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Intelligent Road Lighting Control Systems - Overview and Case Study

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Abstract – *This paper reviews the present status of intelligent road lighting control systems and presents a case study in Finland. The development in road lighting control has started since light sources started to apply in roads. New technologies in the area of lighting and electronics have led to possibilities of intelligent lighting control. In recent years more attention has been paid to intelligent road lighting control due to energy savings. In this paper, the architecture of intelligent road lighting control system is discussed in detail and the applications in the world are introduced. An intelligent road lighting control system installed in Finland is described and studied. The performance of the lighting control system is evaluated according to the data collected from the system of one year's period. This existing intelligent road lighting control system reveals its virtues in considerable energy savings and expanded flexibility. The paper concludes by summarizing the benefits and drawbacks of intelligent road lighting control systems and by recommending critical considerations for future development of intelligent road lighting control systems.* **Copyright © 2007 Praise Worthy Prize S.r.l. - All rights reserved.**

***Keywords**: Intelligent road lighting control, Energy savings, Dimming, Traffic, Weather*

I. Introduction

The development in road lighting control has started since light sources started to apply in roads. Switching on/off of light sources is the most basic and initial form of lighting control.

With the developments in technology, intelligent lighting control is increasingly used in road lighting during the past decade. An intelligent road lighting control system is defined here, as a modern lighting control system, based on technology of computer science, communication, automation and power electronics, which can automatically collect system information, analyze, deduce and estimate the collected information, and realize the optimum lighting control effect by changing lamp light output according to defined parameters, e.g. traffic volumes, weather conditions, road surface luminance. The main purpose of intelligent road lighting control system is to save electricity and maintenance costs but without losses in traffic safety. From lighting point of view this means providing the optimum luminance level based on the prevailing traffic and weather conditions.

In this paper the architecture of intelligent road lighting control system is introduced, and the state-of-art of the systems is investigated. A case study in Finland is given and the performance of the intelligent road lighting control system is evaluated according to the collected data in the host computer. From the first year's experience, the control system has revealed great energy savings, and high flexibility.

The paper summarizes the benefits and drawbacks of existing intelligent road lighting control systems and recommends considerations in the evaluation and development of the systems.

II. Architecture of Intelligent Road Lighting Control System

Two essential missions of a road lighting control system are monitoring and control. Monitoring lamp status can reduce the maintenance cost by well planned lamp group replacement and reduced routine inspection. Control of lamps can lead to energy savings by lowering the lamp power when less light is enough for traffic. An intelligent road lighting control system consists of control centre (host computers), remote terminal units (also called central controllers), light control units (also called local controllers), ballasts and lamps [1]-[4].

The control centre is normally composed of computers and management software. The main functions of the control centre are collecting and estimating the information of lamps, monitoring the lamp operation, sending demand to remote terminal units, and saving the operation information. In an advanced control system, the control center is connected with illuminance/luminance meter and traffic control centre, so that it can collect illuminance/luminance information and information of weather conditions and traffic volumes, compare the information with preset

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parameters and make the decisions to dim or switch on/off lamps. Remote terminal units are installed in the control cabinets of the road lighting installation. A control cabinet normally contains several lighting contactors, circuit breakers, a timer (optional) and a photosensor (optional). With the employment of microprocessor, remote terminal units can collect field information from light control units and send the information to the control center, receive the commands from the control center and transmit them to light control units. Thus a remote terminal unit has two communication interfaces. One is to communicate with the control center and the other is to communicate with light control units. Light control units receive commands from remote terminal unit and execute the command, and transmit the status information of lamps to the remote terminal unit.

Communication is the key issue in an intelligent road lighting control system. Normally the control center is far from the remote control unit and lamps. There are several communication solutions that can be used. Wireless communications, such as radio and GSM/GPRS are possible solutions with high transmission rate and high capability for large-scale long distance communication [5]. Wireless communication results, however, in relatively high operation costs. Wired communication, such as optic fibre and telephone line, are also possible solutions depending on the budget. The use of optic fibres is very expensive but it has high capability and transmission rate. Telephone line is an economical solution but with low capacity and low transmission rate [5].

