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Public street lighting service standard assessment and achievement

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ABSTRACT

Nighttime lighting is an important public service that impacts human activities and promotes transportation and pedestrian safety. Of course, such services are not free and have been found to have negative impacts on the environment. Responsible stewardship of the built environment requires that efficiency and care in the delivery of services be taken, particularly in the context of sustainability concerns. A significant problem with existing urban infrastructure systems like street lighting is that they have evolved over time using rule-of-thumb planning standards. Given this, systematic assessment and re-evaluation offers much potential for enhancing the spatial efficiency of infrastructure but also the opportunity to explicitly account for environmental impacts in combination with safety and security. This paper applies a methodology for studying lighting in urban areas based upon the use of spatial analytics, including GIS and spatial optimization. Findings and results are reported for a study area in San Diego, California, highlighting current system configuration issues, method development and the potential long term benefits of systematic analysis of public sector services.

1. Introduction

Street lighting is an important component of the built environment, contributing to the charm and character of neighborhoods and business districts alike but also serving to make areas safer in various ways. Lighting can reduce crime and violence as well as decrease the likelihood of pedestrian, bike and/or vehicle accidents. Yet, there are quantifiable costs to providing public lighting, consuming significant tax dollars to maintain and operate not to mention the environmental impacts attributable to electricity generation/usage, product manufacturing, etc. Of course there are many non-quantifiable impacts as well, such as physiological disruptions, general altering and reshaping of ecosystems, and contributing to light pollution. Because of the contrast of benefits and impacts, street lighting is a curious public service. Traditionally little systematic planning of spatial efficiency has gone into street lighting, especially once lights have been installed. Increasingly, however, communities across the globe are rethinking street lighting in various ways. Some communities have turned them off to save money. Others have begun to explore more energy efficient alternatives. What has not yet happened is system-wide re-assessment of street lighting that takes into account competing objectives and concerns.

The benefits of nighttime lighting are very compelling, no doubt justifying their widespread adoption. Street lighting reduces/eliminates opportunities for criminal behavior that can be attributable to urban layout and structure, but also the fear of crime [22]. The reason for this is that light increases surveillance potential, improving visibility and making perpetrator detection more likely. Beyond this, lighting can reduce the chance of pedestrian, bike and vehicle (or some combination thereof) accidents [23,31]. Finally, lighting enhances community pride, neighborhood cohesiveness, and informal social control [18].

The impacts of artificial nighttime lighting are also undeniable, consuming nearly 20% of total global electricity and accounting for greenhouse gas emissions of some 1900 Mt of CO_2 per year [43]. Of course, electricity consumption translates into real operational costs for public street lighting. Continuing economic challenges are proving to be motivators for cities and communities (Detroit, Colorado Springs, Santa Rosa, Rockford and others in the U.S. and Surrey, Essex, Northamptonshire and others in the UK) to dim, turn off or remove street lighting in order to save thousands to millions of dollars per year [4,5,14,21]. Beyond direct operational costs, lighting has been found to have serious physiological impacts on humans as well as animal and plant populations [19,25,44]. For humans, this includes disrupting sleep patterns, increased risk of cancer and degraded air quality. For animals, the impacts of

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artificial light have been linked to adverse changes in feeding, reproduction and migration patterns [29,45].

Nighttime lighting of streets is an interesting planning problem given the compelling need for light yet there are competing considerations having to do with costs and impacts. To support a balanced assessment as well as contribute to informed planning and management, this paper details a framework for assessing/planning public street lighting based on location modeling. The next section offers a literature review, including street lighting standards relied upon in planning as well as spatial optimization modeling research. This is followed by details regarding the applied analytical framework, including the specification of the location model. Case study results are then presented. The paper ends with discussion and concluding comments.

2. Background

The provision of public street lighting is essentially regulated through local planning standards and guidelines derived from state/federal agencies. A prominent resource for establishing standards and guidelines is the U.S. Department of Transportation, Federal Highway Administration, and in particular the FHWA Lighting Handbook [31]. This handbook details appropriate street light layouts, such as one-sided, opposite, staggered, median, etc., depending on the type of road but also based on illumination levels. Important here is that desired lighting quality will dictate appropriate street light spacing. Given lighting technology, there is an explicit expectation that a methodology will be employed to minimize the number of street lights needed [31]: 59):

“To lay out poles, the designer must undertake lighting calculations to define optimal pole spacing. Once maximum pole spacing is defined, one can lay out poles on the road drawings using a calculator and scale rule. The design should lay out poles locating a pole at a start points such as cross street, then spacing the poles evenly within the maximum pole spacing defined by the calculations … The pole spacing may need to be adjusted to suit driveways and utility conflicts.”

