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PROCEDURE FOR CONTINUED URBAN LIGHTING MANAGEMENT EVALUATION

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ABSTRACT

In order to evaluate the urban lighting management, a procedure based on the benefit/cost operation relationship is described. Taking into account several types of facilities under different management and maintenance policies, field surveys were carried out in order to correlate cost and benefits. The collected data as well as historical data provided by lighting maintenance companies were analyzed to formulate and test the proposed procedure. A quantification of the benefit based on such factors as the lighting level, the permanent failure rate, the lighting system operating time, etc. is proposed. The management planning based on a simple procedure allows the implementation of a maintenance policy which can be subsequently adjusted with control data. Finally the results achieved on existing installations are described.

1. INTRODUCTION

The aim of urban lighting is to provide a service to the citizens. This service is restricted, on the one hand, by installation performance characteristics (design and equipment) and, on the other hand, by the use that is made of it. Whereas the performance characteristics are determined at the project stage, the usage is established during management, that is control, maintenance, etc.

In practice it can be seen that, according to the different management policies adopted, service conditions are variable – a situation that often leads to a worsening of service conditions, a reduction of higher costs or to lower profitability of the invested resources, when all these conditions are not given simultaneously. The origin of these situations can be due to:

- lack of concern about the real conditions of the service installations;
- limitations of the necessary economical resources invested, whether for the project or the operational phases; and
- difficulties of the definition of appropriate criteria and policies.

The last two are deeply related to the lack of service quantification level, since they make the decision depend exclusively on cost factors and avoid the positive motivations based on the improvement of the service.

The objective of the paper is to establish the bases of a decision and control procedures permitting to guarantee an adequate service level and at the same time to make the economical resources invested efficiently profitable. The procedure would be based on the application of *benefit/cost* criteria for the optimization of the *decisions* and as a way of *controlling* the results.

2. DATA ANALYSIS

In order to evaluate the state of lighting management and its relation with service conditions a series of studies and experiments have been made: *a)* compilation and analysis of data tending to evaluate the effect of the lack of management over energy costs; *b)* surveys enabling lighting managers to determine characteristics of the installations (lamp type, luminaires, operation period, number), maintenance policy, budget, types of contracted tariffs, etc.; *c)* evaluation of the state of installation opera-

* A report on the 24th CIE Session, June 24-30, 1999, Warsaw.

tion; and *d)* analysis of databases from the historical records of lighting installation maintenance operations. The results of greatest interest for this study are now summarized:

a) Energy costs experience variations with respect to normal values due to lack of management and maintenance. Increases in active energy consumption due to overvoltage and lack of maintenance in control switch devices, reactive energy consumption and inappropriate tariff contracts, cause increases of urban lighting costs. These factors and their effects are analyzed in a previous paper [1].

b) The maintenance policies frequently applied are correctives, that is, faults repair at the light point, control panel, electric lines, etc. once they have been detected by inspection, etc. This policy is generally complemented with preventive actions such as programmed group lamp replacement and programmed group luminaire cleaning. The replacement period varies between 2 and 4 years depending on the municipality decision or the type of contract. It is usual to join replacement and cleaning operations to reduce costs. The operating costs are easily quantified when this work is done by a contracted maintenance company. These costs vary between 5,000 and 7,000 Pta. per luminaire-year. Special repairing (i.e., subterranean lines) are treated separately [1].

c) To evaluate the operation of the installations three villages with different maintenance policies have been selected. The average horizontal illuminance over the road (Eh_{ave}) before and after luminaire cleaning and lamp replacement was measured at representative streets. The installations had luminaires with IP54 or greater. In villages *Be (3,500 inhabitanis/900 luminaires)* and *StB (80,000 inhabitants/6,300 luminaires)*, both with corrective (includes spot lamp replacement, SR) and preventive policies (every 2 years group lamp replacement, GR, and group luminaire cleaning, GC) implemented by external maintenance contractor, the observed average depreciation (relation of Eh_{ave} before and after cleaning and lamp replacement) was **0.9**; while for village *EM (1,800 luminaires/20,000 inhabitants)*, with only corrective policy (SR) implemented with their own resources, the average depreciation was **0.6**.

