The Impact of New Street Lighting Technologies on Traffic Safety

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***Abstract*—Street lighting systems are very important in terms of traffic safety and energy saving. For the purpose of energy saving, new technologies of street lighting have been developed last decade and implemented in several cities worldwide. The most common of new technologies, with most potential of energy saving, are Light Emission Diodes (LED) and Adaptive Lighting Systems (ALS). The impact of these new technologies on road accidents is not well examined yet. This study attempts to evaluate the traffic safety impact and traffic risk of these technologies on road users, mainly drivers and pedestrians. Since the new lighting technologies have been recently tested and applied, the safety impact of them on road users could not be evaluated through direct measures of traffic safety e.g. before/after accident rates. Therefore, this study aims to create a new conceptual framework by introducing some indirect safety measures (e.g. speeding profile, behavior adaptation, traffic conflict, jerky driving and visibility of pedestrians) and presenting relevant performance indicators for future experimental design.**

***Index Terms*—street lighting, night traffic, traffic safety, LED, adaptive lighting systems**

I. Introduction

Road accidents are a major problem worldwide, especially in low and middle income countries. The accident rates and severity index, in terms of fatal and serious injuries, are almost 2-3 times higher at night traffic than in daylight despite that only about 20% of traffic flow takes place at night. Keck [1] found that 80% of the vehicle miles driven in 1988 in US were in the hours of daylight but more than half of the fatalities occurred during the night hours.

Street lighting has been proved as an effective counter-measure to prevent road traffic accidents and severities in both rural and urban roads. A meta-analysis study [2] conducted based on 48 studies in 13 countries to evaluate the effects of providing lighting on previously unlit roads. The overall results on all types of accidents, road users and road types show a reduction of fatal accidents and injury by 60% and damage only accidents by 15% due to roadway lighting.

The total electricity consumption of a street lighting in a city is very high, and it accounts between 10-40% of the total electricity bill. Therefore, many countries worldwide are increasingly interested in applying new technologies of street lightings for the purpose of reducing energy consumption costs.

A wide range of new lighting technologies are developed, tested and implemented in road networks. There are mainly two approaches to save energy from street lighting either to use energy efficient lamps as Light Emission Diodes (LED) or to dim lamps on streets at low or no traffic as Adaptive/Smart Lighting Systems (ALS).

To date the main focus has been given on the reduction of energy consumption of road lighting systems while the traffic safety impacts are not well examined.

The aim of this study is to make a survey among literature and performance indicators those can be used for making an evaluation study of the new road lighting solutions in terms of their impact on traffic safety.

II. The Effect of Street Lighting on Traffic Accidents

The main reason of accidents rate at night (darkness) is due mainly to the lack of visibility, which as a result led to difficulties with detecting obstacles and estimating distances. Visual performance in night-time driving is very complex as relates to several visual elements (uniformity, contrast, color, etc.) and several factors related to (human vision, visual targets, weather, vertical illumination (road lighting), horizontal illumination (vehicle headlights), signals, etc.) [3].

Some other reasons for accidents at night/darkness are due to more presence of animals, wet road surfaces, snow, fog, fatigue, drunken drivers/pedestrians, young drivers, high speed, etc.

A closer look in literature studies (e.g. [4], [3] and [5] indicates that there is a greater risk at traffic night, which means greater effect of street lighting, for specific target groups of road users and conditions:

- Pedestrians than for vehicle occupants.
- Rear-end and single collisions than for frontal or side collisions.
- Rural roads than urban roads.
- Rainy than dry weather.
- Elderly pedestrians, young and inexperienced drivers than in daylight weekend.

The Swiss annual statistical report [6] shows that the number of pedestrian fatalities at night is 60 to 70% higher and has a 212% increase of the kilometer risk factor.

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The U.S. pedestrian accident report investigated data from 1997 to 2006 and found that within the time period from 6 p.m. to 6 a.m. 66% of the pedestrian fatalities occurred [7].

A British study [8] used an indicator for the relationship between one fatal collision and 100 collisions based on the British road accident data from 1996 to 2004. It could be shown that the severity of night-time accidents is 2 to 3 times higher than during daytime. A comparison with statistics from Greece, where injury rates are dramatically different, shows nearly the same relationship between night-time and daytime accidents.

The CIE conducted 1992 a meta-analyses of 62 lighting and accident studies from 15 countries. 85% of the results allocate street light as a beneficial countermeasure. Depending on the class of road and the used accident classification the results show reductions of between 13% and 75%, with an overall reduction of 30% [9].

A study of [4] analyzed injury accidents and property damage accidents in Dutch road traffic during the period 1987–2006. An odds ratio of accident rates was used to estimate the effect on roadway lighting on different road types. In total the effect on all roads was -49% on fatal and -46% on injury accidents. The study estimated the road lighting reduction on motorways to be a 49 percent during darkness.

A study at rural intersection [10] showed that street lighting has also similar impact on safety at intersections. In total, the effect of street lighting was 25-50 percent reduction of night accidents at intersections.

