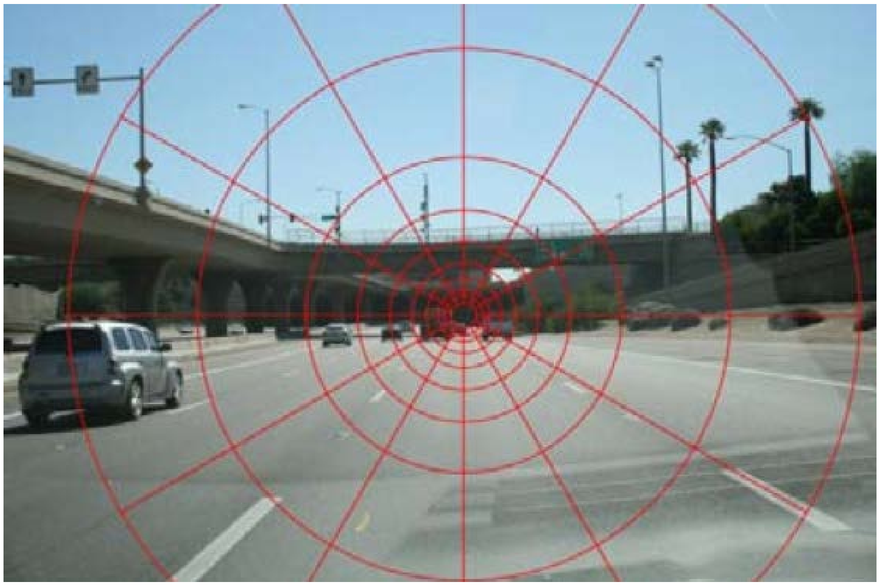
Deck Park Tunnel Energy Efficiency Study Update

Technical Memorandum

November 2014



Aiming at cost-effective solutions to improve mobility and safety

Prepared by:

The Arizona Department of Transportation

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This report has been prepared by Arizona Department of Transportation (ADOT) Phoenix Regional Traffic Office personnel Mark J. Poppe, P.E. and Matthew Reeg and by ADOT Traffic Operations Section personnel Karim Rashid, P.E. and Bob Cook. The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data, and for the use or adaptions of previously published material presented herein. The contents do not necessarily represent the views or policies of ADOT. This report does not constitute a standard, specification, policy, or procedure of ADOT. Products', manufacturers', and consultants' names that appear herein are cited because they are considered essential to the objectives of the report. ADOT and the State of Arizona do not endorse particular products, manufacturers, or consultants.

Executive Summary

This technical memorandum was prepared by the Arizona Department of Transportation (ADOT) as an update to the Option 7 (LED-only) alternative contained in the **2011 *Deck Park Tunnel Energy Efficiency Study.*** This update was prepared to account for improvements in Light Emitting Diode (LED) tunnel lighting technology since 2011. The update also provides information on the potential energy savings that may be realized through the implementation of variable speed limits within the vicinity of the Deck Park Tunnel. This tech memo should be considered a supplement to, not a replacement for, the 2011 energy efficiency study. As such, many of the assumptions used in development of the energy efficiency study were retained as part of the analyses presented in this update.

In 2011, the ***Deck Park Tunnel Energy Efficiency Study*** was prepared for the Governor's Office of Energy Policy. This study found that ADOT spends approximately $370,000 per year in electrical charges to operate the tunnel. Approximately $335,000 of these costs is associated with the operation of the lighting system.

The study included a detailed assessment of the existing tunnel lighting system. Some of the important findings of the 2011 energy efficiency study are summarized as follows:

- The existing luminance levels in the threshold zones are much lower than the levels included in the original design documents.
- The existing luminance levels in all zones are lower than those included in the current "recommended practices".
- Before ADOT can pursue any of the options, it must first be decided if the upgrades are to conform to modern design "recommended practices".
- In the event ADOT decides to increase the luminance levels, then it is unlikely that ADOT will be able to achieve any energy savings as compared to the existing energy costs, as all the efficiencies generated will go toward generating higher luminance levels.

The 2011 energy efficiency study developed several options for improving the performance and energy efficiency of the tunnel lighting system. Conversion to LED tunnel fixtures was considered as part of Option 7. The study found that the LED designs would require approximately double the number of LED fixtures to achieve the same light level that could be achieved using HPS fixtures. As a result, conversion to LED fixture was not identified as the preferred alternative. Recent improvements in LED roadway lighting technology have made LED fixtures a more viable option for all roadway lighting applications including tunnel lighting.

This update will be useful to ADOT decision makers to assess options for upgrade of the existing Deck Park Tunnel lighting system.

I-10, 35th Avenue – Sky Harbor Boulevard Safety Planning Study
In the fall of 2013, the ADOT Multimodal Planning Division initiated a traffic safety planning study of I-10 from 35th Avenue to Sky Harbor Boulevard. The 7.63 mile-long study section includes the Deck Park Tunnel. Kittelson & Associates Inc. (KAI) is currently under contract to complete the safety study. Lee Engineering, Works Consulting, and DiExSys are sub-consultants to KAI for the safety study. The project team is at the mid-point in the study. In September 2014 the KAI team provided preliminary results regarding the magnitude of the safety problem on the various segments within the study section. The analysis indicates the tunnel segment is operating at Level of Service of Safety (LOSS) IV with a crash rate approximately four times the mean rate for similar segments in the MAG freeway system. The KAI team has begun diagnosis and countermeasure identification activities and will be performing benefit-cost analyses beginning in mid-November 2014**.**

Based on the information contained in the 2011 energy efficiency study and the preliminary results of the I-10 safety study it seems reasonable that enhanced tunnel lighting may be a potential safety countermeasure. Based on additional information presented by the KAI team it appears level of congestion may be influencing crash frequency in the tunnel. It seems reasonable to believe there could be a synergistic interaction between roadway lighting conditions and level of congestion within the tunnel as a contributor to an elevated crash frequency in the tunnel.

Variable speed limit (VSL) systems are widely used in Europe as a roadway safety countermeasure under congested freeway conditions however there are limited applications of this technology in the United States. The Washington State DOT operates a VSL system on I-5 as part of the WSDOT Smarter Highways program. Other states have begun to implement and test VSL systems as well. As indicated in the 2011 energy efficiency study, speed limit is one of three variables used to determine the required luminance levels and the lengths of the various zones within the tunnel. Higher speed limits require higher luminance levels as well as longer threshold and transition zones. Variable speed limits based on real-time detection of congestion levels in the vicinity of the Deck Park Tunnel coupled with the real-time ambient light level monitoring and lighting controls could work in concert to reduce energy consumption, travel time delay, and number of crashes.

The current KAI scope of work identifies Option 3 in the 2011 energy efficiency study as the lighting option to be evaluated. It is anticipated this update of Option 7 (LED-only) will be used as the lighting option to be evaluated, in-lieu of Option 3 from the 2011 energy efficiency study.

Findings
The 2011 energy efficiency study established the Revised Base Case as the "existing condition" or more properly, replacement of the existing fixtures with new High Pressure Sodium (HPS) luminaires of the type currently in the tunnel. It should be noted, this option does not conform to current recommended practice for tunnel lighting and therefore was not recommended as an alternative. The revised base case was developed primarily as a basis for comparison. The table on the following page shows the various options for upgrade of the existing lighting system in comparison to the revised base case in the 2011 energy efficiency study.

The options identified in the table are as follows:

- Revised Base Case
- Option 1 – Replace existing HPS fixtures with new HPS fixtures
- Option 3 – Construct shade structures near the portals of the tunnel
- Option 7 (LED-only) – Install new LED fixtures (from the 2011 study)
- Option 7.1 – Install new LED fixtures and controls based on 2014 technology
- Option 7.2 – Option 7.1 plus implement a VSL system in the vicinity of the tunnel

Option 7.1 implementation costs are estimated at approximately $11.8 million and will result in an annual savings of approximately $10,000. Option 7.2 implementation costs are estimated at approximately $20.0 million and will result in an annual savings of approximately $70,000. The estimated yearly energy and maintenance costs for Option 7.1 and 7.2 are significantly better than Option 7 (LED-only) in the 2011 energy efficiency study. The implementation cost for Option 7.1 is comparable to the 2011 energy efficiency study recommended alternative (Option 3) but results in slightly more annual savings. Option 7.2 results in the greatest annual savings, but with an implementation cost nearly double that of Option 7.1.

Cost Comparison Summary

Option	Implementation Cost (millions of $)	Percent of Revised Base	Annual O&M Cost (millions of $)	Percent of Revised Base
Revised Base Case	3.5	100%	0.38	100%
Option 1 (Lth = 350 cd/m2)	5.0	143%	0.81	213%
Option 3	11.5	329%	0.39	103%
Option 7 (LED-only)	9.2	263%	0.70	184%
Option 7.1	11.8	337%	0.37	97%
Option 7.2	20.0	571%	0.31	82%

As predicted in the 2011 energy efficiency study, LED technology has continued to rapidly progress over the last few years. The 2011 study states: "*In the event ADOT decides to increase the luminance levels; then it is unlikely that ADOT will be able to achieve any energy savings as compared to the existing energy costs, as all the efficiencies generated by the implemented Options will go toward utilizing the same amount of energy to generating higher luminance levels.*" This, it appears, is no longer the case. But the improved technology comes at a price.

It should be noted this analysis does not include an assessment of all costs typically included in lifecycle cost analysis of transport systems. Road-user cost is an important factor in assessing the performance of the roadway system and the efficacy of specific roadway improvement options. The two road-user costs that are typically prominent in lifecycle cost analyses are the costs associated with crashes and the costs associated with travel time delay. The I-10 safety study should provide insight regarding the expected reduction in the number of crashes and expected crash cost savings associated with Options 7.1 and 7.2. There are currently no activities underway that would provide insight regarding the expected reduction in travel time delay associated with Options 7.1 and 7.2. Thought should be given to the development of a work plan to assess the expected reduction in travel time delay that may be realized with implementation of Option 7.2.

Introduction

The following technical memorandum was prepared by the Arizona Department of Transportation (ADOT) as an update to the Option 7 (LED-only) alternative contained in the **2011 *Deck Park Tunnel Energy Efficiency Study.*** This update was prepared to account for improvements in Light Emitting Diode (LED) tunnel lighting technology since 2011. The update also provides information on the potential energy savings that may be realized through the implementation of variable speed limits within the vicinity of the Deck Park Tunnel. This tech memo should be considered a supplement to, not a replacement for, the 2011 energy efficiency study. As such, many of the assumptions used in development of the energy efficiency study were retained as part of the analyses presented in this update.

Statement of Need and Purpose

In 2011, the ***Deck Park Tunnel Energy Efficiency Study*** was prepared by the firms Energy Systems Design, Inc. and DH Lighting Solutions. The energy study was prepared for the Governor's Office of Energy Policy. This study found that ADOT spends approximately $370,000 per year in electrical charges to operate the tunnel. Approximately $335,000 of these costs is associated with the operation of the lighting system. Therefore, the lighting system was the primary focus of the energy study.

The study included a detailed assessment of the existing tunnel lighting system. Some of the important findings of the 2011 energy efficiency study are summarized as follows:

- The existing luminance levels in the threshold zones are much lower than the levels included in the original design documents.
- The existing luminance levels in all zones are lower than those included in the current "recommended practices" developed by the IESNA and CIE (RP22-11).
- Before ADOT can pursue any of the options, it must first be decided if the upgrades are to conform to modern design "recommended practices".
- In the event ADOT decides to increase the luminance levels, then it is unlikely that ADOT will be able to achieve any energy savings as compared to the existing energy costs, as all the efficiencies generated will go toward generating higher luminance levels.

The 2011 energy efficiency study developed several options for improving the performance and energy efficiency of the tunnel lighting system. Planning level cost estimates were prepared for the various options. The recommended Option 3 included use of High Pressure Sodium (HPS) fixtures and construction of exterior shade structures at the entrances to the tunnel. This strategy moved a portion the threshold zones to areas outside the tunnel and would therefore help to achieve the target luminance levels in the threshold zones using natural light.

Conversion to LED tunnel fixtures was considered as part of Option 7. The study found that the LED designs would require approximately double the number of LED fixtures to achieve the same light level that could be achieved using HPS fixtures. While the LED fixtures resulted in a maintenance and energy savings when compared to the HPS option, the payback period on the added capital cost was approximately 30 years, which is greater than the anticipated life of the LED fixtures.

Recent improvements in LED roadway lighting technology have made LED fixtures a more viable option for all roadway lighting applications including tunnel lighting. The purpose of this update is to:

- evaluate possible energy savings based on improved LED technology, and
- evaluate possible energy savings associated with the application of variable speed limits in the vicinity of the tunnel.