Between the remote control unit and light control unit, radio and power line carrier are two possible solutions with reasonable costs. Power line communication is economical due to the existing wires but it is easily affected by interference [6]. Radio communication has better immunity to interference but requires antenna and repeaters [7].

The choice of the communication system depends on the specific applications, requirements, and budget. So there is only the right solution for the right application, but there is no single solution that is better than the others in all cases.

Sensors, meters and cameras are accessory components, but important parts in an intelligent road lighting control system. In most systems, combination of photocells and timers is used to decide the switch on/off time.

An illuminance meter can be used in modifying the time of switch on/off or dimming set by the host computer. Luminance meter is also applied in some applications to provide lighting parameters for the control configuration.

One of the main purposes of intelligent road lighting control system is to achieve energy savings by dimming the lamps according to defined parameters. At present medium-wattage high pressure sodium (HPS) lamps are the most popularly used light sources in road lighting due to their high luminous efficacy. Electronic ballasts have many advantages like low energy consumption and excellent regulation of lamp output, but they are still not as reliable as conventional ballasts [8], [9]. Thus conventional electromagnetic ballasts are still the most commonly used in road lighting [10], [11]. Fig. 1 shows a scheme of electromagnetic ballast with electronic dimming unit of 1-10V control signal, which can realize continuous dimming for HPS lamps from 100% to 20% of light level.

Continuous dimming can also be realized with electromagnetic ballasts by electronic circuit for chopping the wave shape [12]. Electronic ballasts are used in some cases when low to medium wattage High Intensity Discharge (HID) lamps are applied in streets with pedestrians [13], [14].

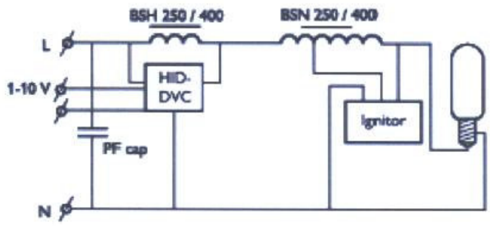

Fig. 1. Diagram of electromagnetic ballast with electronic control [15]

Intelligent road lighting control is still quite new so there are so far no regulations or standards defining the parameters for control configurations. In the existing systems, traffic flows and luminance values are commonly used as input parameters, but further studies are needed to investigate the validity of them while new control parameters may also be introduced.

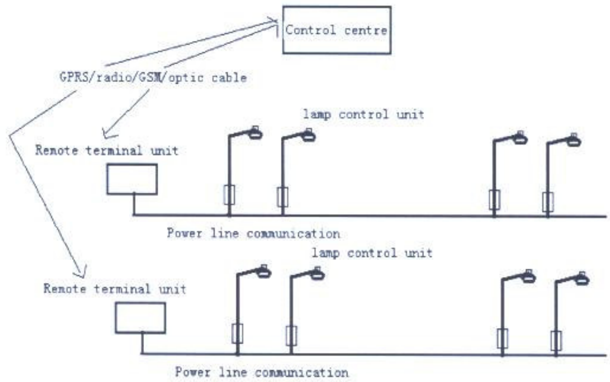

Fig. 2. Basic diagram of an intelligent road lighting control system using power line communication

Fig. 2 shows the basic diagram of an intelligent road lighting control system, which uses power line communication between the remote control unit and lamp control unit.

III. Intelligent Road Lighting Control Systems: an Overview

With employment of intelligent road lighting control system, the most significant benefit is energy savings because the light levels can be decreased according to prevailing traffic and visibility conditions. The maintenance costs can also be reduced because information from individual lamp is collected and analyzed by the control center, and lamp group replacement can be planned according to the lamp information. However, mainly due to the high investment costs, intelligent road lighting control systems have not become general. Most countries are still using traditional road lighting control systems, which can switch on/off or step dim by using a timer and photocell [11], [17]-[20].

