Locating and Scheduling PHEV in V2G

Smart Grid FY2010 Review

Russell Bent, Alan Berscheid, David Izraelevitz, Feng Pan

LANL Smart Grid Team

Renewable, PHEV, V2G

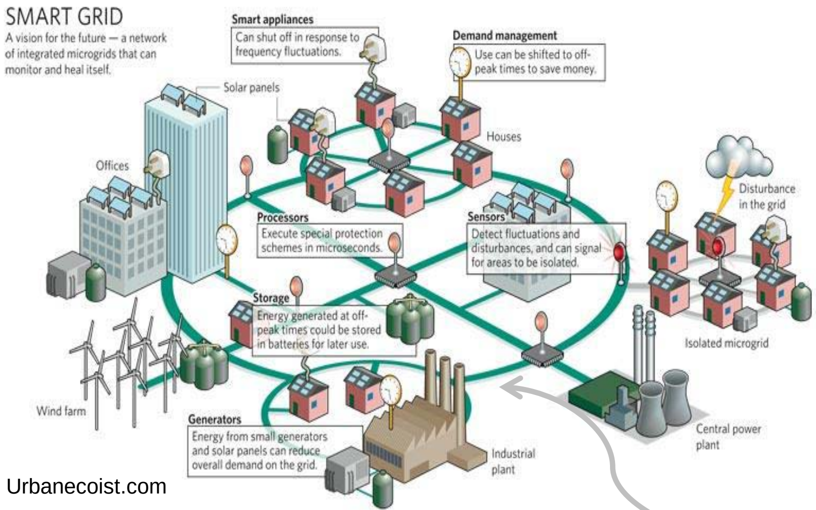
Renewable:

- Clean
- Variability in generation

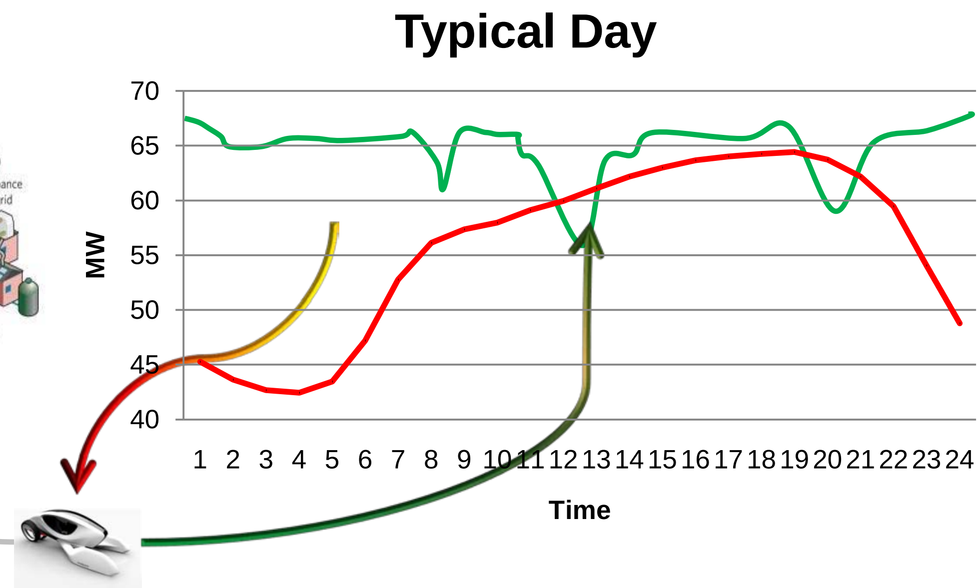
Plug-in Hybrid Electric Vehicle:

- Clean
- Increased demand for power

Renewable, PHEV, V2G



Urbanecoist.com



- PHEVs are storage devices
- Vehicle-to-grid (V2G): valley filling and ***peak shaving***

