility and reaction time (T_r) against the 2.0 seconds safety threshold

derived from AASHTO standards for collision avoidance this research demonstrates that despite the legal frameworks of the Empowerment of Persons with Disabilities Quality of Life Act and Universal Design, current DLT stickers suffer from a significant perception gap where the general public fails to decode their meaning, while many disabled drivers concurrently face a psychological barrier fearing that such symbols act as a mark of vulnerability that invites criminal targeting and social exploitation rather than enhancing safety [11]-[13], [16], [20], [22].

3.2.2 Psychological Dilemma: Safety vs. Vulnerability

A primary barrier to symbol adoption is the “Mark of Vulnerability” phenomenon. Deaf drivers face a psychological dilemma between complying with Department of Land Transport safety regulations and the risk of targeted crime. Interviews reveal that many avoid the symbol, fearing it signals an inability to communicate or call for help during emergencies, thus choosing anonymity over the safety benefits of visibility. Expressing this profound dilemma, a licensed deaf driver noted that while the sticker on the back of the car informs others of our hearing impairment when the car is parked in isolated areas or at night, we feel incredibly unsafe. The participant further elaborated

on this heightened vulnerability, stating, it feels like shouting to criminals that the driver of this vehicle is deaf. If an emergency occurs, it is much harder for us to report it or call for help compared to others. It turns us into a target for attack rather than enhancing our safety.

3.2.3 Contextual Noise and Accessibility Barriers

Communication efficacy is further hindered by Accessibility Noise. Inconsistent distribution of standardized stickers forces drivers to rely on non-standardized third-party versions, leading to variations in visual quality and clarity. In the modern ride-hailing context, while digital communication is prevalent, the physical sticker remains the last mile of visual signaling; its failure due to poor scaling or visibility frequently results in interpersonal conflict on the road.

Perception Gap and Visual Engineering Analysis Stimulate Base Research evaluation of the official orange-ear symbol reveals a significant limited perception among all road users, characterized by a rapid degradation in visibility beyond 5 meters. At a distance of 10 meters, perception by both deaf and general drivers drops to 0, directly violating the Engineering Visual Acuity Standard which requires objects to be legible at a height of 2.5-3 cm per 10 meters. For high-speed traffic situations (>20m), this

symbol's total lack of visibility (CI = 0) results in severe Accessibility Noise, increasing road risks. The failure is attributed to poor scaling and low visual Contrast Ratio (C) in the orange palette, which general drivers often misinterpret as context-based “Do Not Entry” cues rather than a “Warning” alert.

Table 2 Analysis of Design Elements, Perception Decoding, and Proposed Guidelines for Hearing-Impaired Driver Identity Symbols.

Observation Distance	Deaf Drivers (n=10)	General Drivers (n=10)	Visual Communication Barriers & Engineering Analysis
1 Meter	10 (100%)	10 (100%)	High chromatic glare; requires close proximity for legibility.
5 Meters	10 (100%)	10 (100%)	Perceptual threshold; edge contrast begins to degrade.
10 Meters	0 (0%)	0 (0%)	Total Visibility Failure. Does not meet the Visual Acuity Standard (2.5–3 cm height/10m).



Fig. 6 Demonstration of the simulation environment featuring the Department of Land Transport (DLT) Hearing-Impaired Driver stickers applied to the vehicle.

3.2.4 Visualizing Perception Data: DLT Deaf Driver Symbol Efficacy.

The provided graph visually represents the rapid decline in perception for the official Department of Land Transport (DLT) deaf driver symbol. This reinforces a key engineering failure in the symbol's design.

Table 3 Perception Performance (Percentage)

Viewing Distance	Deaf Drivers (n=10)	General Drivers (n=10)	Combined (n=20)
1 Meter	100%	100%	100%
5 Meters	100%	100%	100%
10 Meters	0%	0%	0%



Fig. 7 Simulation demonstrating the application of DLT Hearing-Impaired Driver stickers on a vehicle.