d) The number of failed lamps in proportion to the installed ones in a random sample of streets has been used to estimate the percentage of permanent failed luminaires (PFL). In Figure 2 the frequency distribution of PFL is indicated for 21 villages' survey in Catalunya, Spain. The observed average is 2.9%. However, in villages *Be* and *StB, with appropriate maintenance, PFL is lower than 1%.*

The accumulated effect of depreciation and PFL produces up to 30% difference in the quality service according to the policy followed.

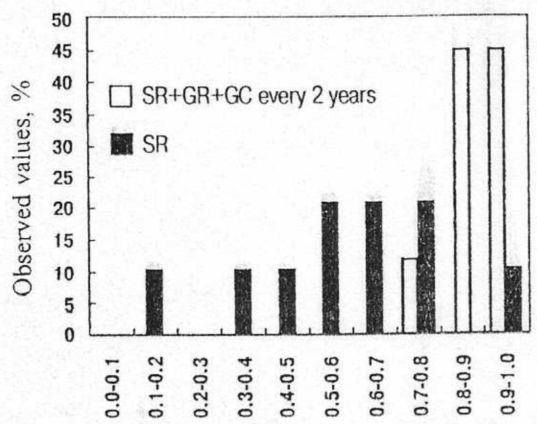

Fig. 1. Influence of lighting management strategies over the maintenance factor. SR: spot lamp replacement, GR+GC: Group lamp replacement and group luminaire cleaning.

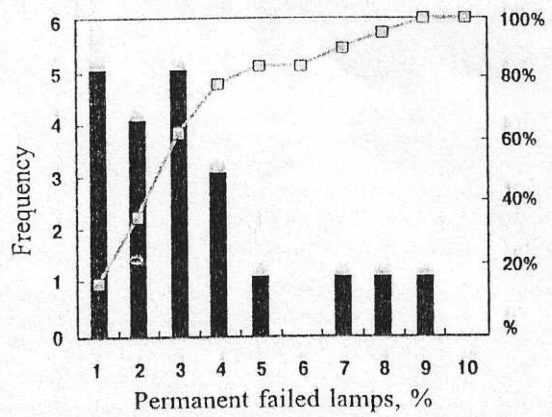

Fig. 2. Frequency distribution of percentage of permanent failed lamps (PFL) in 21 villages in Catalunya, Spain [2].

Table 1

Distribution of Maintenance Operations for Urban Lighting Installations Based on Data Analysis

Operations			
Preventive	50%		
Corrective maintenance	50%	Light points	72%
		Control panels	25%
		Electric wiring	3%
Total	100%		100%

Table 2

Factor $K(E)$

	$E < E_{min}/2$	$E_{min}/2 \le E < E_{min}$	$E \ge E_{min}$
$K(E)$	0	$(2E/E_{min}) - 1$	1

e) Data covering a period of 6 years (1992-1998) and based on a survey of a city where a maintenance company employed a policy of SR and GR every 3 years, and GC every 2 years, were analyzed.

A review of the different maintenance operations performed are shown in Table 1. A total of 72% of the corrective maintenance operations occurred at light points (luminaire + control gear + column + fuse, etc.), including 54% as a result of lamp failures, which is indicative of the importance of this component in the evaluation of costs and security of service.

Analyzing the time passed from a GR until the first spot lamp replacement occurs (failure between GR, excluding vandalism and false contacts), survival curves are obtained under actual burning conditions. Results obtained are indicated in Figure 3 for C.C. mercury lamps (Merc.) and in Figure 4 for high-pressure sodium lamps (HPS).

Regarding the behavior during the manufacturer's tests, noticeable differences can be observed possibly due to the fact that actual burning conditions differ from those under laboratory tests.

