Exhibit A - Statement of Work

This Research Statement of Work is made and entered into effective the 1st day of January, 2018 by Eversource Energy Service Company, for itself and as agent for its affiliates, having principal offices at 107 Selden Street, Berlin, CT 06037 ("Company") and UNIVERSITY OF CONNECTICUT ("University") pursuant to the terms of the SECOND AMENDED AND RESTATED SPONSOR RESEARCH AND SERVICES AGREEMENT between Company and University dated May 1st, 2015 (the "Sponsor Research Agreement").

Both Parties agree to participate in Research to be conducted in accordance with the terms and conditions of the Sponsor Research Agreement and this Research Statement of Work, provided however, that in the event of a conflict between the terms and conditions of the Sponsor Research Agreement and this Research Statement of Work, the terms of the Sponsor Research Agreement shall be controlling.

1. **Title of Research/Project:** Evaluation of Grid Resilience Activities with a Total System Performance Assessment Model
2. **Research/Project Description:**
   - **A. Problem Statement**
   - **B. Proposal Objectives**
   - **C. Methodology**
   - **D. Data requirements**
   - **E. Project Deliverables**
   - **F. Project Timetable and Milestones – 1/1/18 to 12/31/19**

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Date: 12/7/17

Evaluation of Grid Resilience Activities with a Total System Performance Assessment Model

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Collaborator: D. Wanik

1. Project significance/impact

The challenge of optimal power grid asset management based on cost-benefit optimization prior to, during, and shortly after extreme weather and security events is a critical one to solve for a public utility. Addressing this challenge delivers an optimally resilient power grid subject to both business and engineering constraints such as limited availability of capital, utility crews, and equipment. In this project, a total system/performance assessment model is used to integrate key parameters and heterogeneous data from multiple different modules to effectively assess the system-level resiliency of the power grid system and provide recommendations. Independent modules have been and are being developed to formulate dynamic dependencies of each component in the complex power grid system, allowing an optimal solution that takes into account power demand, power supply, grid structure, climate, population growth, business value and economic impact, and soil behavior.

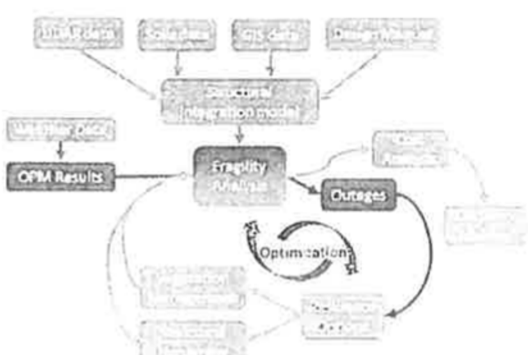

Figure 1. System Performance Assessment Model

This project identifies the contribution of resilience interventions (e.g., tree trimming, installation of stronger poles, and distribution system design improvements) to the system-level power grid resiliency (Fig. 1). A system-level resiliency assessment model will integrate deterministic and empirical fragility functions as well as heuristic and expert judgments and decisions. The effects of resilience interventions – stemming from different disciplines, such as tree trimming, pole and wire strengthening, improvement of distribution system design, installation of automation devices – to the entire system are quantified with meaningful performance-based metrics.

2. Progress to date and Proposed Activities

2.1 Structural Resilience Analysis and Fragility Functions (Task 1)

This research task performs structural resilience analysis. Finite element models are built for the pole-wire structural model using the commercially available software ANSYS (Fig. 2). Monte Carlo simulations are carried out to run the load cases with 10,000 Monte Carlo runs executed for each load case using ASCE07-10 random wind parameters. Limit state functions are defined for weight of falling branches. Figure 3 shows the finite element model for the pole-wire system under wind and falling tree branch loads. The two load cases studied are: L1: direct wind load, and L2: wind induced branch/tree falling load (@ one span center). To account for variability in the materials we considered pole strength as a normally distributed random variable with mean strength of 8000 psi and coefficient of variation (CV) of 0.15. The span center falling tree/branch force was considered normal with CV=0.1. The criterion for pole break was that M > Mr (rupture moment), and for conductor break was that the force F > Fy.

