Linear Airfield Lighting Evaluations: From the Laboratory to the Field

John D. Bullough (RPI Lighting Research Center), Shawn Pruchnicki (Ohio State University), Seth Young (Ohio State University), Garrison Canter (CSRA, Inc.)

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)

(Griffith and Brooks 2000)

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

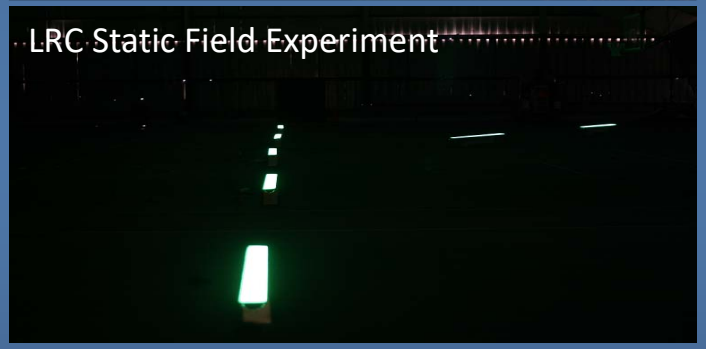
(Gallagher 2005)

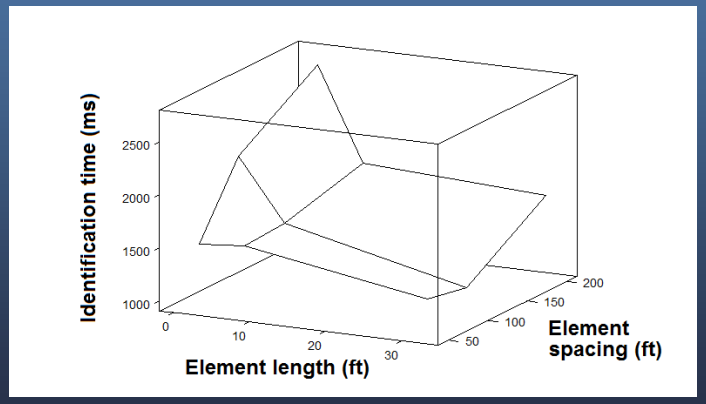
Initial Experiments and Predictive Model

- 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 (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

THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

Center for
Aviation Studies

Field Testing at The Ohio State University

- ***Previous Test Results:***

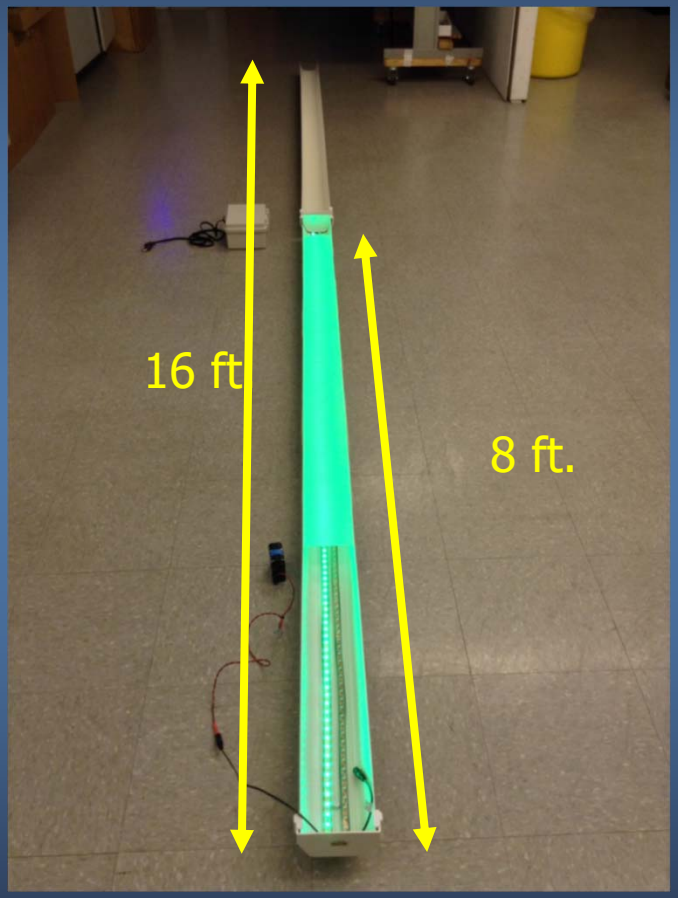
  - The RPI study established that under simulated laboratory conditions, properly defined linear elements with sufficient length and spacing could provide shorter visual acquisition times than conventional point source lights

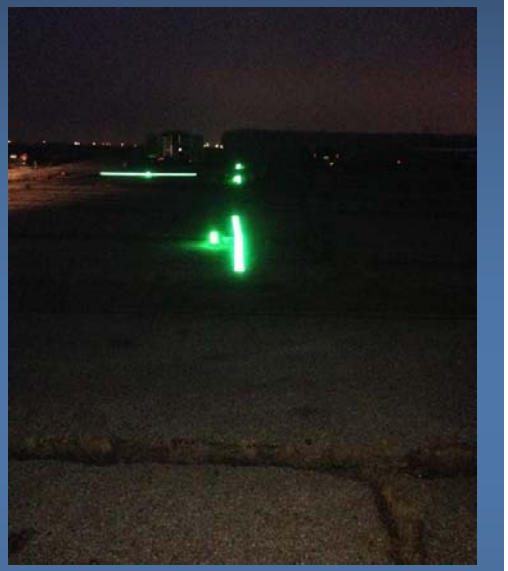
  - LED light configurations with increased light lengths and reduced spacing's between lights provided shorter times over point based light systems