Understand the claimed benefits through model and simulation

Outline

- PHEV – Past, Present, Future
- PHEV – Supporting Infrastructures
- Locating PHEV Exchange Stations in V2G
  - Two-stage Stochastic Program
  - Case Studies
- Scheduling PHEV Charge in V2G
- Conclusion

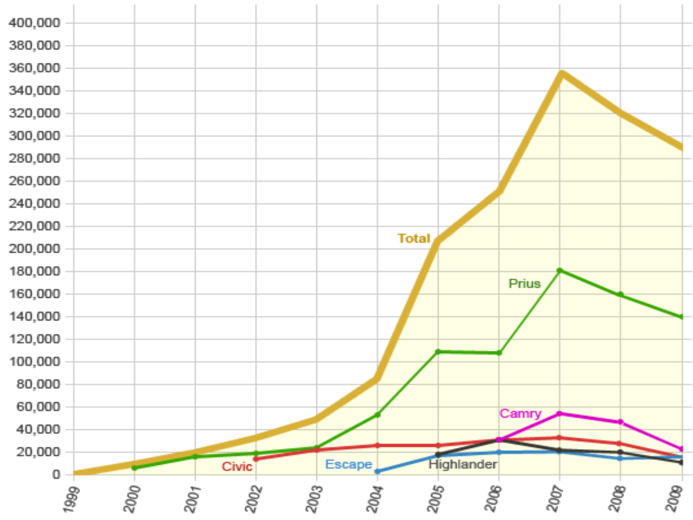
PHEV History

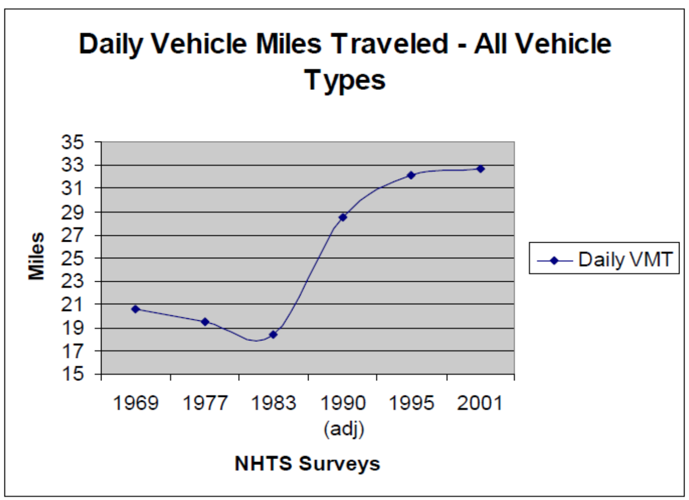
VS

- 1665-1825 Flemish Jesuit Prist, Chinese Emperor, Frenchman, British: Steam "car"
- 1839 Robert Anderson: first electric vehicle
- 1886 28 cell battery taxicab in England
- 1900 **1,575 electric, 936 gasoline cars**
- 1913 **6,000 electric, 182,809 gasoline cars**
- 1966 US congress: EV
- 1977-19979 GM: $20M R&D
- 1993 Toyota:G21
- 1997 Toyota Prius
- 2004 36K-47K Prius in US Market

http://www.hybridcars.com/history/history-of-hybrid-vehicles.html

PHEV Present





PHEV

- 2000: 9367, 2007: 324,318
- 8% increase per year
- Sales up 3% 2010
- 5/10: 28,202; 6/10: 21,679
- 40 miles of charge depleting range
- **Need additional supporting infrastructures**

PHEV Supporting Infrastructures

Charging Station

- Less cost and structures
- Ownership of batteries

Exchange Station

- Higher cost
- Sizable battery bank (**important in V2G**)
- Controllable (**important in V2G**)

Locating PHEV Exchange Stations in V2G

Locate exchange stations to

- Serve PHEV demands
- Support power grid as power storages
- Connect to power grid without expansion

Similar research:

- Facility location: locate facility to minimize the cost of serving all demands
- Generation expansion: optimally site new generation on a power grid

Two-stage Stochastic Program

First stage:

- Decide on the locations and capacities exchanges stations.
- Prior to know the exact battery demand, load, generation capacity (scenario).

