Applying Benefit Metrics to Street and Parking Lot Applications to Increase the Value of Lighting

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What matters to people is value

Value = benefit/cost

Benefit =

- Personal security
- Health and well-being
- Food, furnishings and faces
- Employee productivity
- Driving safety
- Personal security

Images: www.osram.com and www.photos.com
The lumen

$V(\lambda)$ has been the foundation for all lighting recommendations since 1924

Building blocks for benefit metrics

How do we relate these building blocks to safety and security?

Safety: What is the basic problem?

Most crashes are vehicle-vehicle at conflict points (intersections)

Is the gap large enough to turn?

Adapted from connectedvehicle.challenge.gov
Safety: Extracting gap information

Headlamps are highly conspicuous

• So, what’s the problem?

Roadway lighting provides both figure/ground information for judgment by the fovea

Characterizing the lighting in terms of the lumen (L + M cones) should work.

Rea et al. 2010
How can we know if lighting matters statistically?

Converging paths

Statistical approach from Minnesota Highway Safety Information System (HSIS) statewide database including lighting and crash data

Analytical approach using visibility coverage areas based on Minnesota DOT practices
Statistical modeling  (Donnell et al. 2009)

Multiple nonlinear regression models were developed to predict annual number of daytime and nighttime crashes (C) at Minnesota roadway intersections.

Recognizing that lighting is not randomly allocated to intersections, as many other variables as possible were studied:

- \( C = f \) (lighting, traffic volume, urban/rural, signalization, posted speed, % trucks, geometry, access control, median type, left/right shoulder type)

<table>
<thead>
<tr>
<th>Intersection type</th>
<th>Decrease in night/day crash ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban signalized</td>
<td>-7%</td>
</tr>
<tr>
<td>Suburban unsignalized</td>
<td>-13%</td>
</tr>
<tr>
<td>Rural signalized</td>
<td>0%</td>
</tr>
<tr>
<td>Rural unsignalized</td>
<td>-2%</td>
</tr>
</tbody>
</table>
How do we analyze visibility?

Visibility coverage area (gap judgment model) using photometric simulations (AGi32)
How do we analyze visibility?

Apply relative visual performance (RVP) model

Contrast and background luminance based upon $V(\lambda)$

Use IES-defined target for small target visibility (STV)
How do the statistical and analytical approaches converge?

Intersections with and without lighting

<table>
<thead>
<tr>
<th>Intersection type</th>
<th>Decrease in night/day crash ratio</th>
<th>Increase in RVP score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban signalized</td>
<td>-7%</td>
<td>+0.73</td>
</tr>
<tr>
<td>Suburban unsignalized</td>
<td>-13%</td>
<td>+1.86</td>
</tr>
<tr>
<td>Rural signalized</td>
<td>0%</td>
<td>+0.27</td>
</tr>
<tr>
<td>Rural unsignalized</td>
<td>-2%</td>
<td>+0.21</td>
</tr>
</tbody>
</table>

![Graph showing relationship between visual performance improvement and nighttime crash reduction. The graph has a linear trend with the equation $y = 0.072x$ and $R^2 = 0.93$. The x-axis represents visual performance improvement in RVP score units, and the y-axis represents nighttime crash reduction in percentage.]
Crash reductions vs. change in visibility

Roadway lighting, as practiced by MNDOT (based on IES recommendations), is expected to reduce nighttime crashes by 1.5% at rural unsignalized intersections, and by 5.3% at urban signalized intersections.

\[ y = 0.072x \]
\[ R^2 = 0.93 \]
How many crashes could lighting reduce each year?

<table>
<thead>
<tr>
<th>Major Road AADT (annual average daily traffic)</th>
<th>Annual Expected Number of Crashes at Urban Signalized Intersections</th>
<th>Annual Expected Number of Crashes at Rural Unsignalized Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.043</td>
<td>0.032</td>
</tr>
<tr>
<td>200</td>
<td>0.065</td>
<td>0.048</td>
</tr>
<tr>
<td>500</td>
<td>0.109</td>
<td>0.082</td>
</tr>
<tr>
<td>1000</td>
<td>0.162</td>
<td>0.121</td>
</tr>
<tr>
<td>2000</td>
<td>0.242</td>
<td>0.181</td>
</tr>
<tr>
<td>5000</td>
<td>0.409</td>
<td>0.306</td>
</tr>
<tr>
<td>10,000</td>
<td>0.609</td>
<td>0.455</td>
</tr>
<tr>
<td>20,000</td>
<td>0.906</td>
<td>0.677</td>
</tr>
<tr>
<td>50,000</td>
<td>1.533</td>
<td>1.146</td>
</tr>
</tbody>
</table>

5.3% of these values

1.5% of these values
What does a crash cost?

