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Potential Role of Street Lighting System for Safety Enhancement on the Roads in Future

Olegs Tetervenoks, Ansis Avotins, Nadezda Fedorjana
Institute of Industrial Electronics and Electrical Engineering
Riga Technical University
Riga, Latvia
olegs.tetervenoks@rtu.lv

Arturs Kluga, Valters Krasts
P/A Rigas Gaisma
Riga, Latvia

***Abstract*—This paper is an attempt of authors to consider most likely scenario of the further development of street lighting systems, based on current trends in sensors, telecommunication technology and auto industry. Street lighting system previously already was considered as the element of the Smart City by researchers, however, the precise functionality, role and the importance of such a system was considered rather mediocre (ordinary). This article is a holistic view of the Smart Street management system with the street lighting system, which plays great importance of whole transportation and mobility infrastructure functionality and safety enhancement.**

***Keywords*—advanced driver assistance systems, lighting control, traffic control, vehicle safety.**

I. Introduction

Nearly 1.25 million people die in road crashes each year, on average 3287 deaths a day [1]. This statistic shows, that car is a dangerous type of transport, therefore safety enhancement is top priority in modern auto industry. Most accidents occur as a result of the human factor. The human factor should be kept to a minimum, therefore different driving assistance systems were developed and implemented in modern cars during last years, like car self-driving system, human tiredness monitoring, however, the introduction of such a system requires changes in legislation. One of the issues why the self-driving cars are not yet allowed on the streets, is lack of tests and doubts about the behavior of the system in ambiguous situations.

The solution can be borrowed from the most reliable transport type – aircrafts [2]. Aircrafts are equipped with complicated pilot assistance systems, systems for the prevention of dangerous flight conditions and the detection of dangerous actions of a pilot, as well as a warning systems for prevention of dangerous situations and flight conditions. This practice could be applied also in self-driving cars.

Also there are multiple problems related with increased mobility of the people during the last years. The traffic flow capacities of existing roads and streets are limited, heavier traffic leads to a big impact on fuel consumption, and on the amount of emissions [3]. Although there is no clear evidence about relationship between the traffic flow and number of accidents [4], [5], the studies shows that red light running on signalized intersections is affected by heavier traffic [4], thus increasing accident risks.

There were many papers about smart city concept [6]-[8]. However, these papers usually describe general idea, and more detailed consideration of “smart” functionality of particular infrastructure types of smart city in these articles is omitted. This paper is focused on the particular description of potentially possible functions of the street lighting system which can be a key element of transportation and mobility infrastructure of the smart city.

The next sections of this article consider not only standard function of street lighting system, but also highlight potential role of the use of its infrastructure for traffic flow control and distribution, enhancement of self-divining function of future cars and increase of reliability for traffic flow distribution system.

II. The Role of Street Lighting System

Of course, safety enhancement is the main function of street lighting system (it is vital to provide sufficient lighting level in accordance with existing standards and at the maximum possible efficiency). In future there will be self-driving cars, but the driver still will be the essential part of the car, the self-driving ride will not be possible without driver. Therefore comfortable conditions for driver on the road (also lighting) should be kept at a high level also in future smart city.

Street lighting system is the well suited infrastructure for the further development of street management system, which could provide wide functionality including smart traffic flow distribution and assistance functions for self-driving cars. Existing street lighting system already have its own infrastructure near the road. The mounting position of the lamps in respect to the road also is advantageous, the lamps always are above the road or few meters from the road – ideal location/position for different sensors, communication nodes.

The great part of investment in the development of new street management system can be saved by using this existing infrastructure. Also the installation costs can be significantly reduced and the possibilities for the further development increased by using new street lamps equipped with special sockets for the connection of additional control elements. As the warranty lifetime of the modern LED lamps is 5-10 years, but the real lifetime can be up to 20 years, it is good idea to foresee option for easy replacement of the control modules without lamp dismantling and disassembly of the lamp for flexible system upgrade possibilities.

