A Value Driven Design Approach to Municipal Electric Utility Unmanned Aerial Systems Deployment

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Unmanned Aircraft Systems (UAS) are a rapidly growing sector largely due to new technologies that make components lighter, less expensive, and more powerful. The confluence of these advances has decreased cost and increased usability sufficiently for the commercial industry to begin exploring new applications for these systems. The Federal Aviation Administration (FAA) which regulates U.S. airspace has also loosened airspace restrictions sufficiently so that civil UAS operators have the ability to operate. This paper develops a methodology, using a value driven design approach, to better inform municipal electric utilities that are considering the implementation of a UAS program to support the operation and maintenance of their power distribution systems.

Nomenclature

SAIFI	=	System Average Interruption Frequency Index
SAIDI	=	System Average Interruption Duration Index
MAIFI	=	Momentary Average Interruption Frequency Index
MED	=	Major Event Day

I. Introduction

ENGINEERING can fundamentally be viewed as a decision making process whereby the preferred option is that which provides the highest expected value. This process is comprised of three parts: design options, expectations for those options, and their associated values.[1] The word value in this context is taken to mean the subjective "goodness" of a decision while taking into consideration cost.

Quantifying the value of a system can be difficult due to its inherently subjective nature and owing to the variety of stakeholders for the system. A complex system like the power grid may have stakeholders who value different system properties. Consider the example of a strategic air force bomber: the purchasing government values the projection of military power and the perceived benefit to society, shareholders of the company producing the bomber are interested in maximizing profit, the crew of the aircraft value survivability and ease of use, and the air force would like acquisition and maintenance costs to be low. These system properties are often either unrelated or at odds with one another. For example, the engineering design goal for B-52 bomber was to deliver a nuclear weapon accurately to targets at great distance. Yet, the higher level objective of keeping the peace by projecting strength during the cold war was accomplished without ever using the system as designed. To design a system when faced with multiple and competing objectives, a decision maker must have some measure of the value of system properties to be able to rationally choose between competing alternatives. The questions of "Whose Value?" and "Which Value?" must be answered.[2]

This paper explores the answers to those two questions in the context of a decision about if, and how to, incorporate an emerging technology, Unmanned Aerial Systems (UAS), into an existing complex engineered system, the electric grid. Specifically this paper explores the value proposition of using UAS to inspect the portions of the grid operated by municipal utilizes. UAS technology has matured in the last decade sufficiently that relatively low cost commercial off-the-shelf (COTS) devices provide many of the capabilities desired for aerial inspection of bridges[3], powerlines[4], and monuments[5]. New developments in autonomous operation and loosening of FAA regulations offer further potential value. There is significant interest from utilities to use UAS to inspect the transmission portion of the grid.

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The Electric Power Research Institute (EPRI) recently hosted a conference in Charlotte, NC specifically focused on bringing together the UAS and electric utility communities. In Europe, where regulations have been more accommodating, UAS inspections of transmission and natural gas infrastructure are already being performed[6]. However, no publically available formal assessment of the benefit of UAS when applied to the distribution side of the energy grid could be found.

Section II provides background on municipal utilities to answer "Whose Value?", Section III explores the value provided by UAS to be considered in program deployment answering "Which Value?", and Section IV covers UAS costs, Section V is a study performed specifically for the city of Fayetteville, and Section VI concludes the paper.

II. Background on Municipal Utilities

A municipal utility is a public entity owned by a municipality that seeks to provide service to all its residents as a not-for-profit. While these entities vary in size and means, it is estimated that 48 million people in the United States are served by various public power groups.

A. Municipal Utility Organization

Municipal utilities are ultimately accountable to the citizens in the area which they serve through the elected officials. Municipal councils vary in how they interact with their utilities. Some councils appoint board members who run the utility while others are more involved in day to day decision making. Smaller utilities partner with others through non-profit power agencies to provide for common needs and to leverage larger size for more favorable purchase power agreements.

In North Carolina there are two such power agencies: the North Carolina Eastern Municipal Power Agency (NCEMPA) and North Carolina Municipal Power Agency Number 1 (NCMPA1). Individual municipalities also have the option to be members of another non-profit organization, ElectriCities of North Carolina, Inc.,[7] which provides various levels of operational support from high level guidance and new technology integration to employing local and linemen managing distribution operations.

B. Municipal Utility Power Generation and Distribution

To provide power to their customers, municipalities must first purchase it or own a portion of a generator. Electricity is then sent from the generator along high voltage transmission lines to substations that step down the voltage for smaller distribution systems. These distribution systems then connect the end users.

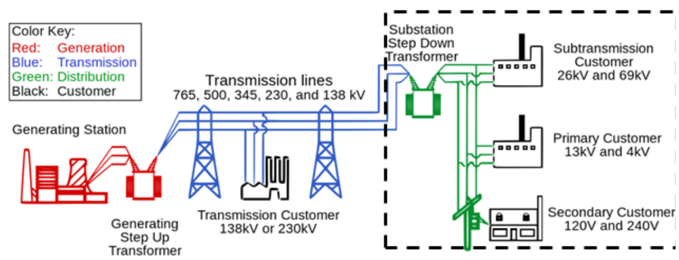

Figure 1. Electric grid example highlighting municipality operated portion [10]

Nationally, municipalities vary widely in the way they acquire power. Some own sufficient generation capacity to allow the sale of excess power. Others have little to no generation capabilities. In eastern North Carolina, NCEMPA represents 32 towns and receives the majority of its electricity from purchase power agreements from private utilities.[8] In western North Carolina, the NCMPA1 owns a portfolio of generation assets including a portion of the Catawba Nuclear Station.[9] Operation of that facility is left to an Investor Owned Utility (IOU). NCMPA1 electricity generation is great enough that excess power can be sold, providing additional revenue to the power agency. In North Carolina municipal utilities are generally responsible for the operation of substations, local distribution systems, and potentially a small portfolio of transmission assets. This study, therefore, focuses on the benefits a UAS program would provide to the portion of the grid from the substations to the customers. Figure 1 identifies this portion with respect to the entire system.

