ORU Storm Outage Prediction

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Background

- **Weather is perceived as becoming more severe**
- **Hurricane Irene, Tropical Storm Lee, October Snow Storm, and Super Storm Sandy occur over 2 years**
- **Regulators react creating new mandates for utilities**
  - **More and better communication to customers, municipalities and State Public Service Commissions**
  - **Outage avoidance and storm hardening of system infrastructure**
  - **Preplanning and preparedness**
  - **Resource management**
  - **Storm outage prediction and damage estimation**

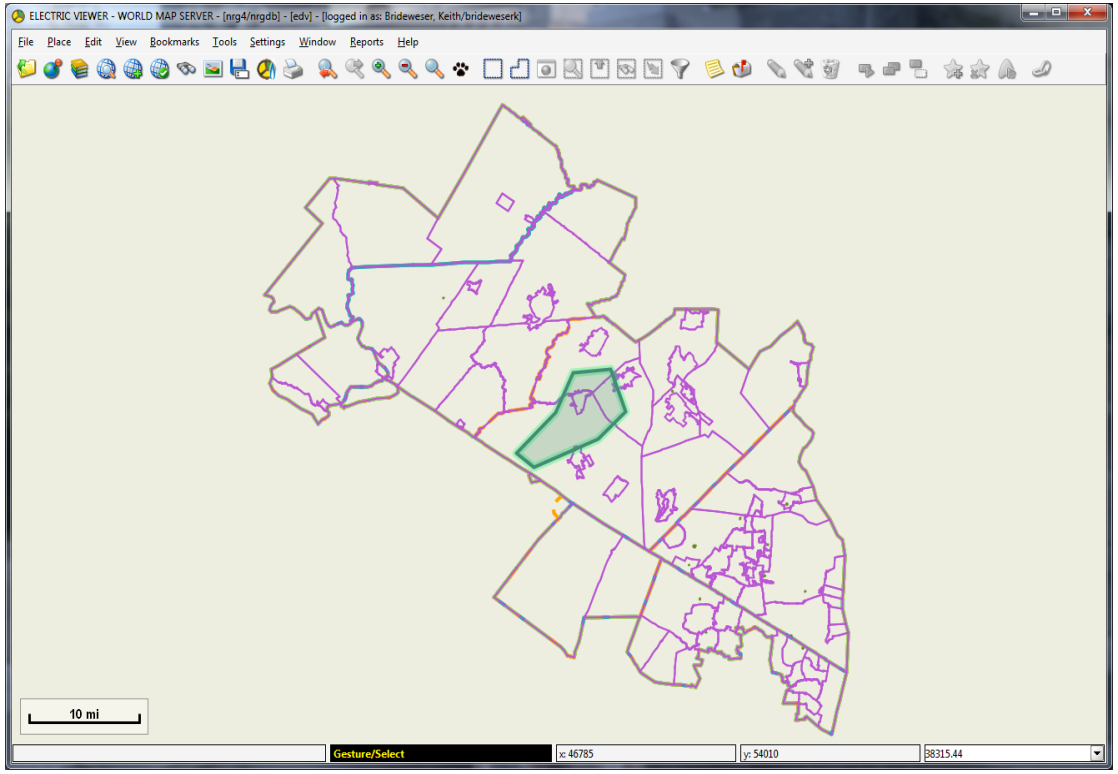
O&R Storm Management System

- **Pre-storm forecasting of damage**
- **Real time evaluation of storm conditions**
- **Fast prediction of the total number of outages**
- **Real time evaluation of outage restoration**