'NumeLiTe' is an EU supported project (2002-2004), consisting of a consortium of 11 partners (industrial and academic) coming from 6 European countries exploring the feasibility of developing a new intelligent roadway lighting system with low energy consumption [13], [21], [22]. This project allowed the demonstration of a modern urban lighting scheme in real scale (121 lighting poles installed in the city of Albi in south France). The pilot installation employed 150 W metal halide (MH) lamps, DALI electronic ballast, power-line and radio communication [13]. However, from a strict point of view, this system is not an intelligent control system in the sense that the light levels do not change with control parameters, but the lamps are dimmed to half of rated power at night hours (23:00-6:00). The drawback of the system is that the time of dimming is set, so the light level can not increase when there are more traffic or the visibility is poor due to bad weather conditions.

The number of road lighting installations has dramatically increased during the past decades in China with the construction of roads and streets. At the same time, more attention has been paid to energy savings from efficient use of road lighting. At the end of 2002, road lighting control systems with time control were introduced in some main roads in Shanghai for the purpose of energy savings [16], [17]. At the beginning of 2004, a new updated control system was developed and employed in some pilot installations. Because of the 20% to 35% of energy saving with the system, it is going to be applied in more streets and roads in Shanghai [17]. Wuxi is a middle-scale city 120 km from Shanghai. In this city there are around 110,000 lamps in street and road installations, of which HPS and MH lamps are the most used [23]. In 1992, road lighting control system was installed in Wuxi, which combines time control and light control. Road lamps are switched on and off according to timer and an illuminance meter. During the past years, the system has been updated for several times and by now it controls all the public street and road lighting in the whole city. In Heshan city, in Guangdong Province China, two-stepped dimming is applied in the road lighting control system with time control [10]. Up to 27% of energy savings can be achieved and more lamps will be involved in the control system after the first phase of the project [10].

The above road lighting control systems are not intelligent control systems as the light levels can not change dynamically with external parameters.

Intelligent road lighting control has received more attention and has been applied in practice since the 1990's [14], [24]. In the past decade there has been fast development of these systems with the development of computer science, communication engineering and automation. At the moment, however, there are quite few intelligent road lighting control systems installed, although they have obvious advantages in flexibility and more potential in energy savings compared to traditional control systems.

Due to the efforts of the European lighting companies, Europe is leading in intelligent road lighting control when compared to North America, Australia and Asia [11], [25]-[27].

In Norway, lighting represents 15-20% of the yearly electricity demand and of this 3% is issued in road lighting [24]. For the purpose of energy savings and reduction in maintenance costs, an intelligent road lighting system was built up in Oslo area, Norway in 2002 [24]. Each lamp can be stepless and individually dimmed depending on traffic and weather conditions. In periods when the traffic is low, or when snow covers the roads, the need for light is lower and the road luminance level can be reduced [24]. About 30% of energy savings have been achieved with the system [24]. Further estimation of the system is still ongoing.

In the Netherlands, a dynamic roadway lighting system is installed and can be operated at three levels of luminance, depending on the amount of traffic and weather conditions [10],[28]. The lighting control system operates at 20%, 100% and 200% of normal lighting levels on a 14 km six-lane highway, and the light levels are 0.2 cd/m^2, 1.0 cd/m^2 and 2.0 cd/m^2, respectively [10], [21]. The lighting level settings are listed in Table I. It was found that under low traffic volumes (less than 800 vehicles per hour) and favorable weather conditions, the lowest luminance level (0.2 cd/m^2) can be applied [29]. Accidents rates for the low-level lighting have been acceptable. To continue gathering information on dynamic road lighting, a second system has been installed in the Netherlands, which only operates at road luminance levels 0.2 cd/m^2 and 1 cd/m^2 [21], [29]. Further study is still underway to study the dimming effects on traffic safety and visibility conditions [28].

