CONSIDERATIONS FOR URBAN LIGHTING MANAGEMENT EVALUATION

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Abstract

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

1. Introduction

The aim of urban lighting is to provide a service to the citizens. This service is restricted on one hand by installation performance features, (designee and equipment) and on the other hand by the use that is made of it. Whereas the performance features are determined at the project stage the usage is established during management, that is control, maintenance, etc.
In practice it can be seen that service conditions are variable, according to the different management policies adopted, situation that often leads to a reduction of service conditions, higher costs, or to a 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
- difficulties on 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 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 procedure to guarantee an adequate service level and at the same time to make the economical resources invested efficiently profitable. The procedure would be based in the application of benefit/cost criteria for the optimisation of the decisions and as a way of controlling the results.

2. State of lighting management

In order to evaluate the state of lighting management and its relation with service conditions a series of studies and experiences have been made: **a)** compilation and analysis of data tending to evaluate the effect of the lack of management over energetic costs, **b)** surveys to the lighting managers to determine characteristics of the installations (lamps type, luminaries, age, number), maintenance policy, budget, types of contracted tariffs, etc., **c)** evaluation of the state of installations operation, **d)** analysis of data bases from historical records of lighting installations maintenance operations.

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The results of greatest interest for this study are now summarised.

a) Energy costs experience variations with respect to normal values due to lack of management and maintenance. Increases in active energy consumption due to over-voltage 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 analysed in a previous paper [1].

b) The maintenance policies frequently applied are: correctives: faults repair at the light unit, 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 lamps replacement and programmed group luminaries cleaning. The replacement period varies between 2 and 4 years depending of the municipality decision or of the type of contract. It is usual to join replacement and cleaning operations to reduce costs. The operation costs are easily quantified when it is executed by a contracted maintenance company. These costs vary between 5.000 and 7.000 Pta. per luminaire-year. Specials repairing (i.e.. subterranean lines) are treated separately [1].

c*)* To evaluate the lighting installations operational condition according to the management policy, four cities with different maintenance policies were studied.

Table 1: Average depreciation in four cities

City	Population	Light units	Policy	Total ave. depreciation
Be.			SR +	0.88
St. B.	80.000	6.300	GR+GC	0.77
E.M.	20.000	1.800	SR	0.60
Gi.	71.000	13.000		0.72

SR: spot lamp replacement. GR+GC: group lamp replacement (GR) and group luminaire cleaning (GC) booth every 2 years, done by an external maintenance contractor.

Illuminance measurements were recorded before and after cleaning luminaries and after lamp replacement. This task was done at representative streets. The illuminance sensor head was located under the luminaries shielded by a short pipe to isolate them from other light sources. Total average depreciation observed is indicated in Table 1.

The number of failed lamps regarding to the installed ones in a random sample of streets has been used as an estimator of the percentage of permanent failed luminaries (PFL). For 21 village's from Catalunya, Spain, the average PFL is 2.9 %. However, with appropriate maintenance PFL is lower than 1%.

d) Data covering a period of 6 years (92-98), from a city where a maintenance Co. employing a policy with SR, GR every 3 years, and GC every 2 years, were analysed.

Table 2: Distribution of maintenance operations for urban lighting installations from data analysis.

Operations			
Preventive	50%		
Corrective maintenance	50%	**Lighting units**	72%
		Control panels	25%
		Electric wiring	3%
Total	100%		100%

A review of the different maintenance operations performed are shown in Table 2. 72% of the corrective maintenance operations take place at the light units (luminaire+control gear+pole+fuse etc.) were of these, 54% corresponded to lamp failures, which is indicative of the importance of this component in the evaluation of costs and security of service.

Analysing 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 Fig.1 for C.C. mercury lamps (Merc.) and in Fig. 2 for high pressure sodium lamps (HPS).

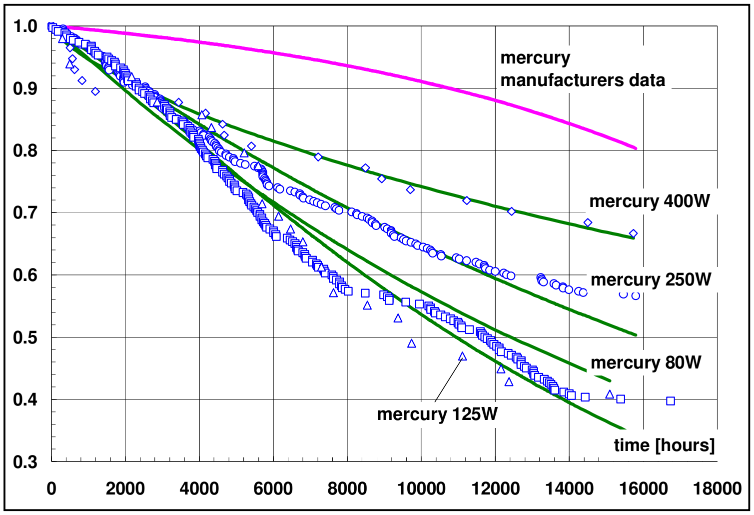


Figure 1: Lamp survival data for 80, 125, 250, 400W mercury lamps with Weibull regression functions and average manufacturer LSF.