Pre Storm Damage Forecasting

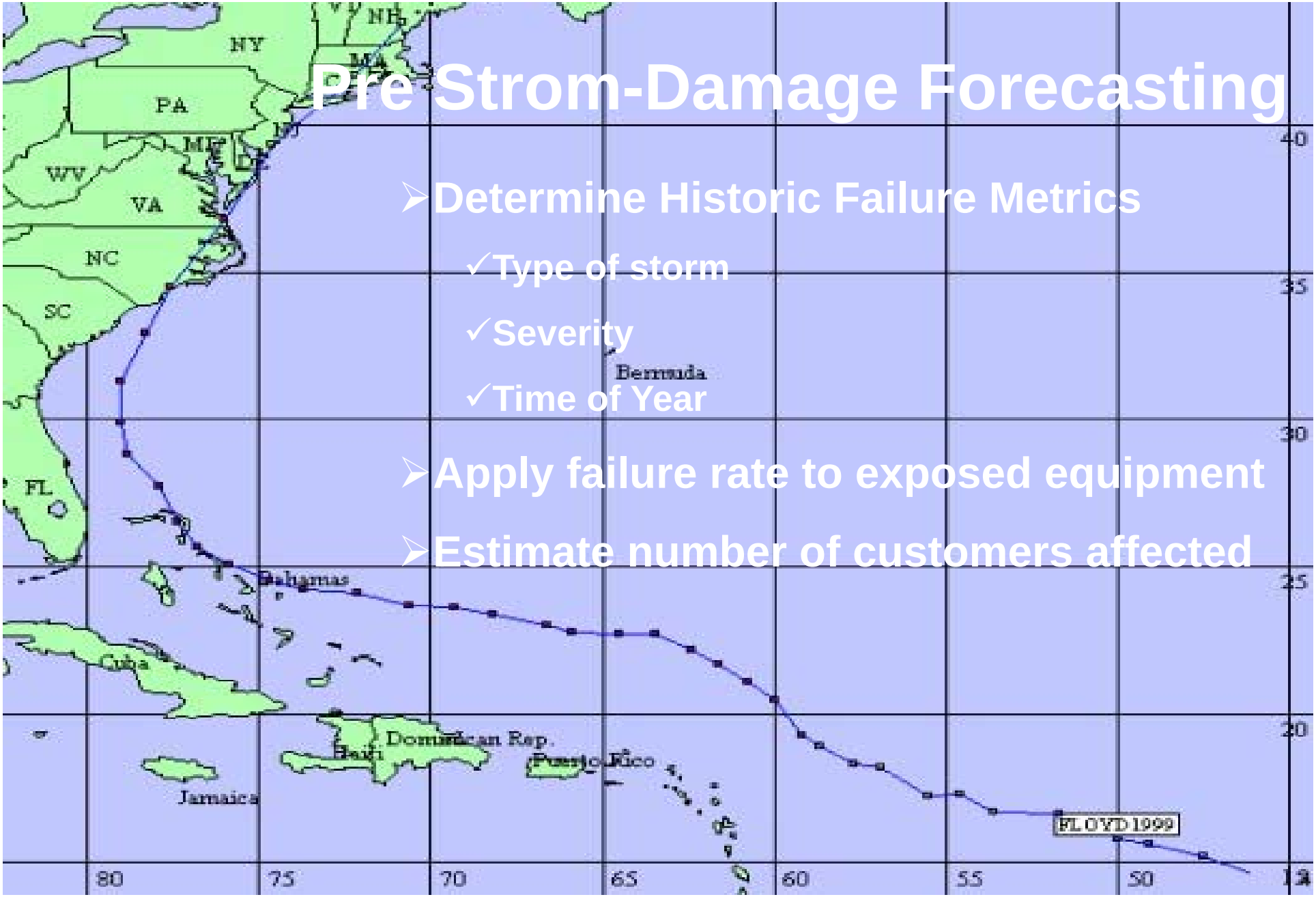
Pre Storm - Damage Forecasting

- **Granular Weather forecast Identifies boundaries of exposed area**
- **Exposed area plotted on GIS system**
- **Facilities exposed are identified and quantified**



Pre Strom-Damage Forecasting

- Determine Historic Failure Metrics
  - ✓Type of storm
  - ✓Severity
  - ✓Time of Year
- Apply failure rate to exposed equipment
- Estimate number of customers affected



Real Time Evaluation of Storm Conditions

Storm Outage Detection

- **Review number of outage incidents received by OMS**
- **Look for an increase in the number of incidents received over time**
- **Determine if storm conditions are reported**
- **Storm conditions plus an increase in the rate of receipt of outage incidents in OMS signals a storm**
- **Program switches to outage prediction process**
- **Analysis shows a theoretical 80% success rate**
- **A much better "Trigger" is needed.**

Fast Prediction of Total Outages

Storm Outage Prediction - Objective

- **Investigate the possibility of creating a mathematical model to predict the number of outages a storm will generate based on the real time receipt of incidents in OMS**

Storm Outage Prediction - Methodology

- **Evaluate historical storm data to:**
  - **Classify storms by type**
  - **Prepare cumulative outage curves for each storm type**
  - **Determine mathematical equations describing the outage curve of each storm type**
  - **Use regression analysis to make an initial prediction of the scope of the storm**
  - **Develop a feedback network to adjust predictions based on real time inputs**
  - **Test the accuracy of the model on actual storm data**