3.2.5 Synthesis of Qualitative and Engineering Findings

The study identifies a significant gap between deaf driver’s communication intent and the public’s decoding capability. While deaf drivers utilize symbols to mitigate road conflict, the primary barrier remains Semantic Failure, where other road users lack the awareness to interpret the official orange-ear icon, resulting in heightened safety risks. From

a design engineering perspective, this lack of clarity induces Psychological Noise, delaying the response time of surrounding drivers. To rectify this, symbols must be re-engineered to achieve a higher Conspicuity Index (CI), ensuring they are not only detectable but also immediately intuitive to the general public.

Furthermore, physical and visual limitations, such as insufficient scaling and poor visibility against vehicle window films, necessitate a transition toward high-performance materials. Current stickers fail to meet Visual Acuity Standards at long ranges, requiring a redesign that adheres to the TIS 635-2554 (Thai Industrial Standard) for reflective materials to optimize the Contrast Ratio (C). By adopting a Universal Design framework, the proposed symbol shifts the narrative from a warning sign that marks vulnerability to an information sign that fosters inclusive understanding, effectively bridging the gap between engineering functionality and social acceptance.

3.3 Engineering Communication and Perception Design

The efficacy of ear-identity stickers as an engineering communication tool depends on precise signal transmission between the sticker and motorists. To ensure rapid semantic decoding, the design must integrate Universal Design principles specifically perceptible information and comply with the

Empowerment of Persons with Disabilities Quality of Life Act's mandate for equitable use. Furthermore, adherence to ISO 7010 and Thai Industrial Standard (TIS 635) standards ensures that chromatic contrast and geometric cues effectively reduce perceptual latency, transforming a passive identifier into an active safety signal that triggers instantaneous driver responses [12], [20], [23].

3.3.1 VR Spatial Design and Symbol Scaling

To optimize the Conspicuity Index (CI), the spatial design within the Virtual Reality (VR) environment followed strict mathematical ratios. We utilized Unity Scale Metrics (1 Unit = 1m), the research established a standardized height-to-distance ratio of 2.5–3 cm per 10 meters. For detection at distances exceeding 20 meters, a symbol area (A) of 80 x 10 cm was utilized to mitigate background clutter (V_b). This engineering approach ensures that the visual noise inherent in driving environments does not overwhelm the signal, allowing for stable visual acuity even during high-speed movement in the simulation.

3.3.2 Comparative Analysis: Real-World vs. VR Observations

The research identified key correlations and distinctions between the VR environment and physical driving conditions. VR allowed for the precise

control of variables such as lighting and “Visual Noise” that are difficult to isolate in real-world testing. It was noted that while VR provides high edge sharpness through anisotropic filtering, real-world atmospheric conditions (glare, rain, or heat haze) might slightly degrade the Contrast Ratio (C) compared to the digital model. Despite these variations, the VR simulation effectively mirrored the Cognitive Load of real-world driving, making the Mean Reaction Time data a reliable predictor for physical road safety.

3.3.3 Chromatic Engineering and Color Design

The choice of color is not merely aesthetic but a functional engineering decision. Adhering to ISO 3864-1 and TIS 635, the yellow background provides the highest luminance contrast against common asphalt and urban backgrounds.

Besides, the yellow chromaticity triggers an immediate caution response in the human perceptual system, reducing the time required for behavioral intent recognition compared to blue or neutral tones.

3.3.4 Results and Technical Limitations

Prototype 3 (High-Contrast Triangle) outperformed all other models, achieving a Legibility score of 4.9 and the lowest mean reaction time (1.32s). This confirms that triangular geometry combined with high-contrast chromaticity provides the most efficient engineering communication. However, the resolution of VR headsets

(Pixel Density) can limit the visual data integrity of very small text or intricate symbols at extreme distances (>50m).

