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LIGHTING STRATEGIES FOR NIGHTTIME CONSTRUCTION AND MAINTENANCE ACTIVITIES ON ROADWAYS

Over the last two decades, an increased number of highway construction and maintenance projects in the United States have been completed at night to avoid or mitigate traffic congestion delays. Working at night has several benefits, including lower traffic volumes, less impact on local businesses, greater flexibility for lane closures, longer possible work hours, reduced pollution, cooler temperatures for equipment and material, and fewer overall crashes due to lower traffic volumes at night. Although nighttime roadway operations may minimize traffic disruptions, nighttime work frequently presents a significant challenge of reduced safety for both workers and motorists due to insufficient lighting and increased glare levels during the nighttime hours. Adverse glare levels caused by improper lighting arrangements or excessive lighting levels provided by temporary lighting systems installed on the job site could result in motor vehicle collisions in the area. For example, 842 work zone fatalities were reported in the United States in 2019, with 48% of these involving fatalities on night shifts and 70% involving drivers/occupants under the age of 50.

This thesis focuses on determining and evaluating disability glare in nighttime work zones as a step towards developing appropriate lighting strategies for improving the safety of workers and motorists during nighttime highway construction and maintenance projects. Disability glare impairs our vision of objects without necessarily causing discomfort and can be quantified using the veiling luminance ratio ($V_{L\ ratio}$), an Illuminating Engineering Society (IES) recommended criterion for limiting glare. Disability glare was determined in this study using lighting measurements of vertical illuminance and pavement luminance from 49 field experiments involving LED balloon lights, metal halide (MH), and LED light towers. The calculated disability glare values for each lighting combination were analyzed later to determine the primary effects of luminaire mounting height, power output, rotation angle, aiming angle, and driver's age on the $V_{L\ ratio}$ values.

Six major findings emerged from the analysis of disability glare levels generated by balloon lights and light towers: (i) an increase in mounting heights over 18 ft for light towers resulted in significant glare reduction levels, similarly, for balloon lights a significant glare reduction was found in heights over 10 ft; (ii) compared to the "perpendicular" and "away" orientations, orienting the light towers (MH and LED) in a "towards" direction (45-degree) significantly increases the disability glare levels of the lighting arrangement; (iii) increasing the tilt angles of light towers' luminaires resulted in a significant increase in veiling luminance ratio values; (iv) for balloon lights, at observers ages are over 50, $V_{L\ ratio}$ values exceeded the IES recommended value (0.3); (v) for LED light towers oriented towards the traffic, at driver's age over

40, $V_{L\ ratio}$ values exceeded the IES recommended value; and (vi) for metal-halide light towers oriented towards the traffic, at driver's age over 50, $V_{L\ ratio}$ values exceed the IES recommended value. The findings of this research study might help State Transportation Agencies (STAs) and roadway contractors improve their nighttime glare control strategies at work zones.