Grid Resilience Assessment Using A Total System Model Considering Pole Aging Effects

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INTRODUCTION

Storm-related damage to power infrastructure every year leads to widespread power outages, millions of upset customers, thousands of additional man-hours, and enormous economic losses and societal impacts. Better prediction of forthcoming damages from future extreme storms is of paramount interest. With projected impacts of various extreme storm scenarios and reliable predictions of damages and root causes, decision makers could take preemptive measures to prioritize the resilience enhancement strategies by, for instance, strengthening physical power infrastructure or reducing the potential risks of impacts from the ambient environment such as reducing potential damages of fallen trees or branches via trimming trees near the power infrastructure.

THE TOTAL SYSTEM MODEL

A total system model was created to integrate environmental parameters, physical power infrastructures, vegetation management parameters, etc. to predict power outages under extreme weather events. Fragility curves, giving the probability of flexural pole failure at various wind speed (Figure 2), were generated to link the number of power outages with gust wind speeds through physics-based modeling of pole-wire structural system. In the model, the number of power outages within each 2-x-2-km simulated grid cells throughout the state (Figure 3) were summed based on the fragility curve and the associated environmental parameters. Various intervention scenarios, such as replacing the old poles and tree trimming using either SMT or ETT, were incorporated into the basic model (shown in Figure 2) for optimization of possible economic solutions..