From the results obtained it can be deduced that in practice a great variability of conditions appears, leading to a deviation from theoretical behavior.

A service level quantifying indicator would permit an evaluation, which, if necessary, could be complemented with a study of each factor in particular.

3. BENEFIT/COST RATIO

A procedure based on the determination of the benefits/annual operating costs ratio for planning and controlling lighting management requires that both the benefits and costs be established and quantified.

The benefit for citizens and road drivers from urban lighting is to find appropriate visual conditions to proceed in safety, creating an ambient of security and comfortable use. Quantifying these aspects presents certain difficulty. This is why it is convenient to look for a more operative indicator relating to the lighting level ($K(E)$), the necessary operating time ($K(T_0)$), reliability and failure duration ($K(PFL)$), and other aspects like the electrical and mechanical safety of the system ($K(S)$), the appearance of the installation, namely, aesthetics, light color, etc., ($K(A)$), and the illuminated area (A). The benefit can be defined as the multiplication of these factors, where the relative weight of each one is considered the same for the moment.

$K(E)$ depends on the road average illuminance (E), which, in spite of known limitations, is chosen as a magnitude representative of the lighting level due to its measurement facility, low cost of measurement equipment and to the fact that it can be compared with reference values conveniently established. Minimum maintained values are used as reference (E_m).

$K(E)$ varies according to Table 2.

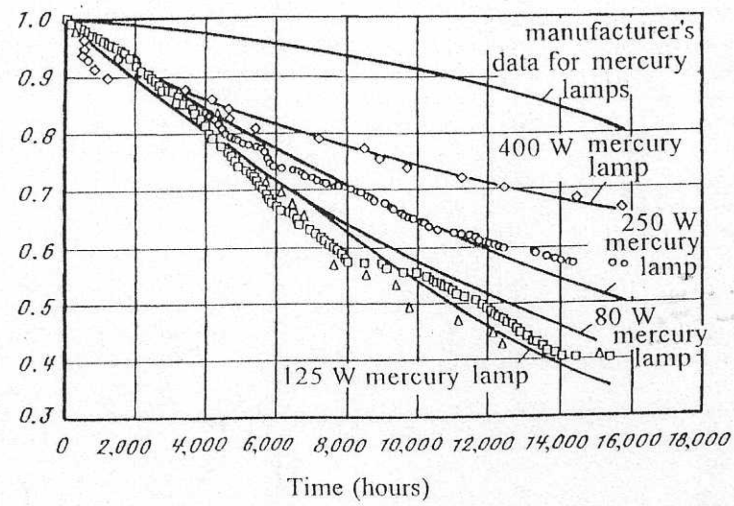

Fig. 3. Lamp survival data for 80, 125, 250, and 400 W mercury lamps with Weibull regression functions and the manufacturer's average LSF.

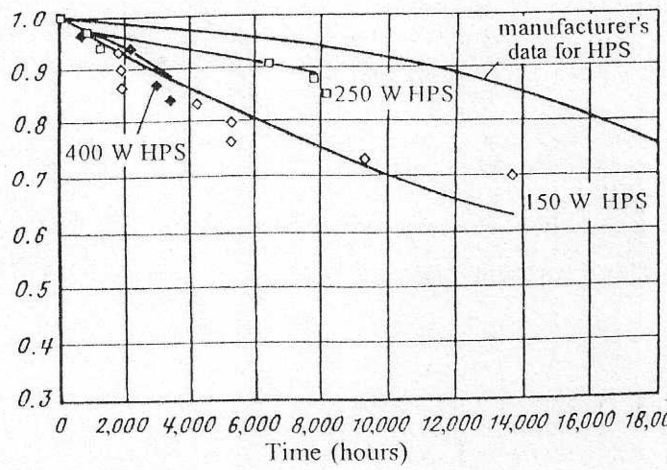

Fig. 4. Lamp survival data for 150, 250, 400 W HPS lamps with Weibull regression functions and the manufacturer's average LSF.

