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A review of design recommendations for P-class road lighting in European and CIE recommendations
Part 1: Parameters for choosing a lighting class

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Abstract
This article is a discussion of the factors that might be used to establish a suitable light level for subsidiary roads where the target users are pedestrians. The weighting parameters used in CIE115:2010 to discriminate between the six levels of the P-series of lighting classes are questioned. Limitations of the weighting parameters include (1) while some of the weighting parameters are associated with pedestrian road traffic collisions, they do not lead to optimal lighting conditions or to predicable relationships, (2) there is no evidence to support the one-class change prompted by a change in level of a weighting parameter nor for the assumed cumulative effect of different weighting parameters, and (3) they do not match the stated purposes of lighting in subsidiary roads. Giving consideration to the situations where evidence indicates a change in light level is warranted, and not assuming that different parameters are cumulative in effect, leads to a three-class system similar to BS5489-3:1992 and IESNA DG5:1994.

1 Introduction

This article concerns road lighting for minor roads. Such roads are known in the UK as subsidiary roads, and are defined as including "*access roads, residential roads and associated pedestrian areas, footpaths and cycle tracks*".[1,2] This definition provides distinction from major traffic routes such as "*motorways and all-purpose traffic routes*".[2] The main purpose of lighting for subsidiary roads and areas associated with those roads is "*to enable pedestrians and cyclists to orientate themselves and detect vehicular and other hazards, and to discourage crime against people and property. The lighting on such roads can provide some guidance for motorists, but is unlikely to be sufficient for revealing objects on the road without the use of headlights.*".[2] For these minor roads the British Standard prescribes six levels of horizontal illuminance ranging from 2.0 to 15.0 lux, formerly known as S-class[1,3] but currently as P-class[2,4] with the lighting conditions for these classes being prescribed in the European standard.[3,4]

Rather than distinguish between major and minor roads, guidance from the International Commission on Illumination (CIE) distinguishes between the type of road user, i.e. between motorists and pedestrians.[5,6] For pedestrians "*The road lighting should enable pedestrians to discern obstacles or other hazards in their path and be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity*".[6] For pedestrian traffic there are again six levels of horizontal illuminance, also known as the P-class, which initially[5] ranged from 1.5 to 20.0 lux but was subsequently[6] adjusted to a range of 2.0 to 15.0 lux.

Considering the definitions in these two sources, and the ranges of illuminances recommended, it is clear that lighting in minor roads is intended to meet the visual needs of pedestrians.

Formerly, these lighting classes were discriminated by descriptions of the likely application. First consider an earlier (1992) version of the British Standard[7] which gave definitions for three categories of subsidiary road as shown in Table 1. The 1995 issue of the CIE recommendations also provided definitions for six types of road as shown in Table 2.
The British Standard increased from three classes in 1992 to six classes in the next (2003) revision. The standard itself gave no justification for the number of classes nor for the need to increase from three to six. An anecdotal comment from a member of the committee drafting BS5489-1:2013 indicated expectation that the new ability to extend toward the higher illuminances allowed by this change would not be commonplace, suggesting a "*general feeling being that … S1 was not used in practice. (It was) most likely being included so that designers could "play safe"*".[8] The current author interprets the expression 'play safe'

as the situation where designers could choose to use a higher illuminance where there were uncertainties regarding the specific situation or where public criticism was anticipated.

Table 1. Definitions of the three categories of road for determining lighting conditions in the 1992 issue of BS5489-3:1992.[7]

Category of road	Maintained average illuminance (lux)	Maintained minimum point illuminance (lux)	Definition
3/1	10.0	5.0	Roads where night-time public use is likely to be high (this may be associated with amenities such as clubs, shopping facilities, public houses, old people's homes etc.); or, the crime risk is likely to be high; or, traffic usage is likely to be high.
3/2	6.0	2.5	Roads that do not fall into category 3/1 and where night-time public use is likely to be moderate (this may also be associated with amenities such as clubs, shopping facilities, public houses, old people's homes, etc.); or, the crime risk is average to low; or, traffic usage is of a level equivalent to that of a housing estate access road.
3/3	3.5	1.0	Roads where night-time public use is minor and solely associated with the adjacent properties; and the crime risk is very low; and traffic usage is of a level equivalent to that of a residential road.

Table 2. The six road descriptions used to define lighting classes in the 1995 issue of CIE115.[5] Note that this document also included a seventh class, P7, defined as "Roads where only visual guidance provided by the direct light from the luminaires is required", but for which there was no specification of illuminance. The P7 class was omitted from the 2010 version.[6]

Lighting class	Horizontal illuminance (lux)		Description of road
	Average	Minimum	
P1	20	7.5	High prestige roads
P2	10	3.0	Heavy night-time use by pedestrians or pedal cyclists
P3	7.5	1.5	Moderate night-time use by pedal cyclists or pedestrians
P4	5	1.0	Minor night-time use by pedal cyclists or pedestrians solely associated with adjacent properties
P5	3	0.6	Minor night-time use by pedal cyclists or pedestrians solely associated with adjacent properties. Important to preserve village or architectural character of environment.
P6	1.5	0.2	Very minor night-time use by pedal cyclists or pedestrians solely associated with adjacent properties. Important to preserve village or architectural character of environment.