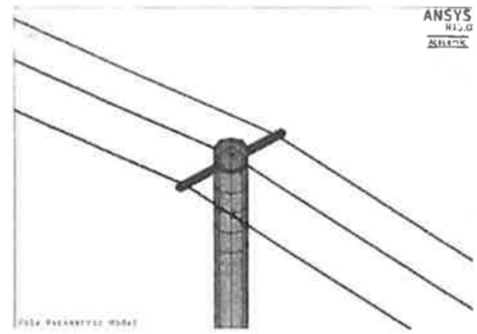

Figure 2. Typical finite element model for pole analysis

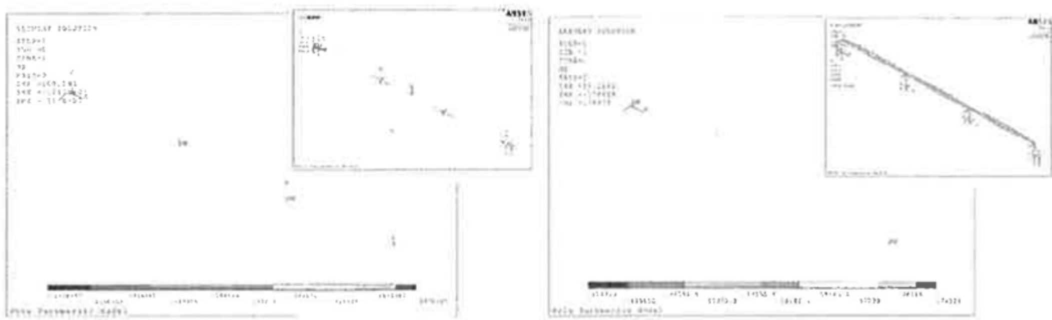

Figure 3. Finite element model for pole-wire system under wind load and falling branch load

Fragility curves for poles under each load cases were generated. Considering the possible deterioration of the pole-wire system, a pole strength degradation model was also introduced. Fragility curves for class 2 and class 3 pole were obtained for new poles and poles that have experienced deteriorations for 30 years, 60 years or 90 years. The fragility curves for the two failure modes are shown in Figure 4.

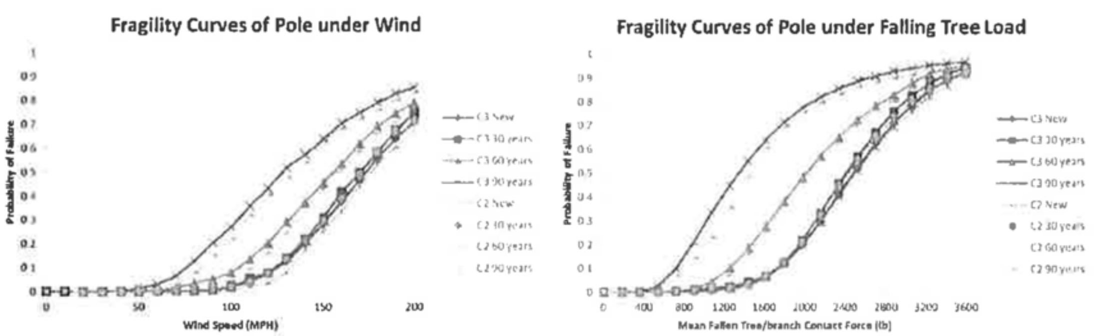

Figure 4. Fragility curves for aged poles under different wind load and falling tree branch load

In the new phase of the project, fragility analysis will be updated to include more realistic failure modes of the pole-wire structures. In the current pole-wire structure model, the bottom end of the pole is fixed. In the new phase of the project simple soil conditions will be included in the model.

Typical soil conditions in the state of Connecticut will be used and fragility curves for different soil conditions will be updated. Meanwhile, a new deterioration model will also be updated using the data in the northeastern region to better reflect the deterioration rate of pole structures in Connecticut. A more comprehensive soil analysis covering the entire state and accounting for varying and spatially distributed soil conditions is proposed in a supplement proposal.

2.2 GoldSim Model and Statistical Analysis of Historical Data (Task 2)

This research task performed statistical analysis of historical data to correlate weather related parameters, such as gust wind speed, temperature, precipitation, etc., with outages. Variable factors, such as wind gust parameters, number of outages, etc. are computed or obtained either from the records for Hurricane Sandy and Outage Prediction Model (OPM) data. Figure 5a and 5b show the preliminary GoldSim model. In this simple model, the probability of power outage is based upon a function of precipitation and whether the day is on the first ½ or second ½ of the year.