  - Field test goals: to validate results

Field Testing at The Ohio State University

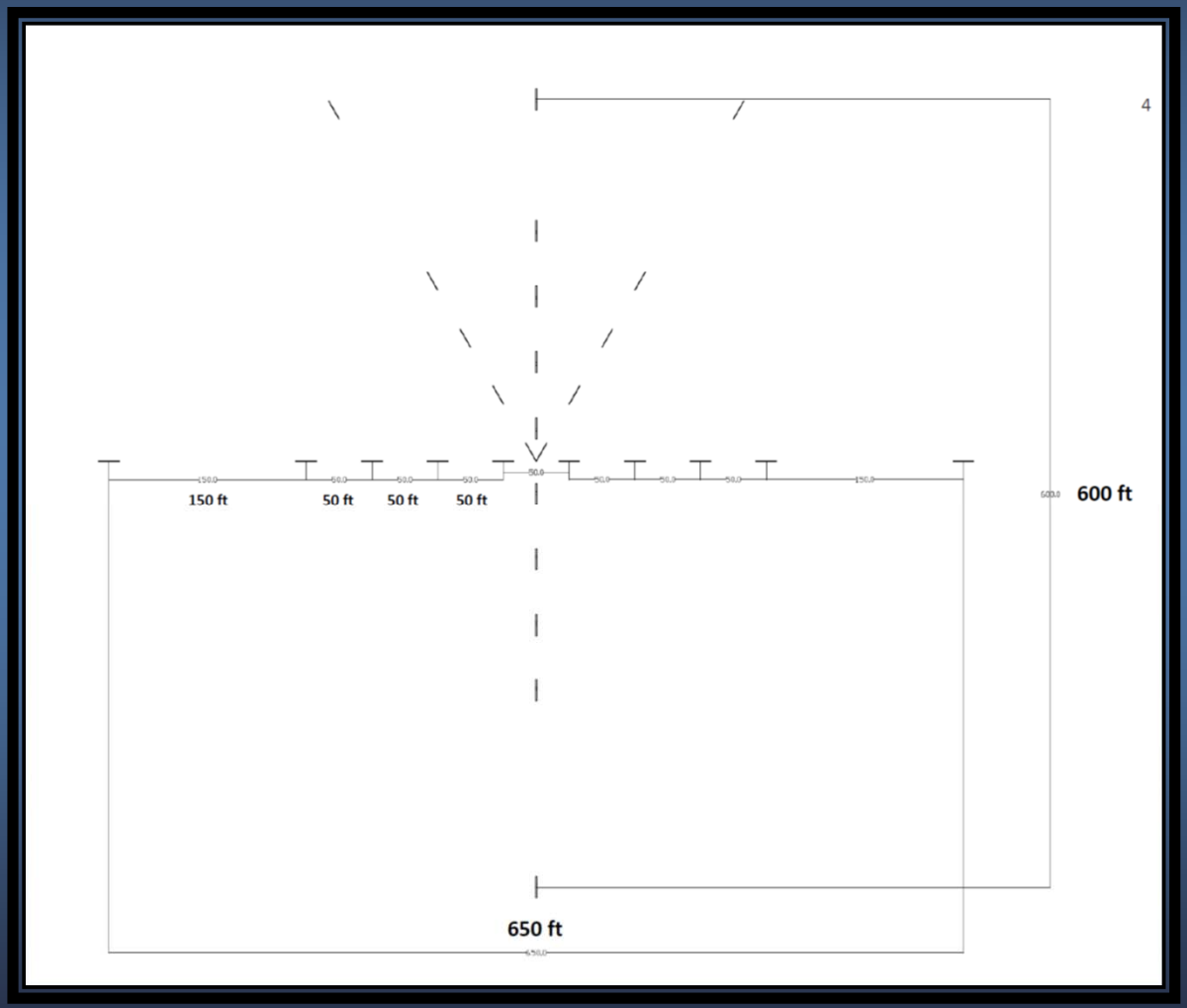
Field Testing at The Ohio State University





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

Field Testing at The Ohio State University

LED Lighting Test Condition Matrix

Condition #	Source Length	Spacing Distance	Direction	Angle	Sample Groups 1	2	3	4
1	point	50 ft.	Left	30°	1			
2	point	50 ft.	Right	30°		1		
3	point	50 ft.	Left	90°			1	
4	point	50 ft.	Right	90°				1
5	point	150 ft.	Left	30°				1
6	point	150 ft.	Right	30°			1	
7	point	150 ft.	Left	90°		1		
8	point	150 ft.	Right	90°	1			
9	2 ft.	50 ft.	Left	30°				1
10	2 ft.	50 ft.	Right	30°	1			
11	2 ft.	50 ft.	Left	90°		1		
12	2 ft.	50 ft.	Right	90°			1	
13	2 ft.	150 ft.	Left	30°			1	
14	2 ft.	150 ft.	Right	30°		1		
15	2 ft.	150 ft.	Left	90°	1			
16	2 ft.	150 ft.	Right	90°				1
17	8 ft.	50 ft.	Left	30°			1	
18	8 ft.	50 ft.	Right	30°				1
19	8 ft.	50 ft.	Left	90°	1			
20	8 ft.	50 ft.	Right	90°		1		
21	8 ft.	150 ft.	Left	30°		1		
22	8 ft.	150 ft.	Right	30°	1			
23	8 ft.	150 ft.	Left	90°				1
24	8 ft.	150 ft.	Right	90°			1	
25	16 ft.	50 ft.	Left	30°				1
26	16 ft.	50 ft.	Right	30°			1	
27	16 ft.	50 ft.	Left	90°		1		
28	16 ft.	50 ft.	Right	90°	1			
29	16 ft.	150 ft.	Left	30°	1			
30	16 ft.	150 ft.	Right	30°				1
31	16 ft.	150 ft.	Left	90°			1	
32	16 ft.	150 ft.	Right	90°		1		
					8	8	8	8