C. Municipal Utility Financing

One additional group of stakeholders in municipal utilities is bondholders. New projects are often financed with bonds and municipalities are obligated to repay these obligations. Interest rates on bonds are influenced by credit ratings which are based on the municipality's ability to meet its financial commitments and it is therefore in the municipality's interest to maintain credit-worthiness. These stakeholders are rarely involved in any operational aspect.

A municipal electric utility is a large system with many different stakeholders. They are overseen by elected officials accountable to the residents of the municipality, are operated by linemen who may be employees of another non-profit, are responsible for maintaining standards in accordance with multiple regulatory agencies, and generate revenue which is used to repay bondholders or contributes to city budgets.

To simplify the following analysis, focus will be primarily on the values of the residents of the municipalities. These stakeholders indirectly provide the highest level of oversight through their elected officials and are also the end users of the system. The values of those who operate the system are also considered since they would be the end users of a UAS program and are the most familiar with how a UAS program could benefit their distribution systems.

III. Quantifying UAS Program Value

The previous section reasoned that the most appropriate values to use when making design decisions which affect properties of a municipal electric grid are those of the residents of that municipality. This section focuses on what these residents value, to what degree it is valued, and how those values can be used to quantify what benefit might come from incorporating a UAS program.

Excluding generation from the scope of this study, an operating assumption of this work is that the primary two system properties of interest to municipality residents are cost and reliability. Other concerns like aesthetics and environmental impact are also important, but less so than cost and reliability. These other concerns are not covered in this work, and are left for future efforts.

To assess the effect a UAS program might have on the properties of the grid, interviews were conducted with employees of four local municipal utilities and a literature survey was conducted. The interviews provided qualitative information about what roles a UAS might fulfill while the literature provided methodologies to quantitatively assess value of those roles.

The following subsections are divided into three categories of properties affected by the implementation of a UAS program. The first section examines the impact a UAS program could have on grid reliability. This begins with a qualitative discussion focused on the specific tasks that were identified as potentially useful. Following that is a quantitative approach to convert increased reliability to a dollar value that decision makers can use to trade against when considering UAS program alternatives. The second section details areas of potential cost savings which could be realized by implementing a UAS program. The third section provides a qualitative analysis of other system performance enhancements like increased safety for linemen and decreased environmental impact.

A. Grid Reliability

Grid reliability is a topic of national importance. A study commissioned by the White House in 2013 concluded that the average annual cost of power outages caused by severe weather is between $18 billion and $33 billion per year. Years with large storms like 2008 have even higher economic costs with outages estimated to be between $40 billion and $75 billion.[10] Estimates of this magnitude reveal a significant economic opportunity if grid reliability can be improved. This section addresses the definition, reporting, and value of reliability followed by a qualitative discussion and quantitative analysis of what improvement a UAS program could potentially bring. Grid reliability for this analysis is defined to be the uninterrupted supply of electric energy at standard frequency and voltages.

1. Qualitative Analysis

Qualitatively the utility interviews and literature review provided several common themes for enhancing grid reliability.

A 2010 study by the Department of Energy (DOE) focused on preparation for hurricane season suggested that utilities operate a distribution system inspection program, perform aerial patrols of transmission lines, have a program to manage encroachment by vegetation, and deploy additional sensors to increase situational awareness.[11]

In biennial reports the American Public Power Association releases the results of a survey that includes both incident rates of customer outages by cause (Fig. 2), and what programs have been undertaken to help prevent outages. In 2015, vegetation management/tree trimming was the most popular program. At number three was routine distribution inspection and maintenance, and number four was to perform thermographic circuit inspections.[12,13]

A 2012 Congressional Research report on Weather-Related Power Outages highlighted the importance of Tree-Trimming Schedules[14]. A 2011 report surveying UAS use in imagery collection for disaster research found that UAS were helpful in providing damage assessment via aerial imagery and were also helpful when performing preventative inspections.[15]

A White House report reviewing the economic benefits of increasing grid resilience to weather outages found that increased visualization and situational awareness was a priority to achieve grid resilience.[10]

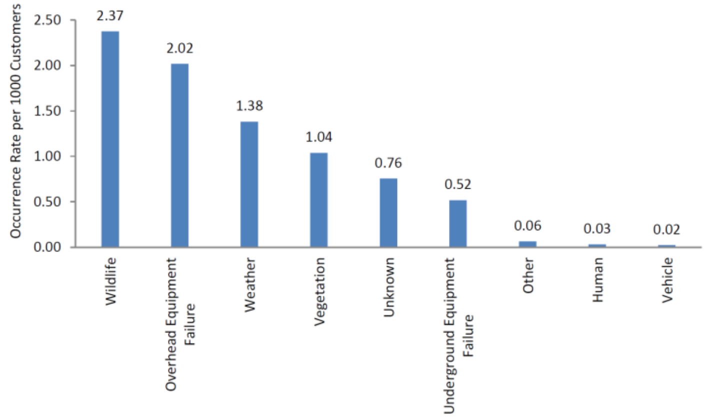

Figure 2. Average customer-weighted occurrence rates per 1000 customers for common causes of sustained outages for APPA members[13]