Table 3

Maintenance Factor According to Maintenance Strategy

Strategy	Maintenance factor
GR+GC: Group lamp replacement + group luminaire cleaning	LLMF × LMF
SR+GR+GC: Spot lamp replacement + group lamp replacement + group luminaire cleaning	
SR+GC: Spot lamp replacement + group luminaire cleaning	(LLMF average value from 0 to $2T_{50\%}$) × LMF [2]
SR+SC: Spot lamp replacement + simultaneous luminaire cleaning	(LLMF average value from 0 to $2T_{50\%}$) × (LMF average value from 0 to $2T_{50\%}/T_0$) [2]

$T_{50\%}$: average rated life, time over which LSF falls to 50% in reference conditions. T_0: annual lamp operating time [hours].

Table 4

Factor $K(PFL)$

PFL	$\leq PFL_{min}$	$PFL_{min} < PFL < PFL_{max}$	$> PFL_{max}$
$K(PFL)$	1	$1 - (PFL - PFL_{min}) / (PFL_{max} - PFL_{min})$	0

The illuminance decreases with time, starting from the initial values when installation is new (E_m), because of depreciation due to reduction of lamp lumen output (lamp lumen maintenance factor, LLMF), lamp failures (lamp survival factor, LSF) and the reduction of luminaire output flux by aging and dirt accumulation (luminaire maintenance factor – LMF). The multiplication of these factors gives the maintenance factor (MF). LSF has not been considered in MF. For uniform luminaire arrangement, that is indoor lighting case, random lamp failures affect the average illuminance. In road lighting one frequently finds a regular row distribution of the luminaires where one lamp failure produces a dark area instead of reducing the average illuminance, which is why LSF is not considered in MF. After a certain period of time:

$$E = E_{in} \times MF \,. \quad (1)$$

Maintenance counteracts depreciation, therefore E will depend on the adopted policy. With the purpose of making a more general analysis, different possible maintenance strategies have been assumed, for which the MF is indicated in Table 3.

LMF curves for different degrees of ingress protection IP and pollution are used from BS 5489 [3] and LLMF curves are employed from the manufacturer's average data.

Similar considerations from $K(E)$ are used for the necessary operating time factor $K(T_O)$. The reference used is T_{OR}, that is annual necessary operating time which depends on the geographical situation. For $T_O < T_{OR}$, $K(T_O) = T_O / T_{OR}$.

The system reliability factor is described by the percentage of permanent luminaire failures observed, $K(PFL)$ accepting a first limit (PFL_{min}) from which the factor decreases lineally up to an unacceptable second limit when benefit is null (PFL_{max}) (*see* Table 4).

The other factors involved will be the subject of a future discussion.

Table 5

Data Obtained from Existing Installations as an Example

E_{in}: 30 lux, E_m: 21 lux
Luminaire per K_m: 29
Road width: 10 m, road length: 1,000 m
Lamp: 250 W HPS
Luminaire ingress protection code: IP6.
Height: 12 m. Utilization factor: 0.33
Atmosphere pollution: Normal
Capital amortization period: 15 years
Typical annual lamp operating time: 4,270 hs/year
Actual annual lamp operating time: 4,270 hs/year
Energy cost: 15 Pta/kWh
PFL_{min}: 2%, PFL_{max}: 20%, PFL: 2%
<u>Costs per luminaire:</u>
Labor group lamp replacement: 3,410 Pta.
Labor group luminaire cleaning: 3,410 Pta.
Labor group lamp replacement & luminaire cleaning: 4,488 Pta.
Labor spot lamp replacement: 6,732 Pta.
Labor spot lamp replacement & simultaneous cleaning: 8,976 Pta.
Installation with IP6: 188,000 Pta.

It is considered that illumining regulation for energy saving purposes at certain night hours when traffic or pedestrian presence is reduced will not affect the benefit if the decision was correctly taken, for instance, if it does not affect personal security, etc. The additional equipment cost has to be compensated by energy cost savings.

