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Smart Road Lighting Management System for Reduction of Energy Footprint

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Abstract

Energy consumption is a major problem nowadays, especially when it comes in mass scale. Cities and larger inhabited areas have to pay huge amounts of money for electricity bills. Municipality of Aspropyrgos in Greece, is one of them due to its old technology and low energy class. Its annual power consumption only for road lighting, is almost 5 million KWh and the average cost of electricity and maintenance is almost 800 thousand euros. This situation also has great environmental impact since the production of power for street lighting emits 3.3 million kg of CO_2. That quantity demands almost 170 thousand trees, in order to be absorbed. For that reason, two layout scenarios are proposed, in order to provide lower power consumption and better management. The first includes the replacement of light bulbs with corresponding LEDs and the second includes smart management systems. The results of this research, clearly indicate, that there are high potentials in energy saving along with environmental and financial benefits.

Keywords: road management; smart lighting layout; lighting management; energy footprint; internet of things (IOT).

1. Introduction

Municipalities and prefectures are facing some major problems; one of them is the lack of a proper network management for street lightning.

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This situation, in combination with the aged road equipment, leads to uncountable power consumption. The main disadvantages of old road lighting networks are mentioned below:

- Short lifespan and reduced luminosity (up to 60%).
- Start and stop function is not based on real-time conditions.
- Insufficient detection of malfunctions (only during scheduled checking or after incoming reports from civilians) that leads to high expenses. It is estimated that 10-15% of network is out of order in a daily basis, due to high shut down time.
- Poor lighting quality (since there is inadequate coordination between the height and density of lighting columns and the demanding of road network).

Electricity is a type of energy that is fueled by the transfer of electrons from positive and negative point within a conductor. For example, an engine or a lightning bulb needs electricity in order to operate. Electricity production is achieved by burning lignite, coal, with nuclear power plants, solar and wind generators etc. Energy itself cannot be stored, so its production rate depends on the demanding rate. Electricity demands a vast distribution network since its consumption is instant. The primary target stands for reduced power consumption on municipal level, especially for road lightning. To achieve this goal, lighting sources of roads, sidewalks and squares should be replaced. Public buildings and machinery with low energy consumption lead to reduced energy footprint and hence lead to reduced environmental footprint due to less gases, solid and liquid wastes during energy production.

The management of carbon footprint includes the following stages:

- Sustainable development based on environmental standards
- Sustainability of power production unit
- Reduced environmental impacts
- Increased reliability through environmental business plan

Eco-friendly footprint measures human demand on nature; the quantity it takes to support people or an economy. In short, it is a measure of human impact on Earth's ecosystem and reveals the dependence of the human economy on natural capital. Intelligent systems are a primary way in order to achieve lower energy consumption, since they are capable of acting without human interference. The appliance of evolutionary algorithms and neural networks are compulsory, and thus the designing of systems that are based on nature and human models [1, 2, 3, 4, 5].

2. Proposed methodology

Road lighting science deals with the illumination of external places, highways, streets, sidewalks, under the instruction of the International Commission of Illumination (CIE) and includes the following categories:

- ME: roads with vehicles (>60 km/h)

- Ce: city streets, circular nodes (pedestrians, cyclists and vehicles)
- S: sidewalks, cyclist roads, squares, parking lots and yard
- Es: high crime areas
- Ev: lighting for vertical surfaces (toll booth)
- Lambency is responsible for the obviousness of all obstacles and it can be determined by 3 coefficients:
- Uo (uniformity): Lmin/Lmed (parallel at road axis)
- Ul (longitudinal riadiancy): Lmin/Lmax
- Ui (transverse uniformity): Lmin/Lmax (vertical to road axis)

Dazzlement is also a main factor that affects vision. It is caused from extreme bright objects and it is divided into physical and psychological dazzlement. A properly illuminated road consists of lanes of luminosity. Every lane has to be around 5 meters in width, so every obstacle could be visible from drivers. Along with lighting harmony, comes a perfect visual guidance [6]. A schematic Figure for configuration and dimensioning of street lighting is shown in figure 1.

