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High Mast Drone Inspection

FINAL REPORT

Submitted by

Christopher Titze
Brian Stewart
Daniel Stock
Cambridge Systematics, Inc.
New York, New York 10016

NJDOT Research Project Manager
Giri Venkiteela

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16. Abstract
In July 2018, Cambridge Systematics, Inc. was tasked by the NJDOT Bureau of Research to quantify to the best extent possible the benefits of using an Unmanned Aerial System (UAS) approach to high mast light pole inspections compared to a traditional, ground-based approach across four project evaluation criteria: safety, efficiency (highway and data), time, and cost. This research utilized interviews with relevant NJDOT personnel to understand the different approaches to inspection, created case studies to explore inspection scenarios, and conducted a benefit-cost analysis to quantify the costs and savings of the various identified approaches.

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In July 2018, Cambridge Systematics, Inc. was tasked by the NJDOT Bureau of Research to provide a comparative analysis between a traditional, ground-based asset management approach and an approach utilizing unmanned aerial systems (UAS) for the structural inspection of 244 high mast light poles as conducted by the New Jersey Department of Transportation (NJDOT). The goal of this research was to document and, to the best extent possible, quantify the benefits of using UAS compared to a traditional approach across four project evaluation criteria: safety, efficiency (highway and data), time, and cost.

The traditional inspection approach requires an initial inspection of all high mast light poles in the state by two engineers with binoculars. If any potential defects are noted, a second inspection using a bucket truck is required. Depending on the location of the pole, the secondary inspection may require a shoulder or lane closure and disturbance of a guiderail with associated impacts on highway safety and efficiency, personnel time and cost. The UAS inspection approach has a higher time requirement and cost during the initial inspection phase but eliminates the need for a secondary inspection and any associated traffic or safety impacts, leading to an overall cost savings. Finally, these approaches are briefly compared to a prior bucket truck approach which required a bucket truck for every high mast light pole initial inspection in the state. These benefits and costs are summarized in Table 1.

Table 1 - Summary of Benefits/Costs

Criteria	**Bucket Truck Approach (For all Initial Inspections)**	**Traditional Approach (Bucket Truck for Secondary Inspection Only)**	**UAS Approach**
Time (Labor-hours)*	3,312	1,264 – 1,552	1,476
Cost*	$477,022	$167,600 - $177,667	$186,025
Safety (cost)	$2,162 per pole requiring a lane closure (6)	$2,162 per pole requiring a lane closure (maximum 6)	$0
Efficiency (cost)	$1,736 per pole requiring a lane closure (6)	$1,736 per pole requiring a lane closure (maximum 6)	$0
Total Cost	$500,410	$190,988 - $201,055	$186,025

Note: * Assumes 10% of high mast light poles require a secondary inspection using the traditional approach.

In addition, the UAS approach provides a number of benefits not quantified in this report, including collection of higher quality data for analysis and future comparison, reduced time, safety risks, environmental impacts, and costs associated with driving to secondary inspections, and reduced injury exposure for workers related to traffic closures and bucket truck deployments.

