ESTIMATION OF NEW TRAFFIC SIGNALLING TECHNOLOGIES IMPACT ON ENERGY CONSUMPTION

Marius MINEA, Răzvan Andrei GHEORGHIU

University "Politehnica" of Bucharest, Transports Faculty, Telematics and Electronics for Transport Dept., marius.minea@upb.ro, andrei.gheorghiu@upb.ro

Abstract **– This paper provides results and conclusions of a study regarding the impact of new traffic signaling technologies on energy consumption. The methodology for energy consumption calculation on the products lifecycle is also presented. The new traffic signaling technologies employ nowadays LED-driven traffic lights and new, environmental-friendly technologies for adaptive traffic management systems. The study has been carried on for the whole traffic signaling network in Bucharest, taking into account both older, incandescence lamps light sources, and the new LED signals (only with spot-centered technology). These research activities are part of a wider, EU co-funded research program, concerning the implementation of a real-time traffic information services to mobile users. This multi-national research tries to introduce a new, inter-operative information platform for Multimodal Real Time Traffic and Travel Information (RTTI) services, with the goal to reduce drastically energy consumption in urban areas across the different modes of transport by changing the mobility behavior (modal shift) of the single traffic participant. The paper is concerning on several stages of the energy reduction, starting with an analysis on the production phase, the lifetime in service and the recycling of the traffic light signaling elements and ending with changing the behavior of the drivers. Conclusions and some results obtained in Bucharest are also presented.**

Keywords: *energy, environment, reliability, costs, control.*

1. INTRODUCTION

The energy consumption is nowadays one of the major concerns of all industry stakeholders and/or competent authorities. The goal would be not only for making financial economies, but mostly for reducing the environmental impact. The transport sector is amongst the most important energy consumers, as it needs, for its normal operation, electrical power for illumination, signaling, power supply in some cases or communications along the roads, or intensive usage of expensive and energy-intensive raw materials. Also, the road traffic and transport are now some of the most important pollutants, partly due to the intensive usage of carbon-based fuels and the massive, continuously increasing number of private vehicles, and partly due to the extent of road arterials networks in the environment, needing more and more energy supply. Examples may be the destructive civil works, modifying the aspect and behavior of the environment, energy consumption increasing for illumination, signaling and information communication services etc. Some recent research activities in Europe are focusing on the reduction of these impacts, employing different, indirect methodologies. This paper presents some of the effects of introducing newer, less energy consumer technologies in the traffic signaling, considering the energy consumption of the products and procedures on their lifetime. The concept is relatively new and makes object of a research project involving several European countries, which gather their efforts for developing and demonstrating new technologies and services that will result in less energy consumption, less pollutions, CO_2 and particle emissions and less noise due to road traffic. There are two specific directions that the research activities are carried on: inducing a different traffic behavior to the traffic participants via mobile information services, with the purpose of reducing the environmental pollution [1], and implementing less energy consuming technologies for the traffic signaling. The present paper is focusing mainly on the second direction, presenting methodologies for calculating the energy consumption and results of a study case for Bucharest.

The concept is to develop and deploy such traffic signaling technologies that are energy saving, starting with the production phase, then the exploitation on a longer lifetime and ending with the recycling. The concept will be piloted in six European cities of six different countries. One of the test beds is Bucharest.

Based on past experiences and current statistics, an estimate energy saving impact of the measures proposed by this project was estimated at:

- modal shift away from individual traffic: around 3%;
- employment of modern traffic management equipment: larger than 50%.