This update will be useful to ADOT decision makers to assess options for upgrade of the existing Deck Park Tunnel lighting system.

Background Information

Energy Efficiency Study Crash Analysis

ADOT Traffic Group prepared a crash analysis at the request of the tunnel energy efficiency study team. The results of the analysis were presented to the study team on August 9, 2011 in the form of a PowerPoint presentation. The analysis examined crash frequency, severity, and type over a five-year period, from June 1, 2005 to May 31, 2010, beginning at MP 143.8 and ending at MP 146.5. This sub-section extends approximately one mile west and one mile east of the limits of the tunnel. A total of 4,056 crashes were recorded in this sub-section. The analysis also examined crash frequency within the limits of the tunnel: MP 144.93 to MP 145.45. A total of 1,562 crashes were recorded in the 0.52 mile–long tunnel sub-section. Using these values, the calculated average crash density for those segments just outside the tunnel is approximately 230 crashes per mile per year while the crash density within the tunnel is approximately 600 crashes per mile per year.[1] The energy study did not indicate the anticipated safety benefits in terms of the expected reductions in crash frequency and severity that may be achieved by improving the tunnel lighting.

I-10, 35th Avenue – Sky Harbor Boulevard Safety Planning Study

In the fall of 2013, the ADOT Multimodal Planning Division initiated a traffic safety planning study of I-10 from 35th Avenue to Sky Harbor Boulevard. The 7.63 mile-long study section includes the Deck Park Tunnel.

This safety study was initiated as a result of network screening for high crash locations performed by the ADOT Traffic Safety Section. The 2012 *Arizona Transparency (Top Five Percent) Report* identified two one-mile segments within the safety study section as high crash locations. A number of segments within the study section have been identified and reviewed for the *Transparency Reports* submitted to the Federal Highway Administration (FHWA) annually from 2006 to 2012.

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[1] It should be noted, MP 145.0 is located within the tunnel. Previous analyses by ADOT have shown a disproportionate number of crashes reported at the xx.0 and xx.5 milepost locations. As such, a crash reported at MP 145.0 may have actually occurred outside the tunnel, depending on the method used by the reporting officer to identify and record the crash location. Analysis performed by the I-10, 35th Avenue – Sky Harbor Blvd Safety Planning Study team using 2011-2013 crash data indicates this disproportionate reporting has been rectified. The improvement coincides with the introduction of TraCS within DPS.

These segments are scattered and are in both the eastbound and westbound directions within the study section of I-10.

The primary goals of the safety planning study are:

1. Apply state-of-the-art predictive and diagnostic traffic safety analytical methods to determine the magnitude of the safety problem in the study section relative to other freeway segments in the MAG freeway system.
2. Identify and evaluate cost-effective safety countermeasures that may be implemented to reduce the frequency and severity of motor vehicle crashes in the study section.
3. Expand ADOT's capacity to apply state-of-the-art analytical methods in traffic safety planning and management.

Kittelson & Associates Inc. (KAI) is currently under contract to complete the safety study. Lee Engineering, Works Consulting, and DiExSys are sub-consultants to KAI for the safety study. The KAI team is applying the crash prediction models developed under ***NCHRP 17-45 Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges*** and a modification of the Level of Service of Safety (LOSS) described in the 2010 ***AASHTO Highway Safety Manual (HSM)***. The NCHRP 17-45 models were recently incorporated into the ***HSM*** as part of the September 2014 ***Supplement*** to the ***HSM***. The I-10 safety study will be one of the earliest substantive applications of the *NCHRP 17-45* models.

The project team is at the mid-point in the study. In September 2014 the KAI team provided preliminary results regarding the magnitude of the safety problem on the various segments within the study section. The analysis indicates the tunnel segment is operating at LOSS IV with a crash rate approximately four times the mean rate for similar segments in the MAG freeway system. The KAI team has begun diagnosis and countermeasure identification activities and will be performing benefit-cost analyses beginning in mid-November 2014**.**

ADOT currently uses cost per crash by severity estimates to assess the potential safety benefit of proposed countermeasures, with the safety benefit being the primary factor in assessing the benefits of the countermeasure. In order to determine if a safety project may be eligible for federal safety funding, it must be shown to be cost-effective. "Cost-effective" has typically been defined by ADOT and the FHWA Arizona Division office as a lifecycle benefit-to-cost ratio (B/C) greater than 1.0. The KAI team, working with ADOT, will develop planning level lifecycle cost estimates for the identified safety countermeasures.

Based on the information contained in the 2011 energy efficiency study and the preliminary results of the I-10 safety study it seems reasonable that enhanced tunnel lighting may be a potential safety countermeasure. Based on additional information presented by the KAI team it appears level of congestion may be influencing crash frequency in the tunnel. It seems reasonable to believe there could be a synergistic interaction between roadway lighting conditions and level of congestion within the tunnel as a contributor to an elevated crash frequency in the tunnel. KAI has developed a proposed process to derive an appropriate estimate of the potential reduction in crash frequency and severity that may be realized with implementation of improved tunnel lighting while controlling for the confounding effects of congestion and other roadway conditions in the tunnel. The current KAI scope of work identifies Option 3 in the 2011 energy efficiency study as the lighting option to be evaluated. It is anticipated the update of the Option 7 (LED-only) will be used as the lighting option to be evaluated, in-lieu of Option 3 from the 2011 energy efficiency study.

Variable Speed Limits
The posted speed limit on I-10 in the vicinity of the Deck Park Tunnel is 65 mph. However, it seems fair to say there are many hours of the day when driving 65 mph is neither reasonable nor prudent, particularly during the AM and PM peak periods when ambient light conditions are at their worst from a tunnel lighting perspective. As indicated in the energy efficiency study, speed limit is one of three variables used to determine the required luminance levels and the length of the various zones within the tunnel. Higher speed limits require higher luminance levels as well as longer threshold and transition zones.

Variable speed limits (VSL) systems are widely used in Europe as a roadway safety countermeasure under congested freeway conditions however there are limited applications of this technology in the United States. The Washington State DOT operates a VSL system on I-5, as shown in Figure 1, as part of the WSDOT Smarter Highways program. Other states have begun to implement and test VSL systems as well.

Figure 1. Variable Speed Limit Signing on the I-5 Smart Highway
Washington State DOT

The KAI team performed a literature review on VSL systems as part of the research completed for the I-10 safety study. The literature review includes information on state-of-the-art practices in the design and operation of VSL systems as well as information regarding the traffic safety and mobility benefits associated with VSL. The literature found the following benefits reported in various published research reports:

- Increase in average congested period throughput by 3% to 7%
- Increase in overall capacity by 3% to 30%
- Decrease in number of primary incidents by 3% to 30%
- Decrease in the number of secondary incidents by 40% to 50%

Variable speed limits based on real-time detection of congestion levels in the vicinity of the Deck Park Tunnel coupled with the real-time ambient light level monitoring and lighting controls could work in concert to reduce energy consumption, travel time delay, and number of crashes.

Method of Analysis

The update of the 2011 energy efficiency study Option 7 (LED-only) includes the analysis of two options for conversion to LED luminaires in the Deck Park Tunnel. The first, Option 7.1, is based on L_{th} = 350 cd/m^2 at a constant posted speed limit of 65 mph. The second, Option 7.2, is based on the concept of variable speed limits, to be applied based on the level of traffic congestion. The energy use and cost analyses for both options includes the application of the lighting controls presented in Option 6 of the 2011 energy efficiency study, which indicates dimming controls could result in 10% to 25% energy when used in conjunction with LED luminaires. For purposes of this analysis, it was assumed that Option 6 would improve the energy efficiency of daytime operations of both options 7.1 and 7.2 by fifteen percent.

Option 7.1 – LED with 65 mph Constant Speed Limit

The 2011 energy efficiency study LED-only option was based on designs provided by LED luminaire manufacturers. Following the same process, ADOT requested from Acuity Brands a planning level design based on application of the Holophane TunnelPass LED luminaire.[2] The planning level design was completed for the eastbound tube following the criteria developed by the energy efficiency study team.[3] The design includes 1895 luminaires with a variety of lighting distributions lumen outputs. The power demands for daytime and nighttime operation were also provided. The design for the eastbound tube is assumed to approximate the lighting needs for the westbound tube. Therefore, the Option 7.1 analysis is based on the application of 3790 LED luminaires with various lumen outputs and power demands. Energy use is analyzed based on the assumption the system will operate (on average) 12 hours per day under daytime ambient outdoor lighting conditions and 12 hours per day under nighttime conditions.

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[2] Catalog information on the TunnelPass LED may be found in the appendix.
[3] The 2011 energy efficiency study lighting criteria document may be found in the appendix.

Option 7.2 – LED with Variable Speed Limits based on Level of Traffic Congestion
The requisite luminance levels in the tunnel are a function of the posted speed limit, the ambient light levels outside the tunnel, and the orientation of the tunnel. The following establishes the methodology used to estimate projected energy use as well as the assumptions regarding dimming in response to changes in posted speed limits and ambient light levels.

Variable Speed Hours of Operation. For purposes of this analysis, it is assumed variable speeds will be in effect during hours of congestion typical of Monday through Friday, excluding holidays, and will operate in the range of 65 mph to 45 mph. The ambient light level outside the tunnel is dark (on average) 12 hours per day, 365 days per year or a total of 4380 hours per year. The requisite luminance level in the tunnel during these hours is 2.5 cd/m^2 ($L_{2.5}$). The 45 mph speed limit will be in effect on workdays for an average of 4 hours per day. The requisite luminance levels in the tunnel when the 45 mph speed limit is in effect will vary by zone but are generally designated as L_{45}. The 55 mph speed limit will be in effect on workdays for an average of 8 hours per day. The requisite luminance levels in the tunnel when the 55 mph speed limit is in effect will vary by zone but are generally designated as L_{55}. The 65 mph speed limit will be in effect all other daylight hours. The requisite luminance levels in the tunnel when the 65 mph speed limit is in effect will vary by zone but are generally designated as L_{65}. This results in the following values for annual hours of operation.

- L_{65}: 1380 hours per year
- L_{55}: 2000 hours per year
- L_{45}: 1000 hours per year
- $L_{2.5}$: 4380 hours per year

Luminance Levels for Various Speed Limits. Using RP22-11 Table 3, the energy efficiency study extrapolated a threshold (1st part) luminance level (L_{th}) of 335 cd/m^2 for a posted speed limit of 65 mph. Based on a limited number of field measurements of adaptation luminance (L_a), the energy efficiency study team settled on a recommended luminance level of 350 cd/m^2 for a posted speed limit of 65 mph (L_{th65}), which is approximately 4.5% higher than the 335 cd/m^2 derived from Table 3. By interpolation, the Table 3 values of L_{th} for 55 mph and 45 mph are 280 cd/m^2 and 240 cd/m^2, respectively. Applying a 4.5% increase (or a ratio of 350/335) to each of these values results in:

L_{th55} = 280 x (350/335) = 292.6 or approximately 290 cd/m^2, and
L_{th45} = 240 x (350/335) = 250.8 or approximately 250 cd/m^2.

On this basis, the following L_{th} target values are used in the analysis of the energy impacts of variable speed.

Speed Limit (mph)	L_{th} (cd/m^2)
65	350
55	290
45	250

Applying RP22-11 methodology to calculate the threshold and transition zone average luminance levels and lengths for the various speed limits results in the values shown in Table 1. These values are also shown graphically in Figure 2.

Table 1. Deck Park Tunnel RP22-11 Lighting Criteria Summary

65 mph Zone	Lavg (cd/sq-m)	Length (ft)	Distance in Tunnel (ft)
1st Part of Threshold	350	404	404
2nd Part of Threshold	275	191	595
1st Transition	142	286	881
2nd Transition	57	381	1262
3rd Transition	23	477	1739
Interior	11	448	2187
55 mph Zone	Lavg (cd/sq-m)	Length (ft)	Distance in Tunnel (ft)
1st Part of Threshold	290	284	284
2nd Part of Threshold	243	161	445
1st Transition	118	242	687
2nd Transition	47	323	1010
3rd Transition	19	403	1413
Interior	11	774	2187
45 mph Zone	Lavg (cd/sq-m)	Length (ft)	Distance in Tunnel (ft)
1st Part of Threshold	250	178	178
2nd Part of Threshold	228	132	310
1st Transition	102	198	508
2nd Transition	41	264	772
3rd Transition	16	330	1102
Interior	11	1085	2187

The tunnel is 2287 feet in length. The 2011 energy efficiency study design criteria indicates the first and last 50 feet of the tunnel do not require luminaires, thereby reducing the effective (lighted under daytime conditions) length to 2187 feet.