The benefit can be quantified as:

$$B = K(E) \times K(T_O) \times K(PFL) \times A. \quad (2)$$

Table 6

Minimum Annual Operating Costs and Benefit/AOC for MF ≥ 0.7 (Luminaire IP6)

Strategies	Interval		MF	AOC [Pta.]		B/AOC
	R	C		M	Total	
GR+GC	65	65	0.70	57,565	953,465	0
GR+GC+SR	38	38	0.75	149,527	1,045,428	0.96
SR+GC		>66	0.72	84,611	980,512	1.0
SR+SC			0.73	78,136	974,037	1.0

R: Lamp replacement period [month]; C: Luminaire cleaning period [month]; M: Maintenance annual cost.

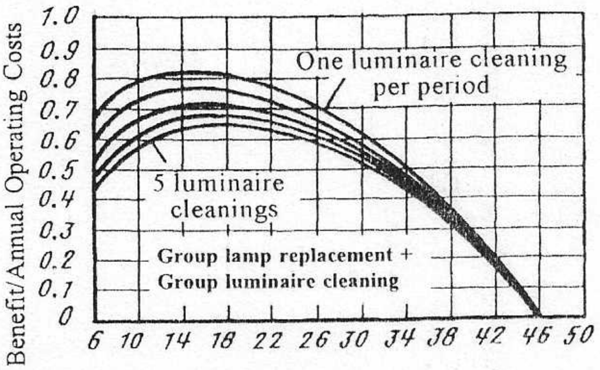

Fig. 5. Data for B/AOC with GR+GC listed as an example.

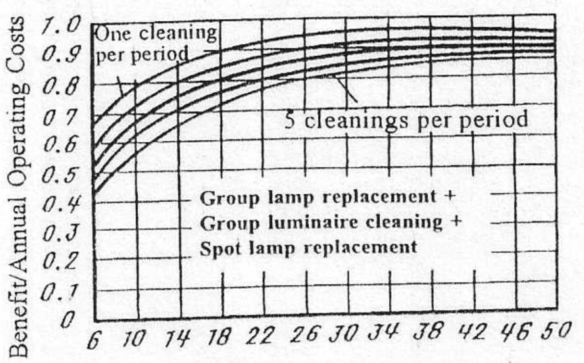

Fig. 6. Data for B/AOC with SR+GR+GC listed as an example.

The annual operating costs (AOC) of a lighting installation can be grouped in:

- Capital: the annual amortization costs against invested capital;
- Energy: active and reactive consumption;
- Management: maintenance operations, control, inspection, administrative measures, etc.

Because the lamp is the component that requires more care, additional corrective operating costs can be attributed to the lamp. Replacement costs are estimated by the use of LSF curves from the manufacturer's and other data in Figures 3 and 4.

4. EXAMPLE OF POLICY APPLICATION

By using a program, costs and benefits relating to existing installations are possible to evaluate under several maintenance policies or strategies for different group lamp replacement periods and group luminaire cleaning frequency.

Installation data are analyzed under two criteria: *a)* minimum AOC for MF ≥ 0.7 and *b)* maximum Benefit/AOC. The results obtained using LSF curves from manufacturers are compared with those obtained from historical records (Figs. 3 and 4). Installation dates are indicated in Table 5. B/AOC is affected by a constant factor scale, making it vary between 0 and 1.