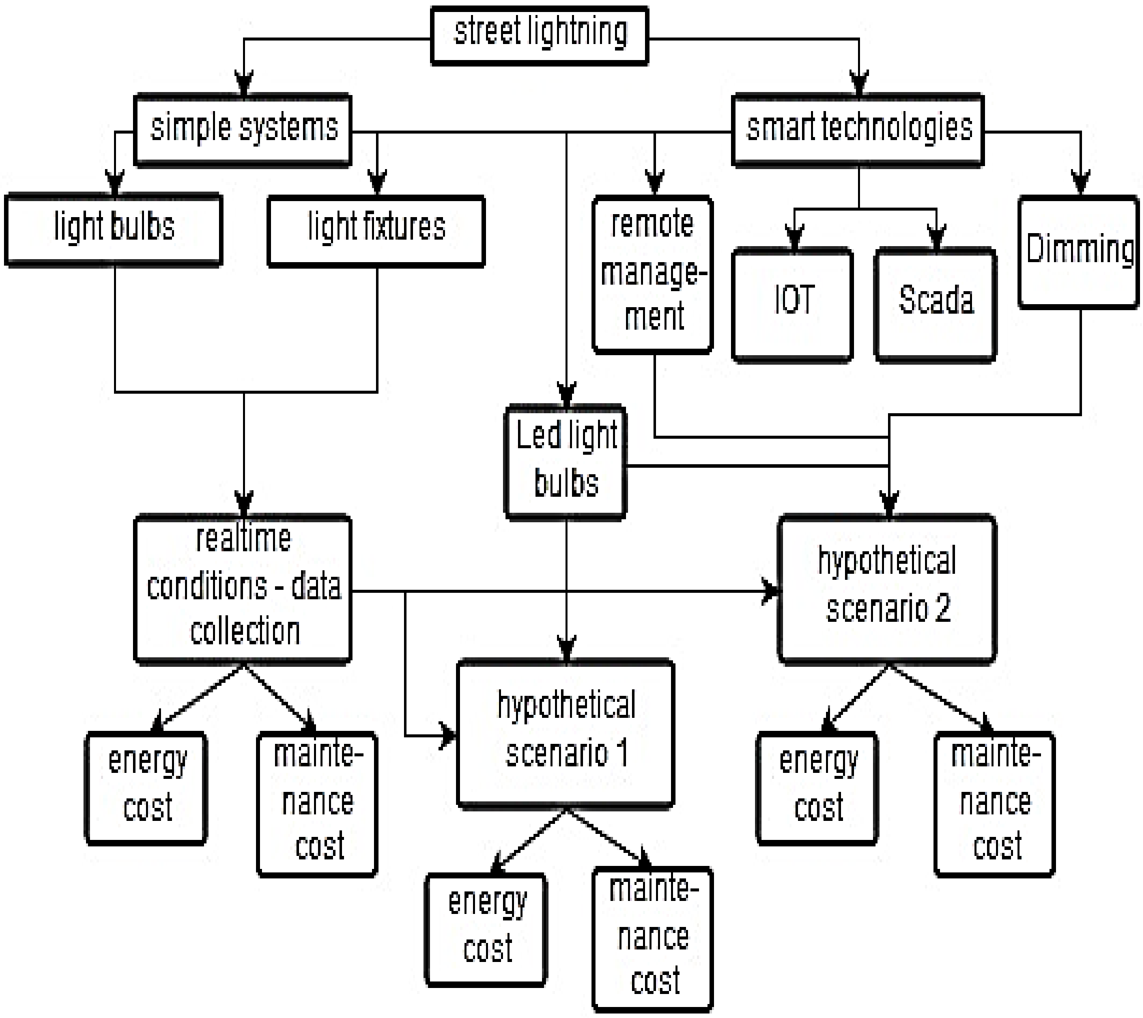

Figure 1: Schematic Figure of street lighting dimensioning

2.1 Simple systems

Metal halides lamps combined with quartz technology: Osram imported those lamps. They operate inside an arc tube manufactured from quartz and they can resist high temperatures despite any fluctuation. They provide high power and a wide range of colors. High pressure sodium bulbs: Those lamps operate in a ceramic tube where sodium, mercury and a gas is. The radiation which is emitted by mercury arc subjects to ultraviolet spectrum. Phosphate covers convert that radiation into visible yellow light. Those lamps achieve complete output after 10 minutes of operation and they need 1-3 minutes for reboot. Despite their poor quality, they do not cause dazzlement. Low pressure sodium bulbs: In order to be achieved stable sodium pressure, the whole operations takes place in vacuum tube. The arc passes through gasified sodium, neon, argon and helium. The color of emitted light is yellow and it has the same wave length as human eyes. That makes them extremely effective. The starting time is about 7-15 minutes. Light emitting diodes (LED): They are semiconductor light sources that emit light when current lows through it. The color of the light is determined by the energy required for electron to close the band gap of the semiconductor. They are characterized by low energy consumption [7, 8]. Road lighting fixtures consist of the light bulb, current stabilizer device, the reflector, the cover and the main body. An effective fixture should facilitate the vision of drivers, should reclaim new generation and high output lamps and should precisely lead the light beam to the point and should be full cut off.

Types of fixtures:

- Non cut off, which disperse light to all directions
- Semi cut off, which disperse the light to 0-90^{o} (5% upward light escape)
- Cut off, which disperse the light to 0-90^{o} (2.5% upward light escape)
- Full cut off, which disperse the light to 0-90^{o} (0% upward light escape)
- Fixtures' installation ordinance:
- One-sided ordinance, the road width should be equal or less than the height of fixture
- Axial ordinance, the road width should be equal to the suspension height (1MH)
- Bilateral triangular ordinance, the road width should be 1-1,5MH