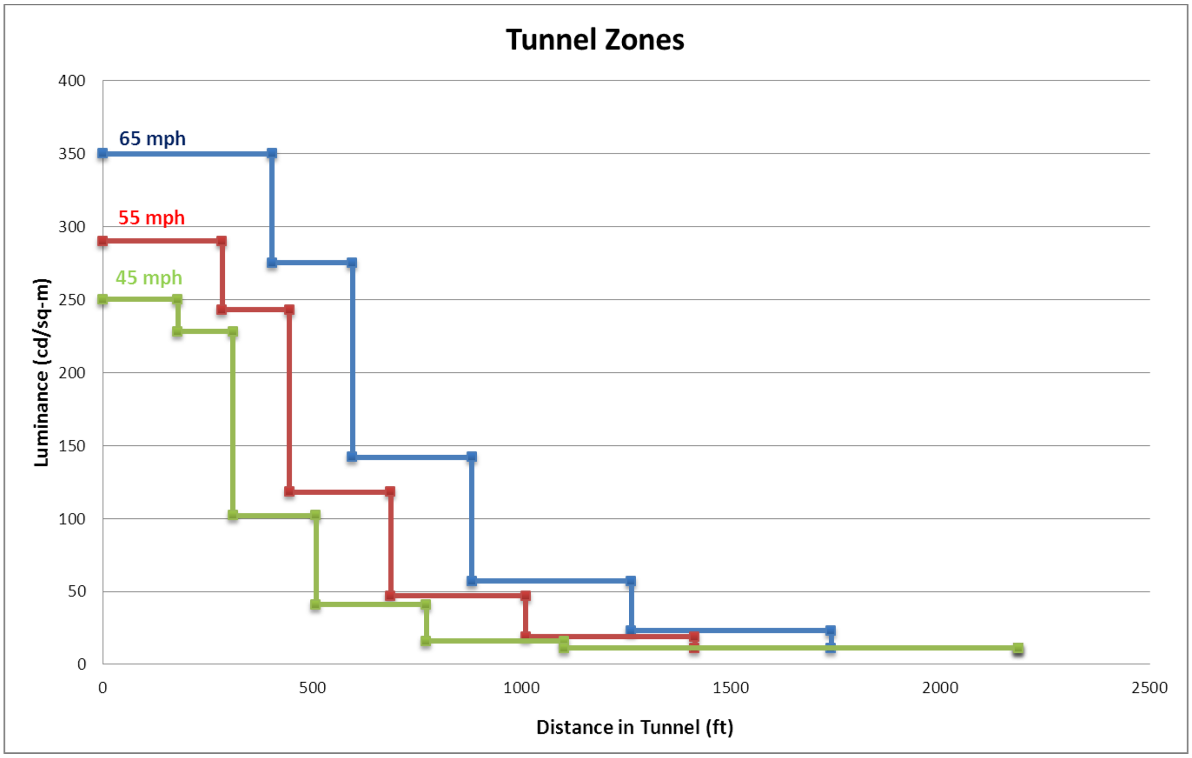

Figure 2. Deck Park Tunnel RP22-11 Luminance Levels for Various Speed Limits

The luminance levels in the tunnel during daylight hours vary by zone. The weighted overall average luminance level within the tunnel for a given speed limit (xx) may be computed as:

$$L_{taxx} = \sum_{i=1 \text{ to } n} (L_i * \ell_i) / \sum_{i=1 \text{ to } n} \ell_i \qquad \text{(Equation 1)}$$

where,

L_i = the luminance level in zone i
ℓ_i = the length of zone i
n = the number of zones for speed limit xx.

Applying equation 1 results in the following daytime tunnel average luminance (L_{ta}) levels for the various speed limits.

Speed Limit (mph)	L_{ta} (cd/m^2)
65	124.44
55	82.94
45	56.16

LED Luminaire Dimming and Power Demand. When an LED luminaire is dimmed from some lumen output necessary to deliver an initial level of luminance (L_1) to a lower level of luminance (L_2), the change in power demand (watts (W)) is proportional to the change in luminance. In other words, when dimming the Holophane TunnelPass LED luminaire for a particular application (e.g. the Deck Park Tunnel) the relation between luminance level and power demand may be expressed as:

$$(W_2/ W_1) \times C = L_2/ L_1 \qquad \text{(Equation 2)}$$

where,

L_1 = some initial level of luminance (cd/m^2)
L_2 = some lower level of luminance (cd/m^2)
W_1 = power demand at L_1 (W)
W_2 = power demand at L_2 (W)
C = some value that defines the relationship between the change in L and the resulting change in W.

Given values for L_1, L_2, W_1, and C, a value for W_2 may be derived using the following equation:

$$W_2 = (L_2/L_1) \times (W_1/C) \qquad \text{(Equation 3)}$$

It should be noted Equations 2 and 3 are constructed such that the value of C will be greater than 1 if the luminaire becomes more efficient when dimmed from L_1 to L_2 and the value of C will be less than 1 if the luminaire becomes less efficient when dimmed. It is generally understood LED luminaires are less efficient under high ambient temperatures and LED luminaires generate more heat at higher lumen output levels. Therefore, it would generally be expected the value of C would be greater than 1.

ADOT requested from Acuity Brands a C-value for the Holophane TunnelPass LED luminaire. In response to the request, Acuity Brands is performing a series of tests to derive the value(s). The tests are on-going and should be completed in early November 2014. For purposes of this draft analysis, a C-value equal to 1.0 is used.

Using equation 3 with:
$L_1 = L_{ta65}$,
$L_2 = L_{ta55}$ or L_{ta45},
$W_1 = W_{65}$, and
C = 1.0

values for W_{55} and W_{45} may be calculated.

These values for W_{65}, W_{55}, and W_{45} in conjunction with the variable speed hours of operation values may be used to calculate the total estimated annual energy consumption for the tunnel lighting system operating under variable speed limits.[4]

[4] The method of analysis is based on the assumption C is independent of L_1 and L_2. If it is determined C is a function of L_1 and L_2, the method of analysis will need to be modified to reflect this relationship.

Lighting Implementation Cost Estimating

The 2011 energy efficiency study contains capital cost estimates for each option for upgrade of the existing lighting system. However, little detail is included in the text to indicate how these costs were derived. Therefore, it is difficult to develop comparable cost estimates for the updated options 7.1 and 7.2 herein. It appears all the 2011 energy efficiency study options are reported based on an incremental increase over-and-above the Revised Base Case and, in some cases, over-and-above, Option 1.[5]

It appears the implementation costs reported in the 2011 energy efficiency study are restricted to replacement of existing fixtures and upgrade to existing electrical panels, as required for the various options. It does not appear the implementation costs reported include replacement of other electrical infrastructure[6] such as the conductors and cable trays. Nor does it appear the implementation costs include other project costs such as work zone traffic control, mobilization, construction engineering, scoping documents, final design documents, and other costs typically included in the design and construction of a project of this type.

Because the analysis herein is intended as an update to the 2011 energy efficiency study, the analysis follows the general implementation cost procedures used in the 2011 study. However, the total anticipated project costs should be calculated and applied in the benefit-cost calculations performed as part of the I-10 safety study.

Variable Speed Limits Implementation and Operations

A separate variable speed limit (VSL) system is integral to tunnel lighting Option 7.2. Therefore the implementation and operations costs of the VSL system must be factored into the costs associated with Option 7.2.

Based on information contained in KAI team VSL system literature search previously discussed and basic traffic engineering principles, the following assumptions were used to establish a planning level cost estimate for the implementation and operation of a VSL system in the vicinity of the Deck Park Tunnel.

- In order to maintain speeds within the tunnel consistent with the posted speed limit, the VSL system should extend a minimum of one mile west and one mile east of the limits of the tunnel. Applying this general principle, the limits of the VSL system in the vicinity of the tunnel were established as I-10 from 19th Avenue to 16th Street, or a total length of three miles.

- VSL sign structures similar to those shown in Figure 1 would be installed at an approximate spacing of 0.5 miles in each direction.

- An average of seven VSL signs would be installed on each structure.

[5] See 2011 energy efficiency study pp. 29, 31, 33, and 59. It should be noted recommended Option 3 would still require replacement of existing fixtures to achieve the luminance levels shown on p. 33 of the 2011 energy efficiency study.

[6] See 2011 energy efficiency study p. 24.

- System detectors for operation of the VSL system would be installed at an approximate spacing of 0.25 miles in each direction.

- The average power demand for each VSL sign is 100 watts.

- The average power demand for each control cabinet associated with a detector station or a sign structure is 200 watts.

- The VSL signs will operate 24 hours per day, seven days per week.

The planning level cost estimate for implementation and operation of the VSL system for Option 7.2 are summarized in the findings below.[7] The implementation cost estimate accounts for all anticipated cost items needed to implement the VSL system, including design, construction engineering, traffic control, and other miscellaneous items not included in the lighting system implementation costs previously noted.

Findings

This section provides planning level cost estimates for two alternative LED Options, 7.1 and 7.2, as an update to the LED Option 7 in the 2011 energy efficiency study.

Option 7.1 – LED with 65 mph Constant Speed Limit
Based on interpretation of the 2011 energy efficiency study, it was determined the implementation cost reported for LED Option 7[8] is based on the material, labor, and equipment costs associated with changing the existing lighting fixtures to LED fixtures minus the implementation cost of Option 1 ($4,200, 000 = $5,700,000 - $1,500,000). The same reporting procedure is used in this update to allow direct comparison of the values reported in the 2011 study and the values reported herein. The Option 7.1 implementation cost is based on a design provided by Acuity Brands to estimate 3,760 fixtures will be required, as described in the method of analysis. A unit bid price of $3,000.00 per fixture is used based on materials costs provided by Acuity Brands and estimates of contractor costs for installation of the fixtures. These values result in a total furnish and install price of $11,280,000 for the luminaires. Option 7.1 also offers the ability to adjust the lighting based on ambient lighting conditions. Therefore, an initial cost for lighting controls must be added to determine a total implementation cost. After discussing with manufacturers, a cost of $125 per fixture was determined to be a fair unit price for lighting controls, for a total of $470,000. Combining the total costs for fixtures and lighting controls yields a total implementation cost of $11,750,000. For the implementation cost value listed in Table 2, the $1,500,000 from Option 1 is subtracted from the total implementation cost to yield $10,250,000, consistent with the reporting method used in the 2011 energy efficiency study.

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[7] Detailed derivation of costs for implementation and operations of the VSL system may be found in the appendix.
[8] See 2011 energy efficiency study p. 59.

The yearly energy cost estimate for Option 7.1 is calculated using the procedure described in the method of analysis.[9] A yearly maintenance cost of $54,000 is provided for Option 1 (HPS lighting system) in the 2011 energy efficiency study. For the planning level cost, it is estimated LED lighting will reduce yearly maintenance cost by 20% as compared to a HPS lighting system, yielding a yearly maintenance cost of $43,200 for Option 7.1.

To determine the 25-year lifecycle cost, the yearly energy cost and yearly maintenance cost over a 25-year period are brought to a present value using an interest rate of 4.6%, consistent with the 2011 energy efficiency study. For Option 7.1, this results in a 25-year lifecycle cost of $15,691,000.[10]

Table 2. Option 7.1 – Implementation, Operations, and Maintenance Costs

7.1 Lighting Summary for 65 MPH with Ambient Controls		
Zone	**Daytime Levels (cd/m^2)**	**Nighttime Levels (cd/m2)**
Threshold Zone 1st Half	350	2.5
Threshold Zone 2nd Half	276	2.5
Transition Zone 1	143	2.5
Transition Zone 2	57	2.5
Transition Zone 3	23	2.5
Interior Zone	11	2.5
Implementation Cost (Lighting and Ambient Controls as compared to Option 1 in the 2011 Energy Efficency Study)	$10,250,000.00	
Yearly Energy Cost* (Lighting Only)	$327,500.00	
Yearly Maintenance Cost**	$43,200.00	
Yearly Savings (As compared to implementing Option 1 of the 2011 Energy Efficency Study)	$427,000.00	
Simple Payback Years	24	
25 Year Life Cycle Cost (Present Value) (Based on 4.6% interest rate derived from LED option in 2011 Energy Efficency Study)	$17,191,000.00	

*See appendix for detailed energy costs
**It is estimated that LED lighting will reduce the yearly maintenance cost by 20% as compared to Option 1 in the Energy Efficency Study.

[9] The calculations table for Option 7.1 lighting system energy costs may be found in the appendix.
[10] The calculations table for lifecycle costs may be found in the appendix.

Option 7.2 – LED with Variable Speed Limits based on Level of Traffic Congestion

One of the determining factors for luminance levels in a tunnel is the posted speed limit. Combining Option 7.1 with a VSL system will allow dimming of the lighting system when the posted speed limit is lowered in response to congestion. Using the aforementioned assumptions, the KAI team developed an estimated cost of $8,250,000 for implementation of the three-mile long VLS system. Combining this with the implementation cost of Option 7.1 yields a total implementation cost for Option 7.2 of $20,000,000. Again, subtracting the Option 1 cost yields a value of $18,500,000.