There are already standardized socket types for street lamps (Zhaga and NEMA/ANSI sockets), which provide opportunity to gain this advantage in a great extent, as shown in Fig. 1.

Also with the development of 5-th generation cellular network (5G) street lamps may become an ideal place for installation of 5G small cells. 5G is designed to work in conjunction with existing 4G networks, using a range of macro cells, small cells and dedicated in-building systems. In this concept 4G provides control signaling and 5G provides fast data connection. Small cell is a key element of 5G network to achieve higher data transfer rates using higher radio frequencies. Higher frequencies also means shorter data transfer rates (in range of few tens of meters to a few hundreds of meters) [9]-[11]. The height of street lamp poles also meets minimal antenna installation height requirements in accordance with standard [12] to keep human out of hazardous exposure of antenna [11]. A concept of 5G network architecture is shown in Fig. 2.

III. Holistic View of the Smart Street Management System

Smart street management system can be a core of traffic flow distribution system, including the following functions:

1) *Traffic flow control/traffic distribution*

   a) *Car precise positioning on the road, street, in car lot, - alternative positioning system of GPS/DGPS.*

   b) *Priority function for public transport and high priority function for emergency transport*

   c) *Connection to network and data interchange between system server for further processing and optimal traffic flow formation*

2) *Environmental monitoring, pollution control.*
3) *Street visual control (safety, warning system, fast reaction on accidents)*

   a) *Street lighting control*

   b) *Video monitoring*

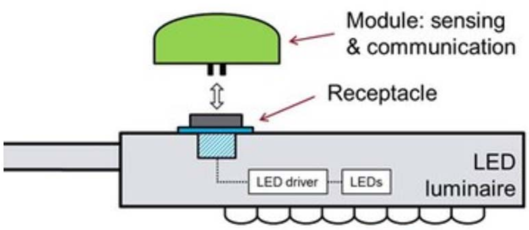

Fig. 1. LED street lamp with socket for external modules [13]

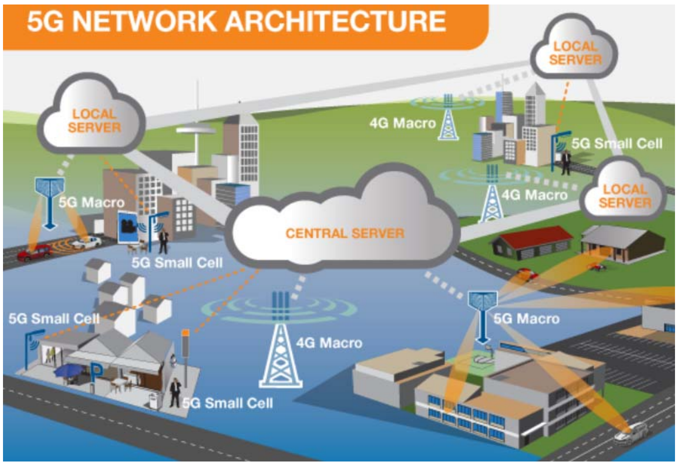

Fig. 2. Concept of 5G network [9]

IV. Assessment of Energy Efficiency for Condition Dependent Dimmable Street Lighting System

Modern lighting systems must fulfil two main requirements: 1) it must provide illumination level in accordance with current standards; 2) it must utilize electrical power with the high efficiency (high efficiency of the electrical power conversion to the light). The development of LED lighting technology allowed considerably improving the system efficiency. While the LED efficacy itself does not give significant vantage over some traditional light sources (low and high-pressure sodium lamps, fluorescent lamps and induction lamps), the construction or LED gives significant benefits. LED can be considered as point light source which facilitates the development of compact efficient optics for uniform light distribution. Therefore, less light is necessary to provide the same illumination level as in case of traditional light sources. Also, LEDs are more convenient for the dimming, in this way they open new opportunities for even greater energy savings and/or lighting quality improvements.

Dimming is an essential function for smart lighting system, which is the latest tendency in lighting industry. To get maximum efficiency, each energy conversion part (light source, optical part and electrical part) of the luminaire also must have highest possible efficiency. As mentioned previously, the control approach may have a great impact on the efficiency of whole system. It is shown that distributed control approach among other control approaches allows to improve light uniformity for moving objects.

