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CENTER FOR MULTIDISCIPLINARY RESEARCH IN TRANSPORTATION

Project Summary Report 1704-S  
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## Evaluation of Roadway Lighting Systems Designed by Small Target Visibility Methods

In 1990, the Illuminating Engineer Society of North America (IESNA) promulgated a proposed new design standard for roadway lighting based on visibility. They called it Small Target Visibility (STV), and it was purported to be a superior to the existing illuminance- and luminance-based methods currently in use. The Texas Department of Transportation (TxDOT) was using an empirical method based on illuminance and the collective experience of Department personnel around the state. Because roadway lighting is strongly associated with nighttime driving safety, it was felt that a serious look at this new methodology needed to be conducted to determine if the increased design effort attendant to implementing STV was offset by a measurable potential benefit accrued by nighttime accident reduction. In a nutshell, the researchers were asked to determine whether TxDOT should support the implementation of this new method at a substantially increased design cost or not.

To fully understand the theoretical thrust of the research, a brief explanation of the development of lighting design as it evolved to STV is in order. The first attempt at roadway lighting design focused on the output of the lighting fixtures, here-

after referred to as luminaires, and used illuminance as the salient design parameter. Later, it was recognized that drivers actually see the light that was reflected off objects in the road and off the pavement's surface, i.e. luminance. Therefore, luminance became the standard for lighting design. Finally, lighting engineers took the problem to its next level of logical complexity by drawing the connection between luminance and the driver's eye and began searching for a method to design roadway lighting based on some component of visibility. STV is effectively the first attempt to relate the physics of roadway lighting performance to the biology of the human eye. From a physics perspective, visibility is a function of contrast. Contrast is merely the relationship between the amount of light reflected off a target and the amount of light reflected off its background (i.e. the pavement). In a static mode, this is easily calculable, but as roads support extremely dynamic conditions, the static calculation of contrast does little to relate the design to its corresponding operating condition. This is further complicated when the attempt to integrate human vision into the calculation is added. Visibility is infinitely random and in-

finitely variable. Thus, the best an engineer can do is hope to make a reasonable approximation to account for the immense range of human vision that will enter the lighted area in question. The validity of the design calculations are further questioned when the fact that many of the physical parameters used in the method are variable over time as well. The pavement's reflective characteristics will change with age. The luminaires will accumulate dirt and burn out thus changing their output characteristics. The amount of off-road lighting that contributes to visibility on the road changes as development along the lighted area changes. Finally, normal weather variations such as rain and ice totally invalidate the design calculations by changing the pavement's reflective characteristics from diffuse to specular. Thus, lighting engineers have set themselves a difficult goal to be able to accurately mathematically model a lighted stretch of highway. To do so, involves developing a complex computer simulation for each and every lighting installation, and this increases the level of design effort by at least an order of magnitude over current luminance or illuminance design. A large public agency, like TxDOT, must re-



alize a distinct benefit of accident reduction due to better quality design to justify implementing such a labor intensive new methodology. Thus, this is the crux of this research project.

## What We Did . . .

- Over 120 articles and books on the subjects of visibility, lighting, roadway lighting design, human factors, and other related topics in three different languages were reviewed to establish the state-of-the-art and look for successful examples of lighting design changes resulting in nighttime accident reduction.
- A tort and liability review of current state and federal case law was completed to define Texas' potential liability if it decided to not implement a new national design standard for roadway lighting.
- A series of experiments were conducted at a test site on Interstate Highway 27 north of Abernathy, Texas to quantify the various parameters involved in visibility calculation and measurement. Computer programs were developed to compare measured visibilities with corresponding calculated visibilities.
- A calculation of propagated error due to design assumptions was completed to understand the effect of those assumptions on final calculated design parameters. This was merged with the field data to give the researchers a means to relate the efficacy of the design to model actual roadway conditions.
- A detailed study of pavement reflectance building on recent work in Canada was completed to relate the primary design parameter of background luminance to visibility. This was combined with photometric measurements made on several different pavements at the General

Tire test site near Uvalde, Texas.

- Information Theory (IT) was applied to the roadway lighting design problem for the first time as a method to quantify safety improvements due to enhanced lighting design techniques.
- Coordination was made with the IESNA and the International Commission on Illumination (CIE) and an in-progress review of the experiments and the theory was conducted by Dr. Werner Adrian of Waterloo University in Ontario, Canada. This furnished an expert, peer review to ensure that the aspects being developed by this project were consistent with current practice. Dr. Adrian is regarded as the father of visibility research having completed most of the seminal work in the area in Germany in the 1970's.
- Assistance with the higher order mathematics was obtained from another international source, the University of

Stuttgart developed a new level of mathematical analysis called Similarity Theory (ST). ST is related to IT and provided the Texas researchers with the theoretical tools needed to quantify several important light-related parameters.