The yearly energy cost estimate for the Option 7.2 lighting system is calculated using the method of analysis described above.[11] The yearly energy cost estimate for operation of the VSL system is calculated based on the assumptions listed in the method of analysis.[12] These two costs are added to determine the total yearly energy costs, as shown in Table 3. Given the additional maintenance associated with the VSL system, Option 7.2 maintenance cost is estimated based on a 10% reduction as compared to Option 1, yielding a yearly maintenance cost of $48,600 for Option 7.2.

Table 3. Option 7.2 – Implementation, Operations, and Maintenance Costs

7.2 Lighting Summary- Variable Speed with Ambient control	**Daytime Levels (cd/m^2)**			**Nighttime Levels (cd/m^2)**
Zone	**65 MPH**	**55 MPH**	**45 MPH**	**All Speeds**
Threshold Zone 1st Half	350	290	250	2.5
Threshold Zone 2nd Half	276	243	228	2.5
Transition Zone 1	143	118	102	2.5
Transition Zone 2	57	47	41	2.5
Transition Zone 3	23	19	16	2.5
Interior Zone	11	11	11	2.5
Implementation Cost (Includes the cost for fixtures, variable speed for 3 miles and ambient lighting controls as compared to Option 1 in the 2011 Energy Efficency Study)	$18,500,000			
Yearly Energy Cost* (Cost for lighting and variable speed system)	$258,000			
Yearly Maintenance Cost**	$48,600			
Yearly Savings (As compared to implementing Option 1 of the 2011 Energy Efficency Study)	$509,000			
Simple Payback Years	40			
25 Year Life Cycle Cost (Present Value) (Based on 4.6% interest rate derived from LED option in 2011 Energy Efficency Study)	$24,493,814			

*See appendix for detailed energy cost

**It is estimated that LED lighting will reduce maintenance cost by 20%. With the additional maintenance cost associated with variable speed, a 10% reduction was estimated as compared to Option 1 in the Energy Efficency Study.

[11] The calculations table for Option 7.2 lighting system energy costs may be found in the appendix.

[12] The calculations table for the VSL system energy costs may be found in the appendix.

The 25-year life cycle costs for Option 7.2 are calculated using the same methodology used in the evaluation of Option 7.1. This results in a 25-year life cycle cost of $24,494,814 for Option 7.2.[13]

Cost Comparison

The 2011 energy efficiency study established the Revised Base Case as the "existing condition" or more properly, replacement of the existing fixtures with new HPS luminaires of the type currently in the tunnel. It should be noted, this option does not conform to current recommended practice for tunnel lighting and therefore was not recommended as an alternative. The revised base case was developed primarily as a basis for comparison. Table 4 shows the various options for upgrade of the existing lighting system in comparison to the revised base case in the 2011 energy efficiency study. Option 7.1 implementation costs are estimated at approximately $11.8 million and will result in an annual savings of approximately $10,000. Option 7.2 implementation costs are estimated at approximately $20.0 million and will result in an annual savings of approximately $70,000. The estimated yearly energy and maintenance costs for Option 7.1 and 7.2 are significantly better than Option 7 (LED-only) in the 2011 energy efficiency study. The implementation cost for Option 7.1 is comparable to the 2011 energy efficiency study recommended alternative (Option 3) but results in slightly more annual savings. Option 7.2 results in the greatest annual savings, but with an implementation cost nearly double that of Option 7.1.

Table 4. Cost Comparison Summary

Option	Implementation Cost (millions of $)	Percent of Revised Base	Annual O&M Cost (millions of $)	Percent of Revised Base
Revised Base Case	3.5	100%	0.38	100%
Option 1 (Lth = 350 cd/m2)	5.0	143%	0.81	213%
Option 3	11.5	329%	0.39	103%
Option 7 (LED-only)	9.2	263%	0.70	184%
Option 7.1	11.8	337%	0.37	97%
Option 7.2	20.0	571%	0.31	82%

Discussion

As predicted in the 2011 energy efficiency study, LED technology has continued to rapidly progress over the last few years. The 2011 study states: "*In the event ADOT decides to increase the luminance levels; then it is unlikely that ADOT will be able to achieve any energy savings as compared to the existing energy costs, as all the efficiencies generated by the implemented Options will go toward utilizing the same amount of energy to generating higher luminance levels.*"[14] This, it appears, is no longer the case. But the improved technology comes at a price.

The simple payback years for Option 7.1 and 7.2 are based on the implementation cost and yearly savings shown in Tables 2 and 3. As previously noted, it appears there may be a number of costs associated with implementation of the upgrade to the lighting system that were not included in the 2011 energy efficiency study implementation cost estimates. In order to realize a more realistic

[13] The calculations table for life cycle costs may be found in the appendix.

[14] 2011 energy efficiency study p. 11.

payback figure, a more detailed implementation cost estimate for the LED lighting system should be developed.

It should be noted there is no indication as to how the 2011 energy efficiency study team determined the yearly maintenance costs, but it is suspected these estimated costs may be low. Therefore a more thorough analysis of existing tunnel lighting maintenance costs may be in order to better assess the expected maintenance savings associated with the implementation of LED lighting.

Finally, this analysis does not include an assessment of all costs typically included in lifecycle cost analysis of transport systems. Road-user cost is an important factor in assessing the performance of the roadway system and the efficacy of specific roadway improvement options. The two road-user costs generally prominent in lifecycle cost analyses are the costs associated with crashes and costs associated with travel time delay. The I-10 safety study should provide insight regarding the expected reduction in the number of crashes and crash cost savings associated with Options 7.1 and 7.2. There are currently no activities underway that would provide insight regarding the expected reduction in travel time delay associated with Options 7.1 and 7.2. Thought should be given to the development of a work plan to assess the expected reduction in travel time delay that may be realized with implementation of Option 7.2.

Deck Park Tunnel Energy Efficiency Study Update

Technical Memorandum - Appendix

TunnelPass LED™

Tunnel and Underpass Luminaire

HOLOPHANE®
LEADER IN LIGHTING SOLUTIONS

AcuityBrands.

LED Lighting in Tunnels

Why LED in Tunnels?

LED technology's growing popularity stems from its ability to significantly reduce energy consumption while offering more uniform illumination and a higher color rendering index than high pressure sodium lamps, which is the source traditionally used in tunnels – important benefits for tunnel environments.

LED luminaires also offer maintenance benefits, providing 20+ years or longer of operation to reduce costs and minimize lane closures. The latter permits the traffic flow volume to be maintained without interruption increasing commerce. Tunnel shutdown time is drastically reduced as there is no need to perform routine maintenance to replace failed high intensity discharge lamps and ballasts.

The luminaires are versatile enough to be ceiling or wall mounted, depending on the tunnel's geometry and height.

A Tough Environment

Tunnels are challenging environments due to pollution from round-the-clock traffic and the corrosiveness associated with high levels of humidity, exhaust fumes and fluctuating temperatures. Luminaires in tunnels are also subjected to wind and reverberation of heavy vehicles passing by which cause vibration.

Lighting systems intended for this environment must include a robust mechanical design and materials capable of withstanding the challenges of a harsh environment over time.

Safely Transitioning Drivers

The goal of any tunnel lighting system is to provide sufficient quality illumination to keep drivers who often travel at high rates of speed safe. Tunnels, however, present many unique challenges because lighting is required for both daytime and nighttime conditions.

To safely drive through a tunnel at posted highway speed during the day, a driver must be able to see into the tunnel. This is not possible if the tunnel is not properly lighted. Without daytime lighting, a tunnel entrance will appear as a black hole. Properly lighting a tunnel allows the driver's eye the time to adapt to the lower light levels inside the tunnel.

During daytime hours ambient light levels may exceed 10,000 foot-candles. The driver's vision will be adapted to this high level of light. Traveling at 65 miles per hour a vehicle is moving at 95 feet per second. In the time needed for visual adaption to occur a significant distance will be traversed, thus the need for a high level of light at the tunnel entrance. This permits time for visual adaption while maintaining visibility into the tunnel. Once inside the tunnel, the lighting level may be gradually decreased and visibility will be maintained.

At night, the situation is reversed. Inside the tunnel the driver's vision is adapted to a level higher than outside the tunnel. Upon exiting the tunnel the driver's vision must have time to adapt to a lower level of light. The road beyond the exit portal should be lighted to at least one third the tunnel's lighting level.

Tunnel Lighting Requirements & Criteria

Daytime Tunnel Lighting Criteria Include Three Lighting Zones to Help Driver's Vision Adapt.

Threshold zone – This is the area beginning at the tunnel portal with a length equal to one Safe Sight Stopping Distance (SSSD) less the Adaptation Distance. Vehicles traveling at higher rates of speed will require longer threshold zones. A tunnel in which posted traffic speed is 70 miles per hour, for example, will require a longer threshold zone than a tunnel where the posted speed is 50 miles per hour.

Transition zone – This is the next area that allows a driver's vision to adapt to lower levels of light in incremental steps. The transition zone length and number of steps will depend upon the threshold luminance, daytime interior luminance and posted speed.

Interior zone – This is the area within the tunnel after the end of the transition zone where the driver's eye adaption is complete.

Nighttime tunnel lighting is recommended to be 2.5 cd/sq. m if the tunnel is divided. If the tunnel is undivided, the lighting level should be the same as the daytime interior level. Nighttime lighting is provided for the entire length of the tunnel. The road before and after the tunnel portal should be illuminated to at least 1/3 the nighttime level for a distance of 1 SSSD.

Tunnel's Three Lighting Systems

Lighting systems for tunnels need to satisfy criteria for daytime, nighttime, and emergency situations. The current recommended practice for daytime and nighttime tunnel lighting is RP22-11 published by the Illuminating Engineering Society (IES). Tunnel lighting requirements are described in terms of luminance for road and wall surfaces. Requirements are determined based upon several factors:

- Approach scene, road grade of approach, and materials around approach
- Average annual daily traffic volume
- Posted speed limit
- Compass orientation of the tunnel's approach
- Direction of travel – one direction only (divided tunnel) or in two direction (undivided tunnel)

Common Requirements for Daytime and Nighttime Lighting Systems

Both the daytime and nighttime lighting systems have common criteria regarding wall luminance and uniformity of light. The lower 6.6-ft portion of the walls above the roadway shoulder should have a maximum ratio of 2.5 between the average roadway luminance and the average wall luminance. Wall luminance is diffuse luminance as opposed to the roadway luminance which is calculated in accordance with the roadway luminance calculation procedure described in IES RP-8. Uniformity for tunnel lighting for the calculation areas within each zone should not exceed 2.0 average to minimum and 3.5 maximum to minimum ratios.

Emergency lighting is prescribed in the National Fire Protection Association (NFPA) publication 502. Emergency lighting is an aid to the egress of people and vehicles from the tunnel in the case of a power interruption. Requirements for emergency lighting are given in units of illuminance rather than luminance. Average levels are to be 1.0-fc with a minimum of 0.1 fc on walkway and roadway surfaces. The maximum to minimum ratio should be less than or equal to 40 to 1.

Holophane: The Tunnel Lighting Expert

Holophane has been the leader in lighting solutions for more than a century and has supplied reliable, durable luminaires for tunnel applications for more than 25 years.

Three Holophane professionals helped form the Illuminating Engineering Society in 1906, and company engineers helped shape industry standards for tunnel lighting as members of the IES Tunnel Lighting Committee years later.

Application Expertise

Tunnel and Underpass Lighting Applications

Today, Holophane experts offer application assistance in tunnel lighting design and provide full application support to see your project through from the beginning to completion. We are committed to help you meet your tunnel lighting goals, providing innovative products designed for performance and versatility – with minimal operating costs and long life.

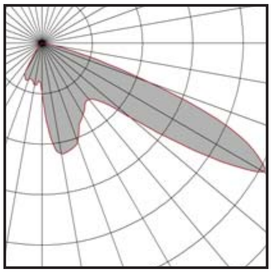
The TunnelPass LED

Features and Benefits

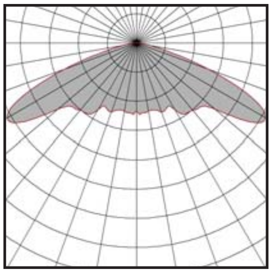
- Borosilicate prismatic glass lens for durability, permanence, and glare control
- Optimized thermal management system for maximum performance, long life, and reliability
- Robust design with IP66 rating, low copper 360 alloy castings, 3G vibration rating, anodized pre-treat and paint finish designed to meet a 9,000 hour salt fog rating
- Universal design that can be applied to either wall or ceiling mount with lumen packages to replace 100 watt through 400 watt HPS
- Dimming capability (0-10v) permits lumen output to be changed as required by control system
- Multiple lighting distributions to include ceiling counterbeam, long and narrow, and wall mount crossbeam
- Product ships complete with mounting brackets attached to aid in the installation of the product by one installer

Lighting Distribution Options

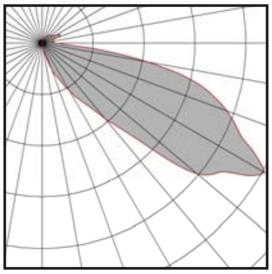
Holophane TunnelPass LED luminaires offer three lighting distribution options to meet the lighting requirements developed using IES RP22-11 and NFPA 502.