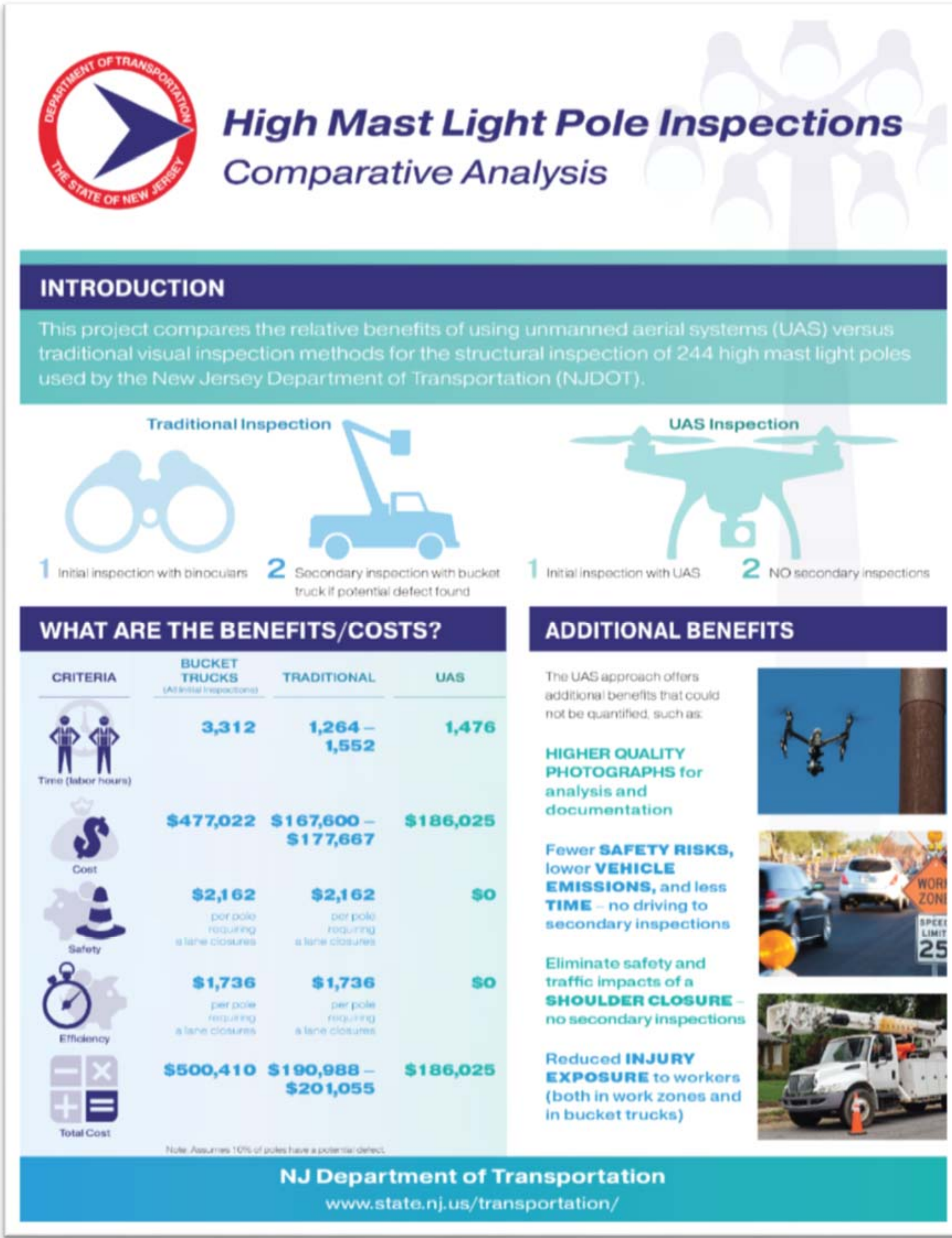

Figure 1. High Mast Light Pole Inspection Overview

BACKGROUND

The NJDOT Bureau of Research is aiding the Bureau of Aeronautics quantify the benefits of deploying UAS for the inspection of 244 high mast light poles in the State and compare it to a traditional, ground-based asset management approach. Use of UAS in the United States is growing across a wide range of activities including inspection/asset management, incident response and management, and construction project management. This research will help NJDOT remain a leader in UAS and serve as a test bed for future deployments in other fields.

OBJECTIVES

The objective of this research was to quantify to the best extent possible the benefits of using an UAS approach to high mast light pole inspections compared to a traditional, ground-based approach across four project evaluation criteria: safety, efficiency (highway and data), time, and cost. This research utilized interviews with relevant NJDOT personnel to understand the different approaches to inspection, created case studies to explore inspection scenarios, and conducted a benefit-cost analysis to quantify the costs and savings of the various identified approaches.

INTRODUCTION

In July 2018, Cambridge Systematics, Inc. was tasked by the NJDOT Bureau of Research to provide a comparative analysis between a traditional, ground-based asset management approach and an approach utilizing unmanned aerial systems (UAS) for the structural inspection of 244 high mast light poles as conducted by the New Jersey Department of Transportation (NJDOT).

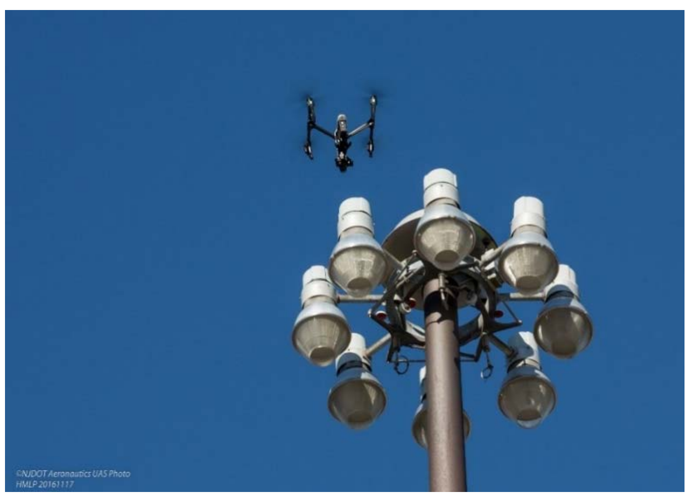

Figure 2. Unmanned Aerial Vehicle and High Mast Light Pole
Source – NJDOT Aeronautics, 2016

The purpose of this report is to provide a comparative analysis between a traditional, ground-based asset management approach and an approach utilizing unmanned aerial systems (UAS) for the structural inspection of high mast light poles as conducted by the New Jersey Department of Transportation (NJDOT). The goal of this research was to document and, to the best extent possible, quantify the benefits of using UAS compared to a traditional approach across four project evaluation criteria, including:

- Safety;
- Efficiency (both for inspection personnel and motorists);
- Time; and
- Cost

SUMMARY OF WORK PERFORMED

This research utilized interviews with relevant NJDOT personnel to understand the different approaches to inspection, created case studies to explore inspection scenarios, and conducted a benefit-cost analysis to quantify the costs and savings of the various identified approaches. The following sections provide an introduction to high mast light pole inspections in New Jersey, an explanation of the inspection process using three case studies, and finally a calculation of benefits using the four project evaluation criteria.

High Mast Light Poles Overview

NJDOT is responsible for inspecting and maintaining 244 high mast light poles in the State. These light poles are typically located at major interchanges and are intended to provide illumination over a large area. These deployments generally provide a uniform level of illumination and reduce glare.[1] The greatest concentration of high mast light poles in New Jersey are located along State Route 3 (SR 3) west of Union City (Hudson

[1] https://www.dot.state.mn.us/trafficeng/lighting/2010_Roadway%20Lighting_Design_Manual2.pdf

County) and along U.S. 46, U.S. 202, and Interstate 80 in Wayne (Passaic County).