Tables 1 and 2 indicate reasonable agreement between the horizontal illuminances for particular situations. High or heavy pedestrian use leads to an illuminance of 10 lux, moderate pedestrian use to either 6.0 lux[7] or 7.5 lux,[5] and minor use to 3.5 lux[7] or 3 to 5 lux.[5] Neither document, however, defined what was meant by high, moderate or minor use.

The road use descriptions were omitted from subsequent versions of these standards and instead a lighting class was defined according to a series of situational criteria. The European Technical Report provides a series of weighting factors for choosing one of the six P-classes of lighting.[4] The current CIE recommendation also presents a series of weighting factors for choosing a lighting class.[6]

Table 3 shows the six lighting classes as specified in CIE 115:2010.[6] The average and minimum horizontal illuminances in the classes described in BS EN 13201-2:2015 are identical except for two instances: in P6 the minimum semi-cylindrical illuminance (E_{SC}) is 0.2 (but 0.4 in CIE 115:2010) and in P1 E_{SC} is 5.0 (but 3.0 in CIE 115:2010). This similarity between the two documents may have arisen because "*many of the members on the CIE committee are also members of the CEN committee*".[10]

Table 3. Lighting classes for pedestrian and low speed traffic areas as recommended in CIE 115: 2010.[6]

Lighting Class	**Average horizontal illuminance (lux)**	**Minimum horizontal illuminance (lux)**	**Additional requirement if facial recognition is necessary.**	
			Minimum vertical illuminance (lux)	**Minimum semi-cylindrical illuminance (lux)**
P1	15	3.0	5.0	3.0
P2	10	2.0	3.0	2.0
P3	7.5	1.5	2.5	1.5
P4	5.0	1.0	1.5	1.0
P5	3.0	0.6	1.0	0.6
P6	2.0	0.4	0.6	0.4

Note in Table 3 that the ratio of minimum illuminance to average horizontal illuminance is 0.2 in every class. The minimum illuminances in some classes were modified from the previous version "*to ensure that the uniformities of each class are now all the same*".[10] In other words, there was a decision to maintain a consistent uniformity. For the facial recognition criteria, the ratio of vertical illuminance to horizontal illuminance is about one-third (i.e. either 0.30 or 0.333) and the ratio of semi-cylindrical illuminance to horizontal illuminance is 0.20. There are no given reasons for these values.

Table 4 summarises the weighting factors that are used in CIE115:2010 to establish a lighting class from Table 3. The table presented in EN 13201-1:2014 is identical except for four items:

- There are descriptions for the two travel speeds, with *low* defined as <40 km/h and *very low* as walking speed.
- There are definitions for two types of ambient luminance.
- There are only three options (busy; normal; quiet) for *use intensity*, whilst *traffic volume* in CIE115:2010 has five options, these giving intermediate weightings. (In the absence of definition in either source, it is not known whether these terms were intended to include pedestrians and/or vehicles).
- Parked vehicles are given a weighting of 1.0 in 13201-1:2014 compared with 0.5 in CIE 115:2010.

For a given situation, the weightings are summated and the resultant P-class is found by subtracting this summated weighting from 6. If the result is not a whole number, users are advised to use the next lower class, i.e. a higher illuminance. In essence this process means the baseline is class P6, the lowest illuminance, and the weightings define where additional illuminance is assumed to be beneficial.

Table 4. Weighting factors for selecting a P-class of road lighting, from CIE 115:2010.[6]

Parameter	Option	Weighting value
Travel speed	Low	1
	Very low	0
Traffic volume	Very high	1
	High	0.5
	Moderate	0
	Low	-0.5
	Very low	-1
Traffic composition	Pedestrians, cyclists and motorised traffic	2
	Pedestrians and motorised traffic	1
	Pedestrians and cyclists only	1
	Pedestrians only	0
	Cyclists only	0
Parked vehicles	Present	0.5
	Not present	0
Ambient luminance	High	1
	Moderate	0
	Low	-1
Facial recognition	Necessary	Additional requirements
	Not necessary	No additional requirements

These weightings, however, have limited relevance to the stated purposes of road lighting, which is to "*enable pedestrians to discern obstacles or other hazards in their path and be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity*".[6] Instead, they relate largely to the potential for, and severity of, collision with a motor vehicle. Whilst that is clearly an important consideration, the disconnection between the stated aims of lighting and the approach to choosing how much light is provided does not provide confidence that the outcome is in any way optimal.

Given that the weighting parameters listed in Table 4 are used to distinguish between different light levels, it would be useful to establish the empirical evidence that was used to characterise the relationship, i.e. evidence demonstrating that option *x* for a particular weighting factor requires a certain higher light level than does option *y*. There are no citations for such evidence within the standards. This means the weighting factors may be leading to lighting design conditions that are not appropriate, which could be light levels that are too high and leading to excessive energy consumption, or too low leading and leading to insufficient visual benefit.

CIE115:2010 presents only limited evidence for the recommendations. This article first seeks evidence to support the relevance of each parameter (Table 4) used to determine a lighting class.

2. The weighting parameters

2.1 Travel speed

For a pedestrian struck by a moving motor vehicle the risk of injury and fatality increases with increasing vehicle speed.[11] For collision at a speed of 50 km/h the risk of a fatal accident is more than five times higher than at 30 km/h and more than twice that at 40 km/h.[12] Table 5 is a summary of three studies. Tefft[13] examined crashes that occurred in the United States in the period 1994–1998 and involved a pedestrian struck by a forward-moving car, light truck, van, or sport utility vehicle. Rosén and Sander[12] examined the German In-Depth Accident Study (GIDAS) for adult pedestrians hit by the front of a passenger car during the years 1999 to 2007. Elvik *et al.*[14] used a meta-analysis to investigate the probability of fatal injury to pedestrians. While the risk of an injury differs between the three studies, they all demonstrate that increasing speed leads to an increase in risk.