- Bilateral ordinance, the road width should be >1,5MH

The installation of fixture should be subjected to some standards, such as, angle of the arm (A), the distance between consecutive fixtures (S), the projection of the arm, the distance between arm and column (Or), the horizontal distance between the center of fixture and kennel (O) and the height of suspension (MH) [9]. Otherwise decision making models may be applied, in order to reach the optimum solution [10].

2.2 Smart technologies

A remote management system is called the network which can control the functions and characteristics of lighting fixtures and bulbs from distance. Moreover, it is able to collect information and survey its function. Usage of such systems is obligatory in order to be achieved better services, low function cost and less energy consumption. A remote management system has a plenty of advantages such as:

- A remote surveillance which provides low cost due to no cable's existence, continuous observation (or through optimization, minimizing the cost of the process in terms of maximizing the result), control through internet access, instant fault alarms.
- Energy saving and lower maintenance cost (usage of led lamps, recording of energy consumption for every single fixture, fast maintenance procedures).
- Flexibility in external lighting management (network depiction with usage of GIS system, easy start and stop functions by using DALI system combined with motion and light sensors).
- Improvement of ecological footprint (dimming is the main function where there is an auto-adjustment of lighting depending on traffic load and daylight conditions during morning and noon).
- A led controller which is installed inside the body of lighting fixtures, provides auto-adjustment, auto-correction to the bulb by using sensors. The controller also records energy consumption and faults.
- Control node (it consists of few nodes attached to each other, a router device and a pillar with getaways). All of these give the ability to the operator for using 3G/4G networks and connectivity for table computers and smartphones which allow the application of schedule modes for start/stop and daytime.
- Combining a VBOX device to record speed limits in order to adjust the illumination of light fixtures [11, 12, 13].