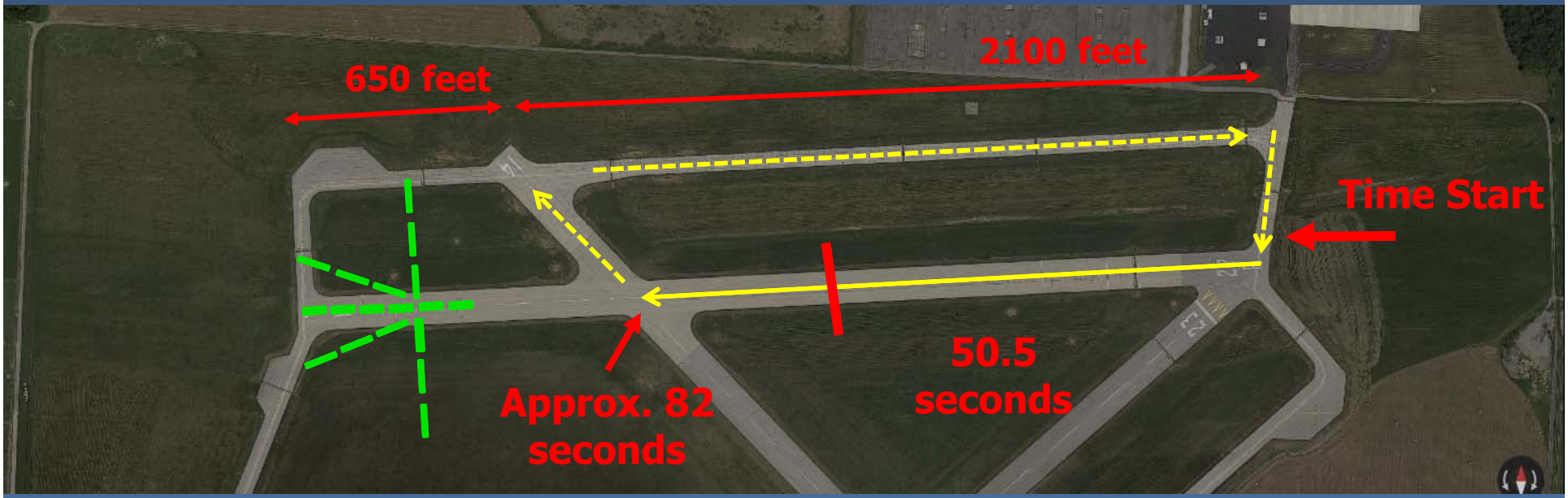
32 configurations

4 Testing Groups

Each participant in each group observed 8 different configurations

Total 45 participants
360 observations

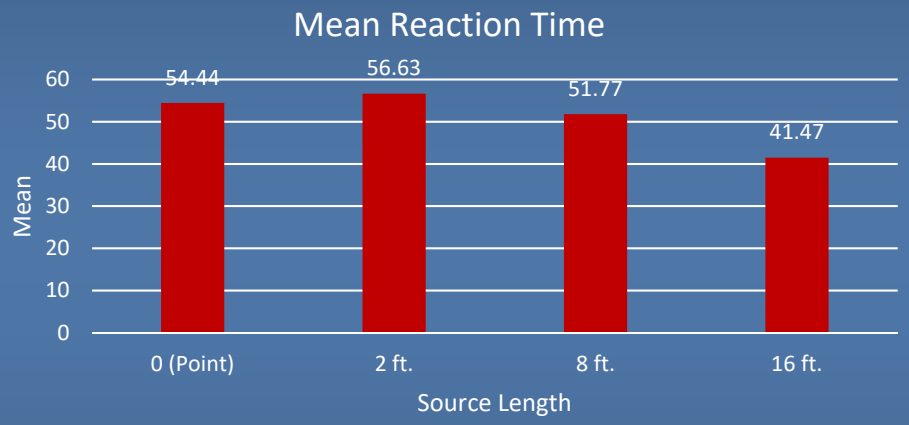
Field Testing at The Ohio State University

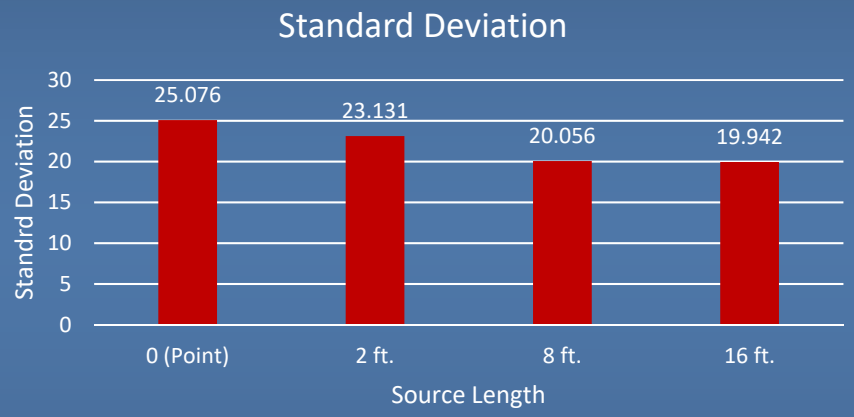


- Approximately 82 seconds to taxi the length of the runway
- 50.5 seconds to make a determination across all light lengths (point, 2ft, 8ft and 16ft), average across all participants and observations

Field Testing at The Ohio State University

Reaction Time:



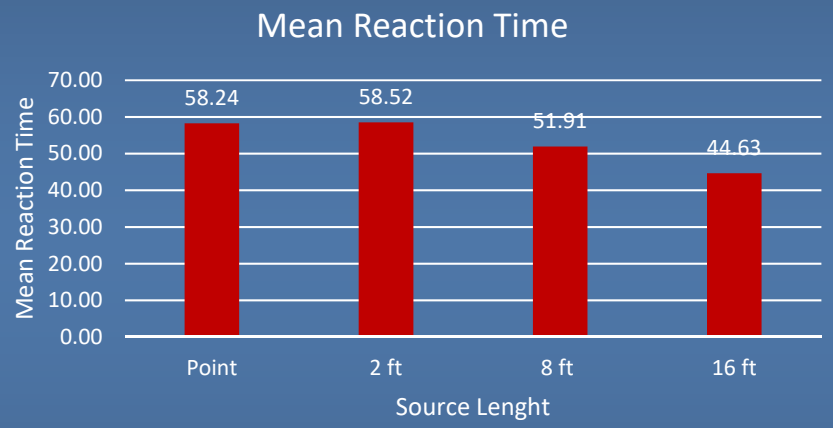


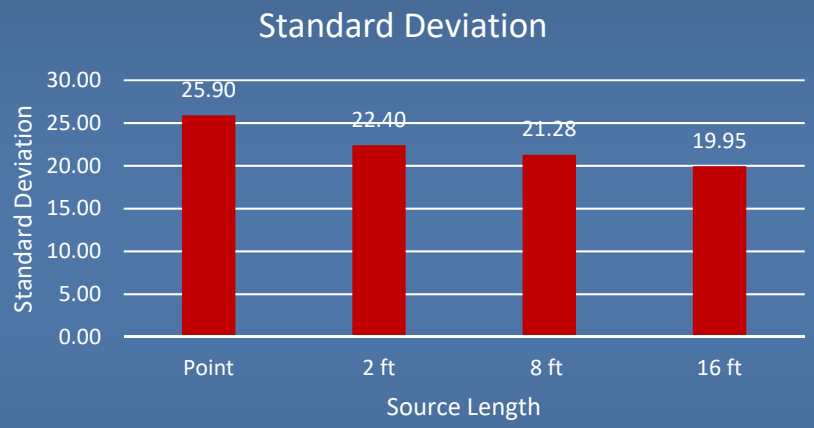
Source Length:	Significance at 95%:			
	Point	2 ft.	8 ft.	16 ft.
Point	-	no	no	yes
2 ft.		-	no	yes
8 ft.			-	yes
16 ft.				-