These percentages are expected to be achieved by optimizing traffic control (the so-called *eco-flowing*), by enhancing the product life-cycle, and by reducing power consumption of the signaling infrastructure, employing LED[1] technologies. The reduction on energy consumption of the traffic management started to be measured in the city of Bucharest, taking into account the whole traffic signaling infrastructure. The main power consumers in such an installation are the traffic lights, with an amount of over 90% of intersection power consumption. In Bucharest, in 2007, the installation of a new traffic control system was announced, the Bucharest Traffic Management System beginning to be operational by 2008. Today, the system manages a network of more than 120 junctions, all equipped with LED traffic lights, traffic sensors, CCTV[2] cameras and FO[3] communications network. Switching to LED traffic signaling is already improving the energy savings, as the system will extend on all the signalized junctions in Bucharest.

2. METHODOLOGIES EMPLOYED AND MEASUREMENTS FOR ENERGY / ENVIRONMENTAL IMPACT

2.1. Introduction - History

The implementation of adaptive traffic management systems helps alleviating the negative impact in terms of emissions, noise and stress, both to traffic participants and to local residents. The introduction of low energy LED-driven traffic signaling also prevents from energy wasting, helps saving the maintenance costs, due to the longer lifetime and operation of LEDs, instead of normal incandescence lamps. In older times, special incandescence bulbs for the traffic lights were created, employing special filaments. Reflectors, high voltage bulbs, low voltage bulbs, transformers, etc. were key components, consuming lots of materials, mostly energy-intensive. For a long period of time, these traditional bulbs were in use in all signalized traffic junctions. The power consumption of each bulb was ranging from around 60W to 100W. During each year, periodically (two or three times), these bulbs had to be changed. They had shorter lifetime (presently, an average quantity of 2 bulb lamps are being replaced daily in each junction) and presented a phenomena of "evaporation" of the filament and metal deposition on the walls of the glass bulb, thus reducing the luminous intensity. After that, a newer technology with low voltage, halogen lamps, became usable. These bulbs had a power consumption of around 20W per unit, and their life cycle was considered to be around half a year.
With excellent luminous efficacy, less power consumption and a higher life expectancy, LED technology came to life also in street traffic signaling. LEDs present many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved robustness, smaller size, faster switching, and greater durability and reliability. However, they are relatively expensive and require more precise current and heat management than traditional light sources. Current LED products for general lighting are more expensive than fluorescent lamp sources of comparable output.
In our days, the LED technology for these appliances is able to produce light sources of a five year life time and more. Beside that, the luminous power of the LEDs can be very useful in observing the aspects of the traffic signals from a longer distance, preventing drivers of committing sudden or unexpected actions that might lead to traffic incidents.

2.2. Impact on the environment during the life time

When studying the impact on the environment for the whole life time of a product, it is important to take into account several aspects:

- the energy consumption and pollution involved by the manufacturing of the product;
- the energy consumption during the life cycle;
- the energy consumption and pollution produced during the maintenance and service activities;
- the recycling activities etc.

Besides determining the overall reduction in power consumption of the LED-module (compared to bulb lamps) all other positive effects of using this technology have to be quantified similarly. Undoubtedly longevity is one of the main advantages of LED-retrofits. A life-time of at least five years consequently means no replacements of LED-retrofits for this period of time. On the other hand it is assumed that bulbs typically have to be replaced three times a year. Direct statistical data confirming these assumptions is not available. As in Bucharest there are still bulbs as well as LED-modules installed, there should be records available allowing comparisons of maintenance requirements of both technologies, but the latter are only at the beginning and are hard to find. Definitely total power consumption of traffic signals is determined by the turn-on time of the signal. Calculating the total power consumption of all LED-signal heads installed therefore requires exact signal-plans of the whole system and represents a time-consuming activity. However, this helps estimating the environmental impact of the new technologies.

[1] Light Emitting Diode
[2] Close Circuit TeleVision
[3] Fiber Optic

2.3. Calculation methodology for the energy consumption of LED traffic signals

Power LEDs were introduced for the first time on commercial applications in 1999, when they were able of continuous operation at one watt. White LEDs quickly matched and overtook the efficiency of standard incandescent light sources. In 2002 the market received 5W LEDs with a luminous efficiency of 18-22 lm/W. For comparison, a conventional incandescence lamp for the traffic signaling is able to produce around 15 lm/W, considering a power consumption of 80 W. Actually, high power LEDs are able to produce around 150 lm/W in lab conditions (low temperature) and around 50 lm/W in normal operation conditions.