Table 5. Risk of pedestrian injury due to collision with a moving motor vehicle at impact speeds of 20 km/h and 40 km/h.

Speed	Risk of fatal injury			Risk of severe injury
	Elvik et al[14]	Rosén and Sander[12]	Tefft [13] *	Tefft, 2013*
40 km/h	30%	4%	48%	72%
20 km/h	3%	1%	<10%	16%

*Determined by linear interpolation from data reported by Tefft[13] who reports vehicle speed associated with risk of outcome occurring.

There are two options for the travel speed parameter, low speed and very low speed, defined in BS EN 13201-1:2014 as <40 km/h and walking speed respectively. (This is not, however, a universal assumption: in the Netherlands these options are defined as >30 km/h and ≤30 km/h)[15]. It can be seen from Table 5 that at 40 km/h the risk of injury is much higher than that at 20 km/h. Vehicles travelling at faster speed require a greater stopping distance: at greater distance, a potential hazard (e.g. a pedestrian) subtends a smaller visual size. While higher luminance increases visual acuity,[16] the ability to see small details, at a certain point the change in acuity with further increase of luminance becomes negligible.[17,18] It is therefore expected that a higher light level may enhance safety when driving at faster speed by increasing the ability to detect and identify likely hazards. This is what the weighting parameter does, with discrimination between two travel speeds. Note also that the relationship between travel speed and crash rates interacts with the type of road.[19] However, literature search has not revealed evidence that a one-class change in light level is suitable mitigation for the increased risk of an RTC at the higher travel speed.

Given that the two options for this parameter are <40 km/h and walking speed,[9] an alternative interpretation of this parameter is that it discriminates between the presence or absence of motor vehicles. In other words, is this a footpath alongside a road where cars are likely, or a footpath separated from the carriageway?

2.2 Traffic volume

There is evidence of an association between traffic volume and collisions between vehicles on major roads in some circumstances.[20] For example, an increase in the volume of light non-passenger cars increases the likelihood of more severe accidents, but the volume of heavy vehicles does not affect no-injury accidents on urban highways and the volume of passenger cars and heavy vehicles does not influence more severe accidents.

Regarding accidents involving pedestrians, there is evidence that the number of collisions involving pedestrians increases with an increase in the average annual daily traffic (AADT).[21] In other words, "*pedestrian crashes are more likely to occur at intersections with higher traffic volume that increases the potential conflicts between pedestrians and vehicles*".[21] Note that these data are for junctions on major roads: data regarding traffic flow and collisions on minor roads have yet to be established. While it is expected, from studies on major roads, that traffic volume will significantly affect the risk of a pedestrian road traffic collisions (RTCs), literature search did not reveal evidence to support the five options within the traffic volume parameter.

2.3 Traffic composition

Traffic composition refers to combinations of pedestrian, cyclist and motorised vehicle road users. The parameter lists five options for these combinations, which means that not all possible combinations are listed. Combinations omitted from the options are (i) cyclists and motorised vehicles, and (ii) motorised vehicles only. The five options that are offered (Table 4) can be simplified to three (Table 6) and what these options distinguish is whether there are one, two or three types of road user. For each additional type of user, the illuminance is increased by one class.

Table 6. A simplified approach to the options for traffic composition weighting parameter.

Option	Weighting
Pedestrians, cyclists and motorised traffic	2
Pedestrians and either cyclists or motorised traffic	1
Pedestrians or cyclists	0

The three types of road user tend to move at different speeds, potentially leading to an increase in conflict and hence to an increased risk of accidents. For situations involving only motorised vehicles, the probability of an RTC is minimised when the driver travels close to the median traffic speed.[22] Larger differences in speed between vehicles are related to a higher crash rate.[19] The range of vehicle speeds tends to be wider on minor roads than on major roads and this leads to the paradox that the number of conflicts between motor vehicles increases as the average speed decreases.[23,24] Regarding mixed types of road user, Chong *et al.*[25] reported the rate of hospitalisations due to RTCs for three combinations of cyclist, pedestrian and motor vehicle. The hospitalisation rate for cyclists suffering an injury in RTCs involving cyclists and motor vehicles was much greater than that between cyclists and pedestrians. This may be because cyclists tend to be co-located on the highway with motor vehicles whilst pedestrians tend to use a separate space, the footpath.

Literature search did not reveal evidence to support a benefit of a change in lighting to mitigate the increased RTC risk associated with mixed traffic compositions.

