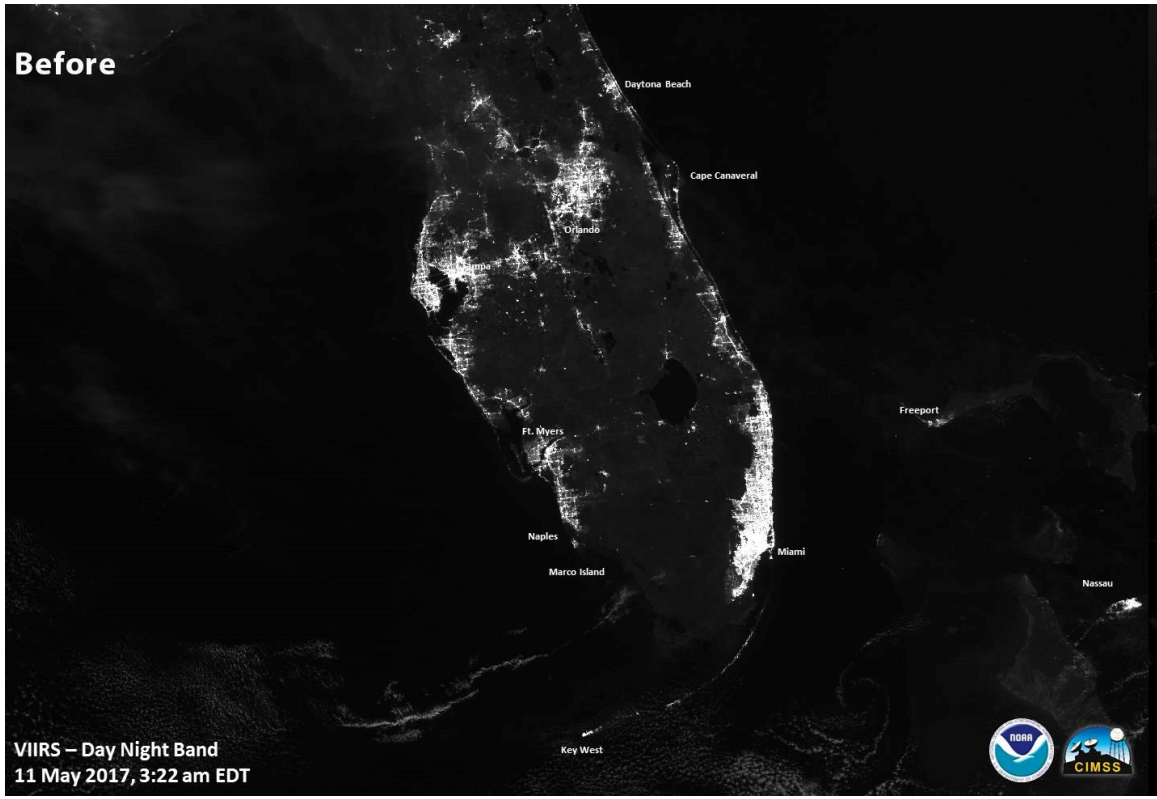
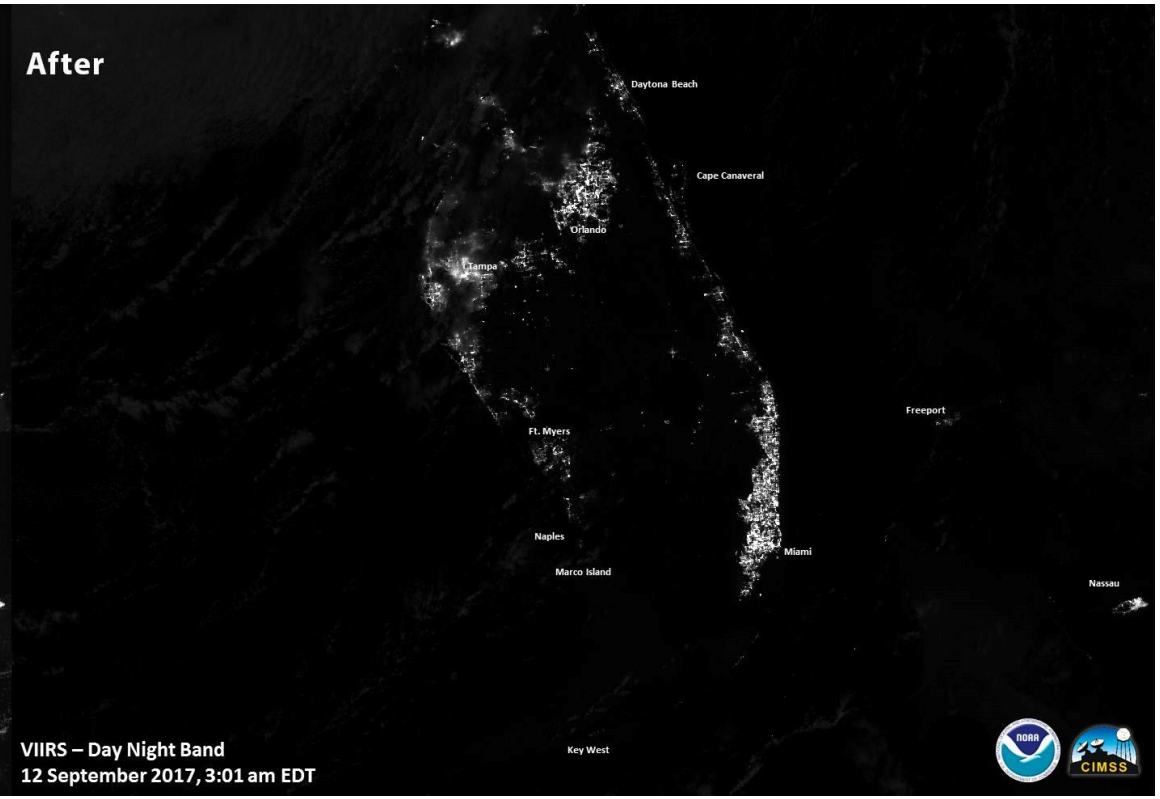
Impacts of Electric Vehicles on Mass Evacuations