When designing traffic lighting systems using conventional incandescent lamps, designers must consider the total illumination, the minimum light level specified, the expected lamp failure rate (mortality), the desired re-lamping interval (mission life), and the lamp operating conditions.

Depending on the traffic light controllers, traditional drivers can adjust the operating voltage for traditional lamps; they also control the integrity of the filament, as a safety function for traffic; reducing the operating voltage reduces the brightness of the lamp but also extends its lifetime. Some of the traffic light controllers are able to do this automatically, when connected to a light sensor (available for night signaling). To manage the same trade-offs for LED installations, designers can specify drivers to control the forward current, and resulting thermal management to control the operating temperature. As noted below, a longer replacing interval can result in large cost savings for the end customer.

In the traffic lighting it is important to consider:

- minimum illumination provided by light sources (LEDs);
- replacing interval;
- initial purchase price;
- operating energy costs.

Lifetime and failure rate are some of the most important indicators to consider the lifetime of a LED light source [2].

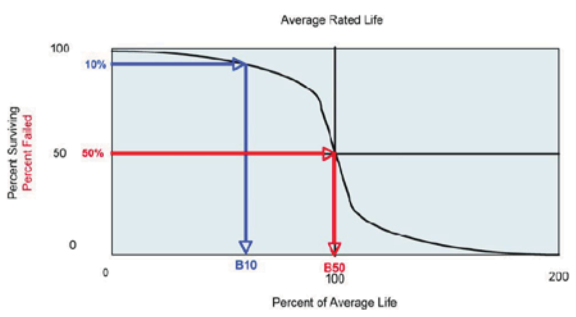

Figure 1. Definition of "B" values for LEDs

For example, a so called "B10" value for any given light source denotes the time by which 10% of that light source population is expected to fail. The "B50" value is also used; the point where the failure rate is 50% - sometimes called the rated or average life.

Recently, the growing adoption of power LEDs in lighting applications presented designers with a new set of metrics for lifetime. Due to the fact that it is rare for a LED to fail completely, instead, the intensity of light emitted tends to fall over time. This effect is termed "lumen maintenance" [2].

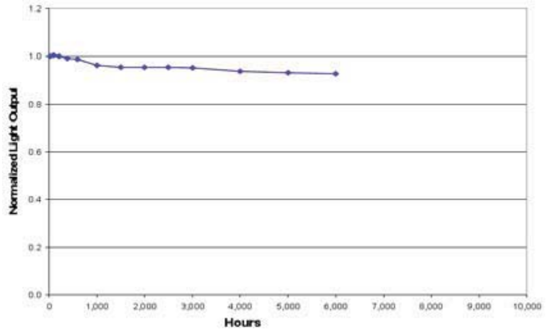

Figure 2. Decrease of light output power in time, for a high-power LED

In a lighting installation, this reduction in lumen maintenance may, eventually, result in a drop in light output to below agreed limits for the environment. The recent researches found that 70% lumen maintenance is close to the threshold at which a human eye can detect a reduction in the light output. Two indicators have been proposed to be used for expressing the useful lifetime of a LED component or system:

- L70, or the time to 70% lumen maintenance;
- L50, or the time to 50% lumen maintenance.

Typical lifetimes are quoted at 25,000 to 100,000 hours of operation. The most typical value determined experimentally and by employing lumen maintenance calculations has been found to be 60,000 hours (around 6 years and 10 months).

Typically, a light traffic signal employs different colors to provide information to traffic participants and drivers. These colors are RED, AMBER and GREEN. These lights do not operate continuously, but according to the cycle of phases that is established for the respective traffic light.