- 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



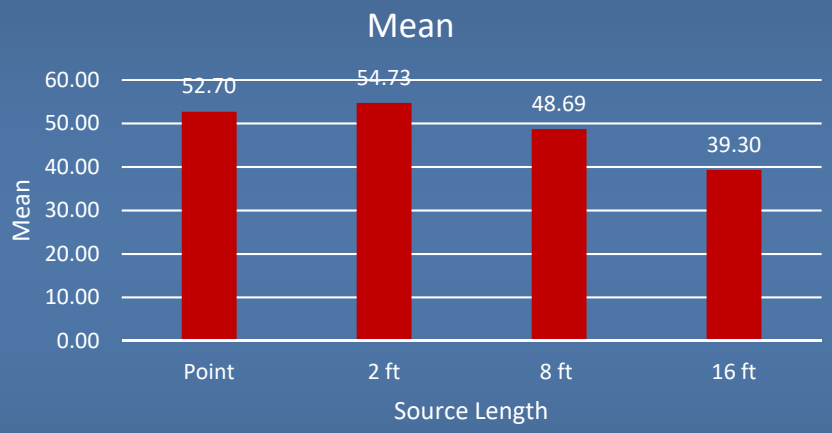


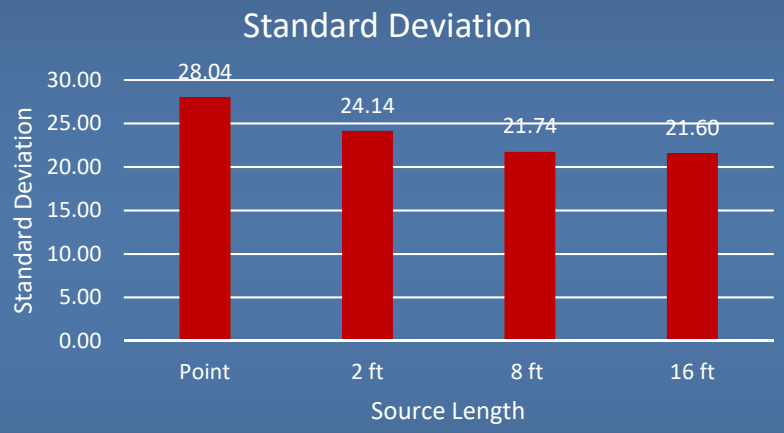
Source Length:	Significance at 95% Level			
	Point	2ft	8ft	16ft
Point		no	no	yes
2ft			no	yes
8ft				no
16ft				

- 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



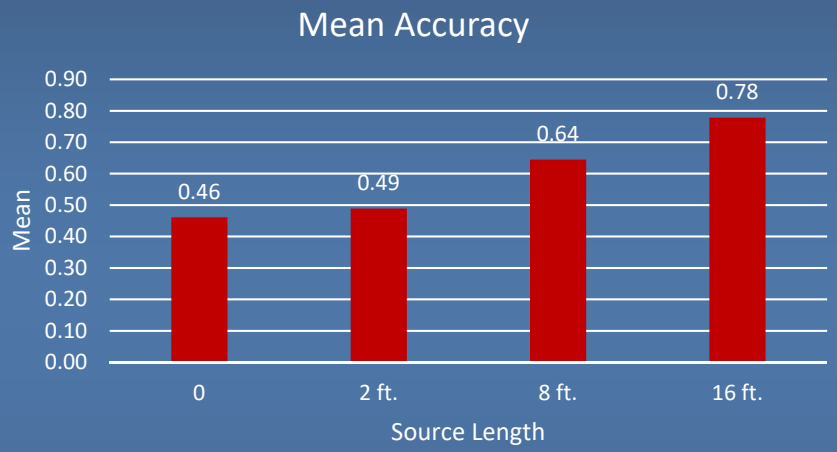


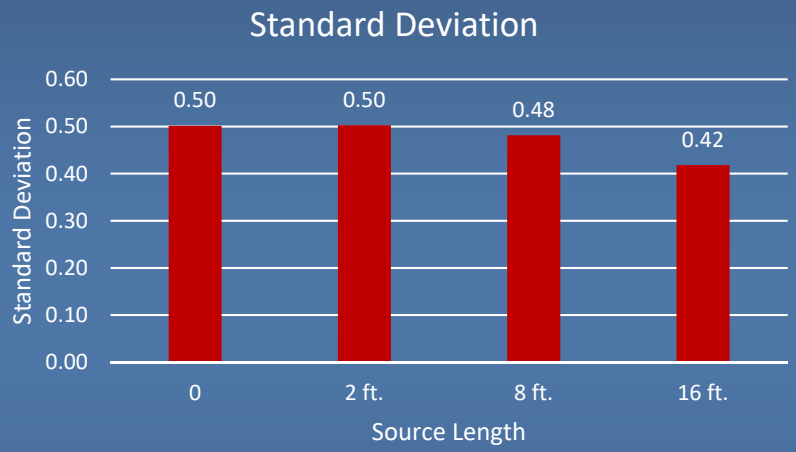
Source Length:	Significance at 95% Level			
	Point	2ft	8ft	16ft
Point		no	no	yes
2ft			yes	yes
8ft				yes
16ft				

- 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

Field Testing at The Ohio State University

Accuracy:



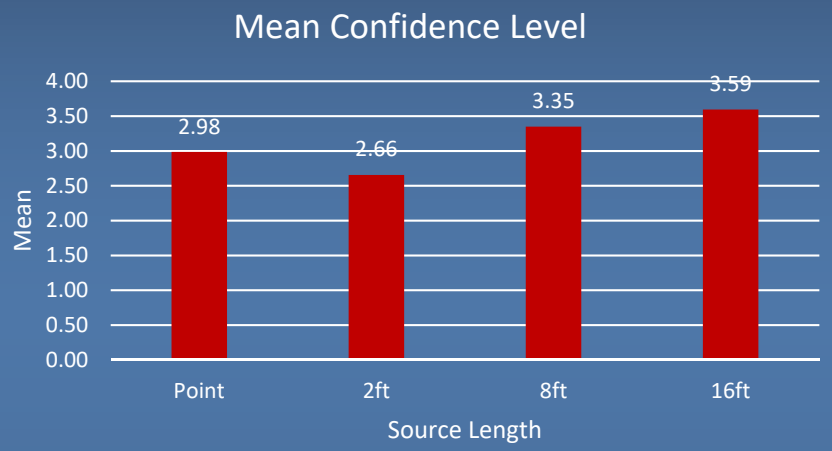


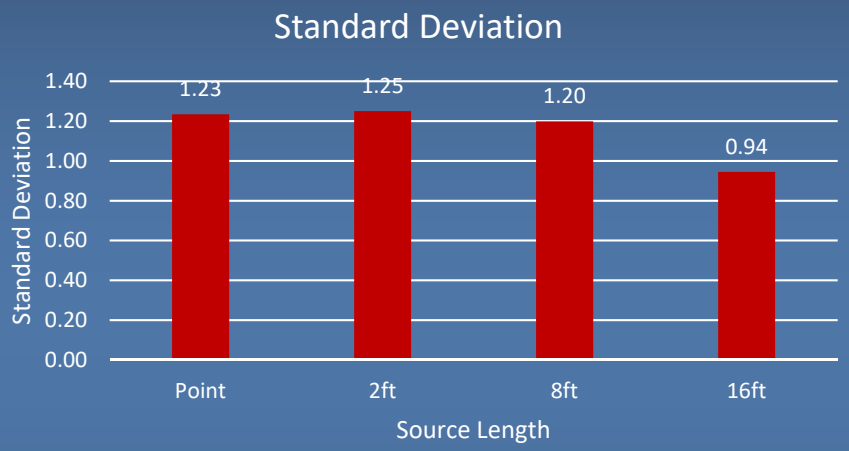
Source Length:	Significance at 95%:			
	Point	2 ft.	8 ft.	16 ft.
0	-	no	yes	yes
2 ft.		-	yes	yes
8 ft.			-	yes
16 ft.				-