2.4 Parked vehicles

Cars parked along the side of a road reduce the width of the road and obscure visibility of latent hazards. In terms of the affect upon drivers, on-road parking can lead to significant increase in speed variability and to significant decrease in reaction time and slower braking.[26] In terms of accidents, the presence of parked cars along the roadside increases the risk of accidents, particularly those involving pedestrians or vehicles from side roads.[26,27] Nearly 17% of pedestrian collisions occurring in Great Britain in 2003 occurred when the pedestrian was masked by a stationary vehicle, and this was particularly the case for children aged between 8 and 15 years.[28]

Literature search did not reveal direct evidence of the relationship between lighting and parked vehicles. Lighting may help to mitigate RTCs associated with parked vehicles if it is sufficient to promote the visual detection of suddenly appearing hazards. An increase in luminance leads to significant decrease in reaction time and increase in detection rate,[29] although this reaches a plateau above which further increase in luminance does not further increase detection performance.[17,30]

2.5. Ambient luminance

The three options for ambient luminance (high, moderate and low) refer to the amount of light in the local environment from sources other than road lighting. In BS EN 13201-2:2015 a high ambient luminance is defined as "*Shopping windows, advertisement expressions, sport fields, station areas, storage areas*" and moderate is the "*normal situation*".[4]

What is not stated is the aim of giving consideration to this parameter. It may be to promote road lighting that is in-keeping with the general environment, e.g. in an rural location, with little ambient light, then the 'low' option promotes a reduction in road lighting illuminance. As adaptation luminance increases, then threshold contrast decreases[31] and acuity increases.[18] Ambient luminance, however, affects the visual field beyond the task, so with high ambient luminance an increase in road lighting provides an increase in task illuminance. Hence an alternative aim of this parameter may be to maintain a given level of task performance when adaptation is otherwise raised by extraneous sources of light. These are simply possibilities. There may have been other intentions, but since none are stated they remain unknown.

Note also that while a change in illuminance may be a suitable response to either of these possible aims, the addition or subtraction of a lighting class does not mean that the problem is alleviated. This is because the change says nothing about the absolute level of lighting as determined according to the preceding parameters.

2.6 Facial recognition

While facial recognition is listed as one of the six parameters (Table 4), it does not lead to a change in lighting class but instead it prompts the consideration of additional requirements if facial recognition is considered to be necessary. The additional requirements are minimum levels of vertical illuminance or semi-cylindrical illuminance (Table 3).

There is no specific guidance as to how to establish the situations where, and where not, facial recognition might be deemed necessary. Making evaluations about other people is likely to be important where such encounters are expected, for example to inform the decision to approach or avoid another person.[32] Given that the P-class is specifically targeted at pedestrians[6] or at roads where pedestrians are the target user[2] then pedestrians are always expected and it becomes difficult to comprehend when facial recognition would not be necessary. Furthermore, it should be noted that the need to visually evaluate other people is better represented by a facial emotion recognition task (i.e. discrimination between facial expressions) than by an identity recognition task.[33]

The minimum values for vertical and semi-cylindrical illuminance given in Table 3 appear to be simply ratios of the horizontal illuminance. In other words, for a given lighting class the vertical illuminance is proportional to the horizontal illuminance rather than having been separately determined. That there is no evidence as to the source of the recommended values means there is no certainty that this leads to sufficient vertical illuminance for the intended facial recognition performance.

Note that BS EN 13201-2:2015 also gives a separate set of Esc values which has nine classes (SC1 to SC9) with values ranging from 10 to 0.5 lux.[4] There does not appear to be any guidance for choosing an SC class. Furthermore, there does not yet appear to be any credible evidence in favour of semi-cylindrical illuminance rather than vertical illuminance.[34] In the Netherlands, the P-class uses the same set of six classes, each having the same average and minimum horizontal illuminances as shown in Table 3, but the values of vertical and semi-cylindrical illuminance are the same in every class (0.5 lux and 0.3 lux respectively).[15] These values were derived from Alferdinck *et al.*[35] where 0.5 lux vertical illuminance was associated with facial recognition at 3 m.

There are some empirical data which describe how a change of lighting affects facial emotion recognition.[36-38] These data follow a plateau-escarpment relationship.[17] Up to a point an increase in vertical illuminance leads to an increase in facial emotion recognition, but beyond this point further increase in illuminance yields negligible increase in emotion recognition. This suggests there are likely to be clear minimum and maximum values of vertical illuminance rather than a ratio to the horizontal value.

Note also that while it is widely stated[4,6] that a higher colour rendering improves facial recognition, this is frequently not supported by research.[35-40]

3 Discussion

3.1 The aims of road lighting

Four of the six parameters used to identify a lighting class (travel speed, traffic volume, traffic composition and parked vehicles) are associated with the risk of RTCs involving pedestrians and motor vehicles. Literature search has identified evidence that pedestrians are at greater risk of a serious injury when vehicles are moving at higher speed, when there are cars parked along the kerb, and when the mix of road users places pedestrians in proximity with other road users moving at different speeds. For traffic volume there is evidence that a higher volume of vehicles at junctions on major roads raises the probability of pedestrian accidents, but the search did not locate such evidence for minor roads.

One counter measure to pedestrian RTCs after dark on unlit roads is to install road lighting, and there is evidence that this will lead to a reduction in traffic accidents.[41] For a road that is already lit, then an increase in light level can also lead to significant reduction in accidents across all traffic groups. One study found that the night-to-day crash ratio reduced in an exponential trend from approx. 0.43 at 0.5 cd/m^2 to approx. 0.28 at 1.5 cd/m^2.[42]