Usually, the functioning of a traffic light is according to the following relationship:

$$T_{Cy} = \tau_G + \tau_A + \tau_R \tag{1}$$

Where:

- T_{Cy} - total period of signaling cycle;
- τ_G, τ_A, τ_R - periods of time where Green, Amber and Red signals are lit (and consuming power).

Different power is employed for different colors displayed at the traffic light, so the total, theoretical energy consumption should be estimated employing the following formula, for each group of traffic signals:

$$W_{Cy} = \tau_G \cdot P_G + \tau_A \cdot P_A + \tau_R \cdot P_R \quad (2)$$

Where:

- W_{Cy} - energy for a cycle period;
- P_G, P_A, P_R - power consumption for each LED group in a traffic light color;

Tipically, 6-7 LEDs are employed in spot-assembled traffic light heads, and 50 to 120 LEDs in dot-matrix signal heads (older technology).

As declared before, different colored LEDs employ different power consumption, and distance between the traffic lights controllers and the signal heads also may need an increased voltage to drive correctly the LEDs. Therefore, an improved formula for the calculation is as following:

$$W_{Cy}^{C} = \delta \cdot (n_G \tau_G P_G + n_A \tau_A P_A + n_R \tau_R P_R) \quad (3)$$

where:

- W_{Cy}^{C} - energy with distance correction factor;
- δ - distance correction factor (value 1,05 – 1,3);
- n_G, n_A, n_R - number of LEDs used in the signal head, respectively to the color employed.

Exact values for the durations τ_G, τ_A, τ_R are difficult to consider for traffic adaptive systems, as they change according to traffic; usually, the amount of the change is comprised in between 12% to 20% of a phase. Instead, a typical percentage is employed:

$$W_{Cy}^{C} = \delta \cdot T_{Cy} (n_G \tau_G^p P_G + n_A \tau_A^p P_A + n_R \tau_R^p P_R) \quad (4),$$

where T_{Cy} represents the period of a signaling cycle.

These values are presented in the table below:

Parameter	Value
τ_G^p	40 [%]
τ_A^p	5 [%]
τ_R^p	55 [%]
P_G	1,5 [W]
P_A	1,33 [W]
P_R	1,33 [W]

Table 1: Energy parameters and theirs values for a typical traffic light

Thus, for a single traffic light, comprising all colors (green, amber and red), the total power consumption for one hour (36 cycles with a length of 100 s, which is 0.027 hours) will be:

$$W_T^C = 36 \cdot W_{CyT}^C = 36 \cdot 0.2563 = 9.2268 \text{ [Wh]} \quad (5)$$

The pedestrian traffic lights only use two colors instead of three, these being red and green. Employing the same formula, but with a time split of 50 % - 50 %, the total energy consumption will be:

$$W_P^C = 36 \cdot W_{CyP}^C = 36 \cdot 2.52153 = 9.339 \text{ [Wh]} \quad (6)$$

A medium-sized intersection comprises an average of 8.4 traffic light signal heads and 10 pedestrian ones, as resulted from a study in Bucharest. So the power consumption for these installations has to be multiplied accordingly:

$$W_{TI}^{LED} = 8.4 \cdot W_T^{LED} + 10 \cdot W_P^{LED} \cong 170.895 \text{ [Wh]} \quad (7)$$

where W_{TI}^{LED} represents the total energy consumption for a medium-sized intersection employing LED driven traffic signals.

2.4. Bucharest Study Case

In the case of bulb lamp signal heads, the power consumption was estimated at 100 W per each unit. Amongst other energy consumer equipment there are also: the traffic controller, with an average power consumption of 100 W and ancillary equipment (traffic detectors, communications, interfaces, alarms, HVAC[4] etc.) with an average of 100 W AAPC[5].