- 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

Field Testing at The Ohio State University

Participant Confidence Level:



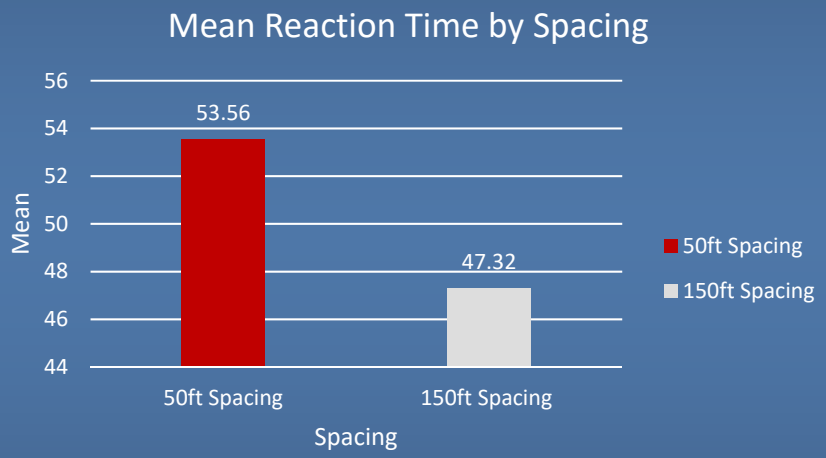


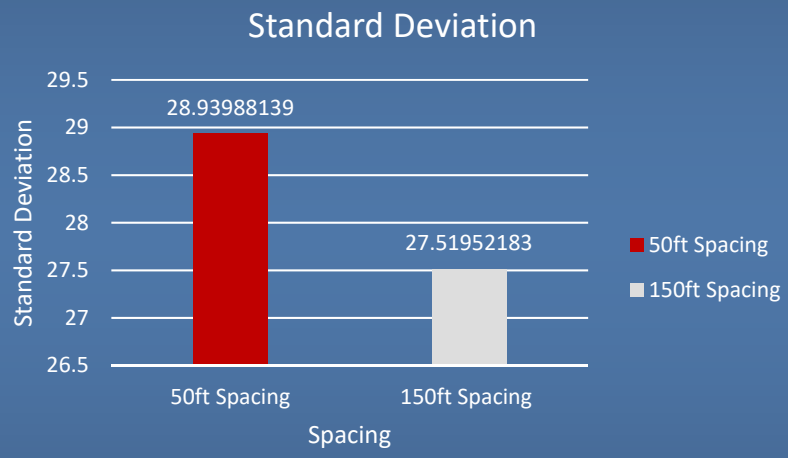
Source Length:	Significance at 95% Level			
	Point	2ft	8ft	16ft
Point		no	no	yes
2ft			yes	yes
8ft				no
16ft				

- 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:



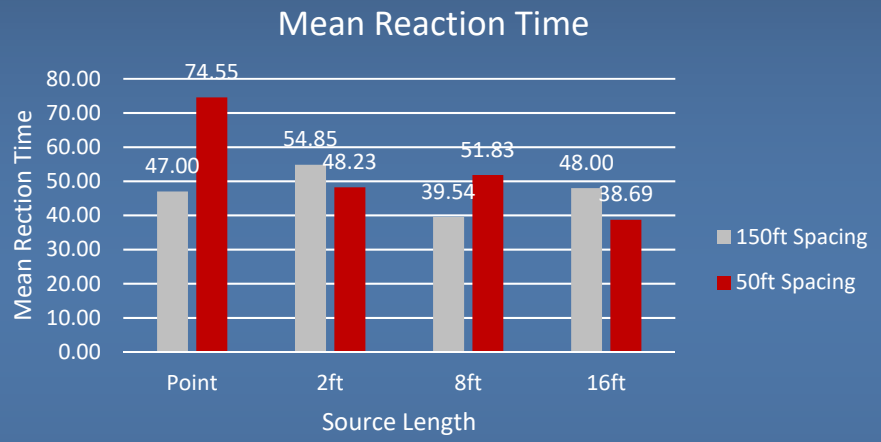


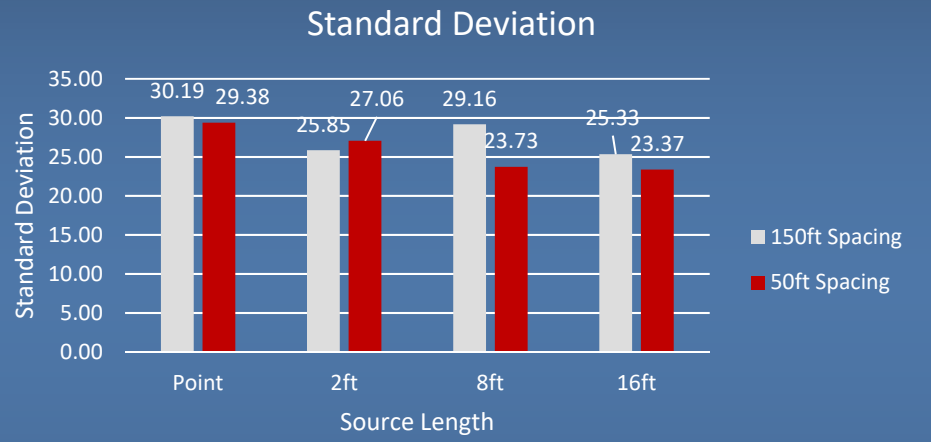
Reaction Time by Spacing					
50 ft		150ft		Significant at 95%	
Mean	Count	Mean	Count		
53.56	50	47.32	50	No	

- 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:



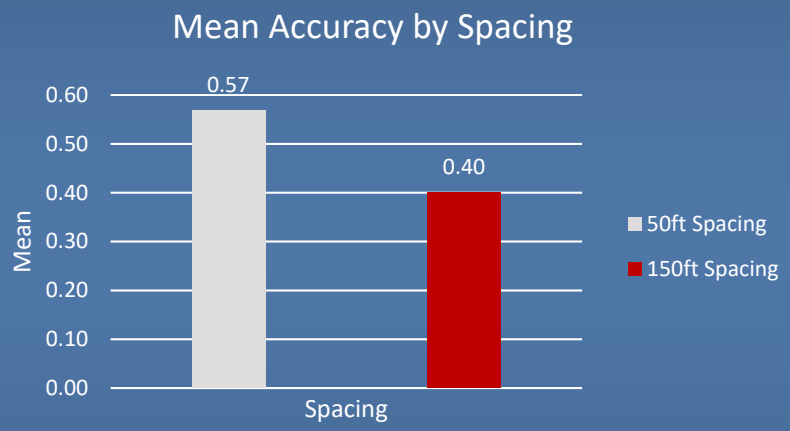


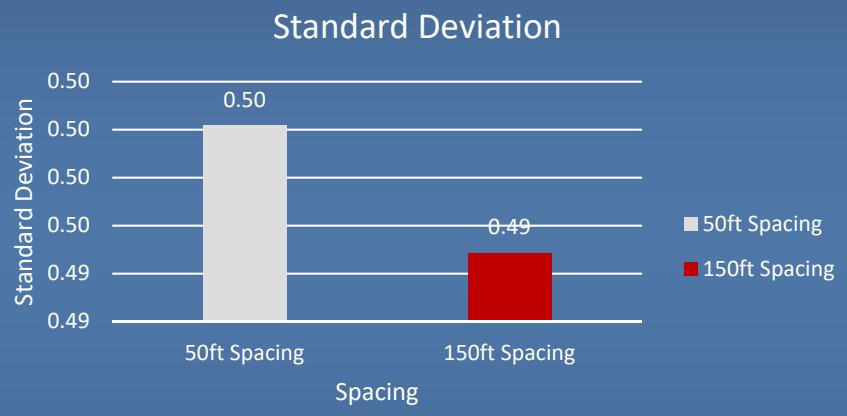
Source Length	Reaction Time by Spacing				
	50 ft		150ft		Significant at 95%
	Mean	Count	Mean	Count	
Point	**74.55**	**11**	**47.00**	**13**	yes
2ft	48.23	13	54.85	13	no
8ft	51.83	12	**39.54**	13	no
16ft	38.69	13	48.00	11	no

- 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:





Accuracy by Spacing				
50 ft		150ft		Significant at 95%
Mean	Count	Mean	Count	
0.57	51	0.40	50	No

Field Testing at The Ohio State University

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

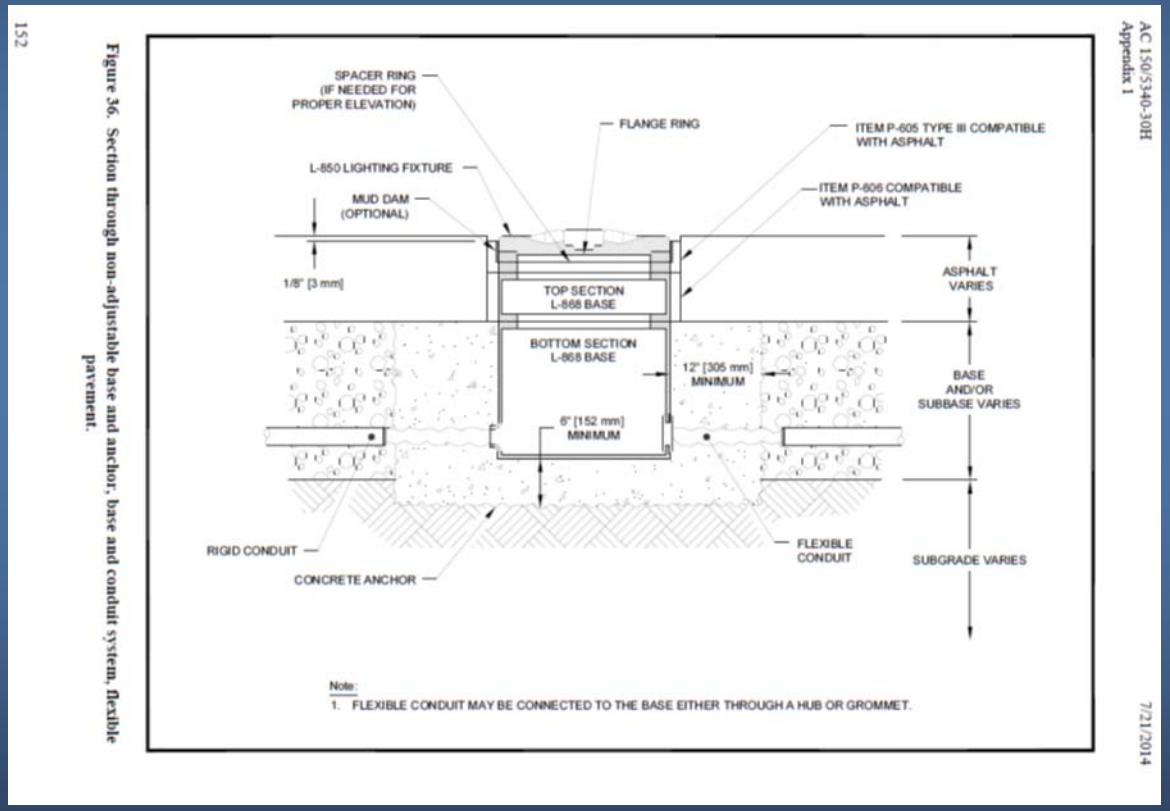
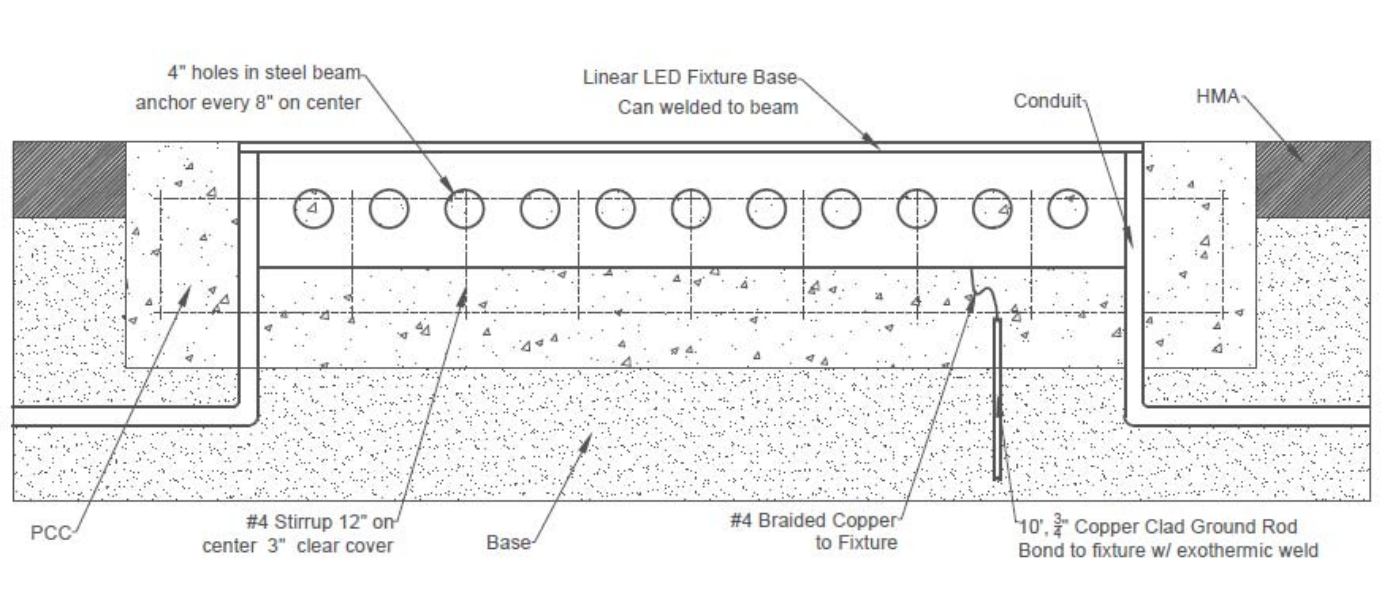