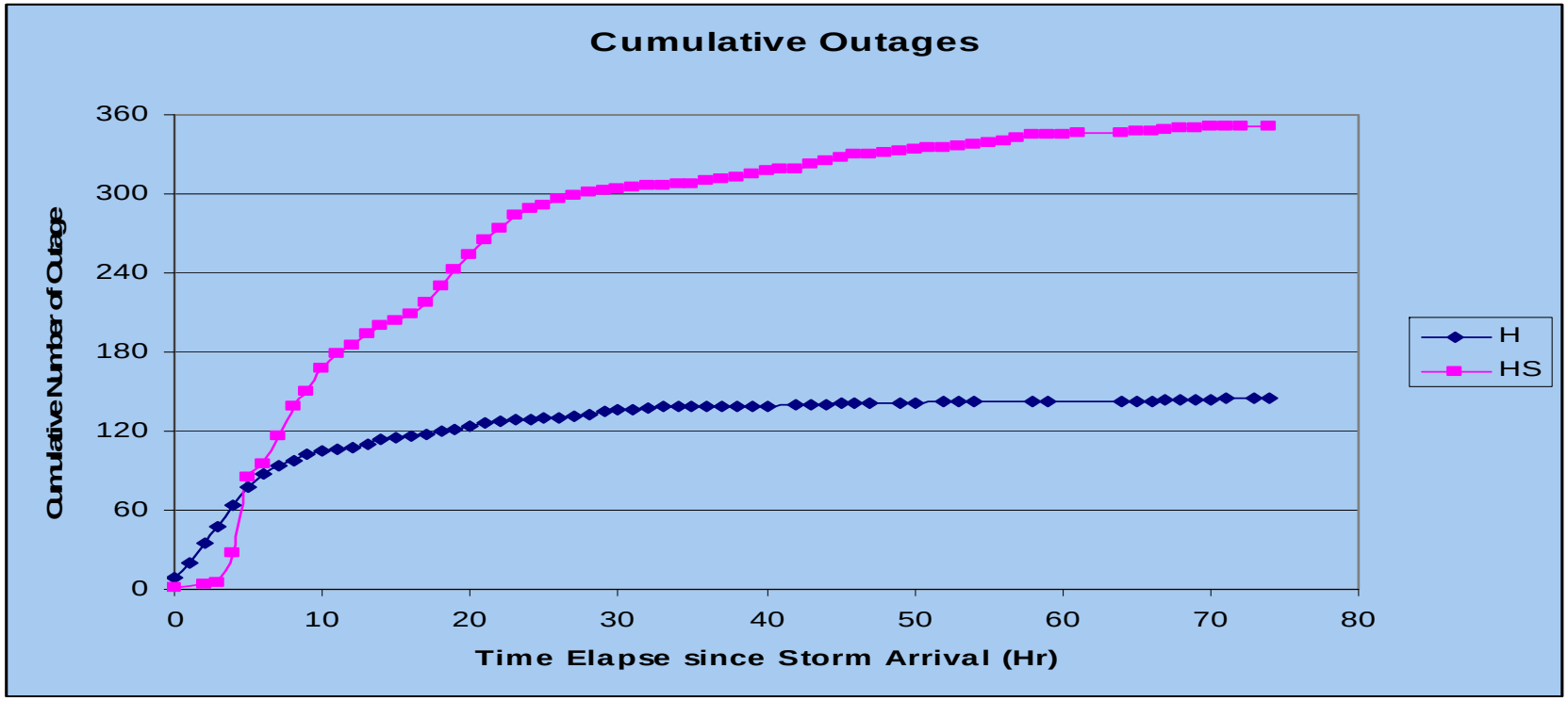
Storm Identification/Outage Prediction

- **Storm modeling**
  - **Sample consists of 89 storms from 10 years of storm data**
  - **Categorize storms based upon temperature, wind speed**
  - **Model storm outages with empirical curves**

Storm Type	Description	T Range (°F)	Wind Speed Range (mph)
H	High temperature, no strong wind	MaxT > 80	WS <= 20
HS	High temperature, strong wind	MaxT > 80	WS > 20
L	Low temperature, no strong wind	MinT < 32	WS <= 20
LS	Low temperature, strong wind	MinT < 32	WS > 20
M	Moderate temperature, no strong wind	MaxT <= 80 MinT >= 32	WS <= 20
MS	Moderate temperature, strong wind	MaxT <= 80 MinT >= 32	WS > 20
MaxT: maximum temperature; **MinT**: minimum temperature; **WS**: wind speed			

Cumulative Outages

- Number of outages by hour changes smoothly with time
- Suggests using cumulative outages for developing analytical models
- Distribution closely matches an exponential distribution



Mathematical Model

- **Least squares approximation applied to an exponential model gives the following equation**