CRAIG MACDONALD

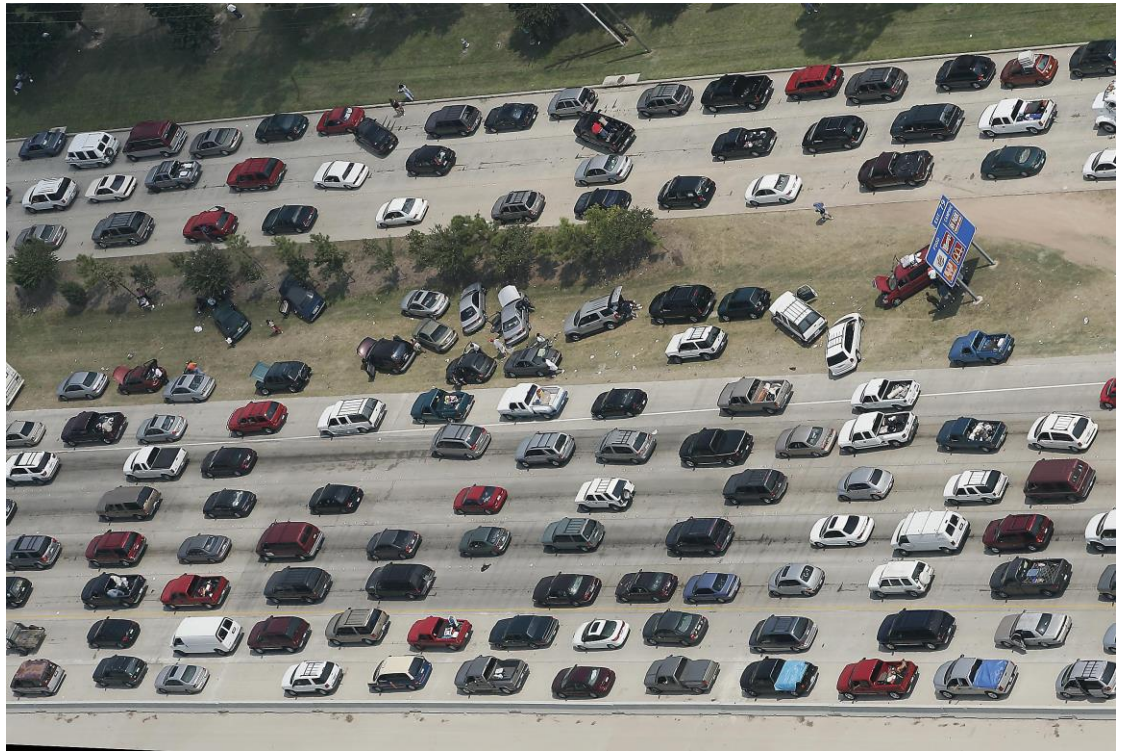
Painting a Picture – Fort Mac

Painting a Picture – Hurricane Irma





Painting a Picture – Hurricane Rita



Assessing the Disruption

- Electric vehicle sales continue to grow
  - Introduction of Electric pickup trucks & SUVs

- We can infer from problems fueling ICEVs that fueling EVs could lead to magnified versions of these problem
  - Charge times
  - Charger availability
  - Charger compatibility
  - Backup charging capacity?