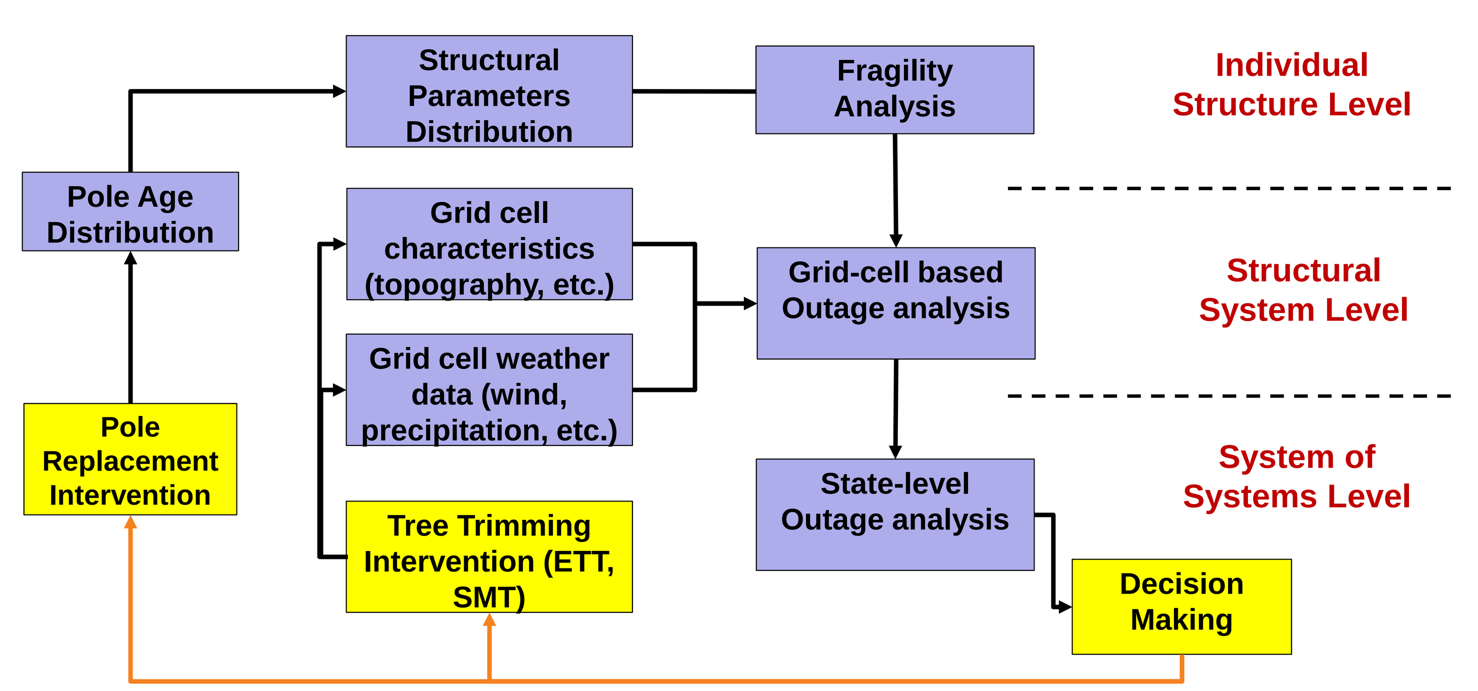


Figure 1: Schematic Flow Chart of Proposed Model Concept

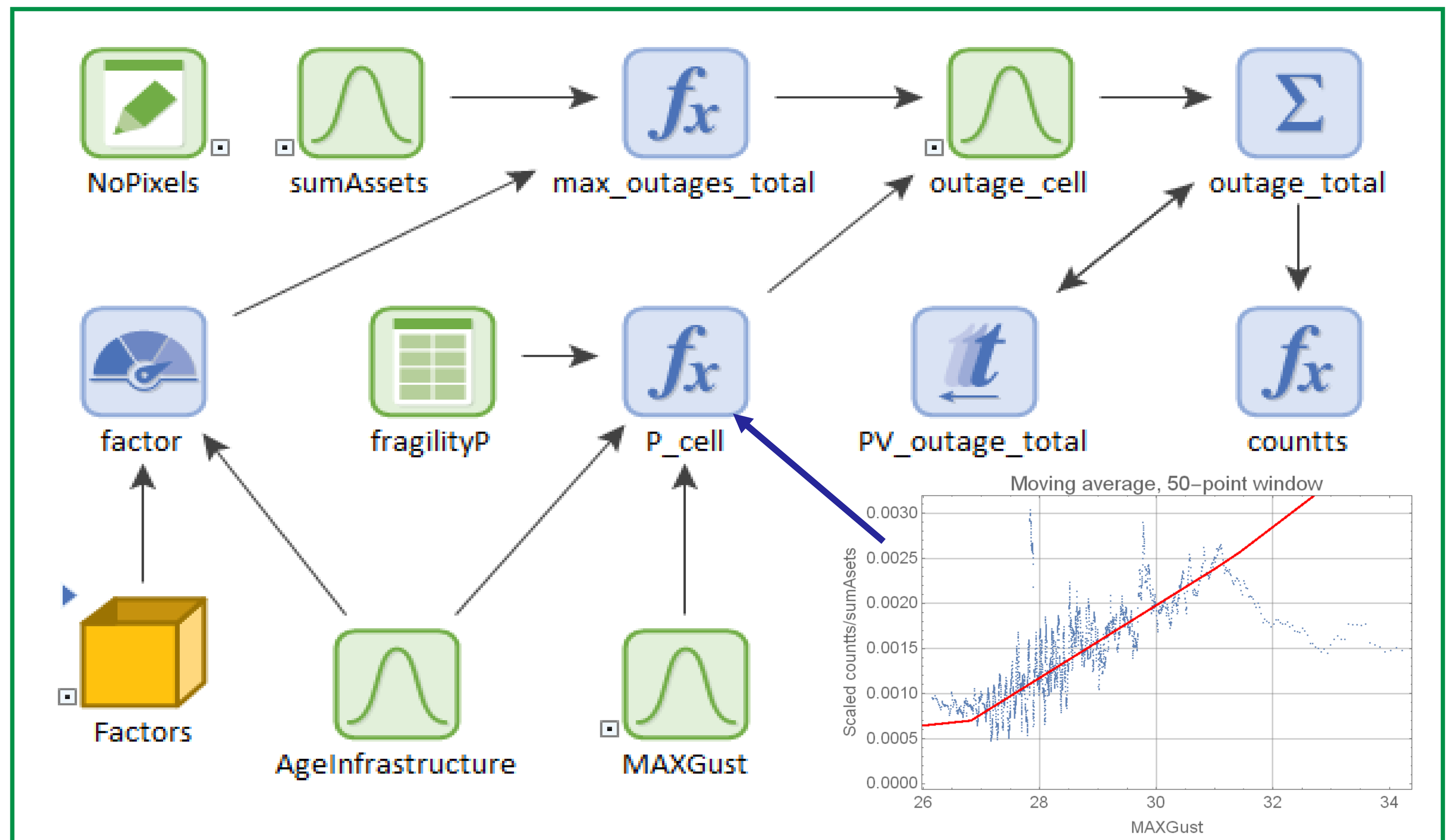


Figure 2: Total System GoldSim Model Setup with Fragility Analysis (Bottom Right)

INTERVENTION ANALYSIS

Two main interventions are considered: **pole replacement** and **tree trimming**. Figure 3 shows the projected impacts of pole replacements over time under a hurricane Sandy scenario.

Assumptions: 1) Pole replacements assumed to occur chronologically, with oldest poles being replaced first.
2) Different fragility curves were used for different age distributions through regression of simulation data.
3) All outages are due to structural failure.