Figure 36. Section through non-adjustable base and anchor, base and conduit system, flexible pavement.

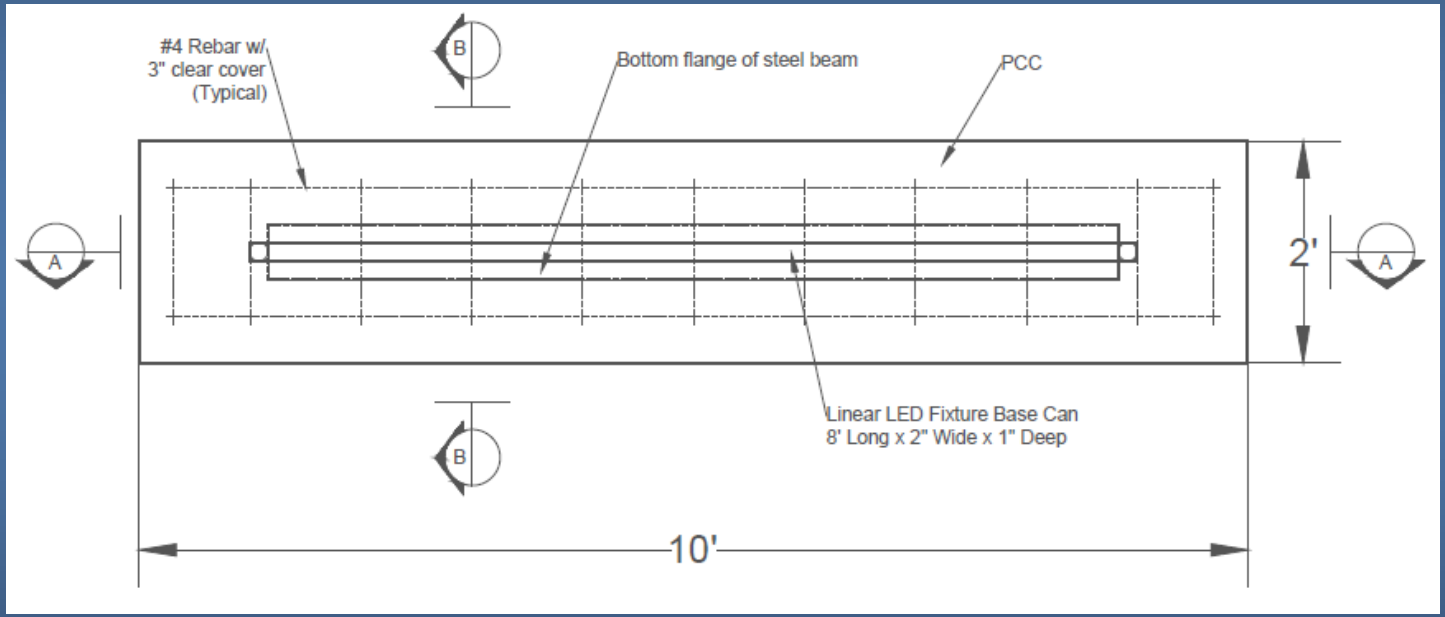
Linear LED Design Sketches

- 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.**

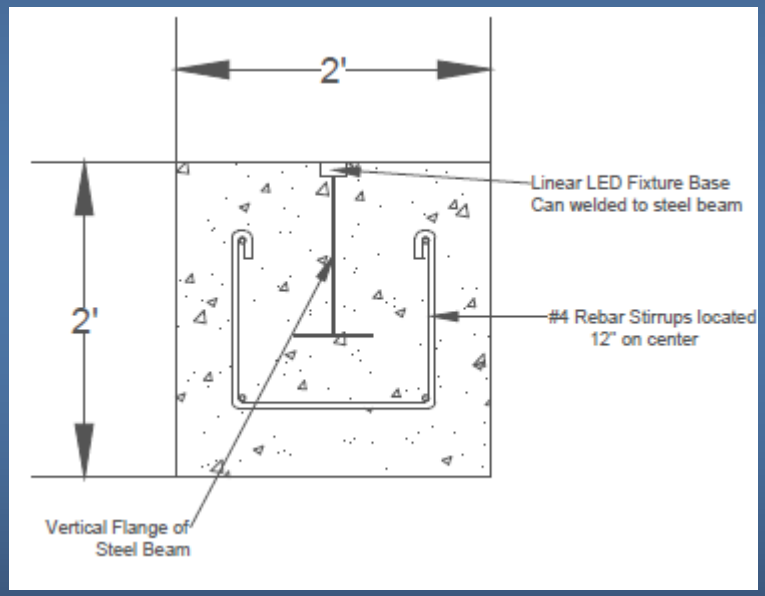
Linear LED Design Sketches (cont.)



Linear LED Design Sketches (cont.)



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
- Asphaltic concrete (AC) patching

Cost Analysis Methodology (cont.)