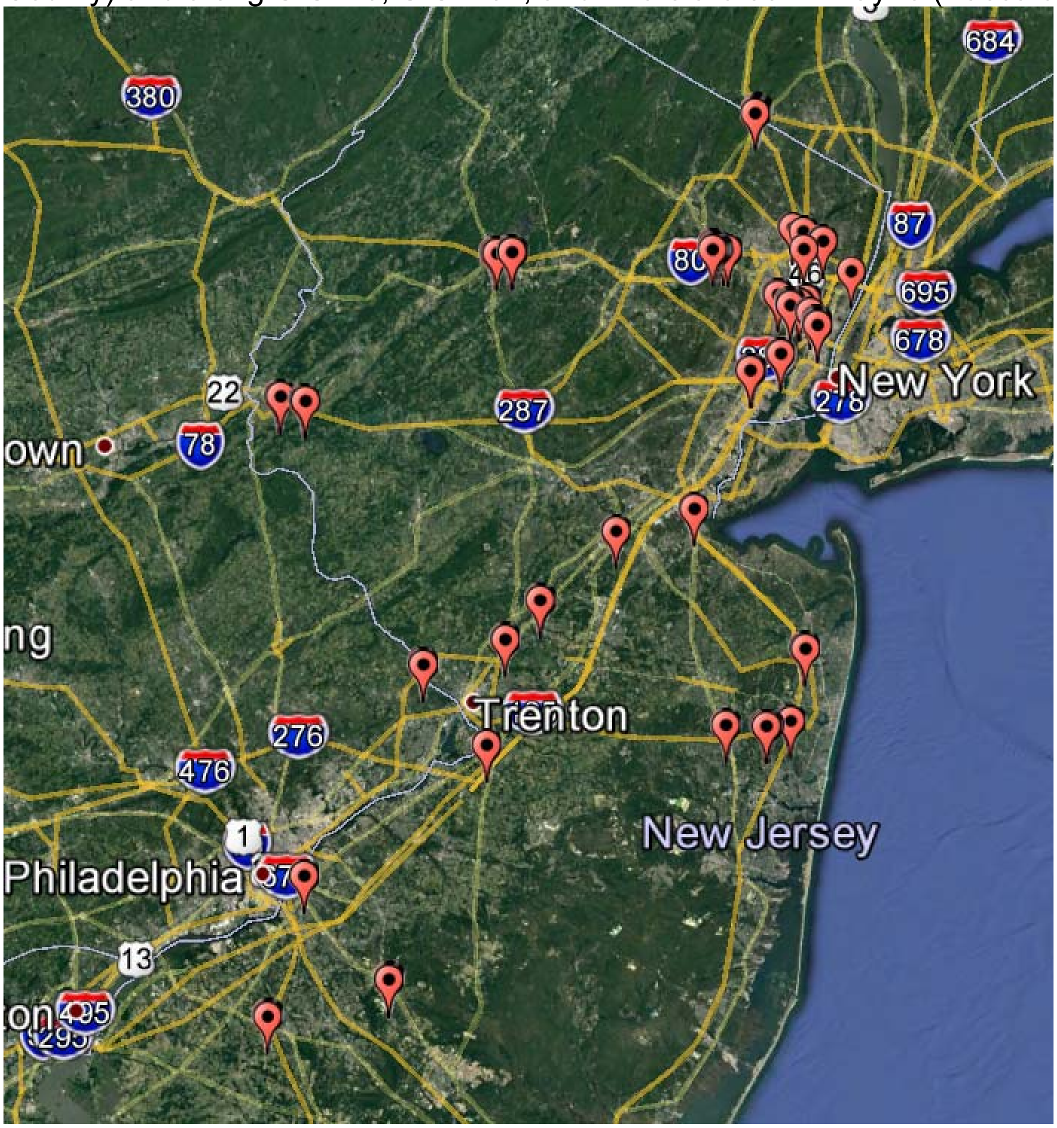

Figure 3 highlights the location of these poles.

These high mast light poles are inspected once every five years, with all inspections being conducted within the same year. The last inspection cycle occurred in 2016. The design lifespan of a high mast light poles is approximately 30 years. Six of the 244 light poles are in locations that are not reachable by UAS, either due to ground cover, flight restrictions, or the inspection would require the UAS to cross active traffic lanes which is not currently allowed by NJDOT.

The inspection of high mast light poles has evolved over the years. Historically, all initial inspections of high mast light poles were done by bucket truck. However, following a tradeoff analysis that compared the cost of this approach, the inspection quality, and the potential risks to public safety, an approach using binoculars for the initial inspection and a bucket truck only for high mast light poles with a potential defect (traditional approach) was implemented. UAS offers a new option, one that balances direct cost to NJDOT and the public, safety risks, and the ability for NJDOT to obtain high quality data and make better-informed maintenance decisions for every high mast light pole in the state.