## What We Found . . .

The extensive literature review revealed just how dynamic the roadway lighting environment really is and just how many "simplifyfing" assumptions have been made to facilitate the calculation of lighting design parameters. The net effect of those assumptions is to reduce a complex dynamic environment to a sterile, static model that does not accurately reflect reality. The apparent result is a false sense of confidence regarding the "quality" of the resultant design. This project identified at least twenty assumptions that potentially introduce unrecognized error into the final design solution. A standard STV target was placed in the road, and the lights were turned out. A



Nighttime View of Target



digital image was taken and the quantity of information contained in the image (i.e. the roadway scene) was calculated using ST. This method creates a three dimensional curve based on calculating spatial frequencies in three directions. The volume under the curve represents the volume of information contained in the image. Taking a second image of the same scene after one half of the installed lighting was turned on yields a second curve, and this can be subtracted from the first curve to quantify the change in information by altering the scene. It was found that the mere addition of light increased the quantity of information by 80%. A third image was taken after the remaining lights were turned on, and it was found that the quantity of information only increased by 2%. Finally, the headlights of an automobile were added to the scene to further increase the illumination on the target, and no increase in information content was found. This verifies the previously unexplained results of the Fisher study, and establishes IT as a viable theoretical foundation for visibility measurement.

During a visit by Dr. Adrian to the Abernathy test site, it was noticed that the reflectance qualities of a small section of pavement varied laterally across the width of the pavement. This is due to the effect that traffic has on the pavement's surface in the wheel paths. STV classifies pavement reflectance into only four categories and about 80% of pavements fall into a single category. Since background luminance is driven by pavement reflectance, this finding is significant. The researchers expanded on data taken by Adrian on over 100 pavement samples taken in Canada using Adrian's photogoneometer. Data was also taken in Texas. The final analysis showed that the impact of traffic in the wheel paths is significant in asphaltic pavements and that both brightness and specularity increase over time. This invalidates an STV assumption that the pavement surface is both uniform in tex-



Daytime View of Target

ture and diffuse in reflectivity. In fact, much further study is warranted to fully understand the actual impact of this effect. Again, the bottomline is simple. The pavement's reflectance is dynamic and must be considered as such in any design method that hopes to improve roadway lighting performance.

### **The Researcher Recommends . . .**

While the move to a visibility-based lighting design method is extremely desirable, Small Target Visibility requires too many simplifying assumptions that introduce unrecognized error into the result. This makes it an approximation at best, and totally inaccurate at worst. If and when it becomes a national standard, the State of Texas should not implement it until the number of assumptions are reduced to a level where the calculations accurately model reality.

Correction factors can be calculated for many of the visibility level (VL) input factors to account for dynamic changes over the installation's life cycle. This would permit a probabilistic design method to be developed based on changes

over time of each of the identified design elements. Development of such a method is beyond the scope of this study, but should be considered for future work in the area.

The contribution of pavement reflectance to visibility-based design is not adequately recognized. This is surprising because background luminance is one of two fundamental design parameters. Before a reliable visibility-based design methodology can be developed, the change in pavement reflectance with respect to traffic, and its impact on contrast must be known. Additionally, the impact of driver observation angle change must also be fully understood before pavement reflectance can be accurately estimated.

Information Theory and the calculation tools provided by Similarity Theory furnish a powerful and attractive tool for roadway lighting design. This method is particularly applicable to the area of safety lighting design where the placement of a relatively few luminaires can be critical to nighttime driving safety. The combination of digital imaging and IT-based processing algorithms can be successfully used to quantify a predictable function of visibility.



### *For More Details...*

The research is documented in the following report:

Report 1704-4R, Analysis of Risk Management and Tort Liability for Roadway Lighting Design  
Report 1704-6, Visibility Calculations from Video Images Using Different Techniques  
Report 1704-8, Evaluation of Roadway Lighting Systems Designed by Small Target Visibility (STV) Methods

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To obtain copies of the reports, contact the Center for Transportation Research Library at (512) 332-3126.

### **TXDOT IMPLEMENTATION STATUS FEBRUARY 2001...**

The project director has indicated the following implementation status:

The products of the report are:

Information about the Small Target Visibility (STV) method in comparison to current roadway lighting design from which TxDOT can create a set of policy statements that detail the specifics of roadway design methodology.

The research found that the "old" TxDOT method is superior to the "new" national method. As a result, AASHTO is re-examining its standards, and the ANSI standard may revert because of this research. No further implementation is needed because it confirms current TxDOT policy.

The research indicated that lighting design procedures are proper, but we need to improve the testing of lighting. This will be incorporated in new revised testing procedures.

### ***Your Involvement Is Welcome . . .***

#### **Disclaimer**

This research was performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. The content of this report reflects the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Trade names were used solely for information and not for product endorsement.

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