Linear Airfield Lighting Evaluations: From the Laboratory to the Field

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IES Aviation Lighting Committee Fall Technology Meeting

October 26, 2016
Outline

- Potential benefits of linear airfield lighting
- Initial laboratory results and predictive model
- Field installations and evaluations
- Economic cost analysis
Potential Benefits of Linear Lighting

- More continuous delineation along roads increases visibility distance (Zwahlen and Schnell 1997) and elicits desirable driving speeds (Griffith and Brooks 2000)

- Pilots report increased visual acquisition distance and greater preference with linear airfield lighting (Gallagher 2005; Stauffer and Hyland 2014)
Initial Experiments and Predictive Model

- LRC conducted laboratory and field experiments using static images, animations and prototype fixtures
  - Results among experiments were consistent, leading to a specification tool to trade off length of light and spacing

\[
RT \text{ (ms)} = 286 - 607 \log L + 989 \log S
\]
  - Where RT is the response time (in ms), L is the length of linear elements (in ft) and S is the spacing between elements (in ft)
  - Longer elements and shorter spacing result in shorter response times
Field Testing at The Ohio State University
Previous Test Results:

- The RPI study established that under simulated laboratory conditions, properly defined linear elements with sufficient length and spacing could provide shorter visual acquisition times than conventional point source lights.

- LED light configurations with increased light lengths and reduced spacing’s between lights provided shorter times over point based light systems.

- Field test goals: to validate results.
Field Testing at The Ohio State University

600 feet.

650 feet.
Array of 30 variable length linear light sources, point source lighting, and control system, placed on runway 9L-27R at KOSU.
Field Testing at The Ohio State University

Aligned to create variable configurations:

- Light Length
- Turn Direction
- Turn Angle
- Light Spacing
Field Testing at The Ohio State University
Field Testing at The Ohio State University
Field Testing at The Ohio State University

16 ft. Linear Lights, 150 ft. separation
90° Right Turn
Field Testing at The Ohio State University

32 configurations
4 Testing Groups
Each participant in each group observed 8 different configurations
Total 45 participants
360 observations
• Approximately 82 seconds to taxi the length of the runway

• 50.5 seconds to make a determination across all light lengths (point, 2ft, 8ft and 16ft), average across all participants and observations
Field Testing at The Ohio State University

**Reaction Time:**

**Mean Reaction Time**

<table>
<thead>
<tr>
<th>Source Length</th>
<th>Mean Reaction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Point)</td>
<td>54.44</td>
</tr>
<tr>
<td>2 ft.</td>
<td>56.63</td>
</tr>
<tr>
<td>8 ft.</td>
<td>51.77</td>
</tr>
<tr>
<td>16 ft.</td>
<td>41.47</td>
</tr>
</tbody>
</table>

**Standard Deviation**

<table>
<thead>
<tr>
<th>Source Length</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Point)</td>
<td>25.076</td>
</tr>
<tr>
<td>2 ft.</td>
<td>23.131</td>
</tr>
<tr>
<td>8 ft.</td>
<td>20.056</td>
</tr>
<tr>
<td>16 ft.</td>
<td>19.942</td>
</tr>
</tbody>
</table>

**Significance at 95%:**

<table>
<thead>
<tr>
<th>Source Length</th>
<th>Significance at 95%:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Point 2 ft. 8 ft. 16 ft.</td>
</tr>
<tr>
<td>Point</td>
<td>- no no yes</td>
</tr>
<tr>
<td>2 ft.</td>
<td>- no yes</td>
</tr>
<tr>
<td>8 ft.</td>
<td>- yes</td>
</tr>
<tr>
<td>16 ft.</td>
<td>-</td>
</tr>
</tbody>
</table>

- Significant decrease in reaction time from:
  - Point to 16ft
  - 2ft to 16ft
  - 8ft to 16ft
Field Testing at The Ohio State University

Reaction Time: 30 deg. turns

- Reaction time decrease proven significant for 16ft lights when compared to point and 2ft
Field Testing at The Ohio State University

Reaction Time: 90 deg. turns

- Reaction time decrease proven significant for 16ft lights when compared to point and 2ft and 8ft lights
- Reaction time decrease proven significant for 8ft lights when compared to 2ft lights
### Accuracy:

#### Mean Accuracy

<table>
<thead>
<tr>
<th>Source Length</th>
<th>0</th>
<th>2 ft.</th>
<th>8 ft.</th>
<th>16 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.46</td>
<td>0.49</td>
<td>0.64</td>
<td>0.78</td>
</tr>
</tbody>
</table>

#### Standard Deviation

<table>
<thead>
<tr>
<th>Source Length</th>
<th>0</th>
<th>2 ft.</th>
<th>8 ft.</th>
<th>16 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.50</td>
<td>0.50</td>
<td>0.48</td>
<td>0.42</td>
</tr>
</tbody>
</table>

#### Significance at 95%

<table>
<thead>
<tr>
<th>Source Length:</th>
<th>Significance at 95%:</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Point</td>
</tr>
<tr>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>2 ft.</td>
<td>-</td>
</tr>
<tr>
<td>8 ft.</td>
<td>-</td>
</tr>
<tr>
<td>16 ft.</td>
<td></td>
</tr>
</tbody>
</table>

- 0-Inaccurate, 1-Accurate
- Increase in accuracy was proven significant when comparing:
  - Point to 8ft
  - 2ft to 8ft
  - Point to 16ft
  - 2ft to 16ft
  - 8ft to 16ft
Participant Confidence Level:

- **Confidence**: 1-5 Scale
- **Increase in confidence proven significant when comparing:**
  - Point to 16ft
  - 2ft to 16ft
  - 2ft to 8ft
Field Testing at The Ohio State University

Reaction Time by Spacing:

<table>
<thead>
<tr>
<th>Reaction Time by Spacing</th>
<th>50 ft</th>
<th>150ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>53.56</td>
<td>47.32</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>28.93</td>
<td>27.51</td>
</tr>
</tbody>
</table>

- While reaction time does decrease from 50ft spacing to 150ft spacing, it is not a significant decrease in reaction time.
Field Testing at The Ohio State University

Reaction Time by Spacing and Source Length:

- There is a difference in reaction times by source length, in different spacing
- But the only significant difference in reaction time was in point source lighting
Field Testing at The Ohio State University

Accuracy by Spacing:

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Mean</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 ft</td>
<td>0.57</td>
<td>51</td>
</tr>
<tr>
<td>150 ft</td>
<td>0.40</td>
<td>50</td>
</tr>
</tbody>
</table>

Mean Accuracy by Spacing

- 50 ft Spacing: Mean = 0.57, Count = 51
- 150 ft Spacing: Mean = 0.40, Count = 50

Standard Deviation

- 50 ft Spacing: Standard Deviation = 0.50
- 150 ft Spacing: Standard Deviation = 0.49

Significant at 95%

No
Hypotheses to Spacing Issue

• 150 ft. Spacing included far separated Light
• Less interference from other ambient lighting
• Use of Peripheral vision from larger distances
Field Testing at The Ohio State University

OSU Field Test Conclusions

- Overall validation of Static tests and simulation tests.
- Lights >8 ft. tend to provide most significant benefits in terms of reduced reaction time and increased accuracy of determination.
- Non-intuitive “spacing” results.
  - Use of peripheral vision at larger distances
  - Less distractive lighting farther from runway edge
Installation Cost Analysis
Installation Cost Analysis

Objective:

- Estimate the cost and time differences between linear LED and traditional point source installations for a high speed taxiway turnoff at a major hub airport in the United States.
Assumptions

- 8-foot LED fixture length
- Installation in an existing flexible (HMA) pavement.
- LED fixture base material properties, fastening techniques, and anchorage would meet the intent of FAA Advisory Circular AC 150/5345-42H Specification for Airport Light Bases, Transformer Housings, Junction Boxes, and Accessories.
Assumptions (cont.)

- Cost analysis would not consider mobilization and demobilization costs, costs of the light fixtures or fixture cans/bases, and costs to connect to existing electrical infrastructure.
- Cost of LED fixture base, or the “linear can”, would be excluded.
Assumptions (cont.)

- Standard and LED fixtures would require appropriately-sized, reinforced concrete anchors to distribute wheel load to the subgrade and to stabilize the fixture, as stated in paragraph 4.3.10.1 of AC 150/5345-42H.

