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OPTIMAL CHARGING STRATEGIES FOR ELECTRIC VEHICLES CONSIDERING USER'S ELECTRICITY CONSUMPTION PATTERNS

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Motivation

- Environmental problem
  - Recently, various environmental problems, including global warming, are increasing and became a big issue
  - About 60% of anthropogenic greenhouse effect is caused by burning fossil fuels (Achtnicht 2012)
  - The main use of fossil fuels in the transport sector is one of the major source of CO_2 emissions
  - Korea is the seventh largest CO_2 emission in the world (Olivier et al. 2016)

- Korean government is planning to increase its share of environmentally friendly vehicles to 30% by 2025

Motivation

- Power grid system
  - Energy use is increasing as the industry grows due to economic development
  - Increase of environmentally friendly vehicles that need to be charged with electric power will increase the demand for energy

- Overload of the power system

The increase in EV increases electricity demand and consumer electricity bills

Prediction for the EV usage is necessary

Optimal charging strategy is required

Literature review

Use of electricity according to user activity patterns

A High-Resolution Stochastic Model of Domestic Activity Patterns and Electricity Demand (Widén and Wäckelgård 2010)

The optimal EV charging strategy for each user based on user activity big data from survey doesn't exist

Optimizing Smart Energy Control Strategies for Plug-in Hybrid Electric Vehicle Charging (Mets et al. 2010)

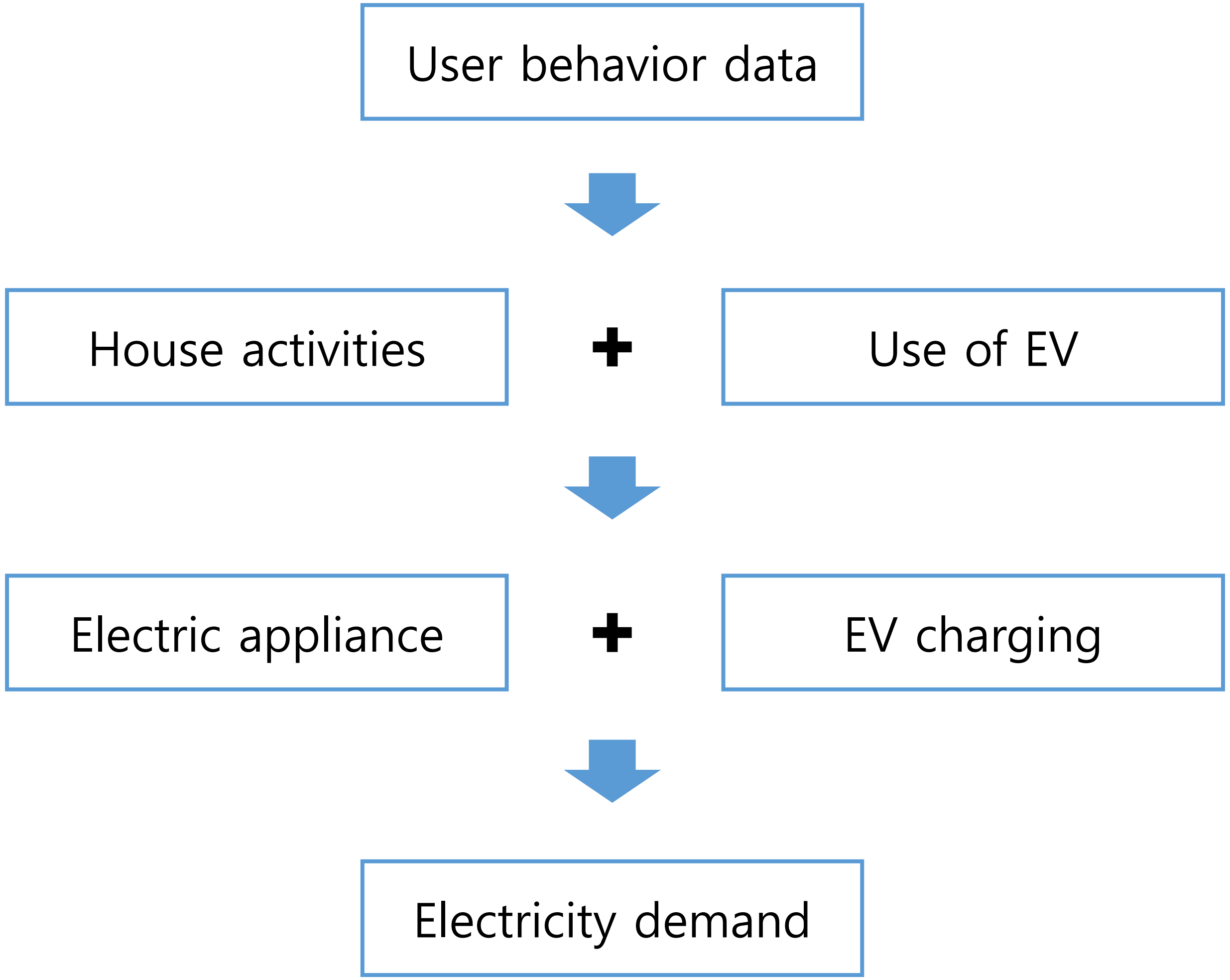
Risk Management of Smart Grids Based on Managed Charging of PHEVs and Vehicle-to-Grid Strategy Using Monte Carlo Simulation (Hashemi-Dezaki et al. 2015)

