DEVELOPING CONTROL STRATEGIES IN SCOPE OF ENERGY EFFICIENCY AND FORMING DIM SCENARIOS DEPENDING ON VISUAL PERFORMANCE CONDITIONS, IN ROAD LIGHTING AUTOMATION SYSTEMS

SUMMARY

Road lighting automation systems, by which the luminous flux of the luminaires can be adjusted according to the conditions, seems to be a significant way to save energy. However, there is not enough research yet on how the reduction of luminous flux will affect the visual performance, safety and comfort conditions of drivers. So there are contradictory approaches when determining control strategies and dimming scenarios. Therefore, tests on real road conditions, surveys with real road users and more research about driving safety must be carried out, as much as possible, before determining the automation strategies and applications.

Istanbul Technical University (ITU) and Istanbul Transportation Communication and Security Technologies Inc. (ISBAK), developing a common project, with the support of Ministry of Science Industry and Technology, established a test road in Istanbul, ITU Ayazaga Campus where different road conditions and scenarios can be practiced in order to assess and measure the visual performance of drivers. The test road is 250 m long with two lanes. Each lane is 3,5 m wide and the total width of the road is 7 m. The lighting arrangement is single sided from the left. Eight lighting poles are installed with 30 m spacing. The height of the poles can be adjusted between 8 to 12 m and the overhang can be adjusted between 0,5 and 1,5 m. Two luminaires with high pressure sodium lamps and two LED luminaires are placed on each pole. The luminous flux of the luminaires can be dimmed to the desired level. Thus, different quality criteria can be ensured for different lighting classes on the test road. In this study 4000 K LED luminaires are used. The luminous flux of the luminaires can be controlled by 1-10V control system and different luminous flux values can be adjusted to deliver M2, M3, M4, M5 road lighting classes according to the EN 13201-2 standard. According to the measurements and experimental results which will be held on the test road, it is aimed to develop a "road lighting automation system" working with correct dimming scenarios.

Technically, it is possible to adjust the luminous flux of luminaires with LED light sources at desired levels. However, when traffic safety is considered in real road conditions, the lack of information about the time and amount of dimming is the biggest obstacle in the application of road lighting automation systems in existing or newly installed road lighting. This thesis describes the studies which are carried out in order to determine the effect of dimming on the visibility performance of the drivers, in terms of driving safety.

In order to be able to determine dimming scenarios correctly, driver's visual performance should be evaluated based on the time-varying parameters, such as traffic intensity and vehicle speed on the road. The visual performance of the drivers are

studied in terms of visibility level (VL) calculations of the critical objects on the test road. In laboratory studies and on the visibility tests for road lighting, a 20 cm x 20 cm flat square object is mostly used. These objects, which are called the critical objects, have been used to form the basis of standards and recommendations for road lighting. Therefore, a 20 cm x 20 cm flat square object with a Lambertian surface is used in this study. In the CIE recommendations the reflectance of the critical object is accepted as 0,20 and in the ANSI/IES standard as 0,50. For the critical object with a reflectance of 0,20, the minimum calculated VL is 2,22. Theoretically, it is stated that for VL values higher than 1,0, the object starts to appear as a silhouette on the road surface background. In order to study the visual performance of drivers in a wider range of VL values, objects with higher reflectances are required. Taking precalculations on the test road into consideration the reflectances of the critical objects were selected as 0,20, 0,30, 0,40 and 0,50. Thus, VL values between 0 and 11 were obtained.

The measurements of the visibility levels (VL) and tests on the road are carried out for the fixed observer, located 60 meters behind the calculation area, which is used in the calculation of the road surface luminance in current standards and recommendations. In order to be able to define the required lighting quality values in different dimming scenarios, VLs of critical objects with different reflectances for all measurement points on the test road are calculated for different lighting classes.

From the measured VL's minimum VL values are found by experiments which were carried out under laboratory conditions. Measurement photographs that are taken for a fixed observer at 60 m are evaluated by real subjects in the laboratory. The intention is to find out which VL values of critical objects can easily be seen and which VL values are hard to see. The experiments, were conducted with a total of 30 subjects aged 25 to 35 years, including 18 men and 12 women. 121 scenes with different object reflectances on different road lighting classes are evaluated by each subject. According to the results, it is evident that critical objects with a VL value of 7 or greater can be seen 100% of the time in all scenarios. The minimum VL value varies between 7 and 8,5 for 100% of the critical objects on the road to be seen, the minimum VL value varies between 3,5 and 5,5 for 90% and the minimum VL value is 2,5 for 80% of the critical objects on the road to be seen.