Results for the criterion *a* are summarized in Table 6 and for the criterion *b* in Table 7. First, it is observed that the policy **GR+GC** leads to minor costs by applying the AOC minimum criterion, that is, the more the maintenance is postponed, the more economical it would be. However, the B/AOC ratio is null due to the fact that PFL is very low in this case. Nevertheless, for the criterion B/AOC maximum the curve presents an inflection point for a 14 months period of lamp replacement and luminaire cleaning (*see* Fig. 5), but under this criterion the other policies present a greater B/AOC ratio,

Table 7

AOC & Maximum B/AOC Both for MF ≥ 0.7 and Luminaire IP6-N

Strategies	Interval		MF	AOC [Pta.]		B/AOC
	R	C		M	Total	
GR+GC	14	14	0.85	267,264	1,163,165	0.81
GR+GC+SR	38	38	0.75	149,527	1,045,428	0.96
SR+GC		>66	0.72	84,611	980,512	1.0
SR+SC			0.73	78,136	974,037	1.0

Table 8

AOC & Maximum B/AOC Both for MF ≥ 0.7 and LSF from Historical Records (IP6-N)

Strategies	Interval		MF	AOC [Pta.]		B/AOC
	R	C		M	Total	
GR+GC	9	9	0.89	415,744	1,311,645	0.67
GR+GC+SR	34	34	0.76	190,446	1,086,347	0.92
SR+GC		>66	0.73	96,036	991,937	1.0
SR+SC			0.74	91,534	987,435	1.0

Table 9

Minimum AOC & B/AOC Both for MF ≥ 0.7 and Luminaire IP2-N

Strategies	Interval		MF	AOC [Pta.]		B/AOC
	R	C		M	Total	
GR+GC	23	4.6	0.70	369,062	1,217,214	0.64
GR+GC+SR	23	4.6	0.70	391,230	1,239,383	0.80
SR+GC		6	0.60	264,411	1,112,563	0.64
SR+SC			0.47	78,136	926,288	0.36

Table 10

AOC & Maximum B/AOC Both for MF ≥ 0.7 and Luminaire IP2-N

Strategies	Interval		MF	AOC [Pta.]		B/AOC
	R	C		M	Total	
GR+GC	11	5.5	0.70	448,034	1,296,187	0.76
GR+GC+SR	19	4.7	0.70	401,133	1,249,285	0.80
SR+GC		6	0.60	264,411	1,112,563	0.64
SR+SC			0.47	78,136	926,288	0.36

SR+GR being the most convenient from this point of view. It is interesting to point out that under this policy new lamps will coexist with the old depreciated ones still working, but with an average MF acceptable in theory. Similar conclusions, but with greater AOC and shorter replacement and cleaning periods, can be reached by using the survival curves with historical data (*see* Table 8).

Figure 6 shows the case for **SM+LM+SC** where the replacement and cleaning periods are the same for both criteria.

If luminaires IP2 are used (cost per light point 163,000 Pta.), the policies **SR+GC** and **SR+SC** would not be the more indicated, because with MF < 0.7 they give uncceptable illuminance values, **SR+GR+GC** being the most convenient for the B/AOC maximum.

5. CONCLUSIONS

The benefit/annual operating costs ratio can be used as a decisive criterion to establish the maintenance policy, lamp replacement period and cleaning frequency. In spite of the fact that benefit quantification can be discussed, its use allows a more complete judgment of the situation.

The optimization procedures according to the maximum B/AOC and minimum AOC criteria differ in some cases only quantitatively, but in others they can lead to different conclusions.

The inclusion of actual control parameters can affect the results allowing a continual evaluation process that could be employed as a tool to stimulate efficient social use. At the present time the study continues in that direction.

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REFERENCES

1. San Martín, R., Manzano, E.R., "A Study of Indirect Energy Cost Due to Reduced Urban Lighting Maintenance." Proceedings of the CIBSE National Lighting Conference, pp. 219-223, UK, 1998.

2. Universitat Politècnica de Catalunya: Encuestas sobre Gestión del Alumbrado en Ayuntamientos de Cataluña, España, en colaboración con los alumnos de la asignatura Proyectos, 1997-1998.

3. Marsden, A.M., "The Economics of Lighting Maintenance." *Lighting Research & Technology*, 25, UK, 1993, pp. 112-125.

4. British standard: BS 5489 Road Lighting, Part 1, 1992.

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