In UK, motorway M65 in Lancashire introduced an intelligent control system in 2002 [14]. The system chosen for this project included electronic ballasts, power line modem, and a road lighting control system. This system incorporates high frequency electronic ballasts for HPS lamps from 50 W to 250 W [14], [30]. It can offer reductions in ballast losses, an improvement in power factor and longer lamp life. Table II shows the parameters of the control system. About 24% of energy savings have been achieved with this system [14].

TABLE I
LIGHTING LEVEL SETTINGS IN ROADWAY LIGHTING SYSTEM IN THE NETHERLANDS [10]

Light level settings	Conditions
200%	Exceptional conditions such as fog or a combination of rain, high traffic density
100%	High traffic density
20%	Low traffic density late at night

TABLE II
PARAMETERS OF CONTROL SYSTEM IN M65, UK [14]

Vehicles per hour	Light levels
>3000	100%
3000-1500	70%
<1500	50%

There are also other European countries which installed or are aiming to install intelligent road lighting control systems in order to get energy savings [2], [31].

In Canada and U.S.A, there are several installations of intelligent road lighting systems under construction [25]-[27].

The benefits of intelligent road lighting control are obvious, such as reduced maintenance costs in routine inspection, better quality of lighting due to programmed lamp replacement (replace lamps before broken), adjustable luminance levels and reduced energy costs. It is expected that these systems will get more attention and that there will be more applications in the coming years. On the other hand, there are still some uncertainties lying in intelligent road lighting control systems.

At present most of the light sources in road lighting are medium-wattage HID lamps, which are hard to be fully controlled [32], [33]. Dimming may have some negative effects on HID lamps, like reduction in lamp life, and change in lamp parameters like color characteristics [8]. Additionally, dimming of HID lamps may introduce high components of harmonics into the electricity network.

At the moment, there are no guidelines or standards specifying which control parameters should be used for intelligent road lighting control systems. The applications discussed above are utilizing traffic volumes as one major control parameter for the energy saving purposes. This is reasonable, but it is also important to guarantee the traffic safety for low traffic volumes. Road lighting design is based on road surface luminances according to standardized lighting classes [34], [35]. In practice road surface luminances are quite dynamic and change to a large extent with different weather conditions. Thus another control parameter in addition to traffic volumes that can be used is the road surface luminance. By combing the use of road surface luminance and traffic volume as control parameters, driving safety can be guaranteed also at low traffic flows and poor weather conditions. However, careful considerations must be made in selecting different light levels according to traffic volume and weather conditions.

Additionally, intelligent road lighting control systems are very complicated, so there are more possibilities to have some faults considering all the parts and components. The maintenance of hardware and software should be done regularly, which requires high-level management of engineers and workers.

Although there are still some problematic issues existing in intelligent road lighting control systems, they are still promising because of their flexibility and great potential savings in energy consumption and in maintenance costs.

IV. Case Study in Finland

In Finland several intelligent road lighting control systems have been installed recently. The installation of Ring III in Vantaa is introduced in the following (Fig. 3).

An advanced intelligent road lighting system was installed in Vantaa Ring III in autumn 2005 for the purpose of energy savings and low maintenance costs. The control system has been in full use since January 2006 [36].

There are altogether 492 luminaires with 600 W HPS lamps on the 4 km six-lane road [36]. In the installation, the lamp, ballast and luminaire are from the same manufacture, which means that the components can work together harmoniously.

Fig. 3. Ring III installation in Vantaa Finland

The infrastructure of the control system is quite similar as those of the systems discussed in previous sections. The control center (host computer) in the traffic center of Finnish Road Administration collects and analyzes the data of traffic flows, luminance information, and road surface conditions, and makes decisions of dimming by comparing the data with the set values. The decisions or commands are transmitted through telephone lines and power line carrier to the light control unit to dim the lamp. The most challenging feature is that the lamps can be continuously dimmed. After switching on the lighting at the time according to time switch in the system and luminance level, the dimming level of lamps is adjustable with traffic flows and monitored road luminance levels. In this installation, electromagnetic ballasts are employed due to their reliability. The dimming characteristics of HPS lamps are shown in Fig. 4. The controlling method is voltage dimming by triac. The HPS lamps can be dimmed down to 20% of light level and to 35% of rated power. In the Ring III installation, the dimming range is set from 25% to 100% of light level and 40% to 100% of rated power. Although the lamp luminous efficiency is decreased when dimmed, considerable energy savings can still be achieved.