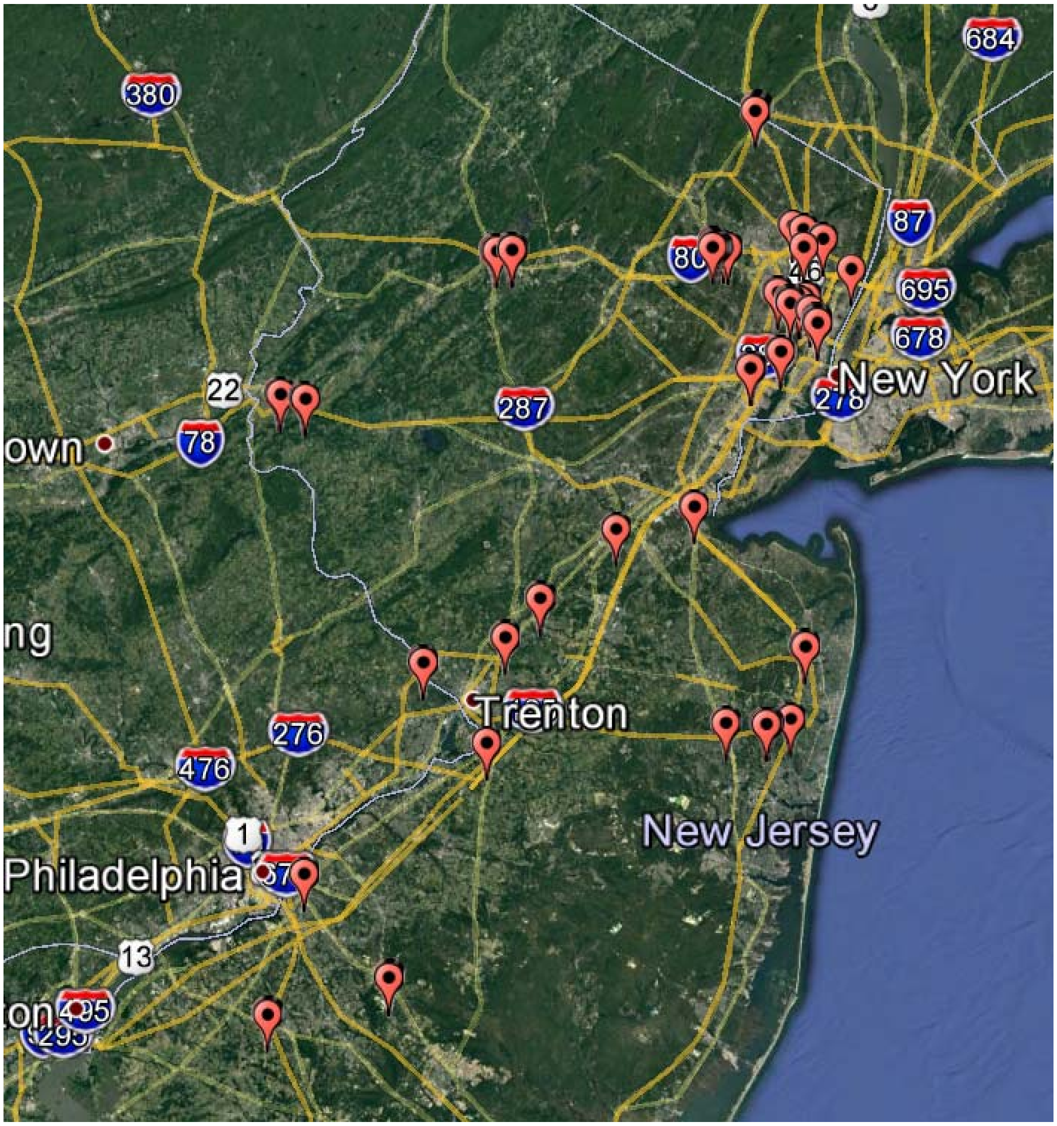

Figure 3. NJDOT High Mast Light Pole Locations
Source – NJDOT, Google Earth.

Case Studies

The following section details the UAS and traditional initial inspection process for all high mast light poles. It then discusses three scenarios where a secondary inspection would be required to highlight the differences between the traditional and UAS approaches.

Initial Inspection

All high mast light poles are subject to an initial inspection. The initial inspection process using the traditional approach and UAS approach are described in the following sections.

Traditional Approach

Using the traditional approach, the initial inspection of each high mast light pole is conducted by a pair of engineers, typically contractors working for NJDOT. The inspection of the high mast light pole covers a number of elements including:

- Concrete base;
- Anchor bolts;
- Lighting elements; and
- Light pole.

The inspection of the light pole itself takes approximately 15-20 minutes and is conducted from the ground with binoculars and photographs of the pole are taken from the ground using a hand-held camera. The entire inspection, including all pole elements, takes approximately two hours to complete.

This initial inspection using the traditional approach has minimal impact on highway safety or efficiency as the inspection team is able to perform the inspection completely off the roadway. There may be a limited issues associated with driver distraction as a result of motorist taking their eyes off the road and looking at the inspectors and vehicles involved in the inspection. However, NJDOT considers this risk to minor.

Figure 4. High Mast Light Pole Inspection Team
Source – NJDOT Aeronautics, 2016.

If no potential defects are detected on the light pole, this is the end of the inspection process. If a potential defect on the pole is identified, a return visit using a bucket truck would be required. Historically, approximately 10% of the light poles require a return visit during each inspection cycle. The impact of this second inspection on the four project criteria can vary depending on the characteristics of each pole and is discussed in the scenarios below.

Unmanned Aerial System (UAS) Approach

Using a UAS approach, the initial inspection of each high mast light pole is conducted by a team of three people including two engineers and a UAS pilot, again typically contractors working for NJDOT. Similar to the traditional approach, multiple elements of each light pole are examined. The UAS is used specifically for inspection of the light pole. The inspection of the concrete base, anchor bolts, lighting elements, etc. is *not* conducted by UAS.

The UAS is deployed from a flat base set near the high mast light pole. Using a video camera to provide constant feedback to the team on the ground, the UAS makes a pass up the pole, rotates 135 degrees and comes down, rotates 135 degrees and goes up, then has a final pass back down to examine any issues if needed. Still photographs are taken of any potential defects. These photographs can be examined on-site by the team or examined back in the office in order to determine if maintenance work is required.

Each high mast light pole inspection requires approximately 2 hours to complete, with the UAS portion of the inspection lasting approximately 15-20 minutes. This initial inspection using UAS has minimal impacts on highway safety or efficiency as the inspection team is able to conduct the inspection completely off the roadway. Similar to the traditional approach, there may be minor concerns due to the presence of a vehicle and people conducting the inspection. Additional concerns due to the deployment of UAS are also minimal. On takeoff, the UAS is immediately flown to a height of approximately 20 feet to minimize potential distractions and the UAS is not allowed to cross moving traffic lanes.

Similar to the traditional approach, if no potential pole defects are detected during this initial inspection, this is the end of the process. The operational case studies below become relevant if a potential defect was detected during the initial inspection.

As detailed below, the traditional approach requires a second inspection if the initial inspection identifies a potential defect. If a UAS is used during the initial inspection, a second inspection is not necessary.

Secondary Inspection

The following scenarios discuss the secondary inspection process for high mast light poles where a potential defect is identified during the initial inspection. The process for inspecting these poles using the traditional approach varies depending on the specific location and operational characteristics of the highway facility in proximity to each pole.

Second Inspection Scenario 1 - No Access Impediments

In this scenario, a potential defect is found during the initial inspection of a high mast light pole in a location that is reachable by bucket truck **without disturbing traffic lanes or requiring the removal of the guiderails**. This scenario accounts for approximately 194 (80%) of the high mast light poles inspected by NJDOT. An example light pole is #1201801, located at the interchange of U.S. 1 and College Rd. West in Plainsboro Township.

