Post-Hurricane Transmission Network Outage Management

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Hurricane Ike

Photo Credit: www.centerpointenergy.com

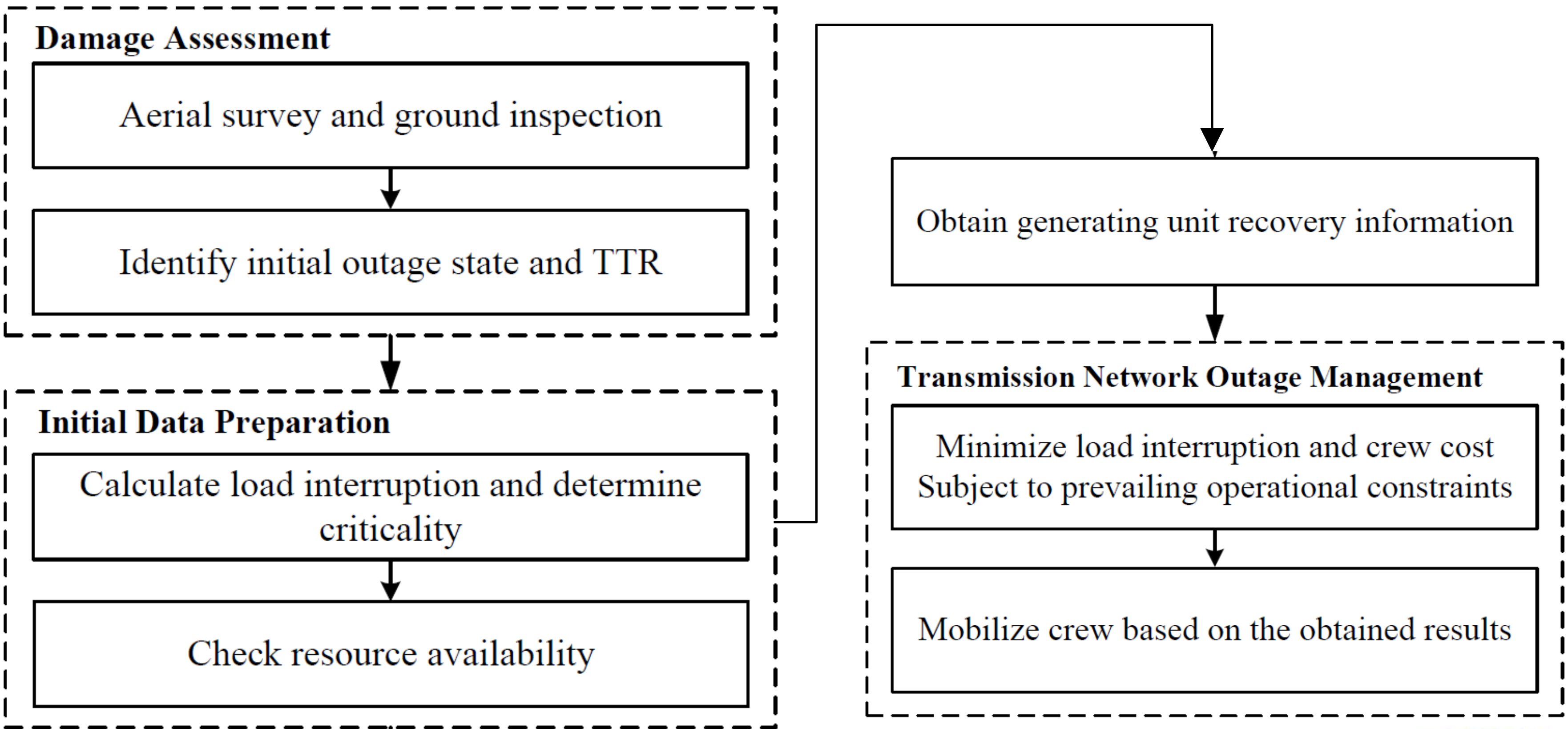
Aftermath of Hurricane

Photo Credit: http://users.ece.utexas.edu/~kwasinski

Problem Statement

- Hurricane Strikes
- Generation units fail
- Substations fail
- Transmission lines fail
- How the limited restoration resources to be allocated?