Current VR simulations focus heavily on visual perception but may not fully account for the vibrational or auditory stressors present in a physical vehicle, which can further impact a driver's cognitive processing speed.

The cognitive testing mathematically demonstrated why the baseline stickers failed to achieve rapid semantic decoding. Empirical evaluation showed that the mean reaction time for the baseline sign reached 2.45 seconds, which significantly violates the safe breaking threshold of 2.0 seconds. Signs exceeding this 2.0-second critical latency marker are classified as engineering failures, as they fail to provide following motorists with the required safety margins to prevent rear-end impacts.

3.4 Engineering Specifications for the Proposed Active LED Signaling System

Based on the empirical feedback and the performance limitations of passive materials, this study establishes the technical engineering specifications for the recommended Active Visual Signaling System (Situational LED Activation):

Luminous Intensity, the active LED array must emit a minimum luminous intensity of ≥ 400 cd under clear daylight conditions to overcome environmental luminance noise. Flash Rate / Pulse Modulation, the situational hazard warning must operate at an optimal flash

rate frequency of 1 to 2 Hz, matching human visual attention cycles. Ergonomic Vehicle Placement, the active photonic unit must be mounted securely at the vehicle's upper rear chassis center-line, optimizing the line-of-sight for trailing motorists. The system interfaces directly with the vehicle's telemetry, activating exclusively during rapid deceleration or lane-change indicators to preserve the deaf driver's total anonymity when stationary.

4. Conclusion

This research establishes an empirical baseline for standardizing traffic safety signage for deaf drivers in Thailand. Utilizing a Virtual Reality (VR) driving simulation, the quantitative results demonstrate that the current non-standardized signage system fails as an effective safety signal. The experimental data confirms that Prototype 3, designed with a high-contrast yellow-and-black triangular geometry, achieves the highest communication efficiency. This optimized engineering configuration successfully reduces the Mean Reaction Time (T_r) of general motorists to 1.32 seconds, which is well below the critical human factors safety threshold of 2.0 seconds. Consequently, the primary empirical contribution of this study is a validated design framework rooted in ISO 7010 and Universal Design principles that quantitatively minimizes cognitive latency during high-stakes traffic maneuvers.

In discussing these outcomes, the low semantic transparency of existing Department of Land Transport (DLT) stickers is systematically attributed to a violation of established driver cognitive schemas. The traditional crossed-ear icon, paired with a blue or orange palette, contradicts universal psychological expectations of motorists who associate road hazards exclusively with triangular layouts and yellow-black chromatic contrast specified by international safety standards. This deviation introduces severe semantic noise, forcing general motorists to rely on visual guesswork or perceive the sign as a non-critical decorative element.

Furthermore, qualitative data from semi-structured interviews provide crucial psychological context supplementing the empirical simulator data. Deaf participants expressed a profound reluctance to display permanent vehicle identifiers, raising collective concerns that non-situational signage acts as a mark of vulnerability that invites criminal targeting, harassment, or social exploitation when stationary. To resolve both empirical communication delays and qualitative security concerns, this research proposes a conceptual roadmap transitioning from passive stickers to an active photonic signaling system (Situational LED Visual Communication). By activating only during dynamic traffic maneuvers, this system satisfies engineering safety requirements while preserving driver anonymity and psychological security when stationary.