$$N = A*(1-\exp(-B*(t-C)))$$

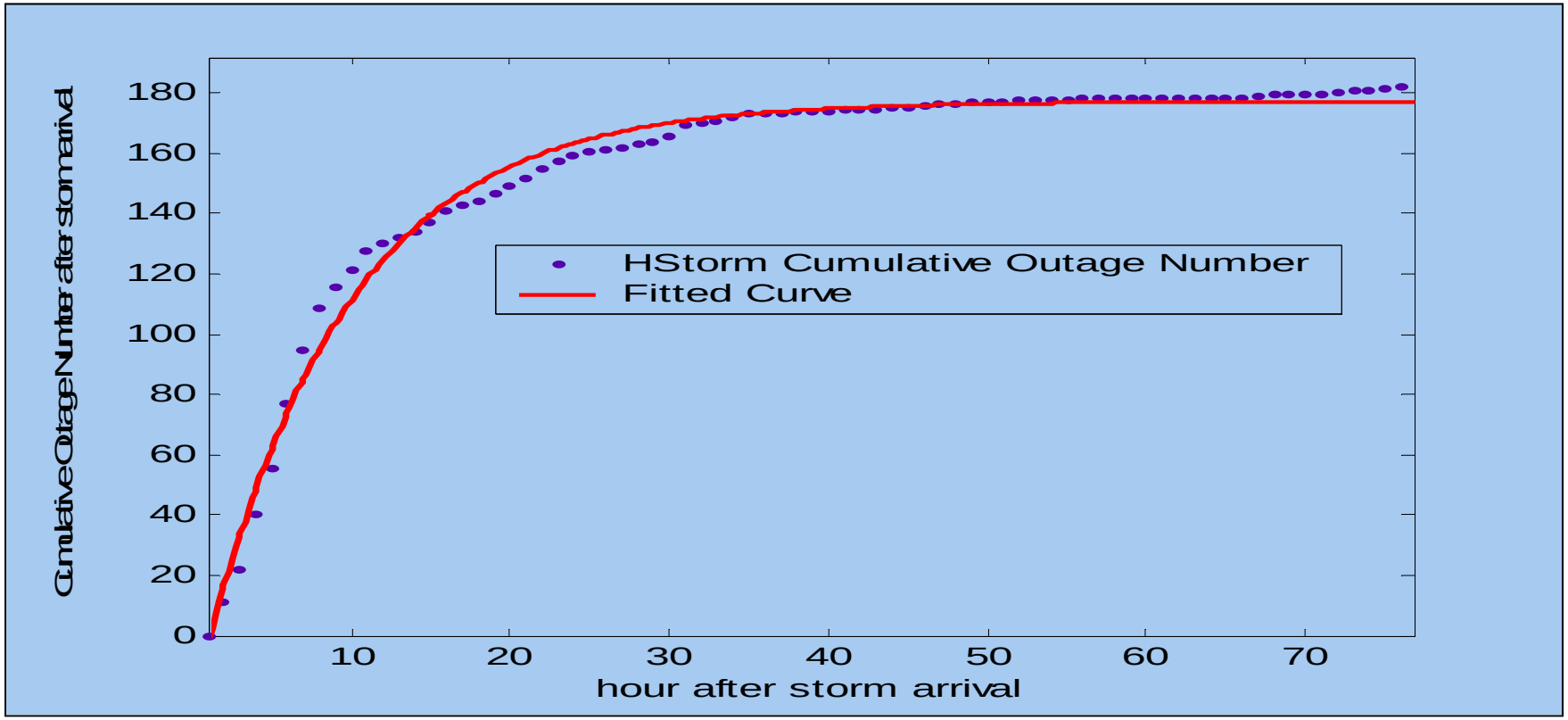
N = the number of cumulative outages

t = the number of hours after the first recorded outage

A, B and C are coefficients that vary with storm type

Results of Curve Fit

- **The model produced results which are in close agreement with the six storm outage curves.**
- **R-squared values range from 0.9834 to 0.9957.**



Outage Forecasting

- **Real-time outage behavior may differ significantly from the empirical model.**
- **The empirical model must be combined with error compensation to create an observer**
- **The output of the Observer tracks the actual storm outages**

Feed Forward Prediction Coupled With Feedback Error Correction

W = weather measurements

$O_{E(k+1)}$ = predicted outages at the end of hour (k+1) from empirical model

O_{Ak} = actual outages measured at end of hour k

$O_{P(k+1)}$ = predicted outages for hour (k+1) at hour k

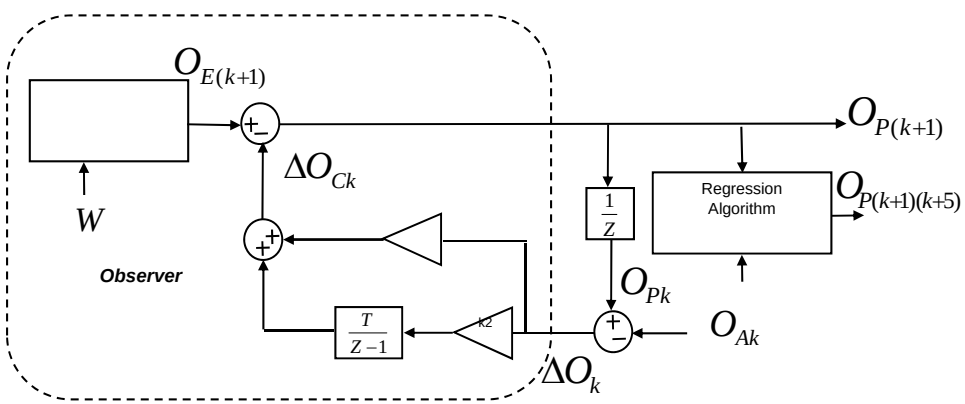
O_{Pk} = predicted outages for hour at hour (k-1)

$O_{P(k+1)(k+5)}$ = predicted outages for the next five hours at hour k

$O_{P(k+5)}$ = predicted outages for hour (+5) at hour

ΔO_k = O_{Ak}- O_{Pk}

ΔO_{Ck} = compensator output.