The Proposed Framework



The Objective Function

- To minimize the repair costs
- To minimize the load interruption cost.

Value of Lost Load

Load Interruption

$$\min_{LI,R} \sum_{t} \sum_{b} VOLL_{bt} . LI_{bt}$$

Resource Cost

Bus Resource

$$+ \sum_{t} \sum_{l} c_l . R_{lt} + \sum_{t} \sum_{b} c_b . R_{bt} .$$

Resource Cost

Transmission Resource

Load Balance and Power Flow Constraints

- Load Balance

$$\sum_{i \in N_b} P_{it} + \sum_{l \in N} PL_{lt} + LI_{bt} = D_{bt}, \quad \forall b, \forall t.$$

Line Power Flow

Load Interruption

Bus Demand

Real Power Generation

- Power Generation

Unit Damage State

$$P_i^{min} y_{it} \leq P_{it} \leq P_i^{max} y_{it}, \quad \forall i, \forall t,$$

A Very Large Number

Element of Gen2Bus Incidence Matrix

$$-M \sum_b \alpha_{ib} z_{bt} \leq P_{it} \leq M \sum_b \alpha_{ib} z_{bt}, \quad \forall i, \forall t.$$

Bus Damage State

Line Power Flow Constraint

Line Power Flow

Line Damage State

Element of Line2Bus Incidence Matrix

A Very Large Number

$$-PL_l^{max} w_{lt} \leq PL_{lt} \leq PL_l^{max} w_{lt}, \ \forall l, \forall t,$$

$$-M \sum_b \beta_{lb}^{from} z_{bt} \leq PL_{lt} \leq M \sum_b \beta_{lb}^{from} z_{bt}, \ \forall l, \forall t,$$

$$-M \sum_b |\beta_{lb}^{to}| z_{bt} \leq PL_{lt} \leq M \sum_b |\beta_{lb}^{to}| z_{bt}, \ \forall l, \forall t,$$

The bus voltage angle constraint should also hold.

Restoration Constraints

Damage State Change

$$0 \leq w_{lt} - (\sum_{k=1}^{t} v_{lk} - TTR_l + 0.5)/M \leq 1 \;\; \forall l, \forall t,$$

$$0 \leq z_{bt} - (\sum_{k=1}^{t} u_{bk} - TTR_b + 0.5)/M \leq 1 \;\; \forall b, \forall t.$$

Line Resource Allocation Indicator

Line's Time To Repair

Bus Resource Allocation Indicator

Bus' Time To Repair

Repair Duration

$$\sum_{k=t}^{t+TTR_l-1} v_{lk} \geq TTR_l(v_{lt} - v_{l(t-1)}), \;\; \forall l, \forall t,$$

$$\sum_{k=t}^{t+TTR_b-1} u_{bk} \geq TTR_b(u_{bt} - u_{b(t-1)}), \;\; \forall b, \forall t.$$

The Resource Constraint Should Always Hold.

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Simulation Results for IEEE 118-Bus

Setups:

Unit Number	Time to Repair
$G1$	17
$G2$	12
$G3$	24
$G5$	8

Bus Number	Time to Repair
$B1$	24
$B2$	11
$B3$	18
$B4$	15
$B5$	5
$B8$	4
$B11$	22

Line Number	Time to Repair
$L1$	20
$L2$	18
$L10$	16
$L14$	10
$L16$	22

Results:

Scenario	R_t=50	R_t=75	R_t=100	R_t=125	R_t=150
Cost ($\times 10^3$)	$144,151	$140,910	$140,070	$139,718	$139,718
Interruption	46 hours	35 hours	29 hours	24 hours	24 hours

The higher the restoration resource level, the lower the interruption time and cost.

Conclusions and Future Work

- Restoration resource availability plays a significant role in system resiliency.
- Securing enough resources, significantly reduces the post-hurricane restoration time and cost.
- The stochastic nature of the problem will be considered in our future work.

Thank you!