The assumption then is that based on light quality and technology, an industry established standard, S, is adopted that reflects the appropriate and meaningful spacing of street lights for an area/region. The IES Lighting Handbook [15], as an example, provides specifics on different luminaire spacing layouts given S, but also how spacing should be reduced as a fraction of S when curves and hills are encountered depending on the abruptness of change.

The standards/guidelines are operationalized in fairly consistent ways by local municipalities. As an example, the City of San Diego [11] mandates:

- Street lighting at intersections
- Staggered street lighting at intervals not to exceed 300 ft. (S=300) for mid-block residential and collector streets (or not to exceed 150 ft within 1320 ft of transit stop or in high crime census tracts)
- Both side street lighting at intervals not to exceed 300 ft. (S=300) for mid-block four-lane (or higher) urban major streets with a center median (or not to exceed 150 ft within 1320 ft of transit stop or in high crime census tracts)
- Street lighting near the end of cul-de-sacs that exceed 200 ft. (or that exceed 150 ft within 1320 ft of transit stop or in high crime census tracts)
- Street lighting at railroad crossings, high pedestrian activity areas (e.g., schools, parks, transit centers, recreational facilities, etc.) and at locations with abrupt horizontal or vertical changes

Other cities generally have similar standards/guidelines. The City of Phoenix [10] suggests street light spacing on arterial roads of approximately 200–250 ft, on collector streets (one sided) of approximately 200 ft. (both sides if 4 + lanes), on local streets of approximately 200–250 ft, and similar requirements as noted above for cul-de-sacs and intersections.

Interestingly, these spacing standards share similarities with other type of public/private services. There are a range of location modeling approaches that have been developed and applied in order to support decision making associated with the siting of facilities. Such facilities are not unlike street lights, and include cellular/wireless antennae, warning sirens, Doppler radar equipment, fire watch towers, bus stops, etc. (see Refs. [13,17,20,35,57]; among others). Many studies in this area have relied on discrete integer programming based models where potential facility locations are finite and known in advance. Prominent models include the location set covering problem of Toregas et al [53] and the maximal covering location problem of Church and ReVelle [9]; as well as extensions of these models (see Refs. [41]; Ratick et al., 2016 [46] for recent reviews).

What is unique about street light placement is that it is effectively a continuous space facility siting problem where lights can essentially be located anywhere along a street. Research focused on continuous space siting has recognized the challenges of dealing with the fact that potential sites for facilities are infinite. Early work in this area includes Kershner [26]; who sought the minimum number of circles of a given radius necessary to cover a rectangle [7]. Church and Meadows stipulated that facilities could be sited anywhere along arcs of a network [6,33,34,55] and Drezner [16] detailed an extension of the MCLP where facilities could be sited anywhere [40]. Murray and Tong also considered the situation where facilities could be anywhere. Further, they demonstrated a transformation of a continuous space problem was possible when demand was represented as discrete polygons.

Not unrelated is work focused on demand, essentially representations of continuous space [47]. ReVelle et al discuss extensions of the LSCP to address the case of continuous demand along a network. Other coverage extensions to address continuous demand along arcs in a network are detailed in Refs. [2,3,17,24,28] and [57]. Suzuki and Okabe, Suzuki and Drezner [50,51] and Wei et al. [56] assumed demand at all places within a region. Murray [36]; Spaulding and Cromely [59], Kim and Murray, Tong and Murray, Alexandris and Giannikos, Murray et al., Cromley et al. [1,12,27,41,52]; Tong [60], Yin and Mu [58], and Murray and Wei [42] recognized that demand in a coverage model was continuously spread across a region and/or sub-areas. Finally Murray et al. [39], and Matisziw and Murray [32] developed approaches that explicitly deal with continuous representation and service coverage of a region.

While there has been a substantial amount of work in this area, the public street lighting context presents new and unique challenges. Addressing these challenges means that problem and application nuances must be resolved, making solution derivation very difficult technically and computationally. Much of this has to do with the standards and guidelines established for street lighting, but also issues associated with where lights may be located in practice, benefits of lighting and negative impacts on people and the environment.

3. Methods

The needs of an area/neighborhood dictate good placement of public street lights. In particular, lighting requirements are location dependent, taking into account streets, sidewalks, travel patterns, behavioral characteristics, safety, security, etc. Given this, a range of