Utility interviews provided information from the decision makers who are in part responsible for grid reliability. Some uses for UAS overlapped with those found in the literature (e.g., preventative inspections and post disaster damage assessment) but provided extra detail about exactly what a UAS could do. For instance, when looking for vegetation encroachment the UAS pilot should also watch for limbs near lines which appear to be burned away. The high voltage lines will visibly damage plants which approach them. Inspections of the distribution system were repeatedly recommended, but interviews uncovered what capabilities would be helpful and what the UAS would be looking for. A thermal imaging system was reported to be an important method of inspection as compromised components will often overheat prior to failure. Other suggestions for UAS value not found in literature included: finding oil leaks from transformers, herbicide deployment, remote distance measuring to check clearances, visual inspections for discharge coronas, chasing away wildlife, and helping to restore power quickly to priority customers like hospitals during a disaster.

2. Quantitative Analysis

Quantifying and standardizing measures of reliability and their value are difficult because the U.S. electric grid is a large and complex system of interconnected systems operating under a variety of ownership and regulatory environments. The lack of central control can make identifying the current state of the system difficult as reporting methodologies used can be inconsistent. A 2008 study by Lawrence Livermore National Lab (LLNL) found that "differences in utility reporting practices hamper meaningful comparisons of reliability information reported by utilities to different state PUCs and, therefore, may limit the effectiveness of efforts to measure the effectiveness of efforts to improve reliability".[16] Additionally a Congressional Research Study suggested that "inconsistency of data from outage reporting is an issue in quantifying the impacts of storm related and other power outages" and that "no central responsibility exists for distribution systems".[14]

There are three measures of reliability which were found to generally be reported to state Public Utility Commissions (PUCs): System Average Interruption Duration Index (SAIFI), System Average Interruption Duration Index (SAIDI), and the Momentary Average Interruption Frequency Index (MAIFI).[16] According to the IEEE 1366-2003[17] these are defined as:

$$SAIFI = \frac{\sum Total\ \ Customers\ Interrupted}{Total\ Customers\ Served} \tag{1}$$

$$SAIDI = \frac{\sum Customer\ Minutes\ of\ Interruption}{Total\ Customers\ Served} \tag{2}$$

$$MAIFI = \frac{\sum Total\ Customer\ Momentary\ Interruptions}{Total\ \ Customers\ Served} \tag{3}$$

The MAIFI is important because momentary outages are the most frequent kind of outage, but reporting data for MAIFI is sparse and varies wildly. Utility reporting for MAIFI is also inconsistent as seen in the 2015 APPA study which found approximately half of respondents defined momentary as less that one minute with the majority of the remainder defining momentary as less than five minutes.

The statistical influence of larger outages could hide smaller daily trends in the above performance indicators so larger outages are supposed to be reported as Major Event Days (MED). Once an outage reaches a certain threshold it is removed from the statistics defined above and is instead reported as an MED event. The interpretation of what constituted an MED event was found to vary between PUCs by the 2008 study.

After determining what measures of reliability will be used, the next task is to establish the value of reliability. This necessitates a conversion between the above reliability measures to a specific dollar value. A 2009 report from LNLL provides a framework from which to attempt exactly this sort of analysis[18].

In brief, the study assembled a collection of databases containing information from different classes of electricity users (Medium and Large Commercial and Industrial, Small Commercial and Industrial, and Residential) to determine the economic damage done by outages of various durations. These damage estimates are based on reported economic loss or a willingness-to-pay to avoid the outage. The breakdown of costs based on business type, size, day of the week, time of day, and even season provide sufficient detail to allow extensive customization based on utility specific characteristics. For the following analysis only the most general information was used and is presented in Table 1.

Table 1. Estimated Average Electric Customer Interruption Costs US 2013$ Anytime by Duration and Customer Type [23]

Interruption Cost	Interruption Duration					
	Momentary	30 Minutes	1 Hour	4 Hours	8 Hours	16 Hours
Medium and Large C&I (Over 50,000 Annual kWh)						
Cost per Event	$12,952	$15,241	$17,804	$39,458	$84,083	$165,482
Cost per Average kW	$15.9	$18.7	$21.8	$48.4	$103.2	$203.0
Cost per Unserved kWh	$190.7	$37.4	$21.8	$12.1	$12.9	$12.7
Small C&I (Under 50,000 Annual kWh)						
Cost per Event	$412	$520	$647	$1,880	$4,690	$9,055
Cost per Average kW	$187.9	$237.0	$295.0	$857.1	$2,138.1	$4,128.3
Cost per Unserved kWh	$2,254.6	$474.1	$295.0	$214.3	$267.3	$258.0
Residential						
Cost per Event	$3.9	$4.5	$5.1	$9.5	$17.2	$32.4
Cost per Average kW	$2.6	$2.9	$3.3	$6.2	$11.3	$21.2
Cost per Unserved kWh	$30.9	$5.9	$3.3	$1.6	$1.4	$1.3

The number of customers and their type are provided by the utility under analysis and corresponding interruption costs are found from the 2009 LLNL report. Outage information is then provided for two categories: outages that would be reported as major events and those that would not. For MED events the inputs include: frequency of occurrence, average and standard deviation fraction of customers to lose service, and average and standard deviation for return to service. The return to service distribution is modeled as a log-normal distribution as its shape best fits curves found in Fig. 3.