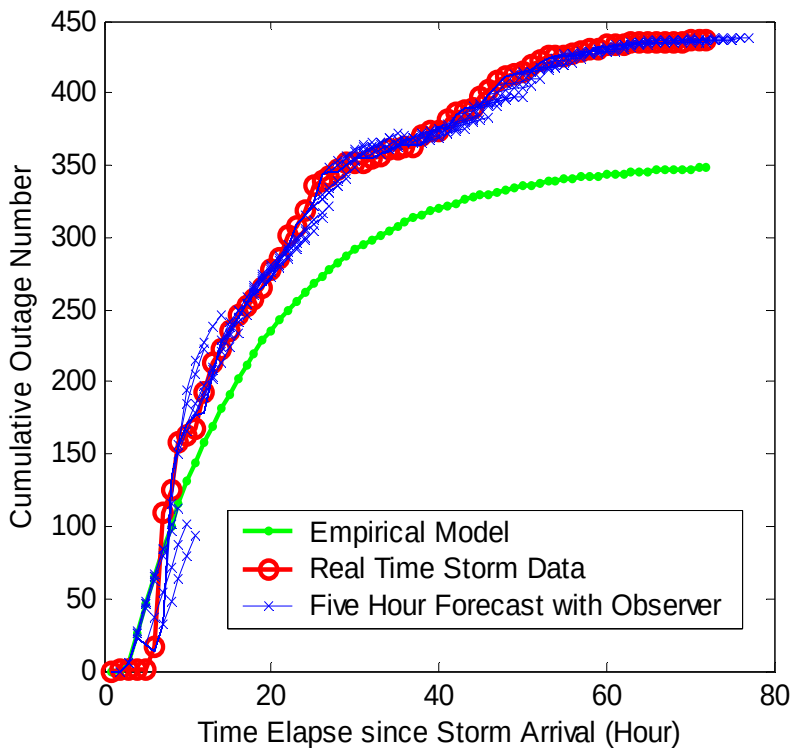


Prediction System

- **Provides a one hour forecast ($O_{P(k+1)}$)**
- **Applies a regression algorithm to the one hour forecast and previous actual data to develop five hour forecast ($O_{P(k+1)(k+5)}$)**
- **Algorithm attempts to recognize when the steep slope associated with cumulative outage curves is occurring**

Storm Outage Prediction Testing

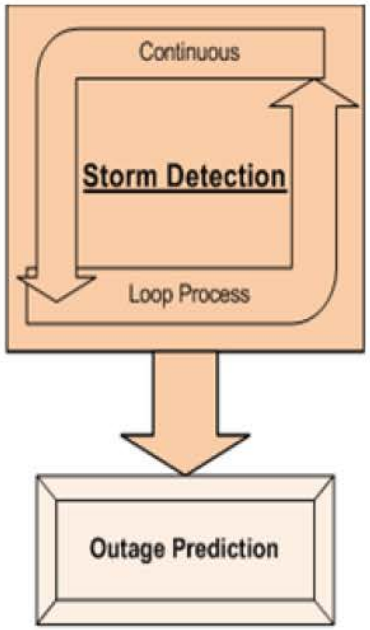
- Tested against historical storm data
- In process of integrating into ORUs distribution management system