A scenario: random variables battery demand, load, renewable generation capacity are realized.

Second stage (recourse action for each scenario):

- Distribute batteries for PHEV demand
- Discharge batteries for loads

First Stage

f_i	fixed cost to open an exchange station at i
r_i	storage cost per battery at station i
x_i	0-1 variable siting an exchange station at i
w_i	number of batteries stored at station i

$$\min_{x,w} \sum_{i \in I} (f_i x_i + r_i w_i) + E_\Omega[h(x, w, \xi)]$$

$$l_i x_i \leq w_i \leq u_i x_i, \ \ \forall i \in I.$$

$h(x, w, \xi)$

- Second stage objective value
- Evaluate *x,w* at scenario ω

Second Stage

At station *i*, batteries can be allocated for battery demand t_i^ω and for grid s_i^ω

$$s_i^\omega + t_i^\omega \le w_i, \;\; i \in I.$$

Serving battery demand is models as a *Transportation Problem*

- Traffics are modeled as routes
- cost of exchanging battery at station i from route j is c_{ij}

Linearized DC power flow is used for grid

- Each exchange stations are linked to a bus and serves as power source

Objective function:

$$h(x, w, \xi) = \min \sum_{i \in I, j \in J} c_{ij} y_{ij}^\omega + \sum_{j \in J} h_j^\omega q_j^\omega + \sum_{u \in N} o_u^\omega \beta_u^\omega + \sum_{u \in N} g_u \delta_u^\omega .$$

Simulation Setting

- Renewable generation
  - Renewable level 0 – 1: for example, at level 0.3, a generator is renewable with probability 0.3
  - Renewable capacity can be 0, 0.5, or 1 of its maximum capacity with equal probability
- Load at a bus is a uniform random variable between 0.5 and 1 of the maximum bus load
- Battery demand
  - Vehicle-to-population: 0.78, PHEV-to-vehicle: 0.1, battery demand: 10%
  - The total demand is equally distributed to each route as the average demand
  - Battery demand at each route is a uniform random variable between 0.5 and 1.5 of the average demand
- 100 scenarios

Case Study I: A Synthetic city

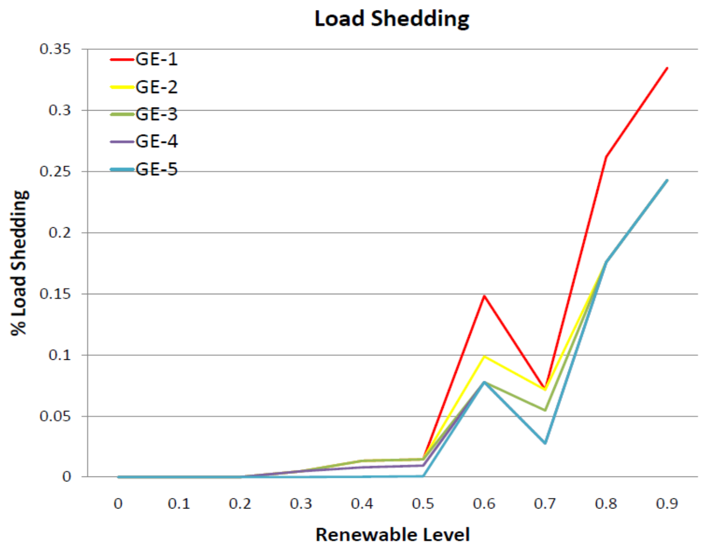
Power grid (IEEE-RTS-79)