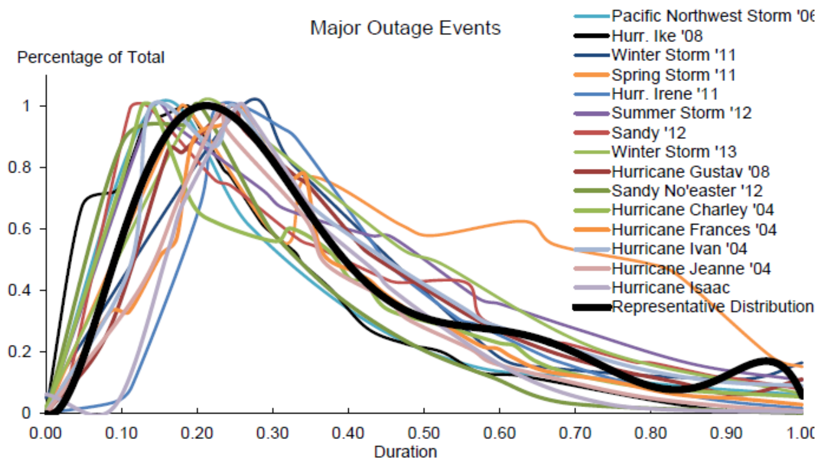

Figure 3. Fraction of Customers Experiencing Outage vs. Duration of Event for Major Outage. [10]

Predicting in advance the impact a UAS program would have on a municipality's grid reliability is a daunting if not impossible task. As seen in the qualitative analysis there are many different roles a UAS could fulfill during preventive maintenance and outage recovery, but predicting the impact those roles would have on reliability indices is not a viable course of action. Instead a Monte Carlo simulation was used to statistically project the economic benefit for a range of improvements to that utilities reliability indices. Figure 4 provides an overview of the process used to calculate the projected value.

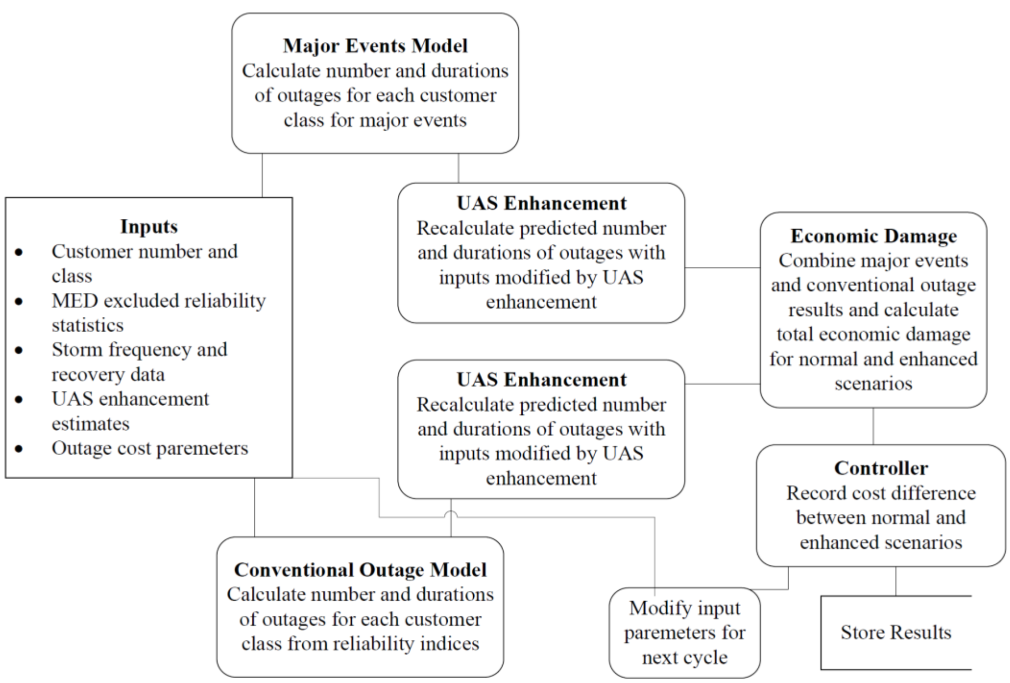

Figure 4. Reliability Model Framework Used in Monte Carlo Simulations

The program has a module for MED events and conventional events. For outages which do not reach a sufficient threshold to qualify as MED event, hereafter referred to as conventional outages, the nominal SAIDI, SAIFI, and

MAIFI (along with a standard deviations to account for index variability) are provided for each category of customer. The number of MED events that occur in each trial is determined by having a user input the number of storms likely to occur that year. This information is then used to determine the probability of a MED event on a given day.

For each MED event the program uses the input distribution to generate the fraction of customers affected by the outage. For each customer experiencing an outage, a return to service time is generated. A similar procedure is used for conventional events. The number of outages affecting each customer is generated from the SAIFI and MAIFI. For momentary outages, a triangular distribution between 0 and 5 minutes is used. For sustained outages the SAIDI and SAIFI are combined to form an outage duration distribution. Generated durations are likewise binned in the appropriate customer category.

Finally an anticipated fractional improvement to MED event outage duration, MED event customer outage fraction, and conventional customer outage fraction attributable to the implementation of a UAS program is input. This final input is based on expert opinion so the program can be run with a set of improvement fractions to determine a range for potential values.