However, despite the fact that roadway lighting has a positive effect on accident rates and number of fatal and severe accidents, it was noticed that drivers adopt their driving behavior after the installation of roadway lighting. Studies (e.g. [11]) showed that due to the improved visibility on the roads it the speed increases and concentration level decreases. This can be explained with Risk Compensation Theory. On one hand reducing luminance levels leads to a reduction in perceived speed, while on the other hand when the perceived speed decrease the driving speed increases.

III. New Street Lighting Technoligies – Advantages and Concerns

Street lighting technologies are evolving rapidly. Our focus in this paper is on two main new technologies in terms of LED lamps and ALS.

LED is a modern technology with a high energy-saving potential. The energy consumed by the LED is less than half of the traditional lamp's energy. According to RCI [12], LEDs have also several other advantages over traditional lighting technologies in terms of longer life period, small size, no emissions, directional light toward target, lower maintenance cost, control options of lighting levels, no dangerous metals, etc. Despite of its advantages, LED technology in street lighting, as an early technology, has in other hand some challenges and problems in terms of high initial costs, inconsistent color, glare, inconvenient for animals due to blue light color. However, due to the many advantages, cities worldwide are increasingly replacing traditional lamps (e.g. mercury vapor lamps, high pressure sodium lamps, metal halide lamps) with LEDs.

ALS is increasingly used in many developed countries. It aims to change lighting levels to suit automatically the existing traffic situation, weather, traffic density and speed. It uses two-ways wireless communication, control and monitoring of the level of lighting system. Luminaire locations can be controlled remotely according to their GPS locations. Studies (e.g. E-street project [13]) showed that it is possible to reduce the energy consumption and maintenance costs for road and street lighting up to approximately 60% via ALS.

In April 2007 the city of Gothenburg in Sweden started to install ALS for road lighting in the district of Tuve and Högsbo. Five years later 20 sites with in total approximately 1800 lamps were implemented. The estimation today is that the average energy consumption per luminaire is reduced to 45-50%.

Additionally, in Sweden, LEDs have been introduced as guide lights in the median of motorways as an alternative to conventional road lighting. Further, many cities in Sweden, have replaced to a large scale the older lamps with LEDs.

IV. Methodology Design – Surrogate Measures

Due to fact that LEDs and ASL are recently installed or tested on some road sections in Sweden and accordingly the number of accidents is yet too small for a before-and-after study, the safety impact of these systems on drivers and Vulnerable Road Users (VRUs) could not be evaluated through direct measures of traffic safety. Further surrogate measures can be applied in evaluating traffic safety measures on the basis of observing none or near-accident events [14].

This study suggests basically four surrogate approaches to evaluate the LED and ALS safety impact.

A. Average Speed and Safety

Average speed or speeding profile can be considered a surrogate measure for safety. Solomon [15] provided some curves displaying the relationship between running speed of vehicles during night-time and day-time with accident probability in terms of accident involvement rate. The curve suggests that "the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in a accident".

The average speed of traffic can either be measured as a Time Mean Speed (TMS) where the speed is measured at a specific cross section within a certain time period or a Space Mean Speed (SMS) where the average speed is measured of all vehicles on a specific road section.

B. Traffic Conflict Technique (TCT)

One of the biggest problems to analyze driving behavior at accidents is that accidents are rare events and are therefore also associated with random variation. Traffic conflict studies can provide surrogate measures of traffic safety when accident rates are not available. A conflict is defined as: "an observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movements remain unchanged" [16].

There is, however, still some debate regarding the connection between conflict measures and accident predictions [17]. The most common indicators in traffic conflict are Time-to-Collision (TTC) and Post-Encroachment Time (PET). Some researchers have indicated that TTC or PET is the surrogate measure of safety. Some research indicates Deceleration Rate (DR) as the primary indicator of severity instead of TTC or PET [18].

C. Naturalistic and Jerky Driving

One of the newest and widespread research methods to observe road users' every day driving behavior is naturalistic driving. Such observations take place during ordinary everyday driving situation, preferably in the own vehicle of the driver, which gets updated with various instruments. Different sensors collect precise vehicle kinematic data (speed, acceleration/deceleration, direction, and position), driver behavior and performance (eye, head and hand maneuvers) or external conditions like characteristics of the road, traffic or weather situation. Since accident situations are rare and random events it is hard to get real data how the driver behaved shortly before the accident.

During the last years a lot of field operational tests (FOT) have been conducted in the United States, Asia and Europe. For example US programs as 100-Car study, 250-Truck study or Strategic Highway Research Program (SHRP2). European projects are TeleFOT, 2BeSafe NDS, INTERACTION, SAFER and the biggest one euroFOT.

According to [19], it is possible to collect data (Acceleration/Deceleration Profile) in order to study jerky driving, and they actually showed how the amount of critical jerks is directly related to the risk of being involved in an accident. Hence, analyzing jerks can be an efficient way for detecting safety critical driving behavior, also called "accident proneness". Jerky driving has also been associated with the tendency to commit driving violations. A study [20] analyzed the relationship between behavioral characteristics and involvement in traffic accidents. The unit used for measuring jerks is the rate of change of acceleration or "jerk rate" (m/s3).