Physics-based and Data-Driven Fragility Curves: Data clustering and statistical analysis will be performed for the design parameters as well as the failure modes of the pole-wire systems. Based on correlation and regression analysis of weather data (wind speed, precipitation data, etc.) and outage data for different regions in Connecticut, the fragility curves will be updated to account for the fact that some data indicate weak correlations between the wind speed and outages at low wind speeds. Therefore, bi-linear fragility curves will be employed in the model with outages assumed to be independent of wind at low speeds and linearly dependent for the high wind speed range. Detailed conditional probability analysis will be performed for different geographic locations with identified key parameters. With regression analysis and learning algorithms the fragility curves will be updated to include the information from other parameters, such as tree trimming levels, etc. from vegetation management efforts. Therefore, the updated "fragility" curves will be physics-based and data-driven relationships.

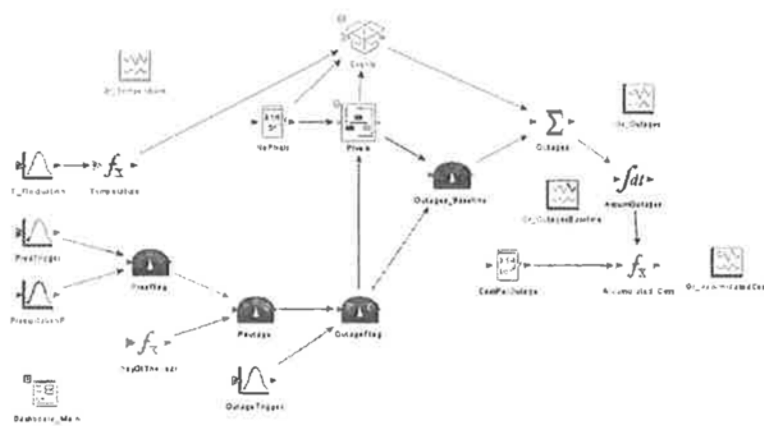

Figure 5a. An early version of the GoldSim Model

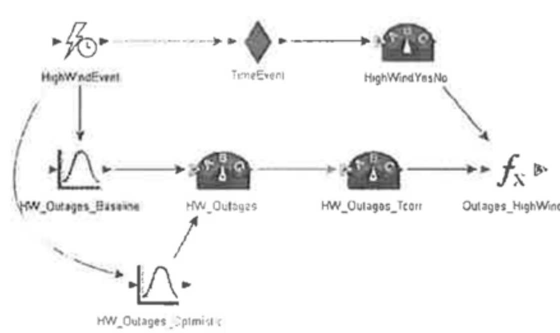

Figure 5b. High-wind event Model

Influence of Weather on Resilience: Many electric distribution utilities and regulators have difficulty discerning whether improvements in reported annual reliability metrics are due to recently made resilience-related investments (e.g., tree trimming, structural and electrical hardening), or to variations in annual weather severity, or to a combination of the above. This is reflected in how reliability metrics (i.e., CAIDI, SAIDI, and SAIFI) are tracked by utilities. Per industry guidelines, storm events such as small thunderstorms that affect power to less than 5% of the customer meter base count towards the reliability metrics, whereas events that affect greater than 5% of customers are allowed to be excluded. Hence, a year with many small thunderstorms can knock the reliability metrics out of balance, even though a utility may be investing hundreds of millions of dollars in reliability upgrades, potentially distorting their perceived value.

We propose a quantitative, data-driven approach that leverages National Weather Service (NWS) products to show the effect of weather on annual reliability metrics. Specifically, we propose to use the **U**n**R**estricted **M**esoscale **A**nalysis (URMA) – an hourly, historical, "actual", 2.5 km gridded weather data set that is a combination of numerical weather prediction (NWP) outputs coupled with observations. The data set is considered the gold standard by NWS meteorologists, and includes such variables as temperature, dew point, wind at 10m height, wind gust, accumulated precipitation and more. We will conduct a preliminary comparison with the current dataset from the OPM framework with the datasets from URMA. Trial tests will also be performed to evaluate the correlation of the weather data with outages based on the two sets of data. Since the two datasets are based on different grid size (OPM is based on 2km gridded data set and URMA is based on 2.5 km gridded data set), different interpolation methods and algorithms will be evaluated to identify the differences. If applicable, the URMA datasets will be used to generate the historical weather data that OPM does not have.