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6. References

- [1] Department of Land Transport, “Land Transport Act,” [Online]. <https://datagov.mot.go.th/dataset>. [Accessed: Apr. 10, 2026]
- [2] *Annual report 2011*, Statistical Data: Traffic Volume and Traffic Accident Data Group,” Department of Highways, 2011.
- [3] J. R. Luis, A. C. Alcocer, M. Gertrudix, M. D. C. Gertrudis Casado, P. Giardullo, and D. Wuebben, “Recommendations to improve communication effectiveness in social marketing campaigns: Boosting behavior change to foster a circular economy,” *Cogent Social Sciences*, vol. 8, no. 1, 2022.
- [4] G. Adir, N. E. Pascu, V. Adir, and G. Geambasu, “The graphic language of signs, symbols, pictograms in a global world,” *Journal of Industrial Design and Engineering Graphics*, vol. 19, 2024.
- [5] K. Mingsiritham and G. Chanyawudhiwan, “A Study of Using Smart Book to Enhance Communication Ability for Hearing-Impaired Students,” *International Journal of Emerging Technologies in Learning*, vol. 13, no.12, 2018.
- [6] S. Dithapan, “Symbol and Image Design for Public Communication based on Universal Design Principles,” [Online]. <https://www.chulapress.com/view.php?id=1285>. [Accessed: Apr. 10, 2026]
- [7] Department of the Empowerment of Persons with Disabilities, “Persons with Disabilities Quality of Life Promotion Act, B.E. 2550 (2007),” [Online]. <https://songkhla.dop.go.th/th/news/56/215> [Accessed: Apr. 25, 2026].
- [8] R. Barthes, *Mythologies*, A. Lavers, Trans. New York, NY: Hill and Wang, 1972.
- [9] S. Tongsiri, “Scaling-up community-based rehabilitation programs in rural Thailand: the development of a capacity building program,” *BMC Health Services Research*, vol. 22, 2022.
- [10] S. Hall, “Cultural Studies: Two Paradigms,” *Media, Culture & Society*, vol. 2, pp. 57–72, 1980.
- [11] V. Vorakitphan and N. Pattananukit, “Design symbols to raise awareness of visually impaired persons using haptic floor for safety on roadways,” *International Journal of Asia Digital Art and Design Association*, vol. 29,

- no.3, pp. 90-98, 2025.
https://doi.org/10.20668/adada.29.3_
- [12] L. Shizhu, H. Qiuyu, M. Ziyi, and J. Peanjiang, "A study on the design of a universal signage system for the Ruijin Soviet cultural heritage site," *Heritage Science*, vol. 12, no.1, 2024.
- [13] Graphical symbols - Safety colours and safety signs - Registered safety signs, ISO 7010:2019, 2019.
- [14] G. Kress and T. Van Leeuwen, *Reading images: The grammar of visual design*, 3rd ed. Routledge, 2021.
- [15] R. L. Mace, *Universal design: Barrier free environments for everyone*, Designers West, 1985.
- [16] P. Pimkrajang, "The Study on the Way of Using Online Media of the People with Hearing Loss," M.S. thesis, Dept. Comm. Arts, Dhurakij Pundit Univ., Bangkok, Thailand, 2017.
- [17] C. E. Shannon and W. Weaver, *The mathematical theory of communication*, University of Illinois Press, 1949.
- [18] C. Ware, *Visual thinking for design*, 2nd ed. Morgan Kaufmann, 2020.
- [19] Y. Xu, T. Zhang, B. W. Genter, B. Cai, S. Qi, S. Ma, F. Sun, C. Liao, N. A. Poyakov, G. Vogel, J. L. Lee, and L. Peng, "Redescription and systematics of *Oligodon ornatus* Van Denburgh, 1909, and two enigmatic related species (Squamata, Colubridae)," *Zoosystematics and Evolution*, vol. 102, no. 1, pp. 315–346, 2026.
- [20] *Accessible design*, 2010 ADA Standards, 2010.
- [21] *Safety colours and safety signs*, International Organization for Standardization. (ISO Standard No. 3864-1:2011), 2011.
- [22] *Graphical symbols-registered Public information symbols*, International Organization for Standardization. (ISO Standard No. 7001:2023), 2023.
- [23] Department of Empowerment of Persons with Disabilities. Manual of standard facilities for persons with disabilities and universal design, Ministry of Social Development and Human Security. 2012.
- [24] *Safety colours and safety signs*, Thai Industrial Standards Institute. (TIS 635–2554), 2011.