The performance of whole system in a great extent depends on the functionality of the separate nodes. The luminaires for smart lighting systems must be equipped with sensors and communication modules to provide motion or presence sensing and data transfer between the nodes [14].

V. Real-Time Locating Systems (RTLS)

As the future street lighting systems (5G, car on-board sensors, RFID tags, etc) will be adopted after various tests, standardization, therefore it will take time till its implementation in real life. Thus we could ask what to do with existing systems or how to improve performance of the existing systems? As we know that most of the systems use Power Line (PLC) or wireless data transmission (ZigBee, radio, etc), realized by communication control node added to the luminary, this way controlling LED power supply through DALI, PWM or 0-10VDC signals. Addition of movement detection sensors to the system [15] actually enables decentralized dynamic street lighting control system, that is capable to adopt to changing traffic intensity during the time of the operation thus actually calculate the appropriate ME class [16] parameters needed for the safe traffic. It means we could get maximum safety with minimum energy consumption in same time if we store such traffic data on each street during the night hours. To calculate analytically the potential savings, two case studies were performed.

A. Case Study 1. "Dienvidu tilts" Bridge in Riga City

In this case the bridge is equipped with Schreder ONYX2 (reflector #1419) 250W High Pressure Sodium vapor lamps (HPS), therefore it could be a good place for renovation to LED based smart lighting system. It is a 3-lane street with pedestrian walkway (Fig. 3.). Currently it is designated with ME2 class lighting parameters, as a typical approach of the municipality agency "Rigas Gaisma" class selection according to road maintenance classes. To assess the lighting quality and potential light output, a Dialux model was created of the site, using maintenance factor 0.75, tarmac: "R3, q0: 0.070".

TABLE I. DIALUX CALCULATION RESULTS

Values	L_{av}[cd/m²]	U0	Ul	TI[%]	SR
Calculated	2.21	0.57	0.74	10	0.52
Required	≥ 1.50	≥ 0.40	≥ 0.70	≤ 10	≥ 0.50

Measurements were obtained using "luxmeter BEHA 93408", where measurement points, geometrical distances and measured values (Lux) can be seen in Fig.4. and they are compatible with the Dialux calculation results.

Traffic intensity data (Fig. 5.) is obtained from measured statistics of state funded company "Latvijas Valsts celi", with peak value of 3068 cars per hour in one direction. According to standard [16], high intensity is above 65%, normal is 35%-65%, and low is below 35% of maximum value (100%=3068). Accordingly we can obtain M-class number for each hour, as it is shown in Fig.5. Here selected M2 class is needed only 5.5 hours from 17.5 hours of that particular day. Interesting that during summer we shouldn't use M2 class at all, in the rest of

Fig. 3. "Dienvidu tilts" bridge and ONYX2 luminary.

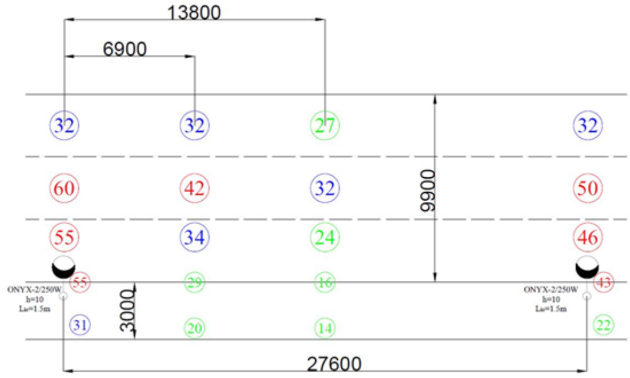

Fig. 4. Practical luminous (Lux) value measurments on site.