CCB, ceiling mount counterbeam – Recommended for divided tunnels with the majority of lumens directed against oncoming drivers to maximize roadway luminance while controlling disability glare. The distribution is similar to IES type III asymmetric distribution but is oriented toward the oncoming driver rather than perpendicular to the direction of travel.



CLN, ceiling mount long and narrow – Used in undivided tunnels, equal lumens are directed with and against the traffic flow. Similar to IES type II asymmetric long and narrow distribution. Distribution is oriented with or against traffic flow so the length of the distribution is aligned with the tunnel roadway.



WCR, wall mount crossbeam – Employed in undivided tunnels, equal lumens are directed with and against traffic flow. Distribution is oriented perpendicular to the traffic flow.

Corrosion Resistance

TunnelPass LED luminaires from Holophane incorporate several corrosive-resistant features to ensure performance and longevity:

- Borosilicate prismatic glass lens for permanence
- Low copper cast aluminum housings
- Stainless steel external hardware
- Stainless steel mounting plates
- Super durable paint over anodized pre-coat finish

Other performance attributes include a thermal management system, surge protection and control integration. TunnelPass LED luminaires offer a 9,000-hour salt fog rating, a UL Marine 40ºC rating to withstand high pressure hose downs and a 3G vibration rating.

They comply with the requirements of NFPA and have undergone impact resistance testing to confirm they will withstand the impact of stones and other objects flung from the tires of passing vehicles.

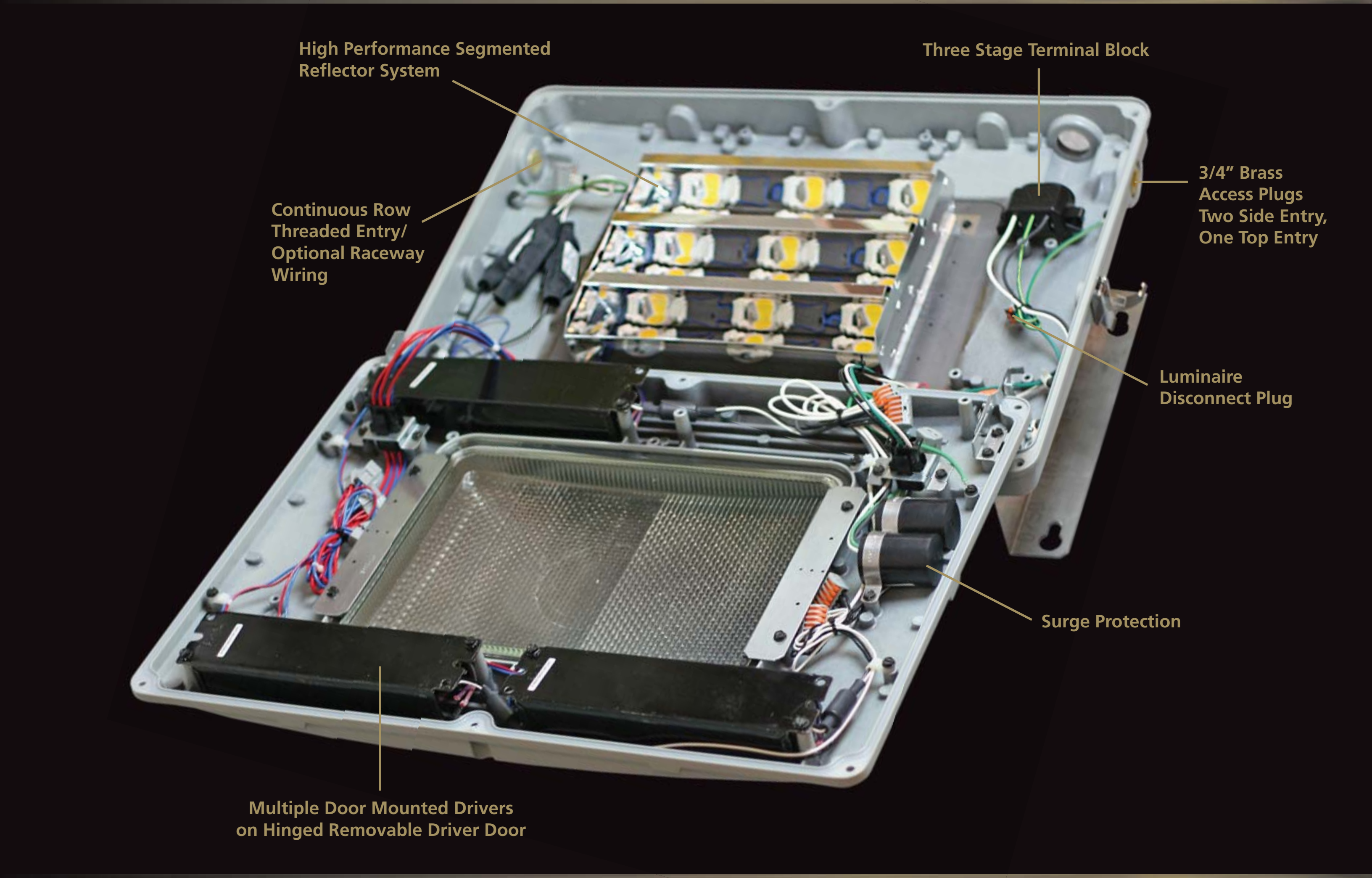
Mechanical Design

External Heat Sink provides excellent thermal transfer resulting in L70 values greater than 100,000 hours

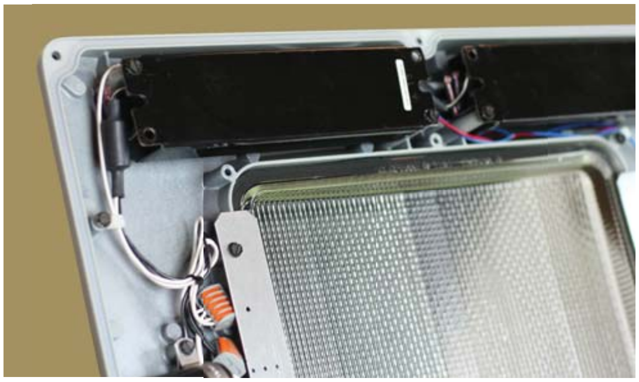
Borosilicate Prismatic Glass refractor for durability, permanence, and glare control

Two Side Entry 3/4″ NPT brass thru-wiring access plugs and one top entry 3/4″ NPT brass access plug

Removable Door with heavy duty latch system



LED Optical Design



Hinged Removable Driver Door mates to optical housing for easy access to terminal block, luminaire disconnect plug, and surge protection.

High Performance segmented reflector system with counterbeam, long and narrow, and crossbeam distributions.

Application Efficacy

Applications of new LED technology in the TunnelPass LED Luminaire make it suitable for retrofit replacement of 400 watt HPS fixtures while satisfying requirements of IES RP22-11. These requirements will be met for longer periods of time with less maintenance and energy consumption than the HPS system it replaces. To illustrate the benefits over time TunnelPass LED will be compared with a HPS lighting system which meets RP22-11 recommendations. The road luminance and energy use of the HPS system will then be compared with the TunnelPass LED fixtures.

The example tunnel is a 250-ft long urban tunnel with posted speed of 60 mph. There are three 12-ft wide asphalt traffic lanes between 8-ft shoulders. No cyclists are permitted. The exit is visible from one safe sight stopping distance before the entrance portal. Daylight penetration is poor. Reflectance of walls is 40%. The minimum recommended average roadway luminance is 160 candelas per sq meter. Uniformity ratios are recommended to not exceed 2.0 average to minimum and 3.5 maximum to minimum. The diffuse wall luminance is recommended to be at least 40% of the road luminance.

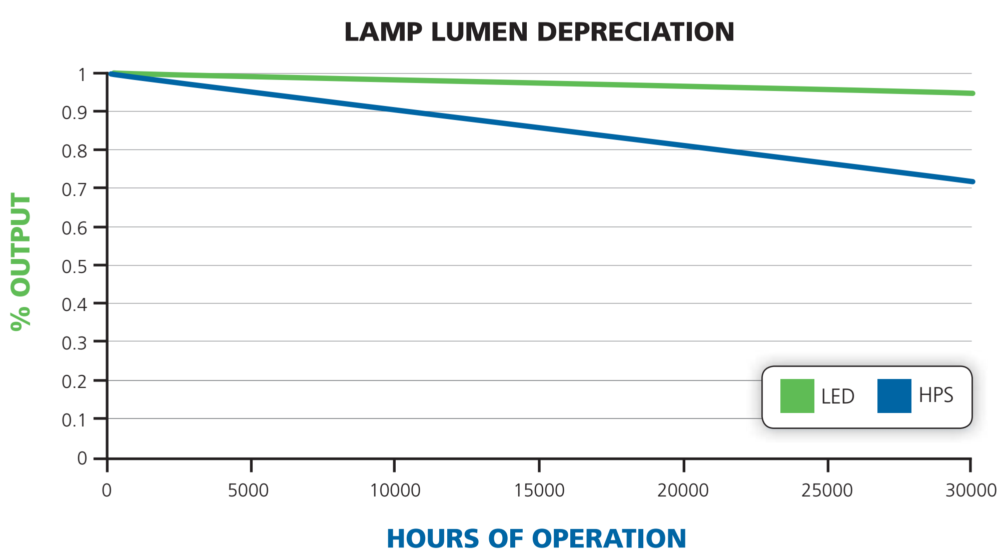
TunnelPass LED		
Luminaire	**400 HPS Counterbeam**	**TNLED61ASCCB**
Quantity	165	165
Maintained Luminance	160 Cd/Sq M	160 Cd/Sq M
Avg/Min	1.42	1.37
Max/Min	1.68	1.58
Wall Luminance	60%	48%
Avg/Min	1.06	1.37
Max/Min	1.12	1.58
Wattage	460	239
$/kwhr	$0.15	$0.15
Hours	4380	4380
Annual Energy	$49,866	$25,909
Energy Savings		**$23,957**
% Energy Savings		**48%**

Comparison of Average Luminance Over Time

Over time, the light level decreases from the initial condition due to lumen depreciation, lamp burn outs, and dirt accumulating on the optics of the fixture. Accumulation of dirt on the fixture will be the same for either the HPS or the TunnelPass LED. In this example it is given that the installation will be cleaned annually when the lumen output due to dirt is 70% of its original value (LLD).

The mortality factor due to lamp burnouts differs between HPS and LED sources (LBO). This information is published by lamp manufacturers. LED lamp mortality is highly dependent upon the heat transfer characteristics of the luminaire. The TunnelPass LED has a L70 rating greater than 100,000 hours.

Lumen depreciation is also very different between the two sources. Similar to mortality factors, lamp manufacturers publish lumen depreciation curves for HPS lamps at 10% intervals of rated lamp life. In this case the life rating of the HPS lamp is 30,000 hours. The lumen depreciation for LED is estimated according to TM-21 data. The rate of lumen depreciation of the TunnelPass LED luminaire is much slower than the HPS. For example, when the HPS is at the end of its rated life the lumen depreciation (LLD) is 72% of the initial value. At this point in time the LED's lumen depreciation is 95% of its initial value.