The table of outage lengths and customer categories are then added for both modified and un-modified outage data. Economic impact is calculated using an interpolation of cost data from Table 1. The economic impact for the modified and unmodified results are calculated and compared to calculate the economic loss offset by the UAS program.

B. Cost Savings

Minimizing cost is an objective over which a UAS has some influence. According to the U.S. Energy Information Administration, 25% of electricity cost is due to distribution while the remainder is from generation and transmission.[19]

The two ways in which a UAS program might reduce operational costs are through a reduction in the number of vehicles required to support linemen and a reduction in the number of man-hours used for inspections (either preventative maintenance or during disaster recovery). The difficulty with determining this reduction in costs is that the potential savings are dependent on how the municipality incorporates the UAS into their operations. This cost savings is hypothesized to exist, but a methodology for projecting what this value could be is left to a future study.

Additional cost offset opportunities may exist for a municipality with a UAS program. Once a new system is fielded the engineers and technicians can use the system for tasks which were initially unanticipated. Discussions with utility employees during interviews revealed two such potential opportunities.

The first task involves counting attachments for joint use poles. Utility poles are often used by telecommunications companies to distribute cable. Upkeep for joint use of poles is split between the parties involved. In order to fairly split upkeep costs the number of poles with attachments from other entities must be inventoried. This is a task which may be suited to a UAS that could travel from pole to pole across rough terrain more quickly than possible on the ground. This could offset the cost of sending linemen to count or contracting the job to a third party.

A second potential opportunity exists with performing GIS mapping. Essentially the UAS would travel from pole to pole recording the identification number and its GPS coordinates. The bulk of potential savings would occur with the initial mapping of the system, but periodic updates could provide occasional additional opportunities.

These two ideas were generated during the brief interviews with utilities. Once utility employees begin to integrate UAS into their day-to-day tasks it is entirely possible that additional opportunities will be identified.

C. Additional Benefits

There are additional advantages to a UAS program which were discovered during interviews and during the literature review. These fell into two categories: enhanced safety and reduced environmental impact.

Enhanced safety for utility employees is an important ancillary benefit. Enhanced safety is difficult to quantify because safety is the absence of employee injury and it is difficult to relate that absence to a specific cause.

For example, using a UAS to perform inspections of overhead equipment would reduce the need for linemen to either use bucket trucks or to climb the poles. Reducing the frequency with which linemen must work at heights should lessen the risk of fall-related injuries. This applies more strongly to transmission lines or distribution equipment located in inaccessible areas which must be inspected by helicopter or by specially trained climbers. San Diego Gas and Electric publicized the use of UAS to deliver tools to employees already working at heights and to string safety nets prior to ascent by a lineman.

Likewise UAS would be useful for right of way management in remote and rugged terrain. North Carolina has swampy terrain in the east, and mountains in the west, which both pose hazards to inspectors. UAS could perform these inspections remotely, removing the need for inspectors to walk these lines.

UAS also offer the potential to minimize the environmental impact associated with the electric grid. One opportunity is to displace bucket truck and helicopter fuel consumption and emissions by performing inspections in their stead. Another opportunity to minimize environmental impact arises when performing inspections of environmentally sensitive areas. Transmission and distribution lines occasionally pass through the habitats of endangered species. Inspections of these lines with a UAS would be less intrusive than inspections performed by truck or by helicopter.

Although the benefits in this section were only qualitatively discussed there is value in enhancing workplace safety and protecting the environment even if that value is in enhancing the public image of the operating utility.

IV. Costs and Other Considerations

This section examines the costs associated with implementing a UAS program for a municipal utility. Costs and capabilities of UAS and associate sensors have changed rapidly. So too have FAA and state regulations governing the use of UAS for commercial applications. As the field is still nascent, the pace of change is expected to continue or even accelerate. For this reason detailed cost estimates and UAS capability analyses are eschewed as they would be quickly become dated. Instead this section provides a guide for what types of costs are likely to be incurred when establishing and maintaining a UAS program. Municipal utilities using this analysis will have to use the current costs and capabilities for each of the areas discussed.

A. System Selection and Purchase

The two largest initial equipment investments required are the UAS and sensors. High end off-the-shelf UAS currently provide many of the features desired for utility inspections and come equipped with visual sensors sufficient to fulfill most needs.

Currently the industry standard for off-the-shelf UAS is the DJI Phantom 4[20], so it will be used as an example. Features of the Phantom 4 include: waypoint and intelligent navigation with GPS, obstacle avoidance, altitude control, a visual positioning system, return to home capability, a 3-axis gimbal, and comes with a camera capable of 4k resolution at 30 fps or HD 1080p at 120 fps. The cost for one UAS with controller and a single battery pack costs $1,399. Extra batteries cost $80.

One of the most important limitations for UAS use is the battery life. The Phantom has one of the best battery life durations of any off-the-shelf system at 22-28 minutes depending on power use in flight. The maximum flight speed of the Phantom is 44 miles per hour, giving a maximum best case range of 8 miles if returning to the point of origin. In practice it is desirable to maintain an energy reserve to ensure a mid-flight failure is avoided. For near-continuous operation it would be necessary to cycle between multiple batteries while charging those not in use.

Additional limitations include the range of the stock controller and Federal Aviation Administration (FAA) requirements to operate with line of sight of the pilot. The first can likely be resolved with system modifications, but the change to the latter is dependent on federal regulators.