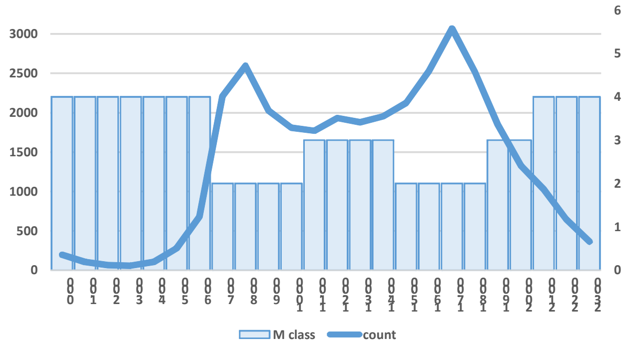

Fig. 5. Traffic intensity data and according ME class for one day.

time the class is lower – M3 and M4, which means also decreased light output, thus less consumed power (W). If we recalculate the M-classes according to obtained traffic intensity and combine it with yearly ON/OFF schedule of Riga city lighting system, we can see that M2 class is needed 454 hours (11.5%), M3 - 401.5 hours (10.2%) and M4 class – 3093 hours (78.3%) of total lighting system working hours. This result shows that in this particular case – system is working **88.5%** of time in wrong regime, causing energy losses and creating lighting pollution.

As HPS luminary is not possible to regulate in full range, a LED luminary would be needed. Thus by modeling same scene in Dialux, and to fulfill all parameters of M2, M3 and M4 classes, we can select "Schreder AMPERA MAXI" with 154W for M2 class and 117W for M3, M4 class. So to obtain energy saving potential of the individual luminary dimming – we will compare situation "1" when only M2 class is applied (no regulation) and situation "2", when we change the classes from M2 (154W), M3-M4 (117W) accordingly. As a result we get yearly consumption of 608.0715718 kWh for situation "1" and 478.7713718 kWh for situation "2", enabling energy savings of **21.26%**, just by applying dynamic dimming function.

B. *Case Study 2. "Jaunciema street", Riga City*

This is a main traffic street located at the lake "Kisezers", it is also equipped with 171 pcs 100W LED luminaries of Photon-L company. In order to obtain traffic intensity data, two sensors were developed basing on Arduino platform, Velleman motion sensor VMA314 and memory card module VMA304. Sensor 1 was installed at the beginning of street (closer to Vecmilgravis), Sensor 2 – at the end of street (closer to Jaunciems), at 1.7m height on the luminary pole. Thus two week measurement data of period 25.03.2019. – 08.04.2019. were obtained. Sensors are developed to register detected motion period (time), it means if motion (sensor voltage) is detected, an instant value "TurnON" is written in memory, when no motion is detected "TurnOFF" is written. In case of more than one car in the row, "motion" is still detected, therefore time of 3 seconds is added to the motion detected period value. In this way we get data about "motion" detectors triggered event count each 20 minutes (Fig. 6.), as well as "motion sensor" summed ON times each 20 minutes, representing more intensive traffic if time value is higher (Fig. 7.).

Sensor values differ, as Jaunciems street has a T-type junction with another street, dividing the total traffic direction and thus also intensity value. Further we could apply two

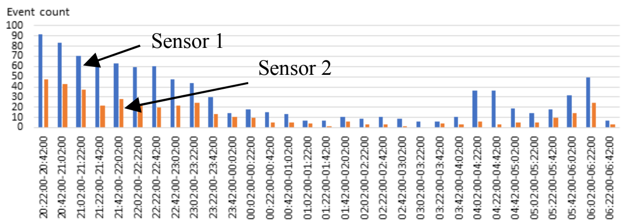

Fig. 6. Sensor event count each 20 min during 03.04.2019.-04.04.2019.

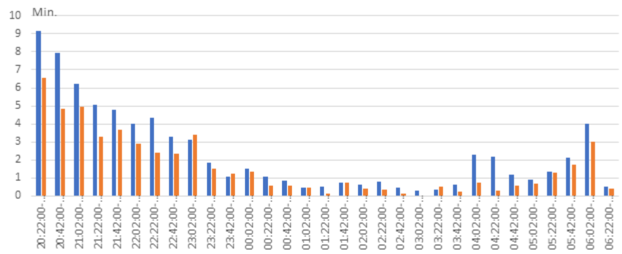

Fig. 7. Sensor ON times each 20 min during 03.04.2019.-04.04.2019.

regulation stages 100% and 20% of light output representing maximum and minimum traffic intensity and ME road class parameters.