Using the traditional approach, if a potential defect was found during the initial inspection, a second inspection would be required. This second inspection would require the use of a bucket truck in order to raise inspectors off the ground and provide a better vantage point to inspect the potential defect. The two engineers involved in the initial inspection join the bucket truck operator and the second inspection can take up to four hours to complete, not including travel time to and from the inspection site. The two engineers use the bucket truck to make a closer examination of the pole, take photographs using a hand-held camera, and then determine if maintenance work is warranted.

If the initial inspection is done using a UAS, there is no need for a second inspection. The initial inspection provides sufficient information to the engineers to determine if maintenance work is required.

Second Inspection Scenario 2 – Shoulder Closure

In this scenario, a potential defect is found on a light pole that **requires a shoulder closure** to inspect with a bucket truck. Within this, there are two potential sub-scenarios. In the first, the inspection does not require removing the guiderail to access the light pole. An example light pole is #1201814 which is located south of U.S. 1 at the interchange with U.S. 130 in Milltown. In the second, the inspection requires the guiderail to be removed in order to access the light pole. An example light pole is #1601808 located at the interchange of SR 3 and SR 21 in Clifton (Passaic County).

This scenario accounts for approximately 44 (18%) of the high mast light poles in the state. Sixteen of the poles are in locations that do not require a guiderail opening, 28 light poles do require guiderail removal.

In this scenario, the second inspection requires a number of additional personnel:

- The two engineers who conducted the initial inspection;
- A bucket truck operator; and
- Two additional traffic safety personnel who set-up the shoulder closure.

All of these personnel must be on-site during the entire inspection process which typically last approximately 4 hours, not including any travel time associated with going to and from the inspection site.

If the guiderail must be opened to allow access, two additional staff are required. Due to liability concerns, only NJDOT maintenance personnel can remove and replace the guiderails that run along the highway. It takes approximately 30 minutes to remove and 30 minutes to replace the guiderails, but NJDOT staff do not have to remain at the work zone during the entire inspection. This does not include any potential travel time associated with driving to and from the site.

Using the UAS approach, this secondary inspection including shoulder closure and possible guiderail removal is not required. The initial inspection with UAS provides sufficient information to make a decision regarding additional maintenance needs.

Second Inspection Scenario 3 – Lane Closure

The final scenario envisions a potential defect being found on a high mast light pole in a location **requiring a lane closure** to access the pole. Similar to the shoulder closure scenario, in some cases a guiderail must be removed to provide access. An example of this is light pole #0204802 located at the interchange of SR 3 and SR 17 in Rutherford (Bergen County). This scenario accounts for only six high mast light poles in the state, four of which require a guiderail removal to access.

Similar to Scenario 2 above, the second inspection using a traditional inspection approach requires a number of additional personnel including:

- The two engineers who conducted the initial inspection;
- A bucket truck operator; and
- Two to three additional traffic safety personnel who set-up the lane closure.

All of these people are required to be at the high mast light pole during the 4 hours it takes to conduct a secondary inspection, in addition to any travel time to/from the site. For the sites where the guiderail must be removed, NJDOT maintenance personnel must be present to remove and replace the guiderail. They do not have to remain on-site for the entire 4 hours, but typically spend approximately 1 hour total per inspection at the site, again not including any travel time.

The UAS approach eliminates the need for this secondary inspection and associated lane closures and potential guiderail removal. As discussed in the following section, secondary inspections of these light poles have the greatest potential impact on highway users in terms of both safety and travel time.

The historic approach which used a bucket truck for the initial inspection of all 244 high mast light poles (no secondary inspections) utilized a similar process as a traditional inspection outlined in the three scenarios above. The corresponding impacts to time, cost, safety and efficiency are summarized at the end of the comparative analysis section.

Comparative Analysis

This section provides a comparative analysis of costs and benefits across the four project evaluation criteria for the two approaches for high mast light pole inspection, and includes a brief summary of benefits/costs for historic, bucket truck approach at the end. The simplest criteria to quantify, time and cost, are detailed first, followed by safety and efficiency.

Time

For the initial inspection, the UAS approach requires more labor-hours than the traditional approach due to the presence of an additional person (the UAS pilot). The traditional approach requires 976 labor-hours (2 people, 2 hours per pole, 244 poles). In this initial phase, the UAS approach requires an additional 476 labor-hours (1 additional person, 2 hours per pole, 238 poles that can be inspected by UAS) versus the traditional approach.

Time savings accrue during the second round of inspections which are not required using a UAS approach. The total amount varies depending on which of the 244 light poles require a secondary inspection. Assuming 10% (24) of poles in a given cycle require a secondary inspection, both a low and high estimate of additional time can be calculated. At the low end, if the 24 poles are all in locations which do not require guiderail removal or a road closure, the second inspection utilizing a bucket truck would require the following:

- 2 engineers and 1 bucket truck operator for 4 hours per pole.

This would entail an additional 288 labor-hours of work, 12 labor-hours per pole.

At the high end, if all 24 light poles required a guiderail removal and a shoulder/lane closure, the following would be required:

- 2 engineers, 1 bucket truck operator, 2-3 personnel (averaged to 2.5) to handle lane/shoulder closure for 4 hours per pole; and
- 2 NJDOT maintenance staff to remove and replace guiderail for 1 hour per pole.

This would entail an additional 576 labor-hours, 24 labor-hours per pole.

Based on 2016 data, if 24 poles require a secondary inspection and half of those required a shoulder/lane closure and guiderail removal, the secondary inspections required an additional 432 labor-hours. This means that the 2016 inspection cycle which utilized drones required an additional 44 labor-hours of time.

These time benefits are summarized in Table 2 below. It should be noted that travel time represents a potentially significant savings but is not included in this analysis. Travel time is highly variable depending on the locations of staff (both contractors and NJDOT maintenance staff) and the particular high mast light poles which require additional inspection.