One approach to isolating the effect of light on accidents is to compare accident rates for the same hour in periods of daylight and after dark, by taking advantage of the daylight savings clock change[43] and the annual variation in daylight hours.[44] Using the latter approach, it was found that after dark there is a 100% increase in the risk of being involved in a pedestrian RTC, compared with a 55% increase for cyclists and no change in risk for car occupants.[44] It is clear that the benefit of road lighting as an accident countermeasure may be significantly greater for collisions involving pedestrians than for other users.[45] An increase in luminance is particularly effective for reducing midblock pedestrian crashes and single-vehicle collision with a stationary object/obstruction located within the carriageway: between junctions a 0.5

cd/m^2 increase in luminances leads to a reduction in crashes of over 50%.[42] An increase in light level also reduces nighttime pedestrian crashes at pedestrian crossings.[46,47]

This focus on pedestrian RTCs is clearly important. In 2017 in Great Britain there were 470 pedestrian fatalities in reported road traffic collisions, an increase of 11% against the 2010-2014 average, and 23,805 pedestrian casualties.[48] Across the European Union there were over 25,000 road deaths in 2017, across all types of road user[48] and internationally there are more than 270,000 pedestrian fatalities every year.[49]

One caveat to the proposed benefit of an increase in illuminance is that drivers are not solely responsible for collisions involving pedestrians. A study of 6,434 pedestrian crashes in Florida, in the three-year period 2008-2010, concluded that pedestrians were at fault in 53% of the cases and drivers for 28.2 %.[50] Improving the visual detection ability of drivers will have less effect at reducing those accidents where pedestrians are at fault.

While it may be concluded that these four parameters are relevant, there are two limitations to their application. The first limitation is that focus on RTCs is not the same as the stated intention of the lighting, which is, as reported above, to "*enable pedestrians to discern obstacles or other hazards in their path and be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity*." Because the four factors relate to accident mitigation and not to ability to discern hazards in their path, it is not possible to say whether this intention is achieved. It is recognised in CIE115:2010 that while the provision of lighting on motorways and other major roads is expected to reduce the number and severity of accidents at night, there are generally few road accidents on minor roads. Lighting on minor roads is therefore not provided mainly to avoid accidents involving vehicles, but instead it is mainly provided to give safe passage for pedestrians so that they can see obstacles and other people, can find their way on foot, and have a feeling of safety and security.

The second limitation is that while the direction of change in lighting appears to be an appropriate response, e.g. an increase in illuminance, the literature search did not reveal evidence for determination of absolute thresholds nor for the appropriate magnitude of change. One parameter (facial recognition) does have some association with the stated aims of lighting minor roads. However, selecting this parameter to be important leads toward consideration of vertical illuminance but does not lead to a change in vertical illuminance nor is there any evidence that the recommended vertical illuminance in each class is appropriate to meet the needs of facial recognition (or other interpersonal evaluation).

3.2 Assumed cumulative effect

To choose a lighting class, the weightings determined for each parameter are summated. This approach assumes a cumulative effect: it is not known, however, whether that is a correct assumption, and they may interact rather than be simply cumulative.[19] Consider a route for pedestrians only: the total weighting value for this situation might be zero, leading to an illuminance of 2.0 lux for lighting class P6 (Table 7). If motorised vehicles are now to be allowed upon the same route, the weighting value increases by 2.5 units to account for low travel speed, mixed traffic composition and the presence of parked vehicles. This leads to an illuminance of 7.5 lux for lighting class P3. It may be the case that a total weighting value of 1.0 would be sufficient to account for the additional risk associated with the presence of motorised vehicles, and hence that the three parameters are a repetition of the same risk assessment. In other words, travel speed and parked vehicles simply replicate the traffic composition factor and thus the same issue is countered three times.

Another way to consider this is to ask whether the parameters offset one another. In terms of an increase in the risk of death or injury, on a minor road after dark, more parked cars are likely to be present, increasing the risk, but traffic density might be less, reducing the risk. Similarly, the increased risk due to parked cars, because they narrow the driving lane and let pedestrians get closer to the traffic without being seen, may be countered to some extent if there is less traffic.

Table 7. Comparison of weighting factors for a situation involving pedestrians only and for pedestrian and motorised vehicles. Option descriptions and weighting values as stated in CIE 115:2010.[6]

Parameter	**Pedestrian only**		**Pedestrian and motorised vehicles**	
	Option	**Weighting**	**Option**	**Weighting**
Travel speed	Very low	0	Low	1
Traffic volume	Moderate	0	Moderate	0
Traffic composition	Pedestrians only	0	Pedestrians and motorised traffic	1
Parked vehicles	Not present	0	Present	0.5
Ambient luminance	Moderate	0	Moderate	0
Facial recognition	Necessary	n/a	Necessary	n/a
Sum of weightings		0		2.5
Determination		6-0=6		6-2.5=3.5
Lighting class		P6		P3*
Illuminance		2.0 lux		7.5 lux

*Rounded down to next whole number from 3.5 in accordance with the general rule.

3.3 Alternative class selection systems

In CIE115:2010 for the P-class there are six weighting parameters, each with two or more options (Table 4). This is somewhat complex given the absence of underlying data supporting the assumed effects. For the developers of this guidance it may have been a convenient process by which to choose between the six light levels available to them, an attempt to give reasons to justify discrimination between light levels, but without asking whether six classes were needed.

This complexity could be put to advantage by designers as it gives them opportunity to reverse engineer decisions and provide reasons to support the light level they had pre-determined. Such an approach is aided also by the absence of quantitative definitions. For example, there are five options within the traffic volume parameter, namely very low, low, moderate, high or very high,[6] but there are no quantitative definitions for these. Allowing designers a degree of flexibility may be advantageous.