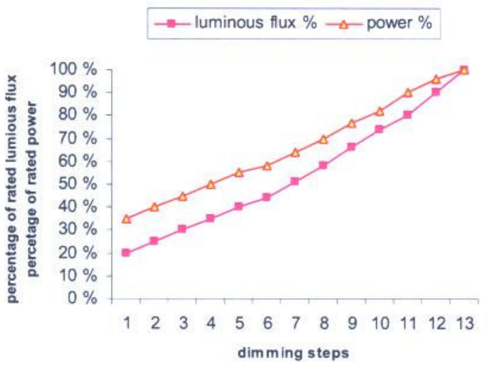

Fig. 4. Dimming characteristics of HPS lamp [15]

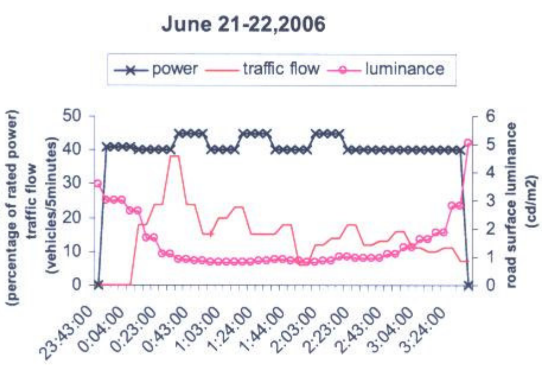

Fig. 5. The lamp power, traffic flow and road luminance level as a function of time on Ring III installation in Finland

In the Ring III installation the luminous output (lamp power) of each lamp changes real-time according to information of road luminance level, humidity of road surface and traffic flow. Fig. 5 illustrates how the lamp power changes with traffic flow and luminance level taking one example from 21-22 June, 2006. Table III shows the parameters of control configuration for the host computer.

TABLE III
PARAMETERS FOR CONTROL CONFIGURATION IN RING III

Traffic flow (vehicles per 5 minutes)	Luminance (cd/m2)	Lamp power (percentage)
1	0.75	40
20	0.85	50
40	1	60
60	1.05	70
80	1.15	80
100	1.3	90
170	1.5	100

In the Ring III the voltage and current of lamps are also monitored by the control system. The information of the lamp is shown in the host computer, as damaged lamp, blinking lamp, link defect (power line cut), and excessive temperature. The host computer can locate the fault lamp and send maintenance workers to fix or replace the fault lamp immediately if it is in critical location. The main reduction in maintenance costs is due to the well planned group replacement so that the lamps are replaced before broken. As the installation has been in use for one year so far, the actual maintenance costs from one lamp group replacement period can not yet be evaluated.

The main motivation to make the installation was to save energy and maintenance costs and to reduce obtrusive light but without decreasing traffic safety. In the first year's experience, the control system has shown its good flexibility and reliability, and has achieved great energy savings. The data from the control center has been analyzed for the whole year 2006, and the results are shown in the Fig. 6 and Fig. 7.The data consists of road surface luminance level, traffic volume, road surface information (wet/not wet) and lamp power (as percentage of rated power), which are recorded at 5 minute intervals. The luminance level is the average value of every 10 minutes. The traffic volume is the total amount of vehicles in 5 minutes from all the six lanes. Fig. 6 illustrates the average daily energy consumption of each luminaire (600 W HPS lamp) in each month from January to December 2006. It is obvious that the energy consumption in June is the lowest due to the long duration of sunshine. November and December have the highest energy consumption because of the darkness in winter time. In theory, the energy consumption in January and December should be bigger than in November, but as there was no snow during November 2006, while full of snow on road surface in January 2006, lower light output and lower energy consumption was needed in January than in November. Fig. 7 shows the average burning hours and average lamp power per day in each month. The average burning hours in June is only 3.7 hours while in December it is 17.5 hours. The average burning hours follow the same trend as average monthly energy consumption, but the average power does not have an obvious trend, because the lamp power is mainly decided by traffic flow which does not vary significantly between months. Fig. 7 also shows that the average power in each month is less than or equal to 60% of rated power. Assuming that the burning hours are the same as those of a conventional lighting system without dimming, it can be deduced that at least 40% of energy savings can be achieved with this intelligent road lighting control system.