Optimal Scheduling of Renewable Micro-Grids Considering Plug-in Hybrid Electric Vehicle Charging Demand (Kamankesh, Agelidis, and Kavousi-Fard 2016)

Objective

- To find optimal charging strategy for each member on each situation and the effect of charging electric vehicles on residential power systems through the big data of residential activity
    - User activity converted from user behavior data
    - EV and electricity appliance usage are predicted through user activity
    - Optimal charging strategy for each user

Model


User behavior data
House activities
+
Use of EV
Electric appliance
+
EV charging
Electricity demand

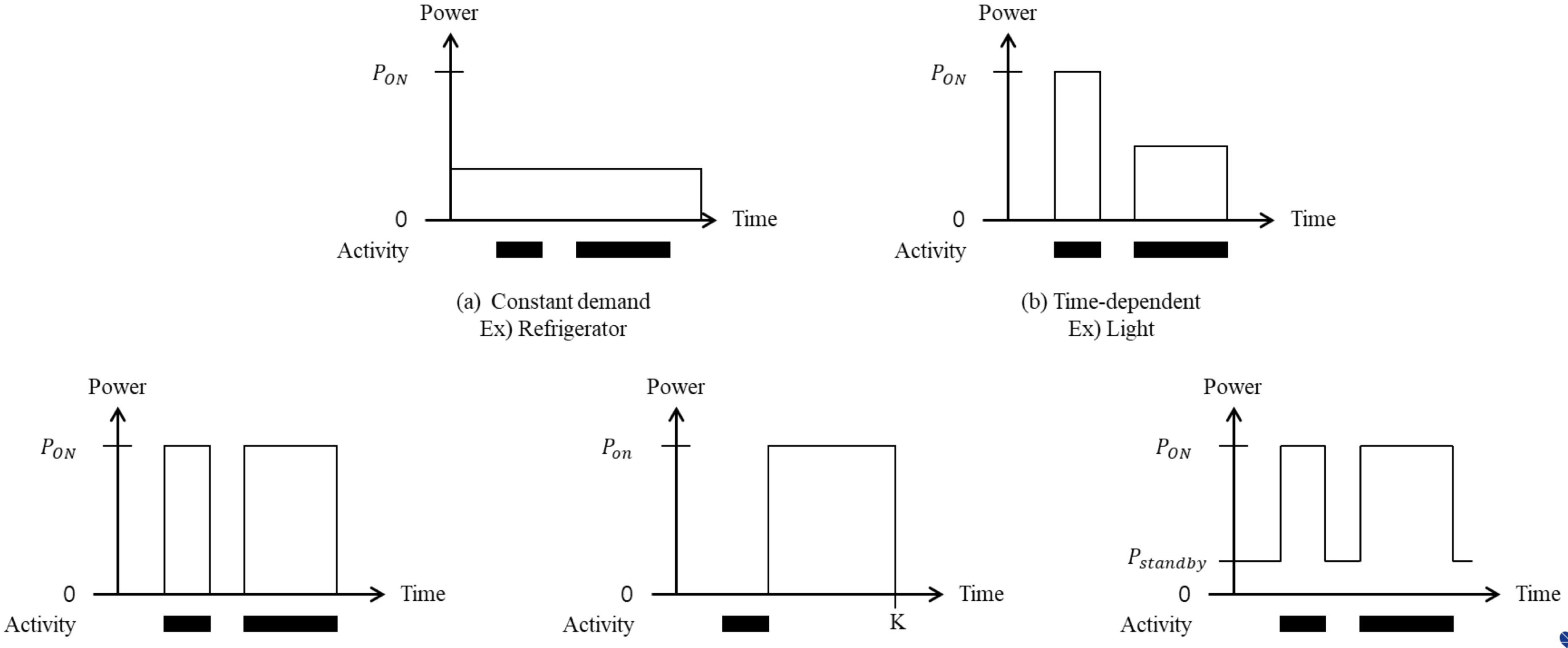
Model

- User behavior model
  - A user can do activity $a \in A = \{1, \ldots, N_A\}$
  - A is set of various residential activities
  - Each user m's activity on time t is $A_m^t = a$

Model

Introduction
Model
Case Study
Result
Conclusion

- Electrical appliance
  - Use of electrical appliance $e \in E = \{1, \dots, N_E\}$
  - Each appliance have different pattern depending on the type of device



(a) Constant demand
Ex) Refrigerator

(b) Time-dependent
Ex) Light

(c) Type A
Ex) Oven