Presently, in Bucharest there are several junctions with traffic controllers that drive bulb lamps traffic lights. The type and number of these was evaluated and is presented in the following table:

Traffic controller type / total number in Bucharest	Total number of 3 aspect signals (traffic signals)	Total number of 2 aspect signals (pedestrian signals)	Total power consumption, including traffic controllers and ancillary equipment [W]
Peek Traffic	120	178	30900
ADCI-2	23	34	6200
EMCS	268	300	60500
ESR CC8000 ESR CC15000	768	822	168800
EPC	184	198	40400
SCAE	199	188	40600
Total	1562	1720	347400

Table 2: Distribution of power consumers in case of bulb lamp traffic signals in Bucharest

[4] Heat, Ventilation and Air Conditioning
[5] Annual Average Power Consumption

By employing the same formulae for the energy consumption, it results for all the bulb traffic lights:

$$W_{TI}^{B} = 36 \cdot W_{CyT}^{CB} + 36 \cdot W_{CyP}^{CB} = 361.02 \text{ [kWh]} \quad (8),$$

Where W_{TI}^{B} represents the total energy in an intersection with bulb lamp traffic lights.

A medium-sized junction equipped with bulb lamp traffic signal heads will have an average energy consumption of:

$$W_{TI}^{B} = 8.4 \cdot W_{T}^{B} + 10 \cdot W_{P}^{B} = 2.024 \text{ [kWh]} \quad (9),$$

which represents a value 12 times higher than if using LED technology.

The total energy consumption, for all junctions, including the traffic light controllers and ancillary equipment rises at:

$$W_{T}^{B} = W_{TI}^{B} + W_{AE} = 379.22 \text{ [kWh]} \quad (10).$$

Next, an approximate calculation can be made for the total energy consumption of the new LED-driven traffic signal heads, considering all 120 intersections that are now equipped with this technology:

$$W_{T}^{LED} = 120 \cdot W_{TI}^{LED} \cong 20.51 \text{ [kWh]} \quad (11).$$

It results that, when using the LED technology, the average energy consumption decreases more than ten times and the lifetime increases about 10 times. Presently, the implementation of LED technology in the traffic signal heads has only few years since it started. Only 40 percent of the total amount of signalized junctions in Bucharest shares the LED technology. It is necessary to extend this technology to all junctions, in order to drastically reduce the energy consumption.

2.5. Equivalence in Car Emissions Eliminated

An interesting approach in this study would be to estimate the economies made if the LED technology would have been totally introduced, by considering the equivalence with car emissions eliminated. For this purpose, it is necessary to know how the production of LED signals, their operation / maintenance, and their recycling might be compared with similar negative effects generated by car traffic in an urban area.

The scale of environmental impacts associated with the manufacture of microchips is characterized through analysis of material and energy inputs into processes in the production chain. The production chain yielding silicon wafers from quartz uses 160 times the energy required for typical silicon, indicating that purification to semiconductor grade materials is energy intensive. Due to its extremely low entropy, organized structure, the materials intensity of a microchip is orders of magnitude higher than that of "traditional" goods [3].

LED fabrication processes use a wide variety of chemicals, many of them toxic, whence potential impacts of emissions on air, water, and ground systems are major environmental concerns. Similar emissions can be found in road traffic environmental impact. One important element of tackling the issue is identification of how much of what substances are used and emitted, and to estimate equivalence with the traffic emissions.

Considering now direct use of fossil fuels, research reports are showing that 83% of total energy consumption in semiconductor is electricity, the remainder a mix of heavy oil, gas, LPG and kerosene.