Table 2 - Time (Labor-Hours) Required For Traditional and UAS Approach to High Mast Light Pole Inspections

Scenario	**Traditional Approach**	**UAS Approach**	**Notes**
Initial Inspection	976	1,476	238 poles can be inspected by either method, 6 by traditional method only
Secondary Inspection – Low Estimate	288	0	Assumed 10% defect rate, all defects are on poles that do not require guiderail removal or traffic closure
Secondary Inspection – High Estimate	576	0	Assumed 10% defect rate, all defects are on poles that require traffic closure and guiderail removal
Secondary Inspection – Medium Estimate	432	0	Assumed 10% defect rate, 12 poles require traffic closure and guiderail removal (6 lane closures, 18 shoulder closures)
Total Time	*1,264 – 1,552*	*1,476*	
Total Time per Pole	*5.18 – 6.36*	*6.05*	

Cost

Using the traditional approach, the estimated cost for the initial inspection of 244 high mast light poles by two engineers is approximately $122,000, for a cost of $500 per pole.[2] Using UAS, the initial inspection cost for 244 high mast light poles by two engineers and a UAS pilot is approximately $186,025.[3] This includes inspecting six light poles using the traditional approach where UAS operation is not feasible. For the 238 poles that can be inspected by UAS, the cost per pole is $738. If none of the inspected poles had a defect, this initial inspection would be the end of the process. Under this scenario, UAS would cost approximately $64,000 more than the traditional approach per inspection cycle due to the presence of a third person (the UAS pilot) at each inspection.

However, because UAS inspections do not require a second inspection with a bucket truck, there are substantial cost savings versus the traditional approach if a potential defect is detected. NJDOT estimates that approximately 10% of poles (24) are found to have defects in any inspection cycle. There is no additional cost to inspect these poles using the UAS approach, since the initial inspection is sufficient to determine if maintenance work is required or not. The cost for a secondary inspection using a bucket truck varies from approximately $1,800 per day ($900 per pole) in locations without a guiderail or traffic disruption to $2,400 per day ($1,200 per pole) for the bucket truck and support crew needed for work zone setup. At the low end, if all 24 poles with a defect do

[2] Approximate cost of $125/hour for each engineer, 2 hour inspection

[3] Approximate cost of $238/hour for UAS pilot in addition to two engineers, 2 hour inspection

not require removal of a guiderail or a highway closure (Scenario 1 above), the additional cost is approximately $45,600. At the high end, if every pole requires guiderail removal and a lane or shoulder closure (6 poles from Scenario 3, 18 poles from Scenario 2), the additional cost is approximately $55,667. Based on the distribution of defects discovered during the 2016 cycle where 12 poles required a shoulder/lane closure and 12 did not, the additional cost of the secondary inspections was approximately $50,633. These costs are summarized in Table 3 below.

Table 3 – Cost of Traditional and UAS Approach to High Mast Light Pole Inspections

Scenario	Traditional Approach	UAS Approach	Notes
Initial Inspection	$122,000	$186,025	238 poles can be inspected by either method, 6 by traditional method only
Secondary Inspection - Low Estimate	$45,600	$0	Assumed 10% defect rate, all defects are on poles that do not require guiderail removal or traffic closure
Secondary Inspection - High Estimate	$55,667	$0	Assumed 10% defect rate, all defects are on poles that require traffic closure and guiderail removal
Secondary Inspection - Medium Estimate	$50,633	$0	Assumed 10% defect rate, 12 poles require traffic closure and guiderail removal (6 lane closures 18 shoulder closures)
Total Cost	*$167,600 - $177,667*	*$186,025*	
Total Cost per Pole	*$687 - $728*	*$762*	

Based on the above information, if an additional 7 poles in locations that did not require any highway closures or guiderail removal had a defect in 2016, the direct costs for using UAS would have been comparable with that of using the traditional approach, not including any safety or efficiency benefits from the UAS approach.

Safety

Safety benefits from deploying UAS to inspect high mast light pols accrue in two different ways. The first is a safety benefit for highway users, the second is a safety benefit to NJDOT and its employees.

Highway Safety

Work zone related crashes are an emphasis area in NJDOT’s 2018 Highway Safety Plan. Between 2011 and 2015 there were 30,702 reported crashes in construction, maintenance, and utility zones in New Jersey.[4] Approximately 60 of the 244 high mast light poles in the state require either a shoulder or lane closure during a secondary inspection if traditional inspection methods are used. These closures are not required if a UAS is deployed for the initial inspection.

Information on the impact of a work zone closure on highway safety provides a wide range of values. For example, the Crash Modification Factors Clearinghouse shows CMF ranging from 1.12 to 1.87 for "Active work with temporary lane closure (compared to no work zone)," indicating an increased potential for crashes in work zones. Due to project constraints, the team employed a traffic incident management (TIM) proxy to calculate the increased risk of crashes. TIM literature on secondary crashes due to a primary crash and subsequent lane closure is extensive but again can vary depending on numerous factors including weather, time of day, time of year, vehicle type, etc. The increased risk of a crash due to the closure of a lane following a primary crash ranges from 3% to approximately 15%. To be conservative, this analysis assumes a 3% increased risk of a crash due to a lane closure.[5]

To calculate the potential safety benefits from not deploying work zones, NJDOT's Crash Rates by Crash Severity Statewide statistics provided a basis for crash rates per million vehicle miles by severity. These rates were multiplied by a vehicle occupancy rate[6] and the statistical cost for each crash severity level[7] was inflated to 2018 using the Consumer Price Index (CPI). These values are then summed and divided by one million to produce a safety cost per vehicle mile of $8.01.

Assuming that each work zone closure associated with a secondary inspection of a high mast light pole is 1 mile long and the total volume of vehicles at the light poles identified by NJDOT as requiring a closure during the non-peak period when work is conducted averages 9,000 vehicles over the 4-hour work time[8], **the safety benefit of avoiding a lane closure is approximately $2,162 per pole**. With 6 light poles in the system that could potentially require a lane closure, the maximum additional safety cost is $12,972. If the added crash risk due to a closure is increased to 15% instead of 3%, the cost per closure rises to $11,412.