2.3 System-level performance assessment and cost-benefit analysis (Task3)

Sensitivity analysis is being performed to evaluate the effects of different fragility curves, various vegetation conditions, and the variable weather parameters from different hurricane events, etc. Integrating cost-benefit analysis into the model, effects of competing alternatives can be explored to select approaches that may minimize detrimental effects on communities. Hardening priorities will be set up to facilitate the decision making for managing operational risks in power systems. Some preliminary, proof-of-concept results follow.

We assumed that 200 Sandy events occurred with the same wind speed input. Using non-aged fragility curve for Class 3 Pole (with wind load only) the mean number of outages predicted is 15,744 (Fig. 6), when the actual outages observed was 15,213. Assuming that a deteriorated 10-yr and 20-yr interpolated fragility was applicable across the entire Eversource network the mean number of outages predicted is 26,600 and 37,400, respectively. These results show how convenient it is to capture the effect of various processes on the occurrence of outages and conduct "what if" analyses for a variety of possible interventions within the GoldSim performance assessment model.

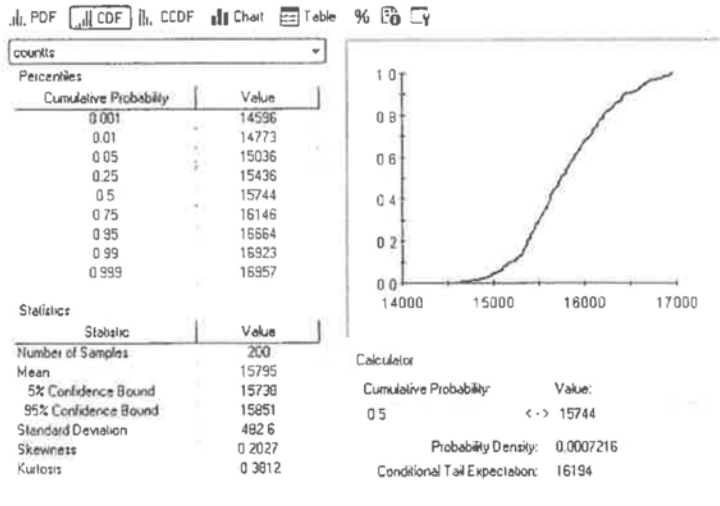

Figure 6. CDF of outages across the 2,851 2-km grid cells in Eversource CT service territory with a new Class 3 Pole.

Optimization: With multiple failure modes included (pole/wire failure induced break circuit, tree branch induced short circuit) and multiple resilience options (structural hardening, vegetation management) considered for outages, optimization of using a finite budget to reduce overall outages could be performed. The available budget could be used either improve the fragility curve by replacing the pole-wires or strengthen them or change vegetation levels. For different regions in CT (east, west, south, and central), the relationship between the weather, infrastructure and soil and vegetation conditions could be different and the optimization strategies could be different, as well.

Economic Value: We will build on the real option methodology of economic value of resiliency treatments in the reduction of SAIDI, CAIDI, and SAIFI across Eversource circuits developed for the 2017 Eversource Energy Center resiliency project (Fig. 7).

Table 1: Estimated Effects of Resiliency Treatments on Performance Measures 2014-2017. The coefficients represent the effect of Eversource's SMT and ETT trimming, Electrical, and Structural Hardening over the previous year on SAIDI, SAIFI, and CAIDI reliability metrics in the current year. Standard errors are reported in the parentheses. Significance at the 10% level is indicated by *, 5% level by **, and 1% level by ***

	SAIDI (1)	SAIFI (2)	CAIDI (3)
Intercept	127.916 *** (5.3499)	0.8575 *** (0.0265)	144.709 *** (4.3299)
ETT_{t-1}	-24.382 *** (6.7665)	0.0012 (0.0335)	-22.994 *** (5.4765)
SMT_{t-1}	-32.939 *** (6.0010)	-0.0647 ** (0.0297)	-23.183 *** (4.8569)
$STRUCTURE_{t-1}$	-30.330 (40.3974)	0.0841 (0.1998)	-25.221 (32.6955)
$ELECTRICAL_{t-1}$	79.8066 (51.7058)	0.4853 * (0.2557)	-1.8275 (41.8479)

Figure 9: Estimates of Treatment Effect on SAIDI/CAIDI/SAIFI

Any corporate investment today, such as an investment in resilience for circuits (or exposure zones) of the CT power grid, generates a possibility of substantial benefits or, equivalently, the prevention of substantial losses in the future. Real options analysis, implemented using the Decision Tree method in the 2017 resiliency project, or using the Black-Scholes financial option model, provides a more accurate way to quantify these uncertain benefits than the standard discounted cash flow capital budgeting model (Luehrman, 1998). We propose the following extensions to improve capital budgeting for grid resiliency at Eversource using the real options framework.