Internet of things (IOT) is referred to electric and electronic devices which can connect to internet without using a computer, a smartphone or a tablet. The primary target of IOT is the wider control of all devices from distance. A proper software is a necessary premise for the function of the application, which should contain different scenarios for controlling different devices. Data may be stored at getaways which they gap the device with a computer or a smartphone. The final receivers are the IOT sensors, which carry out orders [14]. A scada system is the main controlling factor in industrial production since every part of this process depends on parameters like temperature, density, pressure etc. Those parameters are controlled from distance. Main functions of such system are [15]:

- Data collection from PLC's and RTU's
- Data storing
- Analysis and warning in case of faults
- Graphic representation of the whole procedure
- Recording of occurrences and crucial parameters
- Simultaneous support of two different computer systems
- Data transfer to central storing mediums.
- The structural parts of a SCADA system are:
- A central computer station (MTU)
- Communication lines
- RTU's for coding and decoding
- Field instrumentation
- A computer for data collection and procession

- Remote-controlled terminal units
- PLC controllers
- Connection hardware among them

The adjustment of light intensity is a significant factor which is referred to percentage of countable luminosity and perceiving luminosity. It can be distincted into 5 categories:

- Dimming through bi-level electromagnetic ballast
- Dimming through power abatement by using adapters
- Dimming through electronic circuits
- Dimming with electromagnetic ballast with power line modem
- Dimming through electronic circuits for individual light fixtures

Category 1 provides lower energy consumption up to 20%, while categories 2-4 from 30% to 42% [16].

3. Results and discussion

3.1 Energy consumption in real-time

Municipality of Aspropyrgos is using mercury light bulbs (125w, 250w), sodium bulbs (400w) and CFL low consumption bulbs (23w), which are installed at high fixtures at suburbs and lower fixtures at central areas. Table 1 shows the quantities of each light bulb and table 2 shows the annual consumption per bulb (KWh).

Real consumption of common bulbs is increased by 20%and the average operating time is 11 hours per day [17].

Table1: Types and quantities of Aspropyrgos' lights [19]

Type of bulb	125w Hg	250w Hg	400w Na	23w cfl
High fixtures	3,756 pcs	347 pcs	80 pcs	
Low fixtures	3,062 pcs			784 pcs
Sum	6,818 pcs	347 pcs	80 pcs	784 pcs
Total sum				8029 pcs

Table 2: Annual consumption of Aspropyrgos' lights (* low fixtures)

Type of bulb	Pieces of bulbs	Real consumption (w)	Annual consumption (KWh)
125w Hg	3,756	150	2,262,051
125w Hg *	3,062	150	1,844,090
250w Hg	347	300	417,962
400w Na	80	480	154,176
23w cfl	784	23	72,398
Sum	8,029		4,750,677

The average cost of current consumption per KWh is 0.125€ and the average maintenance cost per light and year is 20 €. So, the total cost for road lightning is: 754,415 €/year. Then ecological footprint is being calculated according to annual energy consumption. The amount of 4.75*106 KWh corresponds to 3.35*106 Kg CO_2 and 8,385 operating hours of a 2.3 MW wind generator .The number of trees that are required to absorb that quantity of CO_2 is 167.699 [18].

3.2 Energy consumption based on hypothetical scenario 1 with energy saving lamps (LED)

During current scenario, all kind of lamps are theoretically going to be changed with equivalent led lamps. At table 3 it is shown the correspondence between the categories of lamps.

Table 1: Correspondence between common and led lamps [19]

Existing lamps	Led lamps
125w Hg	45w LED
125w Hg*	25w LED
250w Hg	90w LED
400w Na	120w LED
23w cfl	9w LED

At table 4 it is calculated the hypothetical annual energy consumption. The operating conditions are the same as before but the real consumption is equal to nominal power [20].