While the British Standard is required to adopt the six lighting classes of EN 13201-2:2015, it is not obliged to employ the weighting factor approach to selecting a class. Indeed, it does not do so. The Chairman of the BS5489-1:2013 drafting committee commented about the weighting factors that "*as no rationale could be located then we should follow the current method of following our own guidance on choosing a particular class.*", the *current method* referred to being that used in BS5489-1:2003.[51]

BS5489-1:2013 uses a simpler approach than CIE115:2010. For subsidiary roads there are two tables for identifying lighting class, discriminated by the type of user (Table A5 – subsidiary roads with a typical speed of main user v ≤ 30 mph; Table A6 - mainly slow-moving vehicles, cyclists and pedestrians). Within each table there are two selection factors; traffic flow (busy, normal or quiet, with descriptive definitions given for each) and ambient luminance for which the optional levels, E1 to E4, refer to the environmental zones as defined in ILP GN01.[52] Table 8 shows the lighting classes recommended in these tables.

Table 8. Summary of lighting classes for subsidiary roads from BS5489-1:2013 Tables A.5 and A.6.[2]

Traffic flow	Subsidiary roads with a typical speed of main user of 30 mph or less		Subsidiary roads with mainly slow moving vehicles, cyclists and pedestrians
	Ambient luminance: Very low (E1) or low (E2)	**Ambient luminance: Moderate (E3) or High (E4)**	**Ambient luminance: Any**
Busy	P3	P2	P4
Normal	P4	P3	P5
Quiet	P5	P4	P6

Similar to BS5489-1:2013, road lighting design in Australia and New Zealand also makes use of a simplified set of parameters (Table 9) with which to choose a lighting class (Table 10).[53] A lighting class is determined according to pedestrian/cyclist activity, fear of crime and the need to enhance amenity. While there are three categories of road, with a general description given for each, the resultant lighting class determined according to pedestrian/cyclist activity, fear of crime and the need to enhance amenity are the same for each.

Table 9. Parameters for determination of a lighting class for roads in local areas in Australia and New Zealand (Table 2.1 from draft standard AS/NZ 1158.3.1).[53]

Type of road or pathway		Selection criteria			Applicable lighting subcategory
General description	**Basic operating characteristics**	**Pedestrian/ cycle activity**	**Fear of crime**	**Need to enhance amenity**	
Collector roads or non-arterial roads which collect and distribute traffic in an area, as well as serving abutting properties.	Mixed vehicle and pedestrian traffic	N/A	High	N/A	PR1
		High	Medium	High	PR2
		Medium	Low	Medium	PR3 or PR4
		Low	Low	Low	PR5
Local roads or streets used primarily for access to abutting properties, including residential, commercial and industrial precincts.		N/A	High	N/A	PR1
		High	Medium	High	PR2
		Medium	Low	Medium	PR3 or PR4
		Low	Low	Low	PR5
		N/A	N/A	N/A	PR6
Common area, forecourts of cluster housing.		N/A	High	N/A	PR1
		High	Medium	High	PR2
		Medium	Low	Medium	PR3 or PR4
		Low	Low	Low	PR5

Table 10. Australian and New Zealand guidance for lighting parameters for roads in local areas (Table 3.3 from draft standard AS/NZS 1158.3.1).[53]

Lighting subcategory	Average horizontal illuminance, lux	Point horizontal illuminance, lux	Illuminance uniformity
PR1	7.0	2.0	8
PR2	3.5	0.7	8
PR3	1.75	0.3	8
PR4	1.3	0.22	8
PR5	0.85	0.14	10
PR6	0.7	0.07	10

One limitation of the selection criteria (Table 9) is that the choice of criteria is not flexible. For example, if the pedestrian activity is high, then the designer is forced to assume that fear of crime is medium and the need to enhance amenity is high. It is not possible, for example, to select an area of high activity with a low fear of crime and low need to enhance amenity, nor is it possible to select low pedestrian activity with a high fear of crime. While the approach used in CIE115:2010 (Table 4) does allow levels of the selection criteria to be independently chosen, the process leads to the unqualified assumption of cumulative effect.

Tables 9 and 10 are for roads in local areas and lead to average illuminances in the range 0.85 to 7.0 lux (class PR6, 0.7 lux, is used only in specific circumstances), a lower range than that used in CIE115:2010. There are different selection criteria and lighting classes for pedestrian and cyclist paths and for public activity areas. For pedestrian and cyclist paths the uniformity is increased (mean/minimum is 5 for pathways and 8 for local roads) and the mean horizontal illuminance is increased (for high activity and medium fear of crime, 7.0 lux for pedestrian and cyclist pathways (class PP2) but 3.5 lux for local roads (class PR2) – and note that the PR class "*shall apply across the whole of the road reserve width, including the footpath*" which implies it is intended to include the pedestrian footpath rather than requiring separate consideration. For public activity areas the average illuminances are higher than those for public roads (three classes; 7, 14 and 21 lux).

IESNA DG5 uses a different approach.[54] Rather than employ a system of contextual parameters it instead identifies the type of situation (Table 11), similar to earlier versions of BS5489 (Table 1) and CIE115 (Table 2).