In order to calculate the energy consumption for each junction, when sensor is triggered, thus 100% light output needed, and it means also maximum power consumption, then we use formula (1).

$$E_{100\%} = T_{\Sigma 100\%} \times P \times N_g \qquad (1)$$

Where $E_{100\%}$ – total daily energy consumption (kWh);
$T_{\Sigma 100\%}$ – luminary ON time (h);
P – luminary power (W);
N_g – luminary count in the street.

Energy consumption of the system with luminary control based on sensor (traffic) data is given in formula (2).

$$E_{vad} = (T_{\Sigma 100\%} - T_{\Sigma 20\%}) \times P_{100\%} \times N_g + T_{\Sigma 20\%} \times P_{20\%} \times N_g \quad (2)$$

Where E_{vad} – total daily energy consumption (kWh);
$T_{\Sigma 100\%}$ – luminary ON time (h);
$T_{\Sigma 20\%}$ – luminary ON time (h) with 20% power (no traffic detected);
$P_{20\%}$ – luminary at 20% dimmed power (W);
$P_{100\%}$ – luminary at full power (W);
N_g – luminary count in the street.

After applying these formulas for each day, we can obtain total energy consumption values of the 14 day period, where $E_{100\%}$ = 2485.77 kWh, and E_{vad}=1222.06 kWh. This means we can reach up to **50.84%** energy savings in such situation.

VI. Assessment of Motion Sensors

Motion detectors by their operation principle can be distinguished on two different types:

1) *active motion sensors,*
2) *passive motion sensors.*

Active motion sensors continuously emit energy in surrounding area or part of this area in the form of infrared light, sound waves or electric waves. They combine two circuits: energy emitting circuit and reflected energy receiving circuit. Any changes in surrounding cause changes in received energy amount, therefore also output of receiving circuit.

Active motion detection sensors consume more energy, as they continuously emit some energy in surroundings.

Main active motion sensor types are 1) microwave sensors (operation is similar to the Radar, operation on Doppler effect) [17]; 2) ultrasonic sensors which use ultrasonic waves for movement detection and to detect changes in surroundings, 3) tomographic sensors for precise movement detection on large areas (can be used for detecting motion even in hidden areas) [18], [19].

Passive motion sensor operates by detection of infrared radiation of human or object, radiated by the human or object itself. Passive infrared (PIR) or pyroelectric sensor consumes less energy as it is not necessary radiate any energy for operation. It consists of two halves such, that the infrared radiation of surrounding objects causes the same signal in both halves, canceling these signals [20]. The only limitation is that it cannot detect stationary or very slow motion objects.

Usually the additional optics is required for PIR sensors to cover specific sector of surroundings [18], [19].

Microwave sensor has one important benefits over other movement detection approaches: 1) microwave sensor operates through existing optics (plastic), therefore it can be integrated (hidden) in luminaire without visible changes in luminaire appearance [20], no additional optics is required as in case of PIR sensor.

VII. Conclusion

Potential role of street lighting system in enhancement of self-divining function of future cars and reliability of this system were described in this article. Also holistic view of the future smart street management system was presented in this paper.

Despite the fact that this concept looks too futuristic, the implementation of this idea would allow to achieve a lot of positive effects - controlling traffic flow and increasing the capacity of city streets and roads (which is especially important during peak hours), improving traffic organization and safety, transport distribution by priorities and the allocation of separate lanes for public/emergency transport if necessary (rest of the time is available to all modes of transport).

Furthermore, it also shows the high potential of LED smart lighting systems and movement detection sensor application in various places of the city streets, where much higher lighting classes are applied as needed, reaching up to 88% of total time, therefore during night time energy savings from 20 – 50% can be reached.

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