Results and Discussions:
1) Pole replacements will reduce outages in the short term but not long run.
2) Average of ~7% of poles must be replaced annually to maintain status quo averages.
3) The prediction overestimates actual impact of replacement.

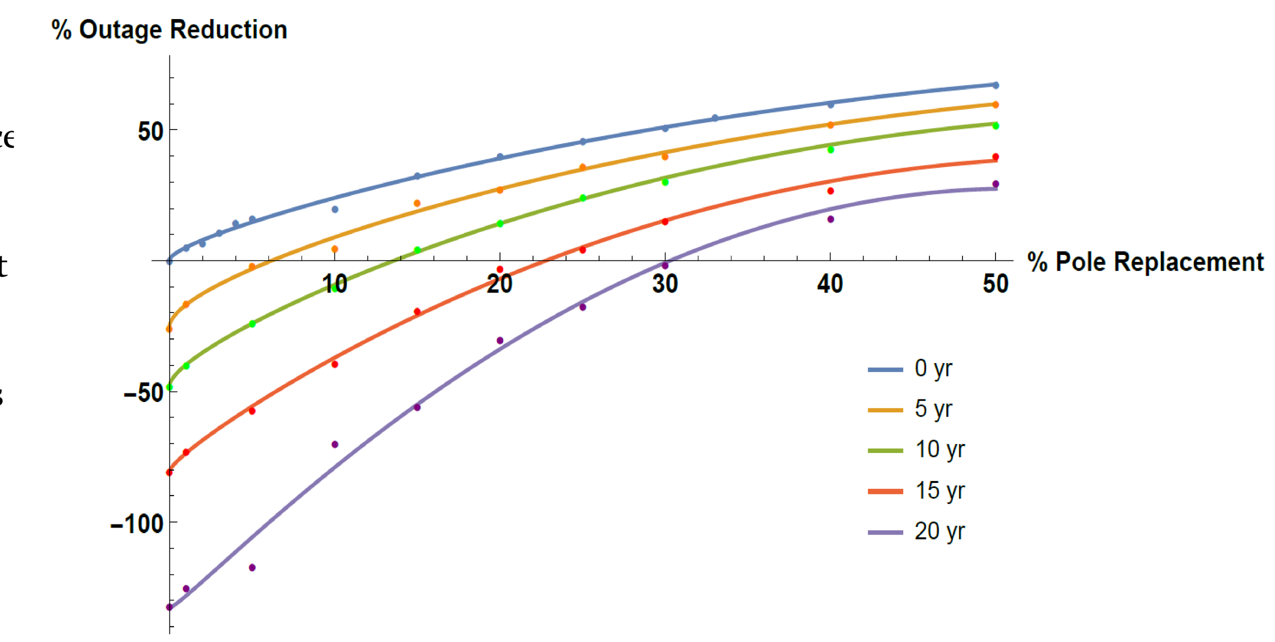


Figure 3: Pole Age Replacement Percent v. Percent Outage Reduction for Sandy

Vegetarian management plans include two typical tree trimming strategies: Enhanced Tree Trimming (ETT) and Standard Maintenance Trimming (SMT). ETT is considered highly effective and is modeled as having permanent effects. SMT effects are more complicated to model as trees grow back and therefore are still currently under analysis.