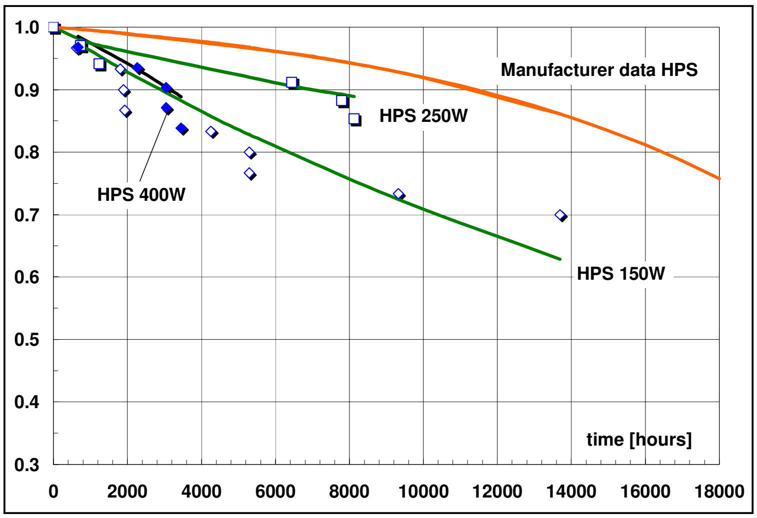


Figure 2: Lamp survival data for HPS 150, 250, 400W lamps with Weibull regression functions and average manufacturers LSF.

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

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

A service level quantifying indicator would permit and 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 ratio benefits /annual operation costs, for planning and controlling lighting management, requires to establish which are the benefits and costs and to quantify both.

The benefit for citizen and road drivers from urban lighting is to find appropriate visual conditions to proceed 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, lighting level (K(E)), the necessary operation time ($K(T_O)$), reliability and failure duration (K(PFL)), and other aspects like the electrical and mechanical safety of the system, the appearance of the installation (aesthetics, light colour, etc). 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.
The benefit can be quantified as:

$$B = K(E) \times K(T_O) \times K(PFL) \quad (1)$$

K(E) depends of the road average iluminance (E), which limitations, in spite to be known is chosen as a magnitude representative of the lighting level due to its measurement facility, low cost of measurement equipment's, use habit and besides 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 3.

Table 3: Factor K(E)

E	**E** $<E_m/2$	$E_m/2 \le$ **E** $< E_m$	**E** $\ge E_m$
K(E)	0	$(2\mathbf{E}/E_m)-1$	1

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

$$E = E_{in} \times MF \qquad (2)$$

Maintenance counteracts depreciation, therefore E will depend of 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 4.

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

Similar considerations from K(E) are used for the factor **K(T_O)**, the operation time The scheduled reference time used is T_{OR} , that is annual necessary operating time which depends of the geographical situation (refer to table 5)

The system reliability factor is described by the percentage of permanent failure luminaire observed, **K(PFL)** accepting a first limit (PFL_{min}) from which the factor decreases lineally up to an unacceptable second limit were benefit is null (PFL_{max}) (refer to table 6).

Table 4: Maintenance factor according to maintenance strategy.

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

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

Table 5: Factor K(To)

T_O	$T_O<0{,}95*T_{OR}$	$0{,}95*T_{OR}< T_O< T_{OR}$	$T_O \geq T_{OR}$
K(To)	1	T_O/T_{OR}	1

Table 6: 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 remaining factors involved will be the subject of a future discussion.

It is consider that illumining regulation for saving energy purposes at certain night hours when traffic or pedestrian presence is reduced, is consider that 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 annual operational costs (AOC) of a lighting installation can be grouped in:

- Capital: the annual amortisation cost from invested capital
- Energy: active and reactive consumption
- Management: maintenance operations, control, inspections, administrative etc.

Because the lamp is the component that requires more care the additional corrective operational costs can be associated to lamp. Replacement cost are estimated by the use of LSF curves from manufacturer and from data of figures 1 and 2.

4. Application example

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

Installation data (table 7) are analysed under two criteria, ***a)*** minimum AOC for FM ≥ 0,7 and ***b)*** maximum Benefit/AOC. The results obtained using LSF curves from manufactures are compared with those from obtained from historical records (fig. 1 and 2). B/AOC is affected by a constant in order to make it vary between 0 and 1.