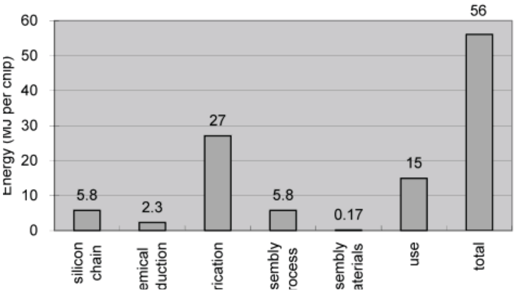

Figure 3. Typical energy consumption values for an usual semiconductor chip [3]

The lower bound of fossil fuel and chemical inputs to produce and use one 2-gram microchip are estimated at 1600 g and 72 g, respectively. Secondary materials used in production total 630 times the mass of the final product, indicating that the environmental weight of semiconductors exceeds by far their small size. This intensity of use is orders of magnitude larger than that for "traditional" goods. Taking an automobile as an example, estimates of life cycle production energy for one passenger car range from 17500 kWh to 33055 kWh. This corresponds to 1500-3000 kg of fossil fuel used, thus the ratio of embodied fossil fuels in production to the weight of the final product is around two [3].

In the Bucharest case study, the LEDs employed in the traffic signaling are produced by a private company that has specific activities in traffic signaling and its own line of production, having conformity with all available standards at European level in terms of environmental protection and quality of materials. The following table presents the harmful environmental emissions recorded for the production of these devices, caused by power generation.

Harmful Environmental Emissions	Value	Measuring unit
Pollution due to energy production	0.70	kg/kWh
Equivalent emission generated by cars	0.191	g CO_2/km
Equivalent annual average pollution generated by cars	3056	kg CO_2 / car

Annual carbon dioxide savings when using LED technology instead of incandescence lamps	592	t CO_2

Table 2: Equivalent emissions for LED versus bulb

From the calculations it resulted that with employing the LED technology instead of incandescence lamps, the economies in traffic would result as following: 194 equivalent cars eliminated by energy savings per year, 16000 km traveled by each car, 592 tons of CO_2 less emissions.

The following diagram presents the time estimate for a horizon of 5 years of LED operation in traffic signaling.

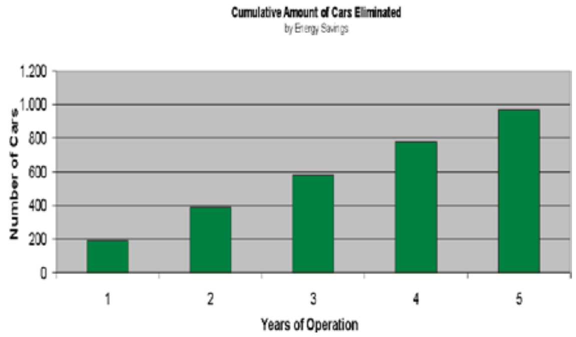

Figure 4. Energy consumption reduction estimates, equivalent in cars reduced from traffic for a 5 years horizon (Bucharest study case)

3. CONCLUSIONS

It is very important to emphasize that the introduction of LED technology in traffic signaling has many advantages. While the LED technology has more energy intensive production process, it finally contributes tremendously to the overall reduction of energy consumption. Beside this primordial advantage, it has also several benefits:

- Improves the visibility of traffic lights and thus reduces chances to traffic incidents;
- Reduces stress when approaching a signalized intersection, by increasing the distance of visibility;
- Involves less maintenance and waste materials dispense costs;
- Has longer lifecycles etc.

The employment of this technology in traffic signaling is equivalent with the reduction of a certain number of vehicles in traffic and if the technology is extended, the number of equivalent emissions increases over lifetime.

Acknowledgments

The authors would like to address their thanks for the fruitful cooperation to all partners in In-Time project.

References

[1] ***. *Intelligent and Efficient Travel Management for European Cities. Project In-Time.* Grant Agreement no. 238880, Description of Work (DoW), CIP ICT PSP 2008-2, EU;

[2] *** Philips. *Technology White Paper. Understanding Power LED Lifetime Analysis.* PHILIPS INC., 2008;

[3] Wiliams, E.D., Ayres, R.U., Heller, M. *Energy and Material Use in the Production of Semiconductor Devices.* United Nations University, 53-67 Jingumae 5-chome, Shibuya-ku, Tokyo, Japan.