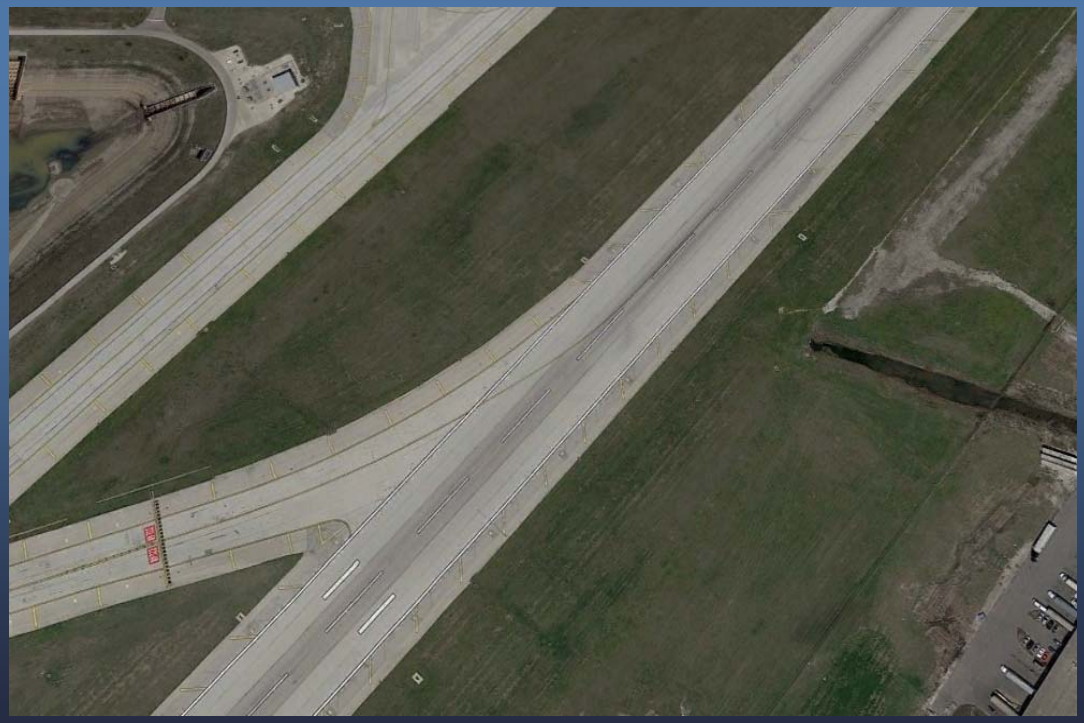
- Unit costs were extracted from RS Means data.
- Quantities were derived from the FAA approved installation design sketches and the ORD layout.

Cost Analysis Methodology (cont.)

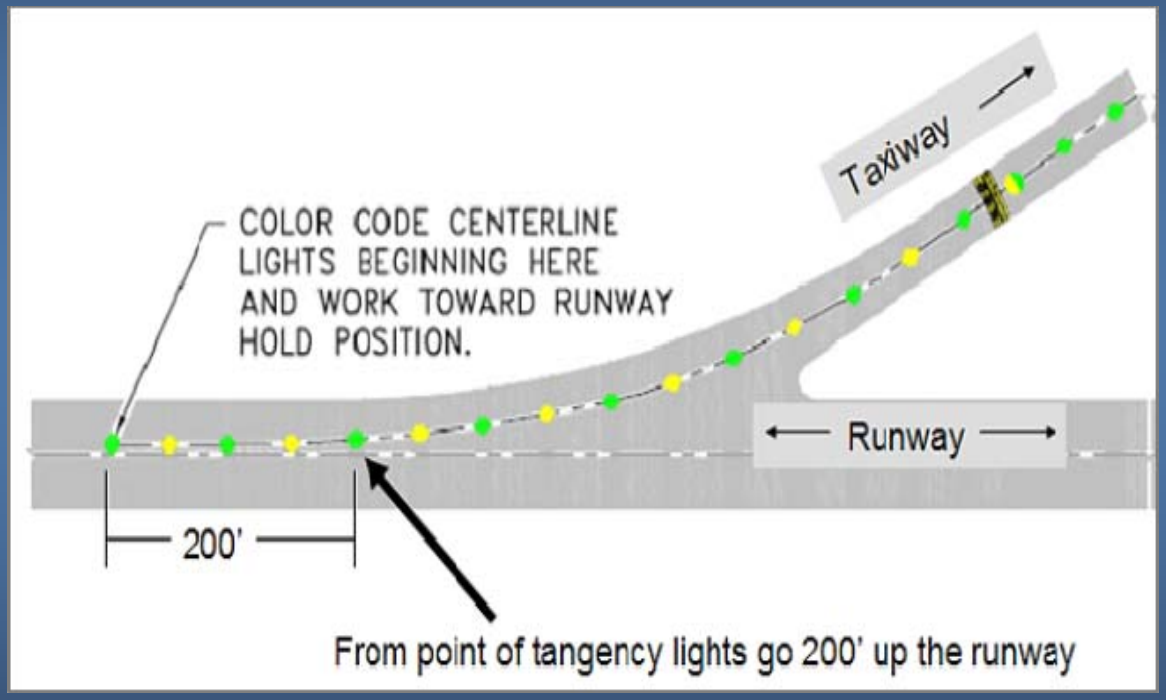
- Estimate intentionally excludes costs for the fixtures and fixture base cans. The costs for L-868 fixtures and cans have a long historical basis.
- The costs for the LED fixtures and associated base cans cannot be determined until they have been certified by an FAA-approved Third Party Certification Body as directed by AC 150/5345-42H.

ORD 4R- 22L Taxiway Y-3 High Speed Turnoff

- 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



Traditional L-868 Foundation Installation Cost Summary

Based on 23 light fixtures along 1,100 feet of pavement			
Subtotals		***Cost***	***%***
Excavation	$	67,773	47.1%
Ductbanks	$	32,870	22.9%
PCC Lights Foundations and Installation	$	8,342	5.8%
AC Patching	$	34,861	24.2%
TOTAL	**$**	**143,846**	**100%**

Linear LED Foundation Installation Cost Summary

Based on 23 light fixtures along 1,100 feet of pavement			
Subtotals		***Cost***	***%***
Excavation	$	60,446	41.5%
Ductbanks	$	28,550	19.6%
PCC Lights Foundations and Installation	$	24,356	16.7%
AC Patching	$	32,181	22.1%
TOTAL	**$**	**145,533**	**100%**

Linear LED and L-868 Cost Comparison

Cost Summary Per Light Type				
	LINEAR SOURCE LIGHTS		TYPE L-868	
Excavation	$	60,446	$	67,773
Ductbanks	$	28,550	$	32,870
PCC Lights Foundations and Installation	$	24,356	$	8,342
AC Patching	$	32,181	$	34,861
SUBTOTAL	**$**	**145,533**	**$**	**143,846**
15% Contingency	**$**	**167,363**	**$**	**165,423**
Difference	**$**	**1,687**		

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.

Conclusions (cont.)

- 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

- 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!