- Costs would include reinforced concrete anchors, conduits between fixtures, and other associated excavation and paving costs.
L-868 Light Base
Linear LED Design Sketches

- Sketches were prepared by engineers to show materials, dimensions, and integration of components within the foundation for the LED fixture.

- These sketches should not be considered as a design for installation. The fixtures have not completed the FAA approval process, and this report does not address the suitability of the fixture for its intended use.
Linear LED Design Sketches (cont.)

- #4 Rebar w/ 3" clear cover (Typical)
- Bottom flange of steel beam
- Linear LED Fixture Base Can
- 8' Long x 2' Wide x 1' Deep
- PCC

Dimensions:
- 10' length
- 2' height
Linear LED Design Sketches (cont.)
Cost Analysis Methodology

- The cost estimate is comprised of four separate construction activities:
  - Excavation
  - Electrical duct banks
  - Portland cement concrete (PCC) reinforced foundations
  - Asphalitic concrete (AC) patching
Cost Analysis Methodology (cont.)

- Unit costs were extracted from RS Means data.
- Quantities were derived from the FAA approved installation design sketches and the ORD layout.
Cost Analysis Methodology (cont.)

- Estimate intentionally excludes costs for the fixtures and fixture base cans. The costs for L-868 fixtures and cans have a long historical basis.
- The costs for the LED fixtures and associated base cans cannot be determined until they have been certified by an FAA-approved Third Party Certification Body as directed by AC 150/5345-42H.
Cost estimate was based on an installation at O’Hare International Airport (ORD) at the intersection of Runway 4R/22L and Taxiway Y3.
Fixture Spacing

COLOR CODE CENTERLINE LIGHTS BEGINNING HERE AND WORK TOWARD RUNWAY HOLD POSITION.

From point of tangency lights go 200' up the runway
Traditional L-868 Foundation Installation
Cost Summary

<table>
<thead>
<tr>
<th>Subtotals</th>
<th>Cost</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td>$67,773</td>
<td>47.1%</td>
</tr>
<tr>
<td>Ductbanks</td>
<td>$32,870</td>
<td>22.9%</td>
</tr>
<tr>
<td>PCC Lights Foundations and Installation</td>
<td>$8,342</td>
<td>5.8%</td>
</tr>
<tr>
<td>AC Patching</td>
<td>$34,861</td>
<td>24.2%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$143,846</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
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Based on 23 light fixtures along 1,100 feet of pavement
Linear LED Foundation Installation Cost Summary

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<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td>$60,446</td>
<td>41.5%</td>
</tr>
<tr>
<td>Ductbanks</td>
<td>$28,550</td>
<td>19.6%</td>
</tr>
<tr>
<td>PCC Lights Foundations and Installation</td>
<td>$24,356</td>
<td>16.7%</td>
</tr>
<tr>
<td>AC Patching</td>
<td>$32,181</td>
<td>22.1%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$145,533</td>
<td>100%</td>
</tr>
</tbody>
</table>

Based on 23 light fixtures along 1,100 feet of pavement
# Linear LED and L-868 Cost Comparison

<table>
<thead>
<tr>
<th>Cost Summary Per Light Type</th>
<th>LINEAR SOURCE LIGHTS</th>
<th>TYPE L-868</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td>$ 60,446</td>
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<td>$ 34,861</td>
</tr>
<tr>
<td><strong>SUBTOTAL</strong></td>
<td><strong>$ 145,533</strong></td>
<td><strong>$ 143,846</strong></td>
</tr>
<tr>
<td>15% Contingency</td>
<td>$ 167,363</td>
<td>$ 165,423</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td><strong>$ 1,687</strong></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

- Overall, the costs to install suitable foundations and associated ductwork for 23 runway/taxiway centerline light fixtures at ORD are estimated to be roughly equal, at approximately $145,000, for both traditional L-868 fixtures and linear LED fixtures.
Excavation, duct banks, and asphalt patching are estimated to be more costly for L-868 foundations.

The foundations for in-pavement linear LEDs are estimated to be approximately three times as large and costly as the L-868 foundations.

The L-868 foundations are estimated to require approximately 37 days for installation compared to 31 days for linear LED foundations.
Questions

Accepted Acknowledgements

- We are very thankful to our FAA sponsor for their full support for this project!
- Thank you to our audience for your interest and attention at this morning’s presentation!

Questions!