Data source: Effects of ETT were determined via regression of historic data from 2009-2014 of cumulative ETT v. percent outage reduction over 76 major events of this period (Figure 4). Trimming effects taper off at higher levels of trimming as only a portion of outages are tree-related. Therefore, achieving high outage reductions is not possible via purely trimming.

Trimming areas were determined by targeting cells with > average outages which did not already have high Trimming levels. Such cells were trimmed up to 70%,at which point trimming benefits are assumed to be negligible based off Figure 4.

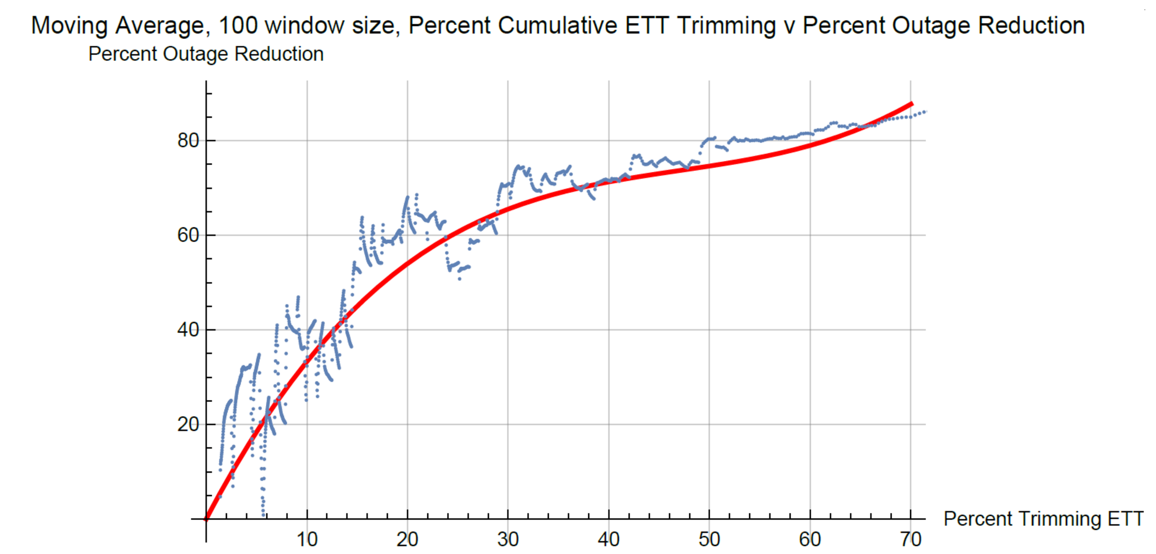


Figure 4: Regression of Relationship between Percent ETT and Percent Outage Reduction

Results and Discussions: Figure 5 shows projected impacts of increased ETT, plotting trimming cost versus percent outage reduction.
--Total trimming was summed up over the cells and multiplied by the average number of kilometers per cell to determine the total length of lines trimmed. This was then multiplied by the average cost of trimming 1 km of line to obtain a company cost. Since ETT is very expensive, it does not appear to be an ideal method under the current metrics. More precise targeting of areas of concern is necessary to reduce the cost, rather than trimming large portions of a cell.