- EV range is another concern
  - Difficult to recharge out-of-charge vehicles
  - Are there en-route charging stations?

What's Been Done so Far?

- One paper on EVs and emergency management
  - Adderly, S. A., Manukian, D., Sullivan, T. D., & Son, M. (2018). Electric vehicles and natural disaster policy implications. *Energy Policy*, *112*, 437-448.h
- One paper on fuel station locations in evacuation planning
  - Gao, Y., Chiu, Y. C., Wang, S., & Küçükyavuz, S. (2010). Optimal refueling station location and supply planning for hurricane evacuation. *Transportation Research Record*, *2196*(1), 56-64.
- Zero papers on refueling models of ICEVs or EVs
- Zero papers on fuel shortages

Modelling the Disruption

- Two part model:
  - Estimate demand which can be served during pre-evacuation period
    - Queuing Model at EV charging stations during pre-evacuation period
  - Estimate impacts of stalled (out-of-charge) EVs during evacuation process
    - Dynamic traffic simulation of evacuation routes

Part 1: Queuing Model

- How many vehicles can be served between an evacuation notice and immediate evacuation?
- M/G/c/N queuing model of all EV charging stations in location
- Monte Carlo simulation of queuing model in R or Python
  - Outputs number of vehicles charged, queue lengths, average waiting times, charge levels of vehicles which were not fully charged, etc.

Part 1: Queuing Model Req. Data

✓Arrival Processes
- Estimated from departure curves from previous evacuations

✓Charging Times
- Estimated from available manufacturers data

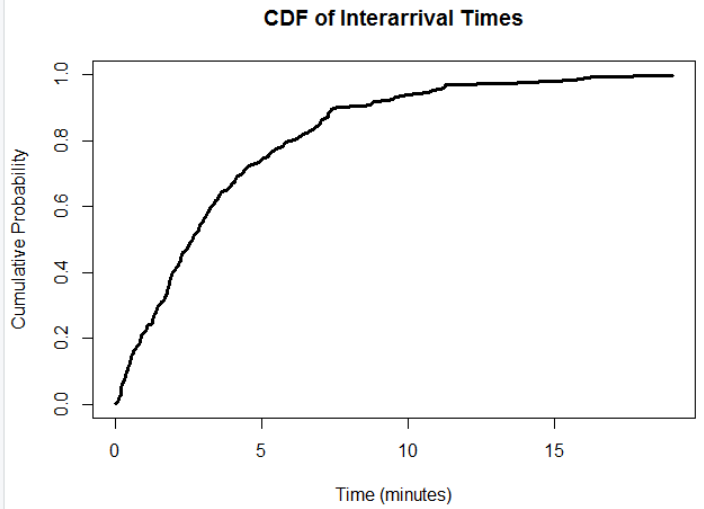
✓Number of Charging Stations
- Estimated from public maps (ChargeHub)