U.S. DOT (2008) estimates for different crash severity:

- Fatal: $5.8 million
- Incapacitating injury: $401,538
- Evident injury: $80,308
- Possible injury: $42,385
- Property damage only: $4,462

Fatal and injury crashes are more prevalent at rural locations (higher speeds), so the average weighted crash costs are:

- Urban signalized intersections: $122,056
- Rural unsignalized intersections: $232,142
How much does roadway intersection lighting cost?

Installation cost of dedicated poles with underground wiring (RS Means, 2008)

- Urban signalized: $13,500 (annualized over 20 yr: $1080)
- Rural unsignalized: $4,600 (annualized over 20 yr: $370)

Operation and maintenance cost:

- Urban signalized: $710 (annual)
- Rural unsignalized: $230 (annual)

Overall annual(ized) cost:

- Urban signalized: $1,790 (annual)
- Rural unsignalized: $600 (annual)

Cost is unrelated to traffic volume
Benefit/cost analysis

Lighting has the same cost whether anyone uses it.
So, how should we illuminate?

Benefit: Safety (on-axis gap judgment)
So, how should we illuminate intersections?

Benefit: Safety (on-axis gap judgment)
Safety: What is the (other) basic problem?

Off-axis pedestrian detection
Benefit/cost analysis: Off-axis detection

No complete data set like that for on-axis gap judgment

Rural unsignalized intersections

Urban signalized intersections

Need estimated benefits of avoided pedestrian collisions
Lighting system costs are easily calculated
Off-axis detection

Luminous efficiency

Starlight \hspace{2cm} Moonlight \hspace{2cm} Dim interiors \hspace{2cm} Office lighting \hspace{2cm} Daylight

Scotopic \hspace{2cm} Mesopic \hspace{2cm} Photopic

Radiant Energy
A system of mesopic photometry

He et al. 1998

Sponsors: DOE, GE, OSRAM Sylvania, Philips, Venture
Driver decision-making (off-axis detection)

Characterizing the lighting in terms of the lumen will NOT work.
Simulated driving performance

Bullough and Rea 2000

Sponsors: DOE, GE, OSRAM Sylvania, Philips, Venture
So, how should we illuminate?

Benefit: Safety (off-axis detection)
So, how should we illuminate?

Benefit: Safety (off-axis detection)
So, how should we illuminate?

Benefit: Safety (off-axis detection)

Rods + L + M cones
Security: What is the basic problem?

Personal security
Benefit/cost analysis: Personal security

No complete data set like that for on-axis gap judgment

Can estimate equivalent benefits for different light sources
Lighting system costs are easily calculated
Brightness and personal security

Locations that appear brighter tend to be judged as safer (Rea et al. 2009)

Therefore, scene brightness can be used as a lighting metric for personal security
Modeling scene brightness

Rea et al. 2010

\[ V_B(\lambda) = V(\lambda) + gS(\lambda) \]

\[ g = f(E) \]

Sponsor: Philips Lighting
So, how do we illuminate?

Benefit: Personal security (scene brightness)
So, how do we illuminate?

Benefit: Personal security (scene brightness)

All cones (S + L + M)
What matters to people is value

Value = benefit/cost

Benefit =

Images: www.osram.com and www.photos.com
Building blocks for benefit metrics
Benefit metric spectral weighting functions

- Visual performance
- Brightness
- Circadian light
Different benefit metrics for different applications

- Driving safety
- Personal security
- Health and well-being
- Food, furnishings and faces
- Employee productivity
Value = benefit/cost

Benefit metrics deliver greater value

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Benefit metric</th>
<th>Benefit metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving safety, employee productivity</td>
<td>$V(\lambda)$, $V'(\lambda)$, $V_{mh}(\lambda)$, $V_{ml}(\lambda)$</td>
<td>Visual performance</td>
</tr>
<tr>
<td>Personal security</td>
<td>$V_{B2}(\lambda)$, $V_{B3}(\lambda)$</td>
<td>Brightness</td>
</tr>
<tr>
<td>Health and well-being</td>
<td>$V_{C}(\lambda)$</td>
<td>Circadian light</td>
</tr>
<tr>
<td>Food, furnishings and faces</td>
<td>GAI, CRI, white, consistency</td>
<td>Class A Color</td>
</tr>
</tbody>
</table>

These metrics have all the features of the lumen. All the rules of photometry, regulation and application can be equally applied to these functions (e.g., lm/m²).
Summary and conclusions

Pick the benefit desired

Select the best benefit metric

Design and regulate for the benefit

Results:

• Greater safety
• Greater personal security
• Lower energy use
• Less light pollution

And, the benefits can be monetized!
Thank you.

Acknowledgment:
Dennis Guyon