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[4] https://www.nj.gov/oag/hts/downloads/HSP_2018_web.pdf

[5] Moore, J.E., Giuliano, G. and Cho, S. Secondary accident rates on Los Angeles freeways, Journal of Transportation Engineering, Vol. 130, No. 3, 2004, pp. 280-285.

[6] Fatality crashes are 1.065 (based on 607 deaths in 570 fatal crashes in 2016 in NJ). Injury crashes are 1.39 based on CBA guidance for average occupancy of passenger vehicles (assumed injury to all persons involved). Property Damage Only crashes are 1.0 (conservative estimate).

[7] FHWA: Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Office of Secretary of Transportation, June 2018.

[8] Based on average AADT of highway segments from 2016 HPMS data within 250 feet of an identified high mast light pole requiring a closure (43,700 AADT). AADT distributed according to NJ Road User Cost Manual, 2015 (Table 3.1). These values were summed over 4-hour increments starting between 9am and 10am and lasting until 3pm to 4pm to represent hours the work zone would be active. The average 4-hour volume between 9am and 4pm is 9,000 vehicles.

There are also an additional 44 high mast light poles which require a shoulder closure in order to provide the bucket truck with access to the pole for the secondary inspection. Data on the impacts to safety of shoulder closures is much less robust and was not included in these benefit calculations. However, it should be assumed that shoulder closures have some negative impact on traffic safety, if for no other reason than they can be a distraction for drivers and limit the amount of space vehicles have to maneuver.

Finally, in addition to the direct safety and financial impacts of work zone crashes, these crashes create delay above and beyond that which would be associated with a work zone and also raise the possibility of additional crashes upstream from the initial incident. This additional crash avoidance and reduction in delay is not included in this analysis, but should be considered when examining the overall impact of UAS and traditional approaches to high mast light pole inspections.

Workplace Safety

Working at height in a bucket truck and working near traffic are both dangerous activities. The need for a secondary inspection using traditional inspection methods for high mast light poles places workers at a higher risk. Personnel working from bucket trucks and those working in roadway work zones are at risk of injury from numerous causes, but falls and being struck by vehicles in the work zone are the most prevalent.

Though data exists to quantify the occurrence and severity of injuries to workers, data on the level of exposure is lacking. Without this, it is difficult to calculate the risk level for any one work zone or operation using a bucket truck is. Additionally, the occurrence of injuries for lift or boom truck operators on a national level is low, therefore risk of injury on any given deployment of a boom truck is miniscule.

The United States Department of Labor Occupational Safety and Health Administration (OSHA) maintains records of “lift truck” injuries in the workplace. These records indicate a total of 13 incidents in 2017 (5 fatal), 8 in 2016 (8 fatal), and 13 in 2015 (12 fatal) across the U.S.

These values are too low to calculate a statistic risk of incident per truck deployment so the benefit is not included in the overall calculations in this white paper. However, the seriousness of the incidents (74% fatalities) emphasizes the potential danger involved with operating a bucket truck.

Worker injuries at work zones are far more common. Between 2011 and 2015, 609 workers were killed at road work zones in the United States.[9] However, similar to bucket truck deployments, quantifying the risk of work zone injuries or fatalities for any one work zone deployment is complicated by a lack of information on the total number of work zones deployed in the U.S., their overall length, and other critical factors. For this reason, a specific benefit for avoiding work zone personnel injuries is not included in the white paper. This notwithstanding, the potential of work zone injury is real and the

[9] Bureau of Labor Statistics, 2017. https://www.bls.gov/opub/ted/2017/fatal-injuries-at-road-work-zones.htm

consequences are severe. Eliminating the need for establishing a work zone to conduct a pole inspection removes the potential for such injuries and is a large benefit of utilizing the UAS approach.

Efficiency

The final project criteria for examining the use of UAS versus traditional methods to examine high mast light poles is efficiency. Similar to safety, efficiency benefits can accrue from a number of sub-categories. The two main ones are increased efficiency for highway users, and an improvement in data quality and storage which leads to more efficient internal processes at NJDOT.

Highway Efficiency

High mast light poles are typically deployed on near high volume roads and interchanges. Closures of a lane due to a work zone associated with the deployment of a bucket truck will have a negative impact on traffic flow, a cost that is avoided by the use of UAS technology during the initial inspection.

To estimate the road user cost (RUC) of delay caused by a lane closure, the team utilized the New Jersey DOT's Road User Cost Manual (2015) and accompanying spreadsheet. As described in the manual, "Road User Costs are directly related to the traffic demand, facility capacity, and the timing, duration and frequency of work zone induced capacity restrictions." For our calculations, the following assumptions were made:

- Work zone length of 1 mile;
- Work zone speed of 35 miles per hour (free flow speed of 55 miles per hour);
- 9,000 vehicles travel the queue over 4 hours during authorized work times (see Safety section above for methodology);
- 10% truck volume;
- Highway capacity of 2,300 passenger cars per hour per lane (based on "Freeway – 6 or more lanes" in Table 3.2 of the NJDOT RUC Manual);
- Used RUC values for vehicle length;
- Value of time are from FHWA: Benefit-Cost Analysis Guidance for Discretionary Grant Programs (2018) and values are inflated to 2018 dollars; and
- Vehicle operating costs (VOC) are based on the RUC model inflated from 1970 to 2018 using the CPI from the U.S. Bureau of Labor Statistics

Based on these assumptions, **the efficiency benefit of avoiding a lane closure is approximately $1,666 per pole**.[10] Similar to the safety calculations described above, shoulder closures also likely have an impact on highway efficiency, though at a lower level than a full lane closure. The NJDOT RUC worksheet does not provide a method to calculate the impact of shoulder closures and any benefits from avoiding them are not quantified in this white paper.