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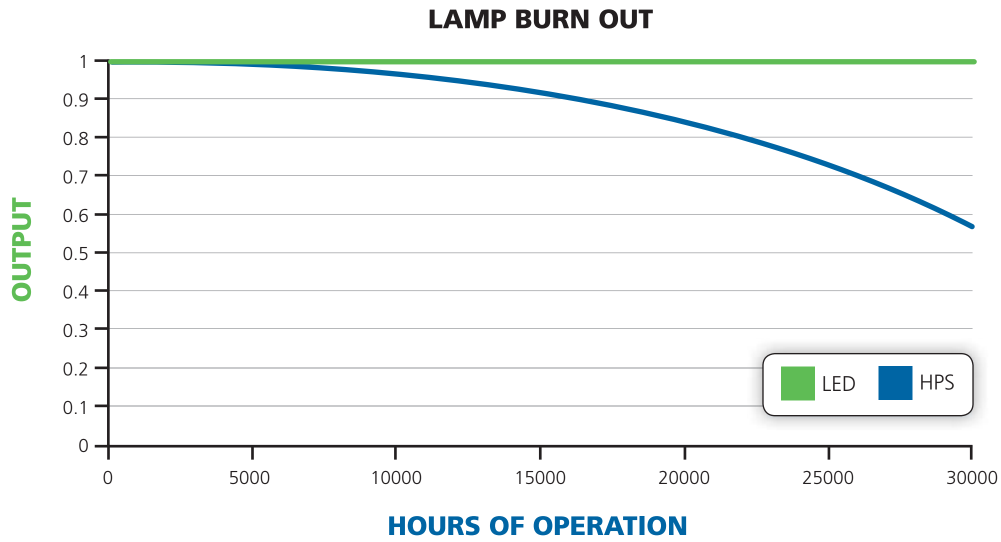
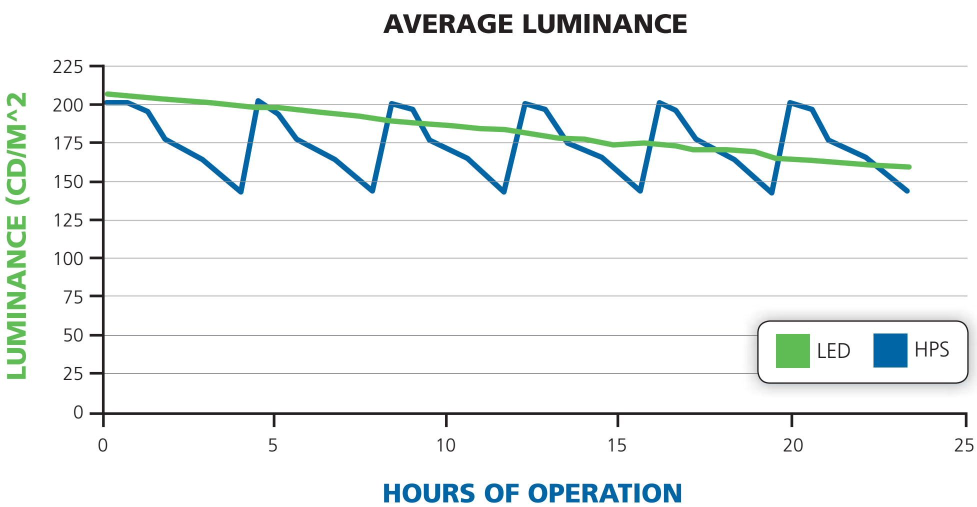
Comparison of Average Luminance Over Time

The LLD, LBO and LDD are the major factors in determining the road luminance at any point in time. Multiplying the factors together results in a product that is referred to as the Light Loss Factor (LLF). The product of the initial road luminance and the LLF is the predicted road average luminance at that point in time The IES recommended average luminance is 160 cd per sq m. The HPS source reaches this value at 16,800 hours of operation, or at 3.83 years. At this time the installation needs relamped. Maintenance will require the cost of lane closures, labor and cost to replace failed lamps and ballasts to restore the system back to designed levels.





After more than 23 years of operation, the TunnelPass LED has a maintained average luminance greater than the required 160cd/ Sq m, which equates to 23 years of maintenance free operation. At this time, the HPS system will have been relamped five times and would be nearing a sixth lamp change.

Additional Savings and Advantages

Public safety is improved with the TunnelPass LED luminaire while reducing operational costs. A more reliable lighting system will provide the required luminance to allow driver's vision to adapt to light levels inside the tunnel. This will keep the traffic moving in a safe manner. Longer intervals between maintenance procedures will also produce operational cost savings resulting from the lighting system needing less maintenance to keep IES recommended average road luminance levels.

The largest savings will come as a result of the reduction in lane closures. Vehicular traffic through a high volume tunnel can exceed 150,000 vehicles per day. The process to implement the lane closure is costly, requires political intervention to execute, and the result is a negative impact on both the state and local commerce.

Minimize Lane Closures

20+ Year Service Life

50% Energy Savings

Performance Specifications

General Construction
Low copper content diecast aluminum A360 alloy electrical and optical housing. Diecast aluminum housing has integral heat sink fins to optimize thermal management through conductive and convective cooling. Stainless steel bolted or latched door closure options disengages top electrical cover for easy access to LED drivers, surge devices, luminaire disconnect plug and terminal block. Vibration rated to 3G applications per ANSI C136.31-2001. IP 66 rated luminaire per IEC 60529. Superdurable TGIC thermoset powder coat finish over anodized aluminum pre-finish. Finish shall pass 9,000 hour salt fog test per ASTMB117 and D1654. Suitable for Continuous Row Mounting and optionally as a Raceway. 3/4-14 NPT top entry and two 3/4-14 NPT side entries. 316 grade stainless steel mounting brackets for ceiling, wall, or optional box mount.

Electrical
Quick disconnect connectors for ease of installation and maintenance. Class 1 drivers rated for 100,000 hours life. Surge protection meets 10KV/5KA per ANSI/IEEEC62.41. Driver power factor is 90% minimum. Driver meets maximum total harmonic distortion (THD) of 20%.

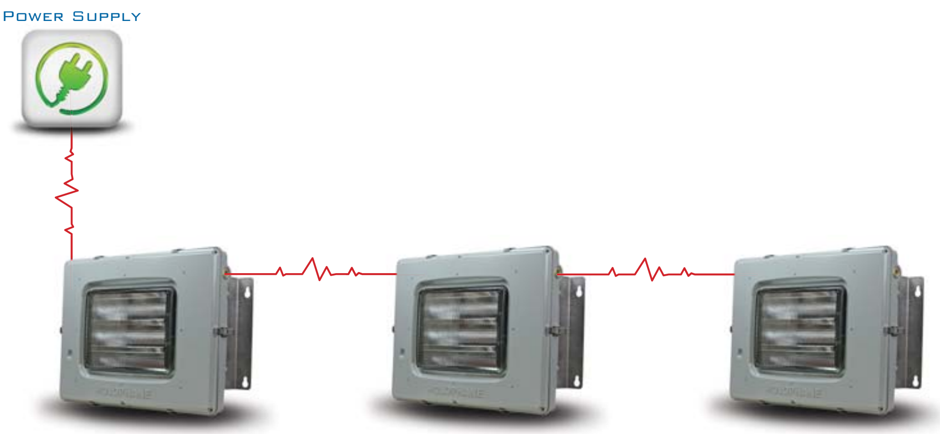
Optical
Multi die LED chip on board (COB) technology, with color temperature options of 4000K and 5000K and a CRI of 70 minimum. Segmented internal reflectors are designed for superior optical control in Counterbeam, Crossbeam, and Long and Narrow distributions. Optical enclosure shall be of borosilicate prismatic glass.

Testing Compliance
Luminaire conforms to following standards:
IEC 61000 - Electromagnetic Compatibility Test (EMC)
FCC Title 47 CFR Part 18 - Federal Communications Commission
ANSI/IEEE C62.41.2-2002 Surge Protection
IEEE 519 - Harmonic control in Electrical Power systems. ANSI C82.77:2002 - Harmonic distortion.
ANSI C136.31:2001 - Luminaire vibration.
ASTM B 117:2003 - Salt spray test.
IEC 60529 - Degrees of protection provided by enclosure (IP).

Regulatory
The luminaire is safety listed to UL/CUL 1598, 40°C, wet location. 30°C when used as a Raceway. Key components including surge protection device, LED drivers, and COB arrays are ROHS compliant.

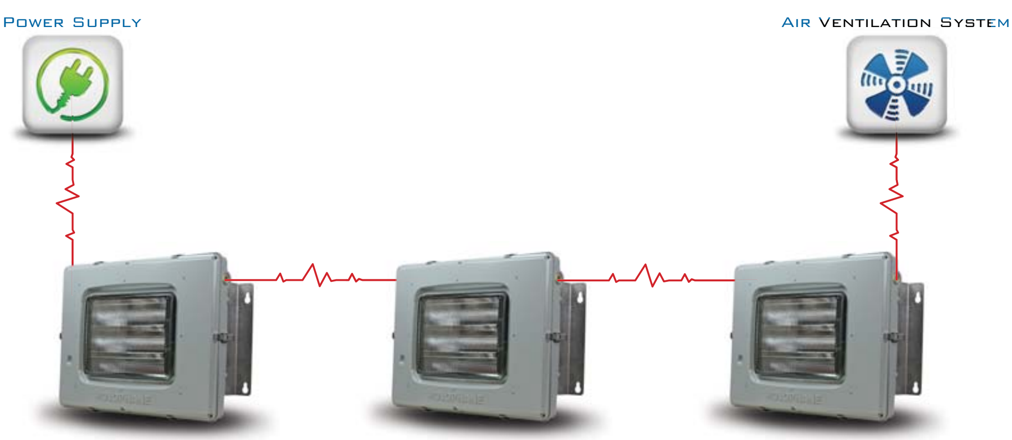
Continuos Row (Standard)

The TunnelPass LED comes standard for continuous row mounting. By definition, this occurs when individual luminaires connected together by a recognized wiring method, shall be permitted to contain the conductors of a 2 wire branch circuit or one multi-wire branch, there by supplying the connected luminaires. One additional 2-wire branch circuit separately supplying one or more of the connected luminaires shall also be permitted. The luminaire would have a 40°C ambient listing.



Through Wiring Raceway (TW-Option)

The TW is for the use of luminaires as raceways. By definition, luminaires intended to serve as a raceway for conductors of a circuit other than the conductors of the branch circuit supplying the luminaire. The TW is a fixture option and allows max 10-#10 conductors, suitable for 90°C permitted in box. The luminaire would have a 30°C ambient listing with the TW option.



Ordering Information

Preferred Selections:

Most Frequently Ordered Catalog Numbers

TNLED	9	5K	1	AH	CCB	DGRA	S
1	2	3	4	5	6	7	8
Luminaire	LED Modules	Color Temp	Drive Current	Voltage	Optics	Color	Door Closure
TNLED	3 6 9	4K 5K	1 7	AS AH	CCB CLN WCR	A DBKA DBZA DGRA DWHA	L S

Catalog Numbers for Entire Product Offering

(Pricing and lead times may be affected)

c UL US LISTED

Next Generation Luminaires Outdoor 2013

STEP 1: Luminaire

TNLED	TunnelPass LED™

STEP 2: LED Modules

3	3 Modules
6	6 Modules
9	9 Modules

STEP 3: Color Temp

4K	4,000 CCT+/-250K
5K	5,000 CCT+/-250K

STEP 4: Drive Current

1	1050mA driver
7 [1]	700mA driver

STEP 5: Voltage

AS	Auto-sensing voltage (120-277V)
AH	Auto-sensing voltage (347-480V)

STEP 6: Optics

CCB	Ceiling mount counterbeam
CLN	Ceiling mount long & narrow
WCR	Wall mount crossbeam

STEP 7: Color

A [2]	As specified
DBKA	Black
DBZA	Bronze
DGRA	Gray
DWHA	White

*Colors are just a representation. Custom colors are available upon request

STEP 8: Door Closure

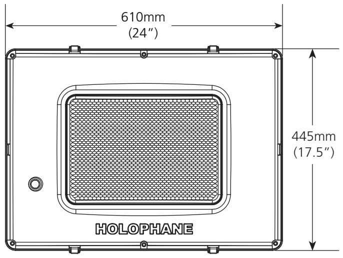
L	Latched
S	Screws

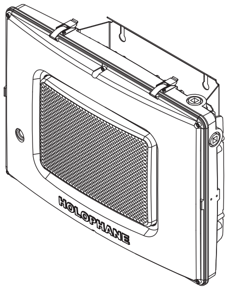
STEP 9: Options

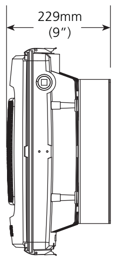
BM	Box mount
DM	0-10V dimming control
F1	Single fusible
F2	Double fusible
TW	Through wiring raceway

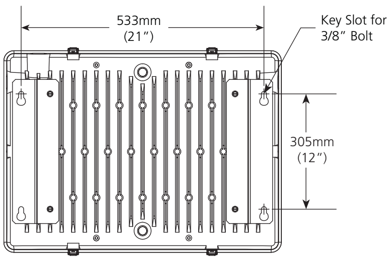
1 Not available with 9 modules
2 Handled as custom

Dimensional Details

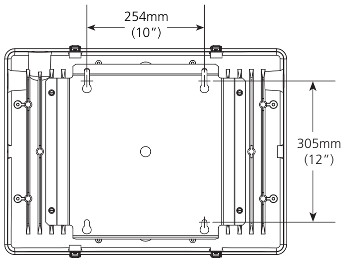








SURFACE MOUNTING DETAIL



BOX MOUNTING DETAIL

TunnelPass LED
Maximum weight: 55lbs (24.9kg)
Maximum E.P.A.: 3.5 sq. ft.