Table 2: Annual consumption of Aspropyrgos' lights (* low fixtures), hypothetical scenario

Type of bulb	Pieces of bulbs	Real consumption (w)	Annual consumption (KWh)
45w LED	3,756	45	678,615
25w LED *	3,062	25	307,348
90w LED	347	90	125,388
120w LED	80	120	38,544
9w LED	784	9	28,330
Sum	8,029		1,178,225

The average cost of current consumption per KWh is 0.125 € but there is no maintenance cost. So, the total cost for road lightning is: 147,278 €/year [19]. Then the ecological footprint is being calculated according to annual energy consumption. The amount of 1,178*106 KWh corresponds to 8,31*105 Kg CO_2, and 2,080 operating hours of a 2.3 MW wind generator. The number of trees that are required to absorb that quantity of CO_2 is 42,591 [16]. Concluding, there are distinct differences between energy consumption of common lamps and LED lamps. Figure 1, shows the categorization of common lamps (blue line) and their corresponding LED lamps (orange line). Namely, category 1 125w Hg-45w Led, category 2 125 Hg*-25w LED*, category 3 250w Hg-90w LED, category 4 400w Na-120w LED and category 5 23 cfl-9w LED. For category 1 there is energy consumption decrease up to 70%, for category 2 up to 83%, for category 3 up to 70%, for category 4 up to 75%

and category 5 up to 61%. Generally, there is a decrease in energy consumption up 75%, concerning the whole lightning network. In conclusion, it has been saved up to 79% of the annually cost of electricity.

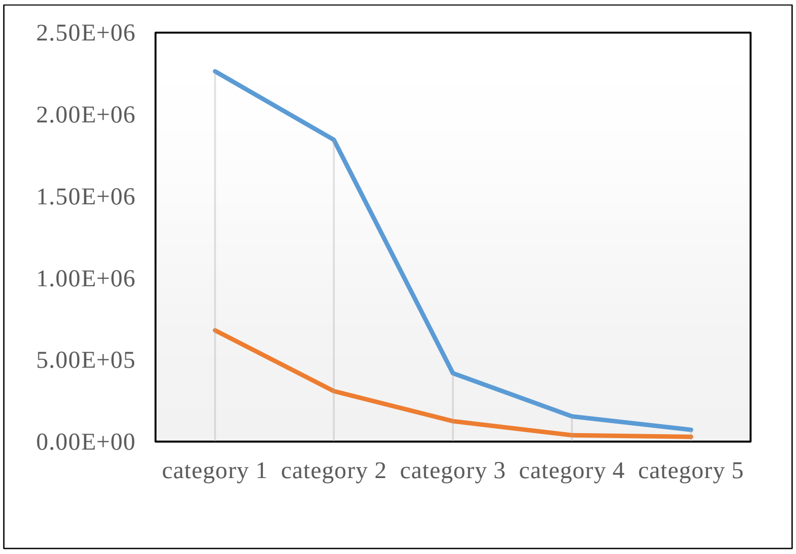

Figure 1: Comparison between existing status and hypothetical scenario of annual energy consumption

Energy consumption based on hypothetical scenario 1 with energy saving lamps (LED) and automated management system (enhanced scenario). In current scenario the management of the system is achieved through hardware and software which are capable of controlling start and stop function, adjusting luminosity level and enabling or disabling auto and manual mode. This automated program will auto-configure the beginning of every lighting fixture separately. Luminosity level will be regulated in accordance with prevailing conditions. This program will collect, process and store data (faults, energy consumption) for every fixture. In this scenario, it is considered that luminosity will be decreased about 30% from 2:00 am until 5:00 am (low traffic hours). Operation hours are the same as before. At table 5, the energy consumption is presented for every lamp after applying the enhanced scenario [20].