Table 11: Recommended illuminances for pedestrian areas in IESNA DG5 Table 2.[54]

Walkway class	Ave maintained horizontal illuminance (lux)	Horizontal ave to min. average	Min maintained ave vertical illuminance (lux)	Ave to min ratio
Sidewalks along streets in area classified as:				
Commercial	10	4:1	20	5:1
Intermediate	5	4:1	10	5:1
Residential	2	10:1	5	5:1
Park walkways and class I bikeways	5	10:1	5	5:1
Pedestrian Tunnels	20	4:1	55	5:1
Pedestrian overpasses	2	10:1	5	5:1
Pedestrian stairways	5	10:1	10	5:1

Commercial: A business area of a municipality where ordinarily there are many pedestrians during night hours. This definition applies to densely developed business areas outside, as well as within, the central part of a municipality. The area contains land use which attracts a relatively heavy volume of nighttime vehicular and/or pedestrian traffic on a frequent basis.

Intermediate: Those areas of a municipality often characterised by moderately heavy nighttime pedestrian activity such as in blocks having libraries, community recreation centres, large apartment buildings, industrial buildings or neighbourhood retail stores.

Residential: A residential development or a mixture of residential and small commercial establishments, characterised by few pedestrians at night. This definition includes areas with single homes, town houses, and/or small apartment buildings. Certain land uses, such as office and industrial parks, may fit into any of the above classifications. The classification selected should be consistent with the expected nighttime pedestrian activity.

3.4 Basis for a new lighting class selection system

It is argued above that the system for selecting a lighting class currently used in CIE115:2010 has a good intention (i.e. the parameters are associated with the risk of a pedestrian RTC) but that there is no evidence supporting the link between this intention and the resultant lighting conditions. For the designer who selects a particular light level to meet the needs of particular road, or who increases the light level to mitigate a particular problem, the lack of evidence means we cannot be at all confident they are properly responding to their design issues. If an increased light level is used to offset (for example) an increase in speed limit, the guidance gives false confidence to the designer that they have mitigated that risk: it is a weakness in the cost-benefit analysis that may be preventing resource allocation to where it is actually beneficial.

Design criteria should first consider the purpose of application. For subsidiary roads, targeting the needs of pedestrians, the stated purposes of road lighting are to enable pedestrians to discern obstacles or other hazards in their path, to be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity,[6] and to enable pedestrians to detect vehicular and other hazards and to discourage crime against people and property.[2] One further aspect not clear in those stated purposes is the need to promote a feeling of reassurance,[55] a useful benefit of lighting as it is associated with increased walking.[56,57]

Consider first a standard situation. This is here defined as a subsidiary road, with a carriageway for motor vehicles and pedestrian footpaths running alongside the carriageway: the road is in an urban location, having a speed limit of 20 to 30 mph; there are escape routes open to the pedestrian (i.e. they do not feel entrapped as might be the case in a back alley) and they are potentially visible to occupants of surrounding buildings. Assume that optimal design criteria are established for this situation, a likely compromise between the direct needs of visual task performance and indirect effects such as road traffic collisions.

For some situations, there is evidence that a higher light level would be beneficial:

- Field studies of reassurance indicate that higher light levels are optimal in areas with a higher degree of entrapment such as car parks[58] than in residential roads.[59]
- The detection of pavement hazards is hindered by the need to (or expectation to) conduct other tasks in parallel and this can be mitigated by a higher light level.[60] The same can be assumed for other visual tasks of pedestrians. Therefore, a higher light level would be beneficial in situations with higher numbers of pedestrians, higher numbers of vehicles, and more-hazardous pavement surfaces.
- Higher light levels can reduce the reaction time to detection of a target[61] and may therefore offset after dark the increased risk of a road traffic collision on roads with a higher speed limit (see Table 5).
- Higher light levels are associated with an increase in walking (and cycling) and thus might be used as a means of promoting active transport.[62,63]

Higher light levels are also beneficial to mitigate the increased impact of darkness on RTCs at pedestrian crossings and junctions[46] but these situations tend to be considered separately from sections of road.

Similarly, lower levels of road lighting may be suitable where the speed limit is less than 20 mph, where the footpath poses little likelihood of trip hazard, in pedestrian-only footpaths, and where there are few other pedestrians or traffic.

Table 12 summarises the assumed standard situation and those situations where the evidence indicates a higher or lower light level is optimal. It is not assumed that situational factors are cumulative, three classes are sufficient: further research would be required to test that assumption. It is not yet possible to define what constitutes higher and lower numbers of pedestrians or traffic. Further research may indicate the need to add, or remove, further situations demanding a change in light level from the standard situation. The outcome is, in effect, similar to the three-class descriptive approaches of BS5489-3:1992 (see Table 1) and IESNA DG5:1994 (see Table 11).

To apply this three-class system requires empirical evidence of optimal lighting for the standard situation, and the magnitude of change for the lower and higher classes. The evidence on which the light levels are based should reflect the stated purpose(s) of lighting. The evidence can be drawn from direct effects of lighting on pedestrians visual tasks and indirect effects of lighting such as RTC risk. Light level recommendations might also be founded in design experience and local custom. Regardless of the type, the evidence needs to be publically available so that it can be independently tested rather than the largely tacit evidence base of current standards.

Table 12. Three proposed lighting classes. These are an assumed standard situation for P-class road lighting and situations where light levels lower and higher than this standard situation are warranted.