Acuity Brands Lighting, Inc.

Holophane Headquarters, 3825 Columbus Road, Granville, OH 43023

Acuity Brands Lighting Canada, Inc., 35B Minthorn Blvd., Markham, ON., L3T 7N5

Holophane Europe Limited, Bond Ave., Milton Keynes MK1 1JG, England

Holophane, S.A. de C.V., Km. 31 Carretera Mexico-Cuautitlan 54900 Tultitlan Edo. De Mexico

Contact your local Holophane factory sales representative for application assistance, and computer-aided design and cost studies. For information on other Holophane products and systems, call the Inside Sales Service Department at 866-759-1577. In Canada call 905-886-8967 or fax 905-886-7973.

Warranty Five-year limited warranty. Full warranty terms located at www.acuitybrands.com/CustomerResources/Terms_and_conditions.aspx

Visit our web site at www.holophane.com

Product specifications may change without notice. Please contact your local Holophane factory sales representative for the latest product information.

The eco savings in the production of this brochure:

- 1 tree preserved for the future
- 4 lbs waterborne waste not created
- 527 gallons wastewater flow saved
- 58 lbs solid waste not generated
- 115 lbs net greenhouse gases prevented
- 878,220 BTUs energy not consumed

Data obtained from the Mohawk Paper environmental calculator

Printed in USA

GIVEN CRITERIA

1. Existing luminaire locations are to be used whenever possible, however new luminaire locations will be considered.
2. The existing luminaires are all surface-mounted, and are a combination of "counter-beam" and "symmetrical" distributions. We strongly prefer that only luminaires with these two distributions be utilized in your analyses.
3. It is preferred that all light sources utilized in the analyses should have a CRI of >= 70, and a CCT of between 3,900K – 4,500K.
4. Only Photopic lumen ratings may be utilized for in the analyses.
5. Analysis methodology must conform to those detailed in IESNA document RP-22-11.
6. Luminance Uniformities must conform to those detailed in RP-22-11.
7. Luminance in Transition Zones, included the recently updated option of transitioning within the 2nd half of the Threshold Zone, must conform to the methodology detailed in RP-22-11.
8. Analysis of Wall Luminance and Uniformity must conform to the updated method detailed in RP-22-11.
9. The target minimum <u>daytime</u> Threshold L^{th} is 350.0 cd/m^2.
10. The target minimum <u>daytime</u> Average Pavement Luminance for the Interior Zone is 11.0 cd/m^2.
11. The target minimum <u>nighttime</u> Average Pavement Luminaire for the Interior Zone is 2.5 cd/m^2.
12. The Adaptation Distance in front of each tunnel portal is assumed to be 50'.
13. The traffic speed is 65 MPH, and so one SSSD is assumed to be 645'.
14. The location for the initial Threshold Zone in each tunnel begins 50' in from the portal, and is assumed to be a total length of 595' (645' – 50'). All subsequent calculations based upon the Threshold length must conform to those detailed in RP-22-11.
15. Luminaires are not required in the first and last 50' of each tunnel.
16. The Approach Characteristic is defined as "Open Road", as per RP-22-11.
17. The Traffic Volume is assumed to be >= 24,000 AADT, as per RP-22-11.
18. The Total Typical Maintenance Factor (TMF) is 0.50 .
19. The tunnel dimensions and ceiling height**s** are detailed in the CAD files.
20. The surface reflectances are as follows: Ceiling - 5% Walls - 46% Pavement - Semi-Specular 26%.
21. Road surface R3 Per AGI files provided.

Additional considerations:

22. All products must conform to the requirements for "Made in America", unless a federal exclusion has been granted.

23. All products must have a minimum rating of IP 66 for this initial analysis. Additional requirements, in conformance with the accepted strict standards for tunnel luminaires, will be instituted for the next phase of analysis.
24. Only new luminaires and/or retrofit modules are to be included in this submittal. Please contact us directly with proposals for any other products, such as new Controls Systems.
25. The minimum submittal should include: product cutsheets/brochures, photometric files in IESNA format, and CAD and/or AGI files containing one photometric study for daytime operation & one for nighttime operation. Photometric studies for transition between these modes of operation are not required at this time.
26. All submittals must be received by D.H. Lighting Solutions by no later than noon on Wednesday, July 27.
27. Although I will remain your point of contact with any questions on the overall project; any technical questions regarding the assumptions utilized in preparing the CAD & AGI files should be directed to Bob Hawthorne (contact card attached).

APPLICATION OF RP-22-11

SUMMARY OF LIGHTING CRITERIA PER RP-22-11		
	L AVG (Cd per Sq M)	ZONE LENGTH (Ft)
1ST Part of Threshold	350	404
2nd Part of Threshold	275	191
1st Transition	142	286
2nd Transition	57	381
3rd Transition	23	477
Interior	11	Balance of tunnel
Nightime	2.5	Length of tunnel

Wall Luminance

Lower 6.6 ft of walls should have a maximum ratio of 2.5 between average road surface and average wall luminance (diffuse luminance is assumed.

Max Veiling Luminance Ratio

Less than or eqaual to 0.3 for zone lengths greater than 273 ft

Uniformity Ratios

Lighted surfaces less thanor equal to 2.0 avg to min and 3.5 max to min.

Flicker Effect Avoidance spacing

Spacing of fixtures where common spacing exists for greater than 20 second exposure at posted speed is to avoid 4 to 11 Hz. (at 65 mph this is an avoidance spacing range of between 8.64 and 23.75 ft on center for zone lengths of greater than 1906-ft.

Assumptions

Road lighting of approach before and after tunnel portals not included in design scope.

Per conference call 7/18/11, complete typical sections prorating the lumens of the Counterbeam to the Color Master Elite lumens.

As time permits, run with Ledgend

Methodology for determining the zone luminance criteria using RP-22-11

Given the 350 Cd per sq m threshold criterion, the luminance of any zone must be above a given value depending upon the distance traveled after half the threshold distance. This minimum value decreases in a linear fashion from the half point in the threshold to 40.7% of 350 Cd per sq m (142 cd per sq m) at the beginning of the transition zone. Beginning at the end of the threshold zone, the minimum luminance level is defined by the following equation:

$$L_{tr} = L_{th}(1.9+t)^{-1.4}$$

Where $L_{th} = 350\,{}^{cd}\!/_{m^2}$ and t is the time in seconds from the end of the threshold zone.

The "Step Method" is used to decrease the required luminance values of each zone until the interior luminance is reached. Length of transition zones and luminance levels in transition zones are determined by the following methodology: Steps should never fall below the minimum values defined by a linear decrease in the second half of the threshold zone nor lower than the luminance as defined by the above equation for L_{tr} in the Transition zone. Incremental steps in the threshold zone should be at least 2 seconds. At 65 mph, a vehicle travels at 95.33 ft per second. A 2 second step equates to a traveled length of 191-ft In the threshold zone. The 100% L_{th} must be maintained for 404-ft and the step level is 191-ft long for the lower step of the threshold zone of which the entire length is 595-ft. The value of the 2 second Threshold step is determined to be 275 cd per sq m using the following calculation.

$$\frac{\Delta Y}{\Delta X} = \frac{(350-142)\,{}^{Cd}\!/_{m^2}}{298\,ft} = \frac{(Y_{step}-142)\,{}^{Cd}\!/_{m^2}}{191\,ft}$$

The time in the first transition step is to be 3 seconds and subsequent step increase by one second. The level should not fall below the minimum level determined by the equation above nor should any step ratio from one step to the next never be greater than 2.5. Transitional steps should continue until the interior level of 11 cd per sq m is reached.

I-10 Deck Park Tunnel Phoenix, AZ

Holophane TunnelPass LED Luminaire

Threshold Luminance: 350 cd per sq meter

65 mph Constant	Nighttime			Daytime			
	EB	WB	Total	EB	WB	Total	Grand Total
Power Demand (kW)	40.0499	40.0499	80.0998	458.4644	458.4644	916.9288	
Hours per year			4380			4380	8760
Energy per yr (kWh)			350,837.12			4,016,148.14	4,366,985.27
Energy Unit Cost ($/kWh)			0.087			0.087	
Energy Cost per yr ($)			$30,522.83			$349,404.89	$379,927.72

Constant 65 mph and Ambient Light Controls	Nighttime			Daytime			
	EB	WB	Total	EB	WB	Total	Grand Total
Power Demand (kW)	40.0499	40.0499	80.0998	458.4644	458.4644	916.9288	
Hours per year			4380			4380	8760
Energy per yr (kWh)			350,837.12			3,413,725.92	3,764,563.05
Energy Unit Cost ($/kWh)			0.087			0.087	
Energy Cost per yr ($)			$30,522.83			$296,994.16	$327,516.99

Real time ambient light controls assumed to save 15% energy on daytime operation but not change peak power demand

Current energy cost based on information in the 2011 Energy Efficiency Study	$335,219

I-10 Deck Park Tunnel
Holophane TunnelPass LED Luminaire

Variable Speed	Nighttime Total	Daytime 65 mph	Daytime 55 mph	Daytime 45 mph	Daytime Total	Grand Total
Power Demand (kW)	80.0998	916.9288	611.1365	413.8381		
Hours per year	4380	1380	2000	1000	4380	8760
Energy per yr (kWh)	350,837.12	1,265,361.74	1,222,273.00	413,838.10	2,901,472.85	3,252,309.97
Energy Unit Cost ($/kWh)	0.087	0.087	0.087	0.087	0.087	
Energy Cost per yr ($)	$30,522.83	$110,086.47	$106,337.75	$36,003.92	$252,428.14	$282,950.97

Variable Speed and Ambient Light Controls	Nighttime Total	Daytime 65 mph	Daytime 55 mph	Daytime 45 mph	Daytime Total	Grand Total
Power Demand (kW)	80.0998	916.9288	611.1365	413.8381		
Hours per year	4380	1380	2000	1000	4380	8760
Energy per yr (kWh)	350,837.12	1,075,557.48	1,038,932.05	351,762.39	2,466,251.92	2,817,089.05
Energy Unit Cost ($/kWh)	0.087	0.087	0.087	0.087	0.087	
Energy Cost per yr ($)	$30,522.83	$93,573.50	$90,387.09	$30,603.33	$214,563.92	$245,086.75

Does not account for additonal energy costs associated with the operation of the variable speed system.
Real time ambient light controls assumed to save 15% energy on daytime operation but not change peak power demand.

Current energy cost based on information in the 2011 Energy Efficiency Study	$335,219

I-10 Deck Park Tunnel
Variable Speed Limit System
Annual Energy Costs

Three Mile VSL System	Signs	Cabinets	Total
Number of Units	84	40	
Power Demand per Unit (W)	100	200	
Total Power Demand (W)	8400	8000	16,400
Hours per year	8760	8760	
Energy per yr (kWh)	73,584	70,080	
Energy Unit Cost ($/kWh)	0.087	0.087	
Energy Cost per yr ($)	$6,401.81	$6,096.96	$12,498.77

Option 7.1- LED with 65 mph Constant Speed Limit Detailed Cost

	Investment Cost	Electrical Cost		Maintenance cost		Total Costs
Year	PV Investment	Lighting Annual Recurring	Total Electrical Cost PV $	Annual Recurring Maintenance	Total Maintenance Present Value	Total Present Cost
0	$10,250,000.00	N/A	N/A	N/A	N/A	$10,250,000.00
1	$0.00	$327,516.99	$313,113.75	$43,200.00	$41,300.19	$354,413.94
2	$0.00	$327,516.99	$299,343.93	$43,200.00	$39,483.93	$338,827.86
3	$0.00	$327,516.99	$286,179.67	$43,200.00	$37,747.54	$323,927.21
4	$0.00	$327,516.99	$273,594.33	$43,200.00	$36,087.52	$309,681.85
5	$0.00	$327,516.99	$261,562.45	$43,200.00	$34,500.49	$296,062.95
6	$0.00	$327,516.99	$250,059.71	$43,200.00	$32,983.26	$283,042.97
7	$0.00	$327,516.99	$239,062.82	$43,200.00	$31,532.76	$270,595.58
8	$0.00	$327,516.99	$228,549.54	$43,200.00	$30,146.04	$258,695.58
9	$0.00	$327,516.99	$218,498.60	$43,200.00	$28,820.31	$247,318.91
10	$0.00	$327,516.99	$208,889.68	$43,200.00	$27,552.87	$236,442.55
11	$0.00	$327,516.99	$199,703.33	$43,200.00	$26,341.18	$226,044.51
12	$0.00	$327,516.99	$190,920.96	$43,200.00	$25,182.77	$216,103.73
13	$0.00	$327,516.99	$182,524.82	$43,200.00	$24,075.31	$206,600.13
14	$0.00	$327,516.99	$174,497.92	$43,200.00	$23,016.55	$197,514.46
15	$0.00	$327,516.99	$166,824.01	$43,200.00	$22,004.35	$188,828.36
16	$0.00	$327,516.99	$159,487.58	$43,200.00	$21,036.66	$180,524.24
17	$0.00	$327,516.99	$152,473.79	$43,200.00	$20,111.53	$172,585.32
18	$0.00	$327,516.99	$145,768.44	$43,200.00	$19,227.08	$164,995.52
19	$0.00	$327,516.99	$139,357.97	$43,200.00	$18,381.53	$157,739.51
20	$0.00	$327,516.99	$133,229.42	$43,200.00	$17,573.17	$150,802.59
21	$0.00	$327,516.99	$127,370.38	$43,200.00	$16,800.35	$144,170.73
22	$0.00	$327,516.99	$121,769.01	$43,200.00	$16,061.52	$137,830.53
23	$0.00	$327,516.99	$116,413.97	$43,200.00	$15,355.18	$131,769.15
24	$0.00	$327,516.99	$111,294.42	$43,200.00	$14,679.91	$125,974.33
25	$0.00	$327,516.99	$106,400.02	$43,200.00	$14,034.33	$120,434.35
	$10,250,000.00		**$4,806,890.52**		**$634,036.34**	**$15,690,926.86**