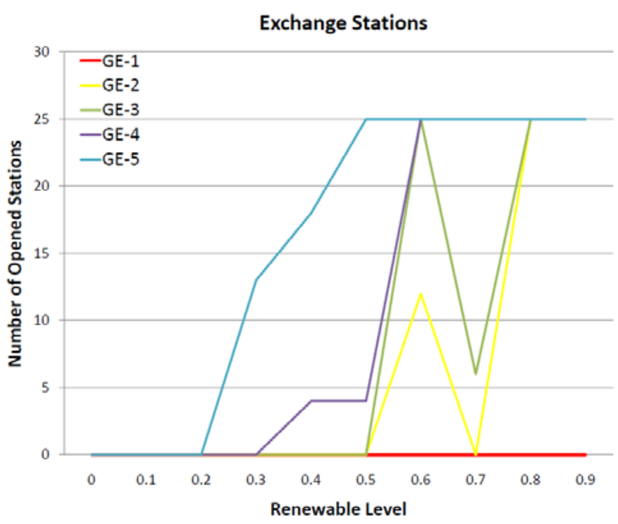
- Generation capacity is 2999 MW, load is 2880 MW

Transportation

- 8 by 11 grid, 10 traffic routes, 28 exchange station locations
- Population is 344850

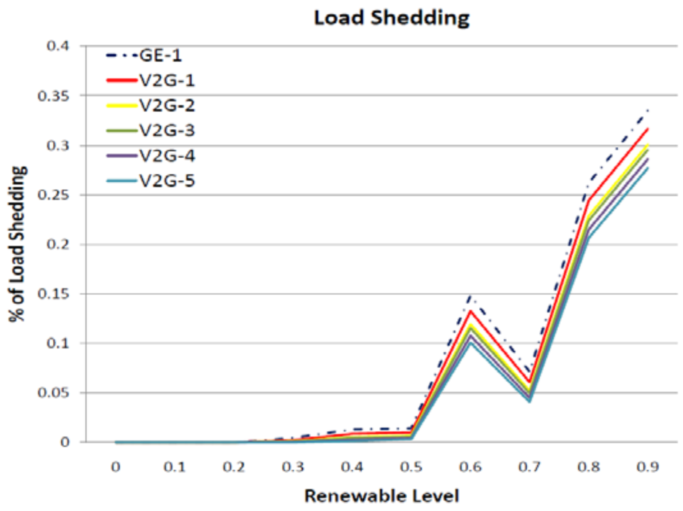
Case I: Grid Only

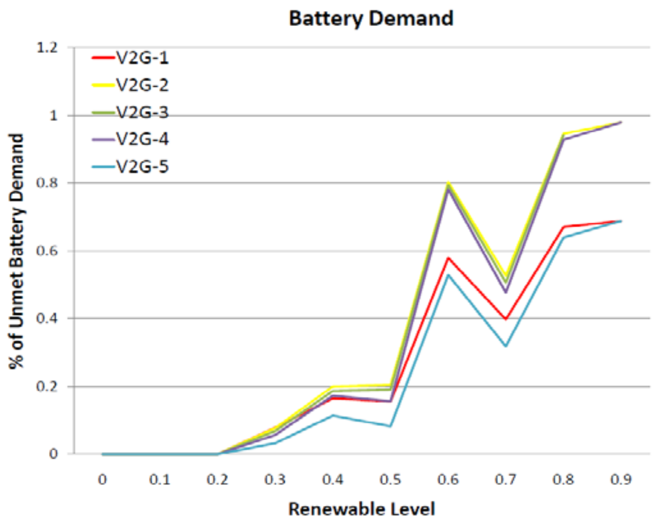




- GE-1 is the base case
- In GE-2 to GE-5, increase penalty cost for load shedding to stimulate opening exchange stations
- Below renewable level 0.3, no much load shedding
- With stations, below renewable level 0.8, less than 10% load shedding
- Maximally 25 of 28 stations without expanding the grid
- Some relief from exchange stations

Case 1: V2G





- Without the grid, opening 6 stations will satisfy all battery demand
- In V2G-1, 6 stations are fixed. In V2G-2 to V2G-5, open 6, 8, 10, 12 stations.
- Reduction in load shedding is limited
- Large increase in unmet battery demand
- 25 stations are needed to reduce load shedding
- The positions of stations in V2G1 limit the discharging capacity

Case I

- V2G reduces the load shedding caused by renewable variability at low renewable level.
- At higher level of renewable, trade-offs between load shedding and unmet battery demand is high. The benefit of V2G is not obvious.
- The synthetic city has relatively low population.