Results for criteria ***a*** are summarised in table 8 and for criteria ***b*** in table 9. First, it is observed that the policy **GR+GC** leads to minor costs by applying the AOC minimum criteria, that is, the more the maintenance is postponed the more economic it would result, however, the relation B/COA is null due to the fact that PFL is very low in this case. Nevertheless, for the criteria B/AOC maximum the curve presents an inflection point for a 14 months period of lamp replacement and luminaire cleaning (see fig. 3), but under this criteria the remaining policies present a greater ratio B/AOC, being **SR+GR** the most convenient from this point of view. It is interesting to point out that under this last policy there will be a coexistence of new lamps with the old depreciated ones still working, but with an average FM 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 10).

In Fig. 4 is presented the case for **SM+LM+SC** where the replacement and cleaning periods are the same for both criteria.

If luminaries IP2 are used (cost per light-unit 163.000 Pta) the policies **SR+GC** and **SR+SC** would not be the more indicated, because FM<0.7 giving illuminance values not acceptable, being instead **SR+GR+GC** the most convenient for the criteria B/AOC maximum (refer to table 11 and 12).

Table 7: example installation data

E_{in}: 30 lux , E_m: 21 lux
Luminaire per Km: 29
Road with: 10m, road length: 1000m
Lamp: HPS 250W
Luminaire ingress protection code:IP6,
High: 12m, Utilisation factor: 0,33
Atmosphere pollution :Normal
Capital amortisation period: 15 years
Typical annual lamp operation time: 4270hs/year
Actual annual lamp operation time: 4270hs/year
Energy cost: 15 Pta/ kWh
PFL_{min}: 2% , PFL_{max}: 20% , PFL: 2%
<u>Costs per luminaire:</u>
Labour group lamp replacement: 3.410 Pta.
Labour group luminaire cleaning: 3.410 Pta.
Labour group lamp replacement & luminaire cleaning: 4.488 Pta.
Labour spot lamp replacement: 6.732 Pta.
Labour spot lamp replacement & simultaneous cleaning: 8.976 Pta.
Installation with IP6 luminaire : 188.000 Pta.

Table 8: Minimum Annual Operation 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

Table 9: 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 10: 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

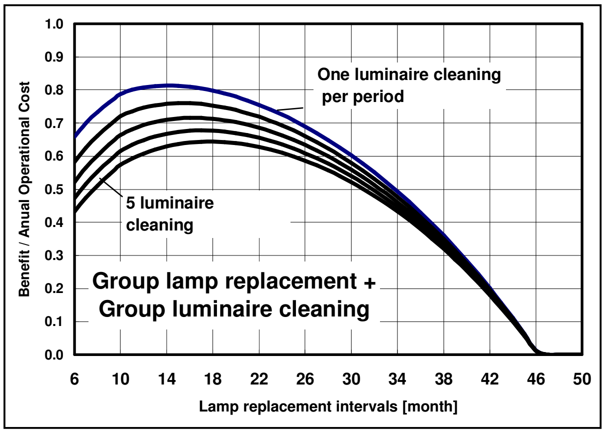
Table 11: Minimum AOC & B/AOC both for MF ≥ 0,7 and luminaire **IP2-N**

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 12: 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	1.249285	0,80
SR+GC		6	0,60	264.411	1.112.563	0,64
SR+SC			0,47	78.136	926.288	0.36

Figure 3: B/AOC with GR+GC for example data.



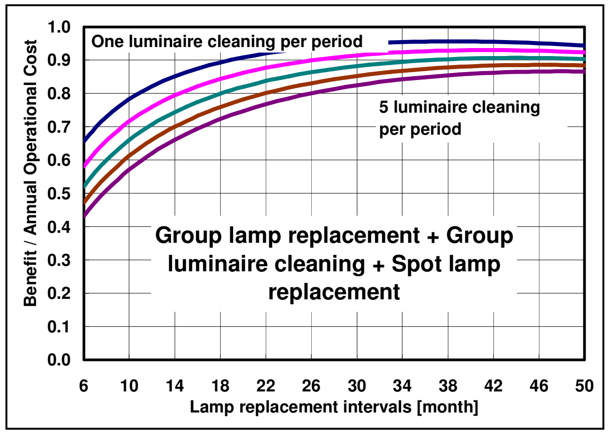


Figure 4: B/AOC with SR+GR+GC for example data.

5. Conclusions

The relationship Benefit/Annual Operational Cost can be used as a decision criteria to establish the maintenance policy, lamp replacement period and cleaning frequency. In spite of the fact that benefit quantification can be discussed, nevertheless its use allows a more complete judgement of the situation.

The optimisation procedure according to maximum B/AOC and minimum AOC criteria differ in some cases only quantitatively, but in others it can guide to different conclusions.

The inclusion of actual control parameters can affect the results allowing a continue evaluation process that could useful as a tool to incentive the efficient social use. The study continues at the present time in that direction.

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