Option 7.2- LED with Variable Speed Limits based on Level of Traffic Congestion Detailed Cost

	Investment Cost	Electrical Cost				Maintenance cost		Total Costs
Year	PV Investment	Lighting Annual Recurring	Variable Speed Recurring	Sum of Lighting and Variable Speed	Total Electrical Cost PV $	Annual Recurring Maintenance	Total Maintenance Present Value	Total Present Cost
0	$18,450,000.00	N/A	N/A	N/A	N/A	N/A	N/A	$18,450,000.00
1	$0.00	$245,086.75	$12,498.77	$257,585.52	$246,257.66	$48,600.00	$46,462.72	$292,720.38
2	$0.00	$245,086.75	$12,498.77	$257,585.52	$235,427.98	$48,600.00	$44,419.42	$279,847.40
3	$0.00	$245,086.75	$12,498.77	$257,585.52	$225,074.55	$48,600.00	$42,465.99	$267,540.53
4	$0.00	$245,086.75	$12,498.77	$257,585.52	$215,176.43	$48,600.00	$40,598.46	$255,774.89
5	$0.00	$245,086.75	$12,498.77	$257,585.52	$205,713.61	$48,600.00	$38,813.06	$244,526.66
6	$0.00	$245,086.75	$12,498.77	$257,585.52	$196,666.93	$48,600.00	$37,106.17	$233,773.10
7	$0.00	$245,086.75	$12,498.77	$257,585.52	$188,018.10	$48,600.00	$35,474.35	$223,492.45
8	$0.00	$245,086.75	$12,498.77	$257,585.52	$179,749.61	$48,600.00	$33,914.29	$213,663.91
9	$0.00	$245,086.75	$12,498.77	$257,585.52	$171,844.75	$48,600.00	$32,422.84	$204,267.60
10	$0.00	$245,086.75	$12,498.77	$257,585.52	$164,287.53	$48,600.00	$30,996.98	$195,284.51
11	$0.00	$245,086.75	$12,498.77	$257,585.52	$157,062.65	$48,600.00	$29,633.83	$186,696.47
12	$0.00	$245,086.75	$12,498.77	$257,585.52	$150,155.49	$48,600.00	$28,330.62	$178,486.11
13	$0.00	$245,086.75	$12,498.77	$257,585.52	$143,552.10	$48,600.00	$27,084.72	$170,636.82
14	$0.00	$245,086.75	$12,498.77	$257,585.52	$137,239.10	$48,600.00	$25,893.61	$163,132.71
15	$0.00	$245,086.75	$12,498.77	$257,585.52	$131,203.73	$48,600.00	$24,754.89	$155,958.62
16	$0.00	$245,086.75	$12,498.77	$257,585.52	$125,433.77	$48,600.00	$23,666.24	$149,100.02
17	$0.00	$245,086.75	$12,498.77	$257,585.52	$119,917.57	$48,600.00	$22,625.47	$142,543.04
18	$0.00	$245,086.75	$12,498.77	$257,585.52	$114,643.94	$48,600.00	$21,630.47	$136,274.41
19	$0.00	$245,086.75	$12,498.77	$257,585.52	$109,602.24	$48,600.00	$20,679.23	$130,281.47
20	$0.00	$245,086.75	$12,498.77	$257,585.52	$104,782.26	$48,600.00	$19,769.81	$124,552.07
21	$0.00	$245,086.75	$12,498.77	$257,585.52	$100,174.24	$48,600.00	$18,900.40	$119,074.64
22	$0.00	$245,086.75	$12,498.77	$257,585.52	$95,768.87	$48,600.00	$18,069.21	$113,838.09
23	$0.00	$245,086.75	$12,498.77	$257,585.52	$91,557.24	$48,600.00	$17,274.58	$108,831.82
24	$0.00	$245,086.75	$12,498.77	$257,585.52	$87,530.82	$48,600.00	$16,514.90	$104,045.72
25	$0.00	$245,086.75	$12,498.77	$257,585.52	$83,681.48	$48,600.00	$15,788.62	$99,470.09
	$18,450,000.00				**$3,780,522.65**		**$713,290.88**	**$22,943,813.53**

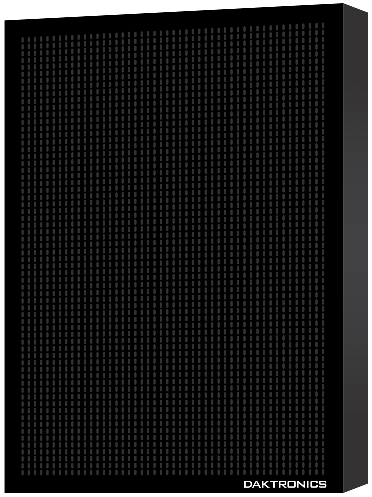
VANGUARD® VX-2420-64x48-20-RGB

Full-Color (RGB)

Display Technology	High-intensity LED
Cabinet Access	Front access
Cabinet Enclosure	NEMA 3R
Face Panel	Aluminum mask over polycarbonate face panel
Weight	310 lbs. (141 kg)
Dimensions[1]	5'0" H x 3'11" W x 1'2" D (1.5 m H x 1.2 m W x .36 m D)
Operating Temp. Range	-30° F to +165° F (-34° C to +74° C)
Humidity Range	0 to 99%, non-condensing
Controller Location	Equipment cabinet
Display Type	Full-matrix (variable text and graphics)
Active Area	4'4" H x 3'2" W (1.30 m H x .99 m W)
Top/Bottom Border Width	4" (101 mm)
Left/Right Border Width	4" (101 mm)
Pixel Matrix	64 rows x 48 columns
Pixel Pitch	20mm (.81")
Viewing Distance	300' (91 m) using 6" characters
Sign Intensity	12,400 candelas/m^2 minimum (white)
LED Color	Full color (32,000 distinct colors using red, green and blue LEDs)
Power Requirements	120 VAC, single-phase power (2-wires plus ground)
Communications Protocol	NTCIP 1203 v02
Communications Options	Cellular, fiber optic, direct Ethernet and radio Ethernet
Structural Design Standard	AASHTO
NEMA Standards	NEMA TS 4 Section 2 Environmental Requirements

Power Specifications

Model	Viewing Angle (HxV)	Amps Per Leg[3]	Typical Power[4]
VX-2420-64x48-20-RGB	30° x 30°	3	241 W



NOTES

1. Display cabinet depth measurement includes "Z" mounting brackets on the rear of the cabinet.
2. Many other font sizes are available.
3. Please contact Daktronics for site-specific power requirements.
4. Typical power includes a partially-illuminated LED sign (38% of the pixels at full intensity) and the sign controller.
5. Sign front face paint color is semi-gloss black. Other sides are mill finish aluminum.
6. With the continuous improvement of all Daktronics products, the features and measurements on this page are subject to change without notice.
7. The product illustration on this page is for conceptual purposes only and may not represent the actual dimensions of the specified display.

117 Prince Drive PO Box 5120 Brookings, SD 57006
tel 888-325-8726 605-692-0200 x57060 fax 605-697-4700
www.daktronics.com/its email transportation@daktronics.com

DAKTRONICS

Variable Speed ENGINEER'S ESTIMATE

Item No.	Description	Unit	Est. Qty	Unit Price	Extended Price
6060036	BRIDGE SIGN STRUCTURE (SD9.52, TYPE 3F, DMS)	EACH	4	$115,000.00	$460,000
6060037	BRIDGE SIGN STRUCTURE (SD9.52, TYPE 4F, DMS)	EACH	8	$135,000.00	$1,080,000
6060080	FOUNDATION FOR BRIDGE SIGN STRUCTURE (SD9.20, TYPE 3F, DMS)	EACH	6	$12,500.00	$75,000
6060083	FOUNDATION FOR BRIDGE SIGN STRUCTURE (SD9.20, TYPE 4F, DMS)	EACH	14	$13,000.00	$182,000
6070055	SIGN POST (PERFORATED) (2 1/2 S)	L. FT.	540	$15.00	$8,100
6070060	FOUNDATION FOR SIGN POST (CONCRETE)	EACH	36	$170.00	$6,120
6080005	WARNING, MARKER OR REGULATORY SIGN PANEL	SQ. FT.	270	$25.00	$6,750
7020011	IMPACT ATTENUATION DEVICE (SAND BARRELL CRASH CUSHION, TYPE A)	EACH	3	$6,000.00	$18,000
7320070	ELECTRICAL CONDUIT (3") (PVC)	L. FT.	1,200	$13.00	$15,600
7320073	ELECTRICAL CONDUIT (2-3") (PVC)	L. FT.	2,800	$15.00	$42,000
7320420	PULL BOX (NO.7)	EACH	32	$625.00	$20,000
7320455	PULL BOX (NO.9)	EACH	10	$2,400.00	$24,000
7320540	CONDUCTOR (NO. 4)	L. FT.	30,000	$1.30	$39,000
7320585	CONDUCTOR (INSULATED BOND) (NO.8 GREEN BOND)	L. FT.	15,000	$0.80	$12,000
7320765	SINGLE MODE FIBER OPTIC CABLE (12 FIBERS)	L. FT.	8,400	$2.25	$18,900
7320794	FIBER OPTIC SPLICE CLOSURE (FMS)	EACH	14	$1,800.00	$25,200
7340103	CONTROL CABINET	EACH	40	$8,000.00	$320,000
7340251	CONTROLLER (MODEL 2070)	EACH	40	$3,000.00	$120,000
7340304	CONTROL CABINET FOUNDATION (CABINET & TRANSFORMER)	EACH	40	$1,200.00	$48,000
7350030	LOOP DETECTOR FOR TRAFFIC SURVEILLANCE (6'X6')	EACH	66	$550.00	$36,300
7350051	DETECTOR CARD	EACH	33	$170.00	$5,610
7350165	LOOP DETECTOR LEAD-IN CABLE	L. FT.	6,600	$0.60	$3,960
7360250	MODIFY LOAD CENTER	EACH	4	$2,500.00	$10,000
7370430	TRANSFORMER (CABINET ASSEMBLY) (3 KVA)	EACH	26	$2,000.00	$52,000
7370431	TRANSFORMER (CABINET ASSEMBLY) (7.5 KVA)	EACH	14	$2,800.00	$39,200
7379111	VARIABLE MESSAGE SIGN ASSEMBLY	EACH	84	$25,000.00	$2,100,000
9240121	MISCELLANEOUS WORK (Microwave/non intrusive detector)	EACH	16	$6,000.00	$96,000
9240122	MISCELLANEOUS WORK (GigE SWITCH)	EACH	40	$2,000.00	$80,000
9240133	MISCELLANEOUS WORK (In Tunnel mounting signs)	EACH	2	$75,000.00	$150,000
9240133	MISCELLANEOUS WORK (MEDIAN BARRIER TRANSITION)	EACH	7	$30,000.00	$210,000
9240133	MISCELLANEOUS WORK (Special Foundation for Sign Structure Elevated area)	EACH	4	$40,000.00	$160,000
9240133	MISCELLANEOUS WORK (Cable BARRIER relocatation)	EACH	2	$15,000.00	$30,000
	SUBTOTAL				**$5,493,740**

Including Design, System integration, Contingency, Communications and other Miscellaneous (1.5*Subtotal) $8,240,610.00

Per mile cost would be ((G36)/3) $2,746,870

Per mile Variable Speed Limit system capital cost would be ***2.75*** million dollars