The stock camera on the Phantom is likely sufficient for any visual inspections, but thermal imaging was frequently mentioned by utilities as a feature that would help identify equipment near failure. A thermal imaging camera with sufficient resolution will likely cost more than the UAS. Two examples are the FLIR E60 camera capable of 320x240 resolutions which can be purchased for approximately $7,000 and the FLIR E4 with a resolution of 80x60 for $925.

B. Auxiliary Costs

In addition to equipment costs there are additional costs which will be incurred if a municipality develops a UAS program. These are costs are primarily associated with labor necessary to set up and maintain a UAS program, but also include additional hardware and regulatory tasks.

Pilot training is likely to be one of the most time intensive efforts required to set up a UAS program. Control technology in higher end COTS systems are advanced enough that a relatively small amount of practice is sufficient for basic videography and crash prevention. However, navigating dense foliage, negotiating optimal imagery range, and remaining outside a live line clearance is more challenging and will require time and training. Larger municipalities may be able to designate an individual or small group to perform all needed inspections, but smaller municipalities may have to add flight training as a collateral lineman duty.

Current FAA regulations also require that pilots hold and maintain an official pilot certification. The FAA has new regulations publically available for review that do not have this requirement, but at the present time certification is required. The least expensive acceptable certification available is the Sports Pilot Certification (SPC). The SPC requires 20 hours of flight time including 15 hours with a qualified instruction. The cost to meet necessary criteria varies but average estimates range between three and five thousand dollars.

Maintenance for the systems used will be an ongoing cost. Motors and batteries will wear out and require replacement. A rough measure of annual maintenance costs can be determined from after-purchase care plans offered. DJI offers a 1 year service[21] plan which covers part failure and most potential damage scenarios for $299. This service plan is only valid for one year and cannot be renewed, but does provide a starting point for estimating annual maintenance cost per system purchased.

There are several other potential costs which should be also be considered. There is the potential that liability insurance companies would require an additional premium to cover the risk of equipment damage due to a UAS. Currently an exemption from certain FAA regulations is required in order to operate a UAS for non-recreational use. The cost of filing and the time necessary to prepare documentation should be considered. Municipalities should also consider the cost associated with educating the public about the implementation of the UAS program. There may be privacy concerns that need to be allayed as a UAS could be operating over private property with a camera.

At present COTS UAS provide most of the desired features a municipal utility might desire. Custom software for additional automation or physical modifications to the system will involve additional cost, but the price of the example UAS is equivalent to or less than the cost of the thermal imaging sensor to potentially be mounted on it. As a rough order of magnitude estimate a conservative all-in price for a program excluding the salary of the pilot would be $10,000 including a thermal imaging sensor. Regulatory compliance, including an SPC, increases that cost as does inclusion of the salary of the operator.

V. Case Study for the City of Fayetteville, NC

A case study was performed with data for the municipal electric utility associated with the city of Fayetteville, NC. As one of the larger municipalities in the state it provides an example of the magnitude of value expected to arise from UAS program implementation. The case study includes a sensitivity analysis to illustrate which of the selected parameters most impacts the projected economic benefit.

Customer distribution information was taken from the City of Fayetteville's Public Works Commission's website.[22] There the numbers of industrial, residential, and non-residential customers were listed. These were assumed to have average annual energy consumption listed in the LNLL outage cost study.[23] In order to match the reported energy sales for the city it was necessary to increase the number of "Medium and Large Commercial and Industrial" customers and remove them from the non-residential category. The final numbers used were: 150 Medium and Large Commercial and industrial, 8702 Small Commercial and Industrial, and 70900 Residential customers.

The SAIDI (146 minutes) and SAIFI (1.31) used are the reported national averages found in an analysis of US outage information.[16] MED events were not included in these indices since disasters would be handled separately. A MAIFI value of two was used to include the effects of more frequent momentary outages.

Several parameters of importance have no reported estimates from which to base a study. For these parameters a range of inputs were used to provide insight on what impact different values would have on the final outcome. For the disaster model these parameters and their values include:

- Average number of MED events per year (1,3, and 5)
- Fraction of residents experiencing a MED event outage (0.2, 0.5, and 0.8)
- Average time to restore power to customers (12, 24, and 36 hours)
- UAS reduction in fraction of initial outages and the fractional reduction in return to service time (0.001, 0.005, and 0.1 for both).
- For conventional outages, the fractional reduction in SAIFI and MAIFI due to UAS was 0.001, 0.01, and 0.05.

A sensitivity study was created to explore the impact that changes to the disaster model parameters would have on the value of using a UAS. The trials which included MED events were observed to have discrete levels of economic damage dependent on the number of events that occurred. This required a large number of trials to average out variations. 1000 trials of each combination of inputs was determined to be adequate by inspecting variation in resulting parameters. The study was run on a 3.2 GHz, i5 quad core processor and took approximately six hours for the MED outage sensitivity study, and half an hour for the conventional outages.

Results for select variables from the sensitivity analysis for conventional outages are shown in Fig.4 to Fig.6. Results for MED event outages are shown in Fig. 7 and Fig. 8. In the conventional outage figures the case number represents the results of a set with all but the variable of interest held constant. In the conventional outage data it can be observed that changing the SAIFI does not strongly impact the value provided by a UAS. An increase in SAIDI on the other hand indicates does correlate with increased UAS value at what appears to be a non-linear rate. The fraction of outages prevented by the UAS has an expectedly strong effect on system value. The lowest value for any case was $51,043 and was found with for a SAIFI of 1, a SAIDI of 100 minutes, and an outage reduction fraction of 0.001.