According to EN13201-3 and CIE 140 standards and recommendations, the observer position is fixed for luminance measurements and is 60 meters from the first lighting pole in the measurement area. However, in real conditions, the drivers move at a certain speed and one of the parameters taken into account when deciding the lighting class in road lighting automation applications is vehicle speed. It is necessary to provide a luminance level that drivers can see the obstacles from a safe stopping distance. For this reason, the VL values are calculated for the moving observers from safe stopping distance to show how changing the road surface luminance will change the VL of the critical objects placed in the calculation area while the vehicle speed is not changed.

The road lighting should be able to provide enough illumination to allow the drivers to notice the obstacles that come into their way when they are moving and to stop within safe stopping distance. The amount of light that drivers will need to drive safely on the road and recognize the obstacles changes with time. The aim of the lighting automation system is to follow the variable parameters on the road and to provide a dynamic lighting accordingly. When a lighting automation system is applied, the luminous flux of the luminaires can be adjusted and the lighting class of the road can be changed between M1 and M6 classes according EN 13201-1 technical report while the vehicles are moving at a certain speed on the road. When choosing the road lighting class according to EN 13201-1, there are many parameters to take into consideration such as; the road design speed or speed limit, the traffic intensity, whether the traffic composition is only motor vehicles or mixed with non-motorized vehicles, whether there is a separation of carriageway, the intersection density, the presence of parked vehicles, ambient luminosity and navigational task. Some of these parameters are related to the geometric structure of the road, while the parameters such as traffic intensity, and ambient luminosity vary depending on time. There is a certain speed limit in urban roads. However, road lighting class may vary according to other time dependent parameters.

When vehicles are moving at 90 km/h, which can be considered as the legal speed limit for M2 class roads, if the luminance is reduced from 1,5 cd/m^2 to 1 cd/m^2 (road class is changed from M2 to M3) and then from 1 cd/m^2 to 0,75 cd/m^2 (road class is changed from M3 to M4) the visual performance of the drivers should not be degraded. In order to reveal the change in the visual performance of the drivers under different road lighting classes, object and background luminances are measured under the lighting quality criteria appropriate to the classes M2, M3 and M4, from 78 meters which is the calculated value of safe stopping distance for the vehicle speed of 90 km/h. Similarly object and background luminances are measured under the lighting quality criteria appropriate to the classes M3, M4 and M5, from 50 meters which is the calculated value of safe stopping distance for the vehicle speed of 70 km/h. VL values are calculated from these object and background luminances. The minimum VL values which are determined by laboratory experiments are then used as indicators to find out how dimming the luminous flux of the luminaires effect the visibility of the critical objects.

As a result of the experimental studies, VL values could be seen with a probability of 80% in all scenarios. It is shown that the variation of VL values in the calculation area for different lighting classes is within acceptable limits, which means that changing the road lighting class up to two levels does not change the visual performance dramatically while the drivers are traveling at a constant speed. In this way, it is acceptable to reduce the road surface luminances at times when the time dependent parameters such as traffic intensity, ambient luminosity and navigational task is changing but the vehicle speeds are not reducing.

The first pilot application, which will be an example of the use of this "automation system and control software" developed in city roads, was established in 500 meters of Cendere Street in Istanbul. The ability to obtain the expected performance of "intelligent systems" intended to provide energy savings without compromising safety and comfort conditions in lighting installations, such as in all applications, depends largely on the quality of the particular installations in which they are installed. When these systems with high costs are used in installations that are not well designed for energy use, the payback periods are very long and the targeted savings rates are not achieved. For this reason, the high-pressure sodium-vapor lamp fittings, which are available in 500 meters of Cendere Street, were replaced with LED luminaires. A total of 25 pieces of LED lamps converted in 500 meters can be controlled with the automation system and control software.

According to the TSE CEN / TR 13201-1 technical report, for the lighting scenarios to be realized in accordance with the road lighting classes, it is possible to determine the lighting rate according to the existing conditions on the road, taking the vehicle speed and intensity information from the traffic sensors and controlling the luminaires accordingly. If a smart road lighting control system which can save energy is applied in Cendere Street, possible lighting class changes are tried to be shown. According to the average speed of the passing vehicles, traffic density, road and ambient conditions, the lighting classes for Cendere Caddesi will be changed between M2 and M5. When the lighting automation system is installed as a result of the calculations, it is estimated that about 58-64% in the summer months and 62-63% in the winter months.