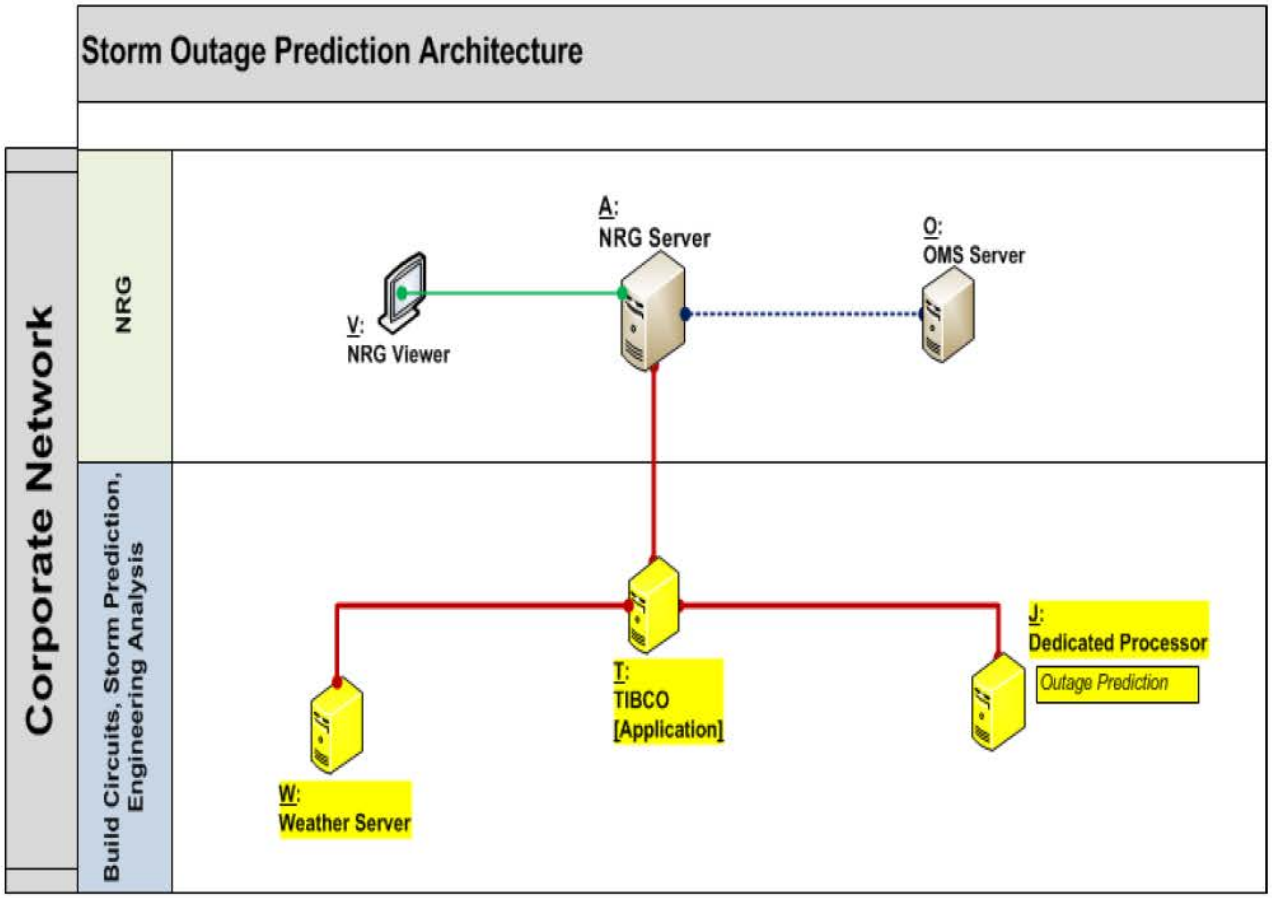


Storm Outage Modeling Publication

- D. Zhu, D. Cheng, R. Broadwater, C. Scribona, “Storm modeling for prediction of power distribution system outages”, Electric Power Systems Research, June, 2007.