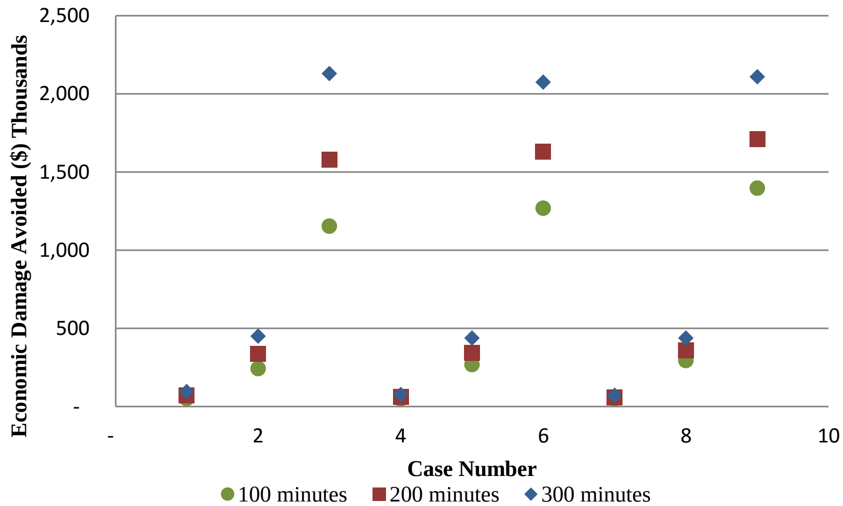

Figure 4. Conventional Outage Sensitivity Study: SAIDI

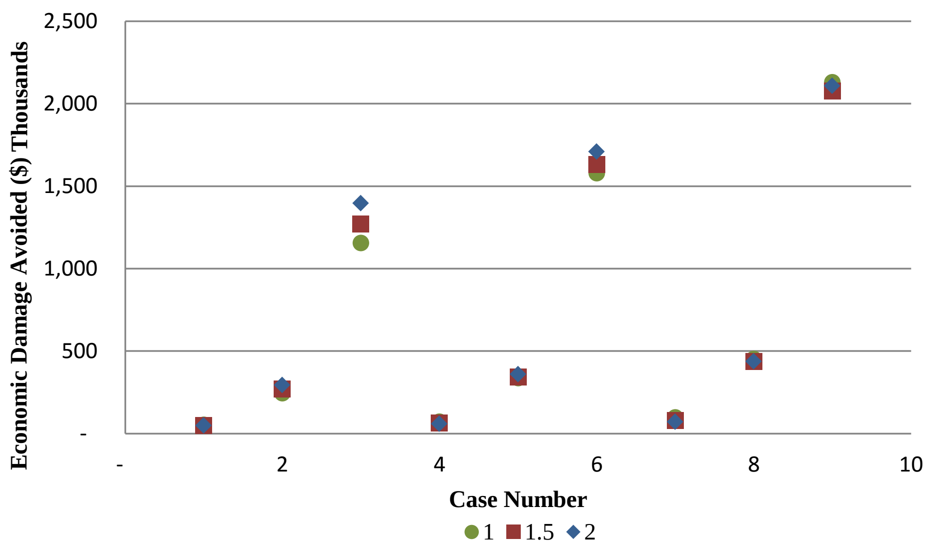

Figure 5. Conventional Outage Sensitivity Study: SAIFI

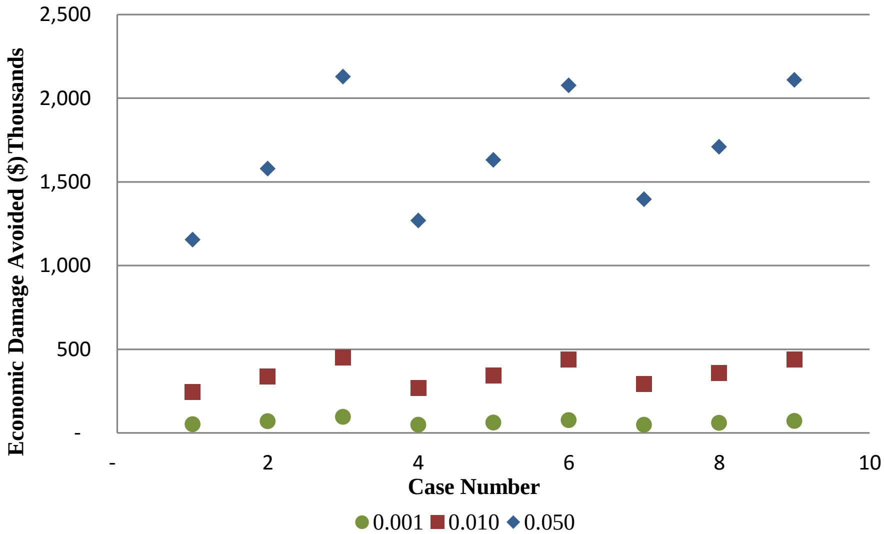

Figure 6. Conventional Outage Sensitivity Study: UAS Improvement Fraction

The MED event sensitivity analysis had 81 combinations for each point of interest, so the approach used was different. For these figures box plots were created to help visualize range of data for each variable of interest. For MED event outages, reducing the number of outages appears to be significantly more impactful on UAS value than reducing the duration of outages. It is likely that this effect is due to cost of an outage when measure per un-served kWh. Since a great deal of lost productivity is reported at the beginning of an outage, the cost of the first minutes and hours is higher than subsequent periods of time. Reducing the duration of an outage reduces the minutes after the cost per un-served kWh has fallen to its lowest point and therefore does not have as much value. This indicates that effort spent on practices like vegetation management and preventative maintenance - which reduce the number of MED event outages – may provide more value than effort spent accelerating recovery from those events. The lowest value for any case was $93,185 and was found with only an average of one MED event per year, average outage duration of 720 minutes, a fraction of customers who lose power of 0.2, and outage duration reduction and fraction of customers affected reduction due to UAS of 0.001 each.