D. Visibility of Pedestrians by Drivers

In Sweden, the duty for motor vehicle drivers to give way at unsignalized pedestrian crossings was initiated in May 2000. The main aim was not to increase traffic safety but to increase accessibility for pedestrians. At a pedestrian crossing, it is very important that a pedestrian who wants to cross the road is seen by a motor vehicle driver approaching the pedestrian crossing. Hence, a relevant question will be discussed in future field study: When and where does a driver look for information when approaching a pedestrian crossing?

In the middle of September 2013, a new camera system will be installed in a car at VTI (the Swedish National Road and Transport Research Institute). The camera system enables eye tracking through video recordings of the road ahead and of the driver's eye movements. This will make it possible to determine where the driver has looked, and driver behavior for instance when approaching a pedestrian crossing with different light levels and systems.

The unsignalized pedestrian crossings will be chosen in order to be visible without other interfering objects. The variables included in the study will be: Dependent variables: detection distance; and independent variables: type of road lighting (LED vs high pressure sodium) and luminance at the pedestrian crossing.

V. Discussion

Based on the selected technique for evaluation of safety (surrogate safety measures), relevant data should be collected. Choice of time period (dry weather) and its length for data collection is a matter, which needs to be taken into consideration carefully. Depending on the selected surrogate safety measure, the experiment setup requires equipment, safety indicators and criteria, which are summarized in Table I.

TABLE I. Experiment Design for Indirect Safety Evaluation of New Street lighting Technologies

Indirect Safety Measure	Indicators/ Experiment Design and Equipment
Safety and Speed	***Indicators:*** Individual/ Average Speed of the traffic flow ***Experiment Design*** Calculating individual speed of the motorist vehicles passing the designated section of the road for evaluating the deviation from mean operating speed. The variation in speed of any vehicle from the average speed of all traffic in both before/after field study will be used as a measure of safety evaluation. Calculating TMS and SMS. Consideration: The length of the road sectors as well as the number of sites should be discussed carefully. ***Equipment:*** • CCTV-Camera • Vehicle Re-Identification Systems (VRIS) • Floating Car Data (FCD) • Applications via Smart Phones e.g. accelerometer, etc.
Traffic Conflict Technique	***Indicators:*** TTC or PET ***Experiment Design*** Calculating TTC or PET for a specific type of conflict (for example, rear-end conflict) and comparing the result for the before/after study. The higher values of TTC or PET indicate the higher level of safety. Consideration: the number and types of selected intersection are important and could help to generalize the result. The type of the camera system, the installation height, location, angle, period of recording etc. needs to be discussed further. Implementation of automated video analyser will facilitate the process of data analysis. ***Equipment:*** • CCTV-Camera • Automated Video Analyzer
Jerky driving	***Indicators:*** Jerk Profile/Jerk Rate ***Experiment Design*** Installing a number of GPS loggers in designated vehicles, and obtaining speed, acceleration and

Indirect Safety Measure	Indicators/ Experiment Design and Equipment
	corresponding jerk profile of the vehicles. The higher Jerk rate (m/s3) indicates the lower level of safety. Consideration: The location and length of the road sectors as well as the number of sites should be discussed carefully. The number of selected vehicles for installation of on-board units (OBU), the type of GPS loggers, the characteristics of the drivers (i.e. age, gender etc), the period of data collection should be based on the experiment design. ***Equipment:*** • Floating Car Data (FCD) using GPS traces • Vehicle Re-Identification Systems (VRIS)
Eye tracking of drivers	***Indicators:*** Dependent variables: Gaze behavior, detection distance; and Independent variables: Type of road lighting (LED?, high pressure sodium?) and luminance at the pedestrian crossing ***Experiment Design*** The unsignalized pedestrian crossings should be chosen in order to be visible without other interfering objects. ***Equipment:*** Eye tracking through video recordings of the road ahead and of the driver's eye movements.

VI. CONCLUSIONS

While new street lighting technologies offers a wide range of unique potential benefits (mainly in terms of energy saving), it is necessary to evaluate the safety impact of this technology on road users. One potential approach for evaluating the safety impacts of them versus conventional road lighting systems is to conduct a before/after study. In order to have a direct comparison between the two technologies, it is necessary to conduct the before/after study in a same section of road or motorways or intersection. Conducting the before/after study in a same section of the designated road, will help to have a control on the local factors (i.e. geometric design, traffic volume) which may also contribute to the level of safety. However, since the new generation of street/road lighting is an early technology, the number of accidents is yet too small for a before-and-after study. Therefore, it is necessary to implement surrogate safety measures. Three main approaches in terms of average speed, traffic conflict and Jerkiness are suggested for evaluating the safety impacts of the new street lighting technologies. The naturalistic driving data has potential in comparing driving behavior in segments of the road with and without LEDs and ALS, but one of the main concerns of this approach is the access of data according to GPS locations. It is also necessary to conduct a controlled field study in a large scale in order to minimize the impact of other external influential factors.

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