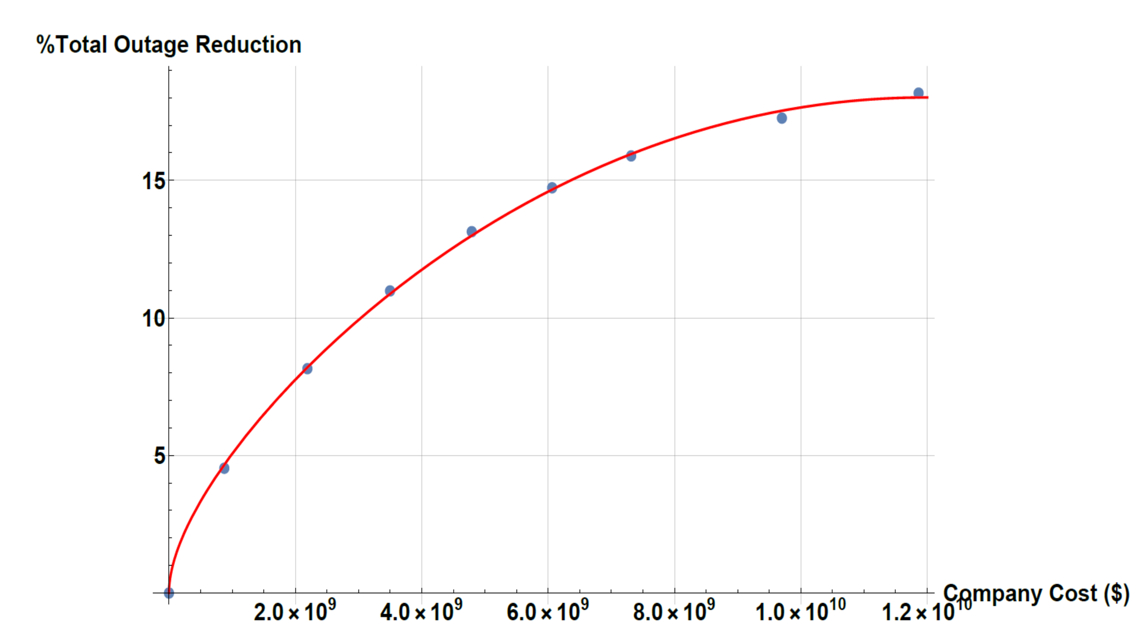
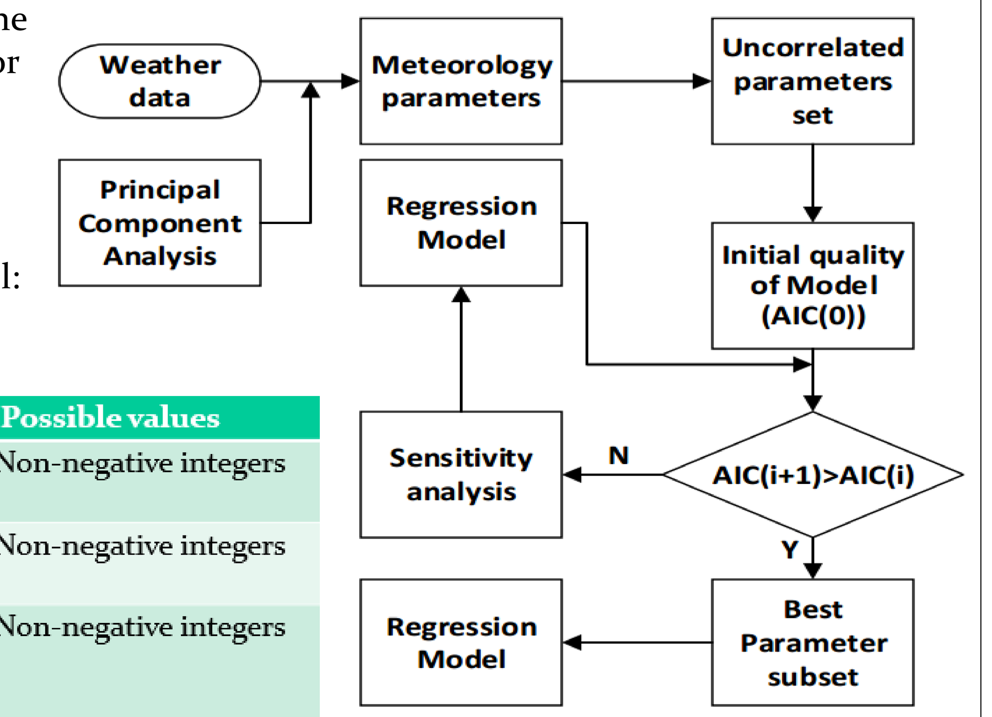