Case II: Greater Miami Area

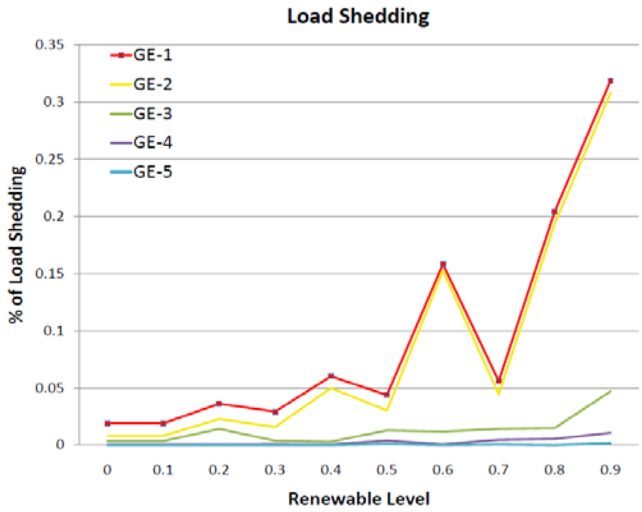
Power grid

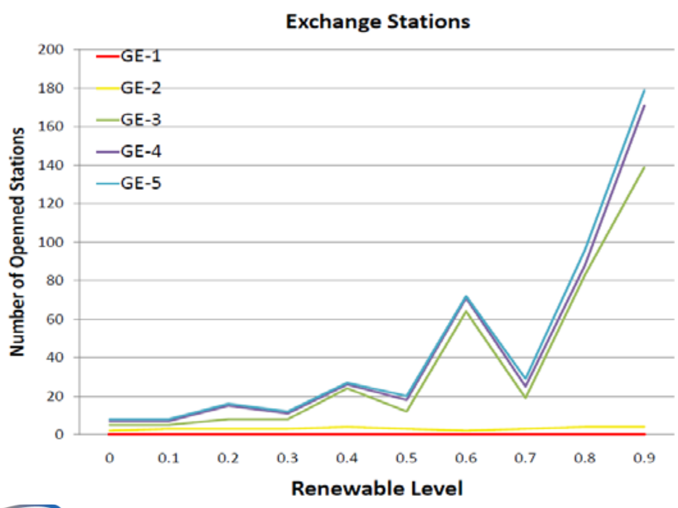
- Generation capacity is 8200 MW, load is 6400 MW