✓Number of EVs to evacuate
- Estimated from EV sales data at the provincial level in Canada or federal level in US

```
#SC
if ((l3SC>0)&(as.numeric(min(which((EVs$ChargeType==1) & EVs$Rank>0,arr.ind=TRUE))!=Inf)==TRUE)){
  k=as.numeric(min(which(EVs$ChargeType==1 & EVs$Rank>0,arr.ind=TRUE)))
  l3SC=l3SC-1
  EVs$Rank[EVs$Rank>=EVs$Rank[k]]=EVs$Rank[EVs$Rank>=EVs$Rank[k]]-1
  EVs$Rank[k]=0
  EVs$TimeToCharge[k]=(1-EVs$CurrentCharge[k])*EVs$Level3[k]
  l=as.numeric(which(EVs$TimeToCharge==min(EVs$TimeToCharge[EVs$TimeToCharge>0]),arr.ind=TRUE))
  EVs$Served[k]=1
  time=time+min(EVs$Arrival[j+1],min(EVs$TimeToCharge[EVs$TimeToCharge>0]))
  tn[n+1]=tn[n+1]+min(EVs$Arrival[j+1],min(EVs$TimeToCharge[EVs$TimeToCharge>0]))

  if (EVs$Arrival[j+1]<EVs$TimeToCharge[l]){
    n=n+1
    EVs$TimeToCharge[EVs$TimeToCharge>0]=EVs$TimeToCharge[EVs$TimeToCharge>0]-EVs$Arrival[j+1]
    aTracker=1
    j=j+1
    rank=sum(EVs$Rank>0)+1
    EVs$Rank[j]=EVs$Rank[j]+rank
  }
  else{
    n=n-1
    aTracker=0
    EVs$Arrival[j+1]=EVs$Arrival[j+1]-min(EVs$TimeToCharge[EVs$TimeToCharge>0])
    EVs$TimeToCharge[EVs$TimeToCharge>0]=EVs$TimeToCharge[EVs$TimeToCharge>0]-min(EVs$TimeToCharge[EVs$TimeToCharge>0])
    if (EVs$Served[l]==1){
      l3SC=l3SC+1
    }
    else if (EVs$Served[l]==2){
      l3CDMO=l3CDMO+1
    }
    else if (EVs$Served[l]==3){
      l3CCS=l3CCS+1
    }
    else if (EVs$Served[l]==4){
      l2c=l2c+1
```

```
    i=i+1
  }
  else if (EVs$CarUniformSample[i]>0.2651){
    EVs$CarModel[i]="Chevrolet BOLT"
    EVs$ChargeType[i]=3
    EVs$Level2[i]=558
    EVs$Level3[i]=80
    i=i+1
  }
  else if (EVs$CarUniformSample[i]>0){
    EVs$CarModel[i]="Tesla Model S"
    EVs$ChargeType[i]=1
    EVs$Level2[i]=720
    EVs$Level3[i]=40
    i=i+1
  }
}

#IATs

Arrival=rexp(numberEVs,(numberEVs/cutofftime)/lambda)*60/lambda
CumuArrival=cumsum(Arrival)
max(CumuArrival)
1] 970.3721
ecdfPlot(Arrival,main="CDF of Interarrival Times",xlab="Time (minutes)")
EVs$Arrival=Arrival
```

EVsCopy	46 obs. of 10 variables
Values	
Arrival	num [1:266] 5.23 2.62 15.88 7.26 5.72 ...
arrival	num [1:266] 1.1 3.26 7.75 4.09 6.33 ...
aTracker	0
carunif	num [1:266] 0.947 0.488 0.786 0.849 0.218 ...
chargeunif	num [1:266] 0.089 0.274 0.0328 0.7274 0.3911 ...
chargeVector	num [1:46] 0 0 0 0 0 0 0 0 0 0 ...
CumuArrival	num [1:266] 5.23 7.85 23.73 30.99 36.72 ...
cutofftime	16
f	2
i	267
j	1
k	0
l	0
l2c	4
l3CCS	0
l3CDMO	1
l3SC	0
lambda	8.1
max	1033.74508327669
n	0
numberEVs	266
r	1
rand	Large numeric (400000000 elements, 3 Gb)
rank	1
time	num [1:266] 1.1 4.35 12.11 16.2 22.52 ...



Part 2: Dynamic Traffic Simulation

- Gao et al.,2010, use DynusT
  - Could use any DTS models
- Assigns 5% (or more) capacity reduction for each stalled vehicle
- Outputs are total number of stalled EVs unable to reach destination from these numbers
  - Outputs could include total number of vehicles unable to reach destination if ICEVs are incorporated as well

Part 2: Dynamic Traffic Simulation Req. Data

- ✓Vehicle characteristics (including charge economy profiles) and initial levels of charge
  - Estimated from Part 1: Queuing model
- ✓Evacuation routes and destinations
  - Can be inferred relatively easily in locations with few evacuation routes. Assumed under more complex scenarios
- ✓Location of Charging Stations along Evac Route
  - Estimated from public maps (ChargeHub)

Potential Case Studies

- Prince George, BC (pop 74,000)
  - Wildfire risk
  - Presence of EVs and EV charging stations
  - Limited evacuation routes & long distance evacuation
- Redding, California (pop 38,000)
  - Wildfire risk
  - Large presence of EVs and EV charging stations
  - Limited evacuation routes & moderate distance evacuation
- Hurricane Scenario?
  - Much larger scale, more complex evacuation routing

Responding to Disruptions

- Qualitative identification of problems
  - Useful for practitioners
  - Important part of emergency management is identifying disruptions before they occur
- Quantitative estimates of magnitude of problem
  - Provides evidence that this problem is worth considering in evacuation planning
- Policy recommendations for emergency managers or policymakers

Questions?