Figure 5: Effects of Tree Trimming (ETT), Company Cost v % Outage Reduction

REGRESSION MODEL

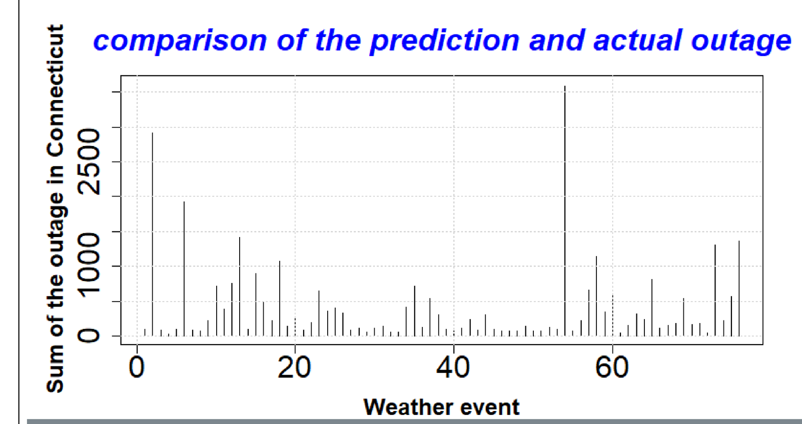
Regression analysis describes the relationship between two (or more) variables.

- A simple regression model: Consider a model with only one independent variable.
- A multiple regression model: a model with multiple independent variables.



Variable	Type	Possible values
Observed number of outages(y)	Interval	Non-negative integers
Maximum gust wind seped(m/s)(x_w)	Interval	Non-negative integers
Sum of the assets of the electrical components(S_a)	Interval	Non-negative integers
Binaryst	Binary	Damage (0) or not (1)

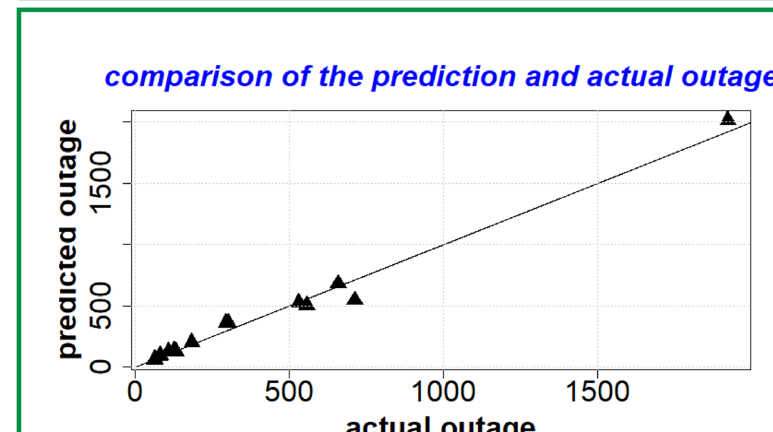
Table 1: Parameter Selection and Regression Model flowchart



Datasets	Percentage
Training Datasets	80% (61 events)
Test Datasets	20% (15 events)

Figure 6 : 76 Weather events outage data and Table 2: Model Dataset Assignment

MODELING RESULTS



Model	Accuracy
Poisson GLM	1.043279
Negative Binomial GLM	1.061693

Figure 7 : Poisson Generalized linear Model and Table 3: Model Accuracy

SUMMARY AND CONCLUSIONS:

1. A Total System model was created to predict storm power outages under different intervention scenarios. Effects of ETT and pole replacement were analyzed. About 7% of poles must be replaced annually to maintain status quo averages. ETT can reduce up to about 20% of outages, but is very costly and must be targeted much more precisely.
2. A regression model was created to predict outages. Two GLM models were tested, with the Poison GLM having a 11.04 accuracy and Negative Binomial GLM with a 1.06 accuracy.

ACKNOWLEDGEMENTS & REFERENCES

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