Lighting class	**Situation**
Lower	• Speed limit is less than 20 mph. • Pedestrian-only footpath • Lower numbers of pedestrians and motorised vehicles and well-maintained footpaths.
Standard	Subsidiary road, urban location, speed limit of 20 to 30 mph; there are escape routes open to the pedestrian and they are visible to residents of surrounding buildings.
Higher	• Higher degree of entrapment such as car parks and back alleys. • Higher numbers of pedestrians, higher numbers of vehicles, and more-hazardous pavement surfaces. • Speed limits higher than 30 mph • Rural location • The local authority is promoting walking.

3.5 Defining the application

The P and M classes of CIE 115:2010 distinguish between the type of road user, i.e. between pedestrians and motorists. A similar distinction is made in the European documents.[4,9] In contrast, the P and M classes of BS5489-1:2013 distinguish between the type of road rather than the type of user, i.e. the M classes for traffic routes and the P classes for subsidiary roads (residential and minor roads). The design criteria associated with a particular level of the P and M classes in BS5489-1:2013 are however the same as those in CIE115:2010 and EN13201-2:2015. Note that there may be different intentions behind these documents, with, for example, CIE 115:2010 offering overarching advice about road lighting while BS5489-1:2013 focuses on more specific applications.

Guidance from Australia and New Zealand makes a clear distinction between the two categories of lighting: [64]

- Category V lighting: Lighting that is applicable to roads on which the visual requirements of motorists are dominant, e.g. traffic routes.
- Category P lighting: Lighting that is applicable to roads and other outdoor public spaces on which the visual requirements of pedestrians are dominant, e.g. local roads, outdoor shopping precincts and outdoor car parks.

On major roads, where pedestrians may be purposefully excluded (such as along a motorway) or otherwise infrequent, then the method by which application is determined is irrelevant. It becomes relevant on subsidiary roads where both motorists and pedestrians are present. In the CIE system, the same area should fulfil both the requirements of the relevant P and of the relevant M class. BS5489-1:2013 takes a different approach, stating pedestrians to be the target type of user for subsidiary roads and applying only the P class. A weakness of the BS5489-1:2013 approach is that the assumed focus on pedestrians may be incorrect if, for example, the lighting does not sufficiently support motorists' ability to detect pedestrians. A weakness of the CIE system is that the criteria for determining a P class (Table 4) do not account for the stated purpose of lighting for pedestrians but largely to traffic conditions and the risk of a RTC. Similar criteria are used to determine a suitable M lighting class (Table 1 of CIE115:2010). In effect, both the M classes and P classes using weighting factors derived from parameters associated with traffic conditions. Because the foundations of current standards are unknown it is not possible to determine which approach is better.

4 Conclusion

This review has focused upon the criteria for picking a class of road lighting class for minor roads as given in CIE115:2010. This lists a set of parameters (travel speed, traffic volume, traffic composition, parked vehicles, ambient luminance and facial recognition) with weighting factors given for different options within these parameters (Table 4). For a particular road, the summated weighting factors lead to a particular lighting class and for each lighting class the guidance gives average and minimum illuminances.

Literature review has confirmed that some rating factors (e.g. traffic speed, traffic composition and presence of parked vehicles) are relevant as they are associated with the risk of a pedestrian RTC. However, the review has been unable to substantiate the class selection process:

- There is little evidence, if any, of the optimal lighting needed to offset risks such as different traffic speeds.
- The literature does not establish whether the weighting factors and the option intervals are appropriate.
- The literature does not establish whether parameter weightings are cumulative as is currently assumed.

The review has also shown that the stated aim of lighting for pedestrians (to enable pedestrians to discern obstacles or other hazards in their path and be aware of the movements of other pedestrians, friendly or otherwise, who may be in close proximity) is not reflected in the weighting parameters as these tend to focus on the risk of an RTC. The guidance is therefore giving designers false confidence that their design is meeting the needs of pedestrians.

Giving consideration to the situations where evidence indicates a change in light level is warranted, and rejecting the un-tested assumption that different parameters are cumulative in effect, leads to a three-class descriptive system similar to BS5489-3:1992 and IESNA DG5:1994. Further research is required to establish the optimal lighting conditions for these three classes, and such work is currently ongoing. One key requirement of any new recommendations is that the evidence is publically available rather than the tacit basis of current recommendations.

Road lighting standards are consensus documents: which means that they are written and reviewed by committees representing a cross-section of the industry – manufacturers, designers, installers and researchers. One caveat of the current article is that it represents a consensus of only one person (the author). On the other hand, one advantage of the current article is that it reveals the sources of evidence upon which decisions were (or could be) made.

This article is titled part 1. Part 2 will be a discussion of the lighting criteria that might be optimal for different lighting classes such as those outlined in part 1 (Table 12). Optimal lighting may be interpreted from empirical data investigating the effect of changes of lighting on the performance of specific tasks: this first requires a discussion of the critical road users and their critical visual tasks. For pedestrians, some information about critical tasks has been established using eye tracking[65,66] and open-question qualitative methods.[55] Discussion of the optimal criteria for these different tasks has been conducted through Technical Committee 4-52 of the CIE. Investigations of optimal lighting for a specific task may use research by experiment (e.g. [30,40]) or by modelling.[67] Alternatively, optimal criteria may be identified through analyses of the consequences of changes in lighting, such as crash data, and cost-benefit analysis of the provision of lighting.[68] Analysis of the consequences of changes in lighting mean that both visual and non-visual components of task performance are included. Optimal lighting will be a compromise between the needs of the intended users, the unintended detrimental effects upon others (such as sky glow), the ability of technology, and wider political and economic forces.[69]

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