

A Study on a Quantitative Evaluation Method for Daytime Visibility of Automotive Interior Illumination Using CIELAB

Kim Seong uk ¹⁾

1) Hyundai Motor Company, 15, Hyundaiyeonguso-ro, Namyang-eup, Hwaseong-si, Gyeonggi-do, Republic of Korea (E-mail: kaka@hyundai.com)

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This study addresses the limitations of subjective and qualitative visibility assessment methods for automotive interior lighting by developing a quantitative evaluation framework based on human visual perception. The research utilizes the CIELAB color space and $\Delta E00$ color difference metrics in conjunction with an LMK6 luminance meter to systematically evaluate lighting components under various environmental conditions. Three representative samples from Vehicle A, including two with documented low visibility problems and one with excellent visibility performance, were measured across four simulated environmental scenarios: daytime (high illuminance), evening-on (intermediate illuminance with lighting active), evening-off (intermediate illuminance with lighting inactive), and nighttime (low illuminance with full lighting dependency).

The primary challenge addressed in this research stems from the increasing trend toward bright background colors in switch lighting design, which creates inadequate contrast between illuminated symbols and their surroundings, particularly during twilight and intermediate lighting conditions. Previous subjective evaluations proved inconsistent and failed to predict visibility issues even after mass production, necessitating objective quantitative standards.

Experimental findings revealed a critical discrepancy between $\Delta E00$ values and actual visual visibility. Despite $\Delta E00$ values as high as 17.15 and 6.3 for samples #1 and #2 under evening lighting conditions—values indicating clear color differentiation according to standard colorimetric interpretation—the corresponding visual evaluations were rated as "severely insufficient." This contradiction demonstrates that while $\Delta E00$ effectively measures static color differences in controlled laboratory settings, it inadequately captures the dynamic, high-luminance environment characteristic of automotive interiors.

In contrast, luminance difference (ΔL^*) and Michelson contrast ratio (LCR) demonstrated strong correlations with subjective visibility ratings. Components exhibiting excellent visibility consistently achieved ΔL^* values exceeding 30 and LCR values between 0.37 and 0.99, with nighttime conditions showing LCR of 0.99 representing overwhelming contrast. Conversely, components with severely compromised visibility exhibited ΔL^* values between 0.44 and 1.66, with LCR values ranging from 0.00 to 0.02, creating the "washout" phenomenon wherein illuminated symbols become indistinguishable from bright surroundings due to insufficient luminance contrast.

Based on these findings, quantitative acceptance criteria are proposed: $\Delta L \geq 4.5$ and $LCR \geq 0.06$ constitute acceptable visibility performance*. These threshold values are derived from the critical transition point between perceptible and imperceptible symbol visibility across all measured environmental conditions. Additionally, this research notes that L^* values occasionally exceeded the theoretical CIELAB range of 0–100 in high-illuminance daytime conditions, reaching 212.2, reflecting the reflection of bright external light rather than equipment error. Such phenomena underscore the importance of relative contrast metrics over absolute luminance values in high-luminance environments.

This quantitative approach effectively addresses the complex, multifactorial nature of visibility performance, which depends on symbol size, geometry, lens transmittance, lighting luminance, background reflectance, and viewing geometry. The proposed ΔL^* and LCR criteria enable standardized quality control and early-stage design validation, providing automotive manufacturers with reliable tools for predicting and preventing visibility failures across diverse lighting component designs and environmental extremes.

Category	Condition		Symbol(Region 1) $L^*a^*b^*$			Background(Region 2) $L^*a^*b^*$			ΔL^*	$\Delta E00$	LCR (L^* based)	Visual Visibility Qualitative Evaluation (5 scale)
	Ambient Illuminance	Illumination	L^*	a^*	b^*	L^*	a^*	b^*				
Sample 1	Daytime	ON	96.93	4.499	-11.26	212.2	-23.75	-15.74	115.3	39.46	0.37	5
	Night time	ON	57.8	-3.8	-8.878	0.1592	-0.1112	0.07505	57.64	60.3	0.99	5
	Early Evening	ON	59.83	16.52	-10.79	59.39	10.03	23.17	0.44	17.15	0	1
	Early Evening	OFF	23.8	10.59	7.562	59.48	10.03	23.3	35.68	37.07	0.41	4
Sample2	Early Evening	ON	42.82	-2.195	-3.788	41.16	-7.838	1.205	1.66	6.3	0.02	1
	Early Evening	OFF	45.41	-0.4372	-3.222	41.05	-7.582	1.059	4.36	8.39	0.05	2
Sample3	Early Evening	ON	42.2	2.353	12.73	11.92	1.841	5.395	30.28	31.33	0.56	5