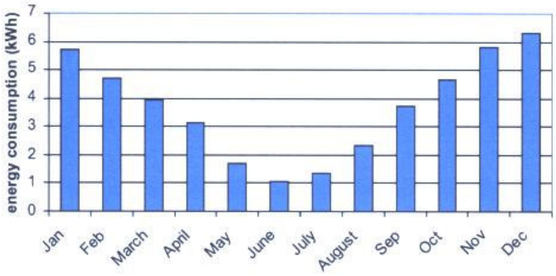

Fig. 6. Average daily energy consumption per luminaire in each month in Ring III road lighting installation in Finland

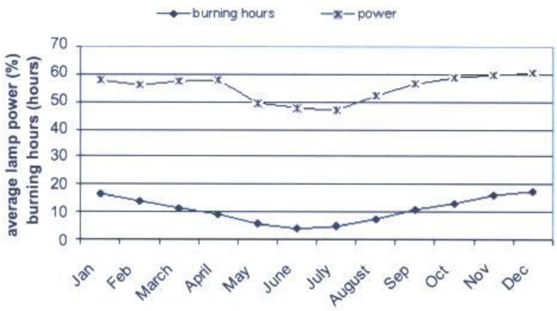

Fig. 7. Average burning hours and lamp power per day in each month in Ring III road lighting installation in Finland

Intelligent road lighting control installation of Ring III has been working properly for one year since its implementation in January 2006. However, there are still some problems existing, e.g., the accuracy of luminance meter in different weather conditions and the management of huge amount of data. Lighting Laboratory of Helsinki University of Technology is doing research to optimize and evaluate the functions of the Ring III control system, so that the right quantity and quality of light can be offered by the control system besides considerable energy savings and savings in maintenance costs.

V. Conclusions

Intelligent road lighting control systems are based on technology of wired/wireless communication, automation, computer science, and power electronics. With the adoption of these new technologies, it is possible to get good quality and right quantity of road lighting. Further more, because of reduction in unnecessary light, 20%~50% expected energy savings can be achieved and light pollution will be reduced significantly. Additionally, the flexibility and intelligence of control system will reduce the maintenance costs and operation costs. It can be expected that there will be more applications of intelligent road lighting control systems due to its good virtues.

On the other hand, careful consideration should be taken into account when employing the intelligent road lighting control systems, such as maintenance costs of the control system components, the update and maintenance of software and database, cost of communication systems, and security issues of communication systems.

At the moment there are still some uncertainties lying in road lighting control. There are no general guidelines to evaluate the behavior of the overall road lighting control system yet. In order to evaluate the performance of the systems, many factors should be taken into account, such as accuracy, flexibility, reliability, real-time information, and EMC (Electromagnetic Compatibility). The quality and quantity of light output, energy savings, and environmental effects should also be taken into consideration. Meanwhile, more study should be done on the standardization of parameters of intelligent control configuration. At present, there are no guidelines or standards specifying which control parameters should be used for intelligent road lighting control systems. Further study is needed to investigate the effects of different weather conditions (e.g. snow, fog, rain) on road surface luminances and luminance distributions, and the effects of intelligent road lighting control on road users and traffic safety.

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