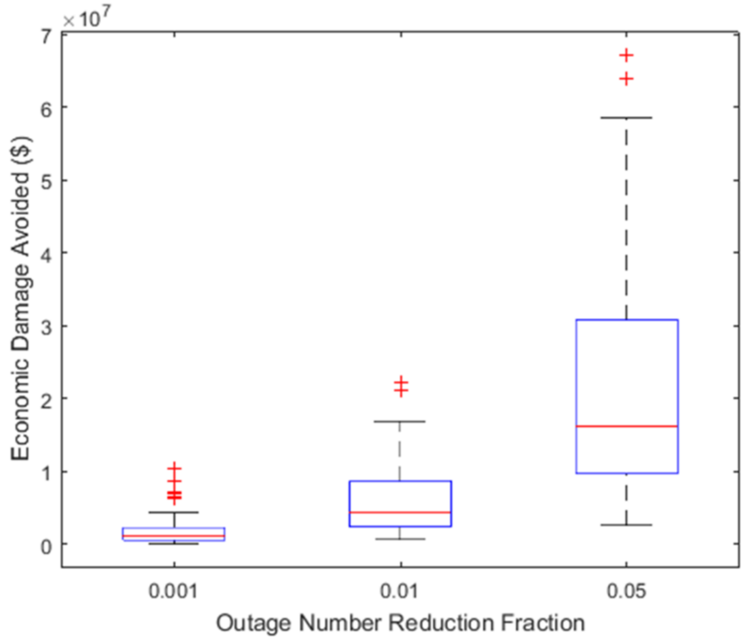

Figure 7. Major Outage Sensitivity Study: Reducing Outages with UAS

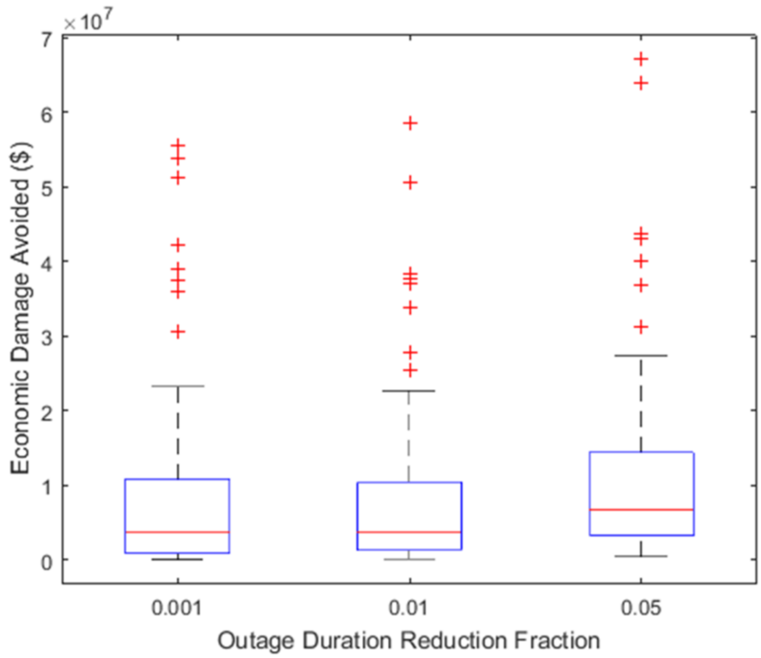

Figure 8. Major Outage Sensitivity Study: Reducing Outage Duration with UAS

These two minimum numbers combine to an expected annual avoidance of $144,228 in economic damage by the implementation of a UAS program. An additional test was run which used the best guess estimates of 1 MED event per year, 0.4 of the customer base affected by the event, an average return to service time of 12 hours, a 0.001 fractional improvement to MED outage duration, and a 0.001 fractional improvement to number of customers affected by a conventional or MED event. This best guess projected annual avoided economic loss of $282,813.

VI. Conclusion

This study was performed with a desire to determine if the value provided by implementing a UAS program at a municipal utility was sufficient to justify the costs. To provide guidance a methodology was developed to quantitatively project what the avoided economic loss would be worth and what the qualitative uses for a UAS might be to achieve those improvements.

A qualitative analysis of other potential benefits of a UAS program including avoided costs, enhanced safety, and a reduced environmental impact was performed. The costs of a UAS program including hardware, training, and regulatory expenses were estimated to be in the range of $10,000.

This methodology was then used to study what the economic impact a UAS program would have if incorporated into a municipality with the characteristics of the city of Fayetteville, NC. The sensitivity analysis showed saving over a wide variety of inputs with a minimum avoided economic loss of $144,228. A comparison of the expected cost of a UAS program even adding a full time position for an operator with a salary of $75,000 per year and neglecting any cost savings for efficiency increases benefit of a the program far outweighs the cost.

Future studies in this area could include extending this tool to fully integrate with Interruption Cost Estimator developed by LLNL, developing a methodology for projecting cost savings, or deploying a UAS program at a utility to see how the program develops and narrow the ranges for improvements to reliability indices.

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