Transportation

- 100 traffic routes, 316 exchange station locations
- Population is 5414712

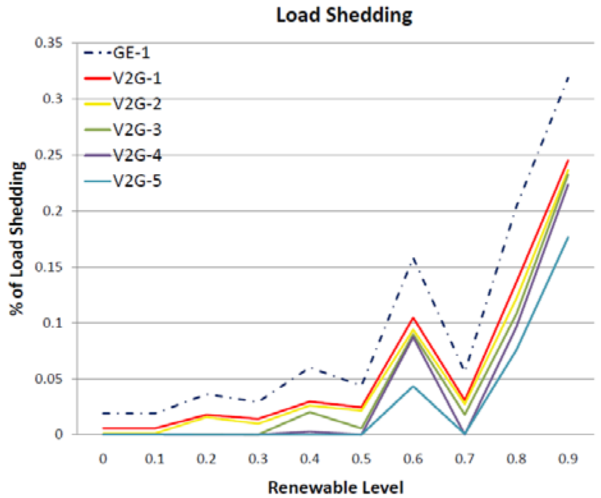
Case II: Grid Only

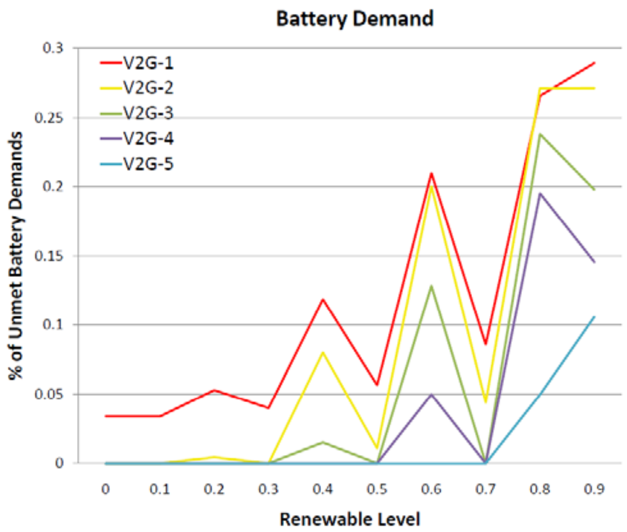




- There is 2% load shedding without renewable.
- In GE-3 to GE-5, load shedding is less 5%
- In GE-2, opening 2 – 4 stations reduces load shedding at low renewable level
- Maximally 180 stations without expanding the grid

Case II: V2G





- Without the grid, opening 106 stations will satisfy all battery demand
- In V2G-1, 106 stations are fixed. In V2G-2 to V2G-5, open 0%, 10%, 20%, 50% more stations.
- In V2G-1, reduce load shedding but increase unmet battery demand
- In V2G-2, by relocating 106 stations, reduce load shedding and almost serve all demand at low renewable levels
- In V2G-3, V2G has obvious benefit even at renewable level 0.5

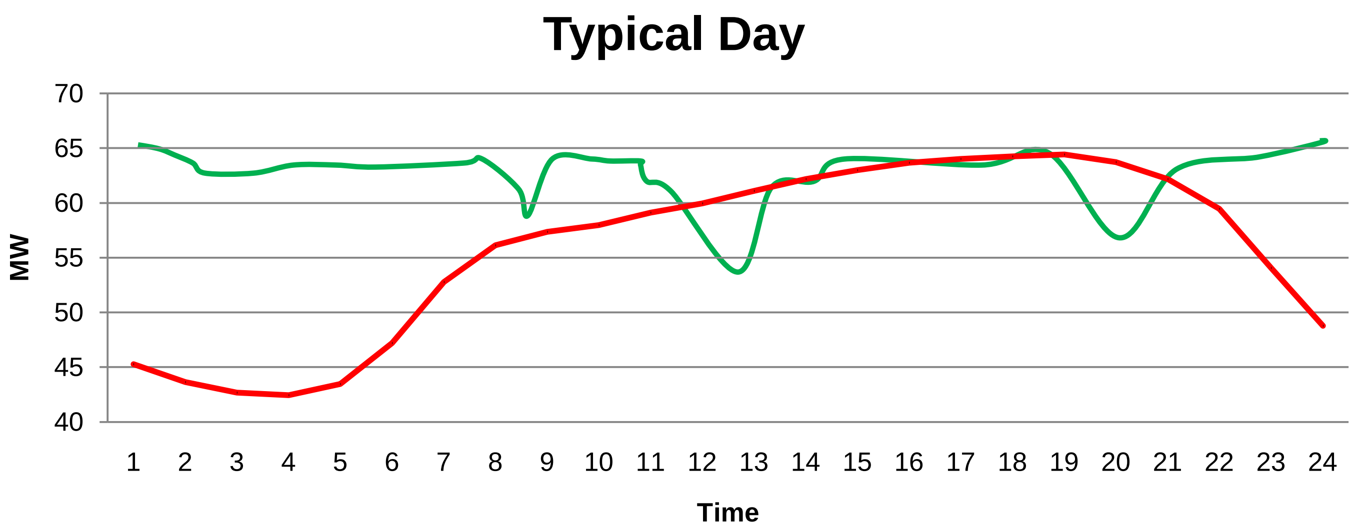
Case Study: Conclusion

- Proposed a two-stage stochastic program for locating exchange stations
- Locations of exchange stations are important.
- The benefit of V2G is more obvious at renewable level ≤ 0.5.
- The benefit of V2G is more obvious with higher population-to-load ratio.