Incorporation of economic value into GoldSim systems model: The systems model takes into account weather, vegetation, soil, and infrastructure fragility conditions to produce forecasted performance measures (SAIDI, SAIFI) as a function of resiliency treatments.

Improvement of treatment impact estimation: The simple comparison of weather-driven outages before and after resiliency treatment may produce a biased estimate of resiliency benefits if zones receiving treatment are not selected at random. For example, if zones that experience more weather-driven outages in the past were ones that received resiliency treatments, the resiliency value estimate would have a selection bias that can be corrected using the Heckman (1979) selection model. Furthermore, additional data on the extent of prior treatments, if available, would allow us to take the scale of treatment into account, improving on the current yes/no treatment model. Finally, the incorporation of the broad array of characteristics included in GoldSim into the predicted effect on SAIDI/SAIFI will improve accuracy.

3. References

- American Society of Civil Engineers (ASCE), Reliability-Based Design of Utility Pole Structures (No. 111), 2006.
- Black, F., and M. Scholes, "The pricing of options and corporate liabilities." The Journal of Political Economy, 81(3): 637-654, 1973.
- Heckman, J., "Sample Selection Bias as a Specification Error." Econometrica, 47(1): 153-161, 1979.
- Luehrman, T., "Investment opportunities as real options: Getting started on the numbers." Harvard Business Review (July-August 1998).
- Shafieezadeh, A., U. P. Onyewuchi, M. M. Begovic and R. DesRoches, "Age-Dependent Fragility Models of Utility Wood Poles in Power Distribution Networks Against Extreme Wind Hazards," in IEEE Transactions on Power Delivery, 29(1): 131-139, doi: 10.1109/TPWRD.2013.2281265, 2014.

4. Targeted budget

The budget of this proposed continuation project is an approved contract agreement for the total amount of ***$292,000*** for a period spanning from January 1, 2018, through Dec 31, 2019. However, as stated in the original proposal this amount did not cover the economic impact estimation work. Furthermore, based on interactions with Eversource managers, Sam Woolard and Diego Castillo, we were asked to incorporate a soil component in our work. We have included most of the economic impact estimation work in this proposal. However, additional funds are requested to cover the remaining economic ranking and soils work as described in the supplement proposal.

5. Inputs required for the project

a. SAIDI/SAIFI/CAIDI and resiliency treatments by circuit through 2017 for direct resiliency effects outside of systems model.

b. Zone definitions if we want a zone-based rather than circuit-based analysis.
c. From the National Weather Service, the UnRestricted Mesoscale Analysis (URMA) data set. This is 2.5 km, gridded, "actual" weather data.
d. The annual TDRP report filed by Eversource Energy-CT to the Public Utilities Regulatory Authority (PURA).
    1) This will include aggregated measures of tree trimming, maintenance activities, and levels of investment.
    2) If available, we will also leverage the raw tree trimming or resilience files to see if areas with more resilience activity have improved reliability compared to previous years.
e. Outage management system records, or equivalent, to be able to analyze the customer impacts and reliability metrics across individual events (i.e., what was the SAIDI during Hurricane Sandy?)

6. Project Deliverables and Timeline

Date (2018-2019)	Activity Reports	Deliverables	Related Tasks
July 2018	Economic effects I	Effect of ETT/SMT/hardening on SAIDI/SAIFI/CAIDI	3
Sept. 2018	Fragility curve updating	Report and data on updated fragility curves	1
Sept. 2018	Economic effects II	Selection-bias adjusted coefficients on SAIDI/SAIFI/CAIDI using the Heckman (1979) approach	3
Dec. 2018	• Comparison of OPM data and URMA data • Influence of weather on resilience	Report	2
Dec. 2018	Optimization for resilience options in Goldsim	Report and algorithm	3
Dec. 2018	Incorporation of economic value in Goldsim	Report on economic value model for arbitrary circuit	3
Mar. 2019	Physics-based and data driven fragility curves	Report and algorithm	2
June 2019	Improvement of treatment impact estimation	Report and algorithm	3
Dec. 2019	Suggested resilience options	Report	3