Table 5: Annual consumption of Aspropyrgos' lights (*low fixtures), enhanced hypothetical scenario

Type of bulb	Pieces of bulbs	Real consumption (w)	Annual consumption (KWh)
45w LED	3,756	45	623,091
25w LED *	3,062	25	282,201
90w LED	347	90	115,128
120w LED	80	120	35,390
9w LED	784	9	26,011
Sum	8,029		1,081,821

After calculations an additional decrease in energy consumption and consequently in energy cost up to 8.2% is obvious: 135,227 €/year. In the following Figure 2 the difference between initial common lamps (blue line) and the enhanced hypothetical scenario (orange line) is presented. Categorization is the same as before, so for category 1 there is energy consumption decrease up to 73%, for category 2 up to 85%, for category 3 up to 73%, for category 4 up to 77% and category 5 up to 64%. Generally, there is a decrease in energy consumption up 77%.

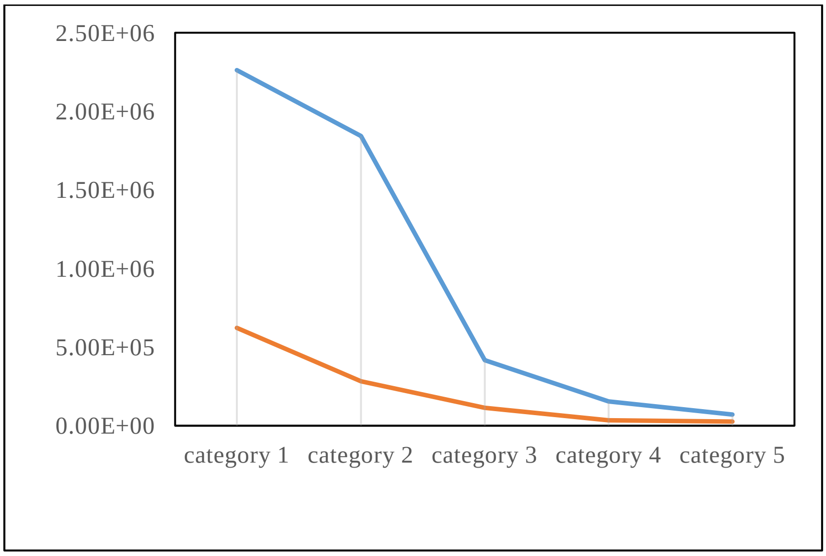

Figure 2: Comparison between existing status and hypothetical scenario of annual energy consumption

4. Suggestions – conclusions

A great suggestion for energy and money savings, is autonomous lighting fixtures with solar panels. Unfortunately, solar radiation is not a stable but it is changing during the day. Such an installation consists of charging regulator which stabilizes the output power, a battery that gives autonomy to system, an inverter for changing the kind of power (ac/dc) and a control panel with electric fuses and a changing switch among battery, generator or public electric network. That kind of lighting fixtures are ideally for remote areas, railroads, national roads and rural areas since they provide low consumption, low maintenance cost, quick installation, longevity, automated and autonomous function, no pollution etc. On the one hand there is high energy saving potential and on the other hand the alteration of linear luminaires to LED lighting in road networks according to an appropriate design will lead to positive results in terms of safety and mobility behavior. LED technology enables higher granularity of light sources in an area with coalescent dimmability. Analytical method, AHP evaluation or equivalent uniform annual cost may provide a reliable approach for the most effective technology, as well as an illumination mapping could provide even more data about visual situation. That evaluation method takes under consideration different practices and in terms of proper criteria reaches the most effective goal. Moreover, universities and campuses should use such installations in combination with installations with solar panel and thus it could provide electricity for all infrastructures. Zeb and his assistants proved that changing dormitories lamps managed to save 15.400 Kwh per month. The use of LED lamps is obligatory for achieving better results. The research projects of Papageorgiou and his colleagues could be used in order to record the quality and kind of lighting and estimate the annual consumption of electricity on those roads. Meaning that bad lighting situations worsen circulation problems and thus may increase maintenance cost either in relation with pavement (the corruption of each pavement depends on its construction technology) or lighting aspects. [19, 20, 21, 22. 23, 24]. In conclusion, smart and intelligent technologies offer a green future with less energy consumption, best ways of management and more effective results.

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