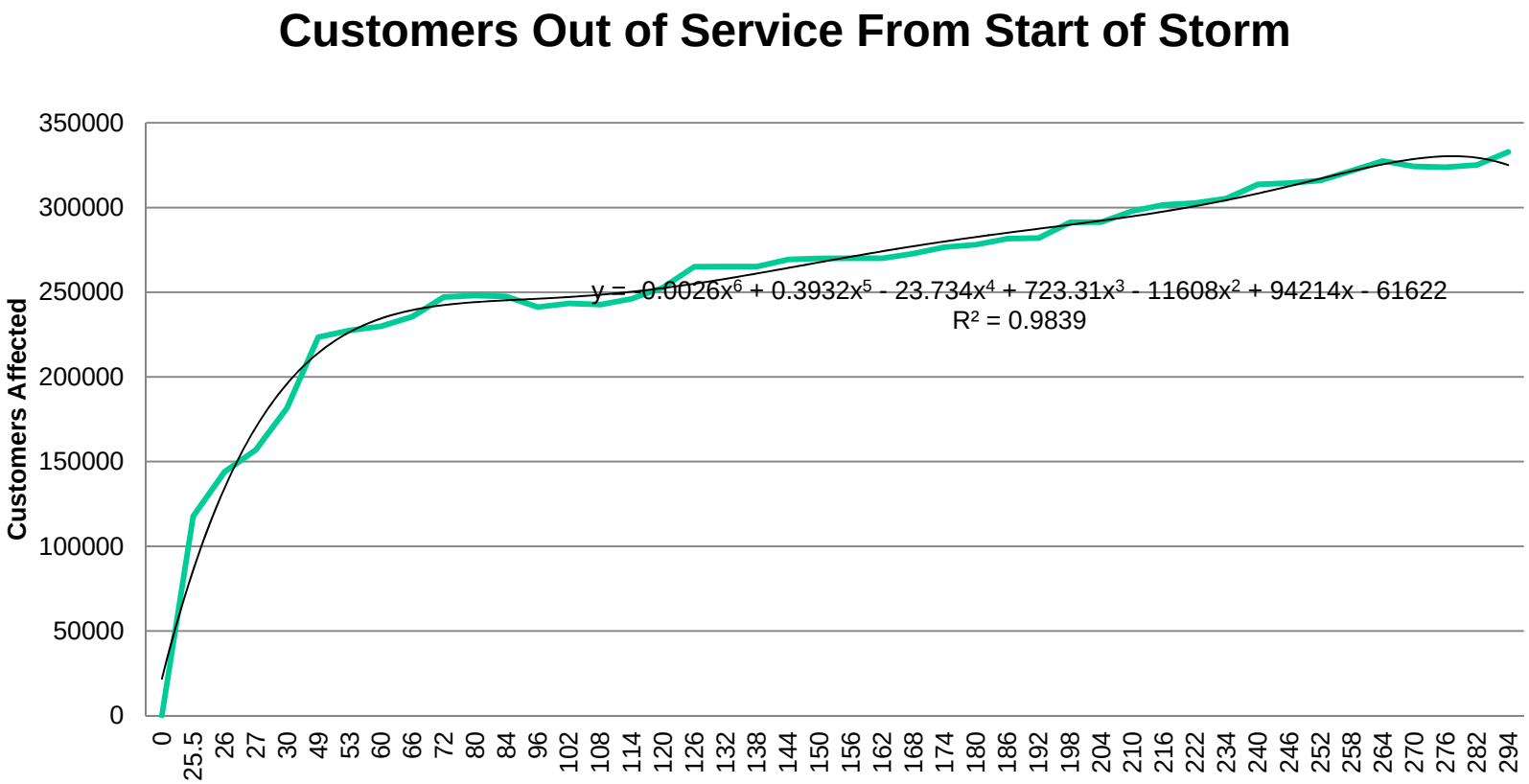
Storm Outage Prediction Architecture





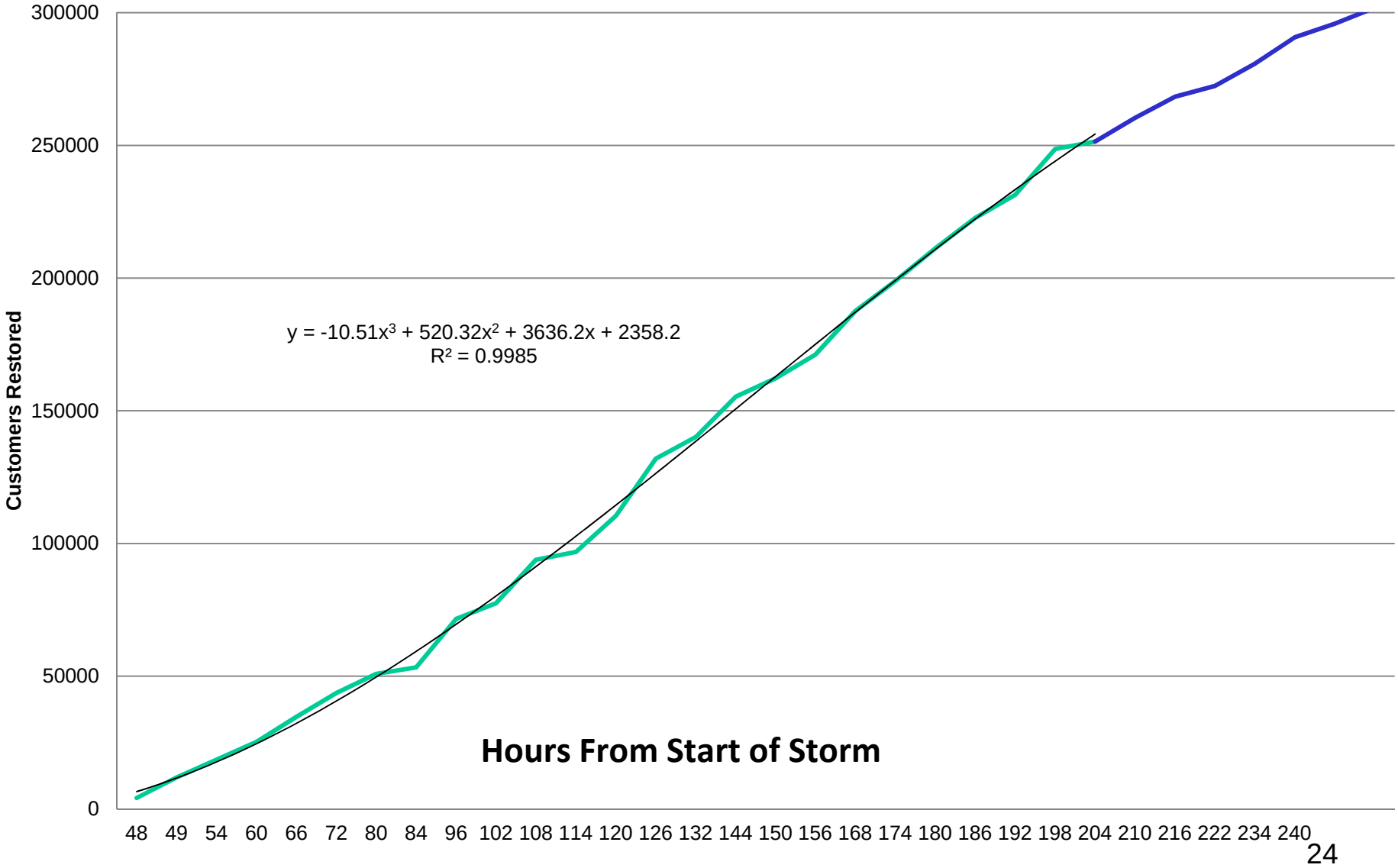
Real Time Evaluation of Outage Restoration