Scheduling in V2G

- Scheduling of charging batteries
  - Uncertainty in demand
  - Centralized charging v.s. decentralized charging (pricing)
- Scheduling of charging and discharging batteries
  - Storing power for later use

Scheduling Battery Charging in V2G



[2,6],20

[2,20],300

[10,11],5

...

- Battery charging request
  - [starting time, end time], unit
- Power grid
  - Available generation capacity, cost

A Scheduling Model

Assumption:

- No penalty on preemption
- Uniform charge rate

Parameter (random):

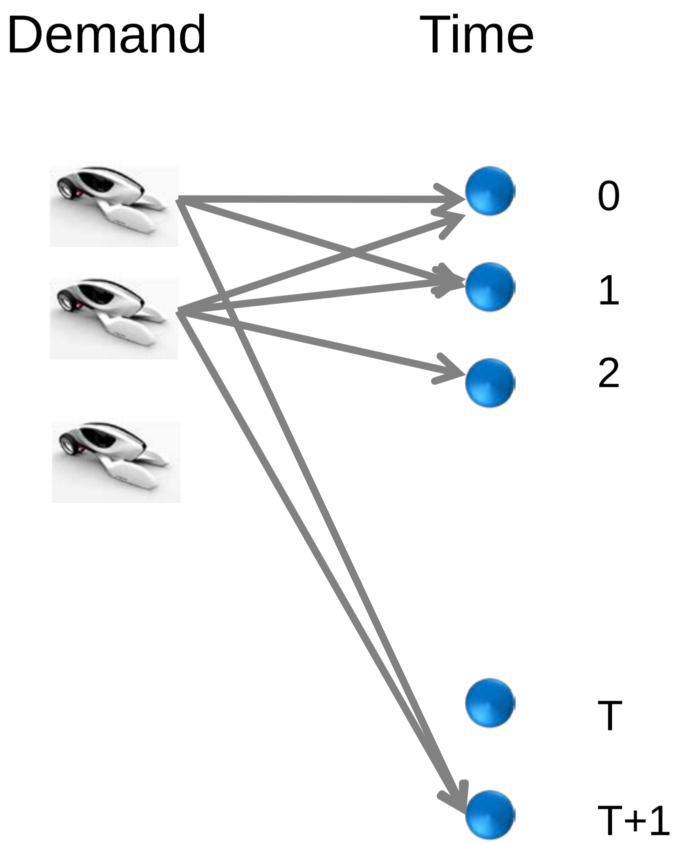
- Demand: size (d_i), starting time (a_i) and end time (b_i)
- Supply: generation capacity (g_i), cost (c_i)

Variable:

- X_{it}: 1 if charging demand i at time t

Multi-stage optimization problem – Online Optimization

Deterministic Version



Transportation Problem

$$\min_x \sum_t c_t \sum_i x_i + L \sum_i x_{i(T+1)}$$

$$s.t. \quad \sum_t m_{it} x_{it} + x_{i(T+1)} \geq d_i$$

$$\sum_i x_{it} \leq g_t$$

Bipartite graph links demands and time step

$$m_{it} = 1 \text{ if } a_i \leq t \leq b_i$$

Polynomial time algorithms

Future Work

- Scheduling problem:
  - Online optimization – make here-and-now decision hedge future uncertainty
  - Control decentralized decision through pricing
- Location problem:
  - Algorithms to solve large instances