Improving highway efficiency will also have environmental benefits through the reduced emission of pollutants including carbon dioxide, nitrogen oxide, particulate matter (2.5), volatile organic compounds, sulfur dioxide, and carbon monoxide. Based on the reduced travel speed associated with the work zone, **avoiding a lane closure adds approximately $70.46 in environmental benefits per pole**, a total of $422.75 for the six poles with a lane closure.

Additional environmental benefits would accrue from not sending out a bucket truck for the secondary inspection. The impact of the 24 additional trips are not included in the quantifiable benefits due to the range of possible drive times, driving conditions, and other factors that influence the calculations depending on the location of the poles with potential defects.

Data Efficiency

NJDOT staff indicated that one of the largest benefits they see from using a UAS approach is the higher quality of data. This information is useful both during the initial review process to determine if maintenance work is necessary and as a historical marker to identify and track changes over time.

The UAS uses a high definition video camera during the inspection process to identify in real-time potential defects on the high mast light pole. The flight path of the UAS is consistent from pole-to-pole, reducing the variability between inspections. The UAS pilot and engineer on the ground monitor the feed and can take 20 megapixel (mp) photographs of any potential defects from close range (approximately 10 feet) during the initial inspection.[11] Figure 5 shows a picture taken via UAS of a potential defect. The traditional approach relies on engineers on the ground using binoculars or taking photographs from a camera with zoom during the initial inspection, or engineers in a bucket truck with a single vantage point to the pole using a hand-held camera during the secondary inspection. During both phases, the image quality is lower than available using UAS due to the need to utilize a zoom feature. While sufficient to meet inspection requirements, the higher quality data available from UAS is preferred and offers a better record to compare against future inspections.

[10] This estimate may be conservative. A 2015 study by Michigan DOT found that user delay costs for closing one lane for 10 hours on a four-lane highway over a bridge in a metro area totaled $14,600, or $1,460 per hour. See: http://asphaltmagazine.com/wp-content/uploads/2016/05/Dronesss.pdf

[11] This data is compressed to a 5mp image for storage.

The still images captured by the UAS also provides more redundancy during inspections as multiple people can examine the photographs in the office after the inspection. This helps control for differences in experience, eye strength, and other human factors that could impact the inspection process as well as provides consistency between inspection cycles to protect against personnel turn-over. The high resolution images are also potentially useful as training tools.

Figure 5. UAS Photograph of Potential Defect
Source: NJDOT Aeronautics, 2016.

Bucket Truck High Mast Light Pole Inspection

Historically, NJDOT deployed a bucket truck to inspect every high mast light pole in the state. This process and the associated costs are very similar to those accrued during a secondary inspection using the traditional approach, except they apply to every high mast light pole in the state instead of a selection with potential defects. A total of 212 high mast light poles would not require a guiderail removal, 32 would require a guiderail removal. The costs of this across the four project criteria were[12]:

- Time: 3,312 labor-hours total, average of 13.6 labor-hours per pole
- Cost: $477,022 total, average of $1,955 per pole
- Safety: $2,162 per pole requiring a lane closure (6 total). Total cost = $12,972
- Efficiency: $1,736 per pole requiring a lane closure (6 total). Total cost = $10,416

SUMMARY AND CONCLUSIONS

As detailed above, there are numerous differences between a traditional and UAS approach to conducting high mast light pole inspections. The quantifiable benefits across the four project criteria are summarized in Table 4 below.

[12] Using the same cost data as applied for the secondary inspections using the traditional approach

Table 4 - Summary of Benefits/Costs

Criteria	**Bucket Truck Approach (For all initial Inspections)**	**Traditional Approach (Bucket Truck for Secondary Inspection Only)**	**UAS Approach**
Time (Labor-hours)*	3,312	1,264 – 1,552	1,476
Cost*	$477,022	$167,600 - $177,667	$186,025
Safety (cost)	$2,162 per pole requiring a lane closure (6)	$2,162 per pole requiring a lane closure (maximum 6)	$0
Efficiency (cost)	$1,736 per pole requiring a lane closure (6)	$1,736 per pole requiring a lane closure (maximum 6)	$0
Total Cost	$500,410	$190,988 - $201,055	$186,025

Note: * Assumes 10% of high mast light poles require a secondary inspection using the traditional approach. The range of values in the traditional approach accounts for the possible locations and access requirements of the poles requiring a secondary inspection.

At a quantifiable level, the UAS approach balances NJDOT's need to comprehensively manage and inspect high mast light pole assets in the state with cost considerations. In addition, the traditional approach values assume a 10% defect rate to determine benefits; as the high mast light poles in New Jersey age, this defect rate may rise which would increase the benefits of a UAS approach compared to the traditional approach.

Finally, the benefits of using UAS are not fully captured in the above numbers. For example, the following considerations are not included:

- Value of higher quality photographs of potential defects for analysis and documentation;
- Fewer safety risks, lower vehicle emissions, and less time spent due to reduced trips to/from poles for secondary inspections;
- Eliminate safety and traffic impacts of a shoulder closure due to no secondary inspections; and
- Reduced injury exposure to workers (both in work zones and in bucket trucks).

For some of these potential benefits, such as the cost of additional travel time to and from a work site for a secondary inspection, the potential variance in each inspection cycle makes it difficult to provide a numerical benefit.

For other categories, such as the value of capturing higher quality photographs where numerical values cannot be calculated, the qualitative impact for NJDOT is still very high. The UAS approach provides better photographs that can be examined by multiple people in an office setting and compared to historical photographs to track change over time. This redundancy improves the quality of the inspection process and can save time and money, especially as the existing inventory of high mast light poles in the state continue to age and the possibility of secondary inspections using a traditional approach rises. In addition, as technology and UAS experience evolves, the UAS approach will likely become faster and cheaper to deploy helping ameliorate cost concerns.

Finally, this program can serve as a test bed for future UAS deployments in construction project management and incident response and management, providing NJDOT with valuable experience and lessons learned that can be applied across multiple programs in the years to come.

Figure 6. UAS Inspecting a High Mast Light Pole
Source: NJDOT Aeronautics, 2016.