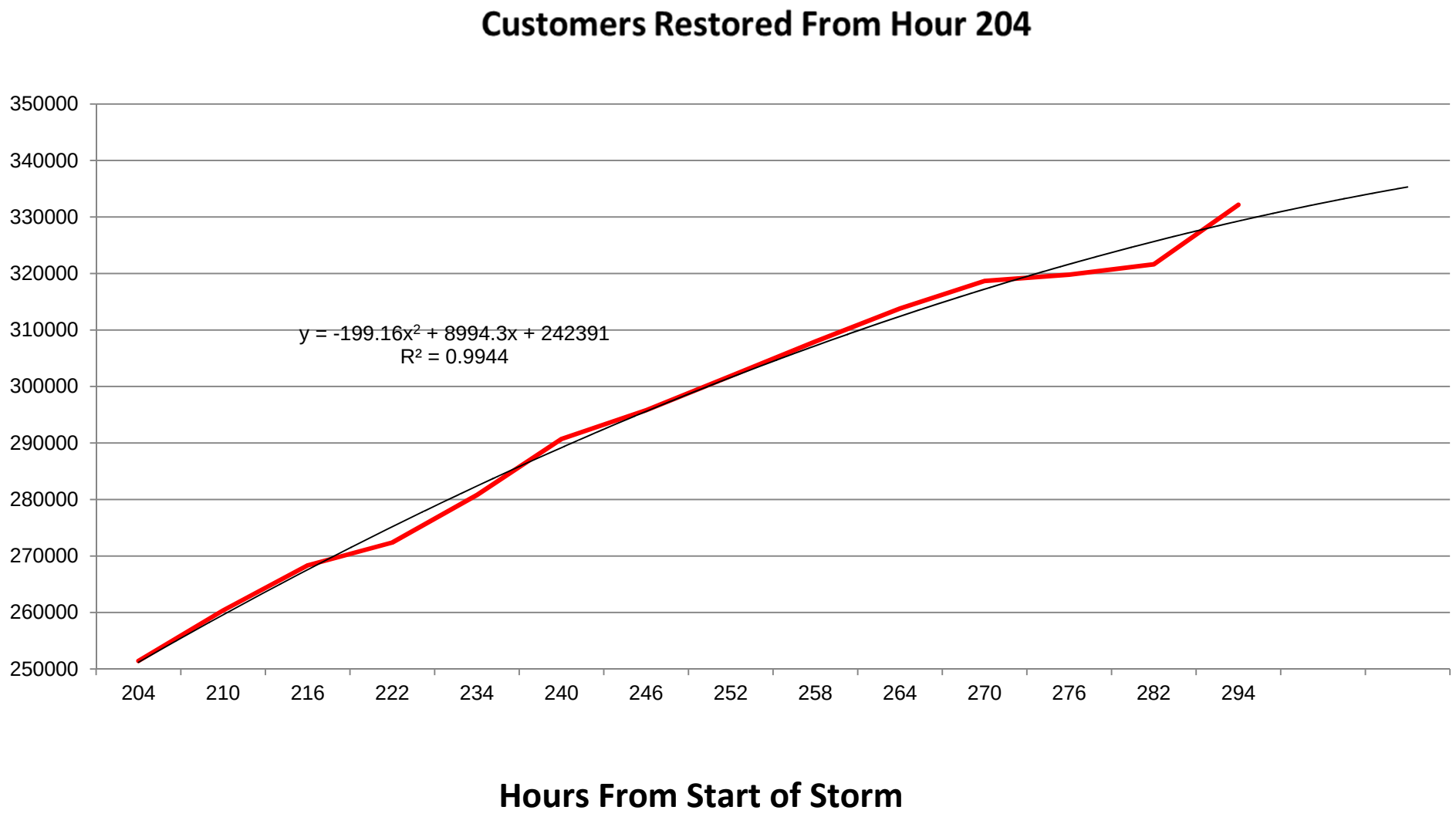
Super Storm Sandy
Cumulative Customers Affected



Note: An Issue with OMS caused the customers affected to continue rising. The true customers affected was approximately 250,000, which is just past the knee of the curve. This did not affect the prediction s because the predictions are based on the rate of restore.

Super Storm Sandy
Customers Restored From Start of Storm To Hour 204




Customers Restored From Hour 204
350000
340000
330000
320000
310000
300000
290000
280000
270000
260000
250000
y = -199.16x² + 8994.3x + 242391
R² = 0.9944
204
210
216
222
234
240
246
252
258
264
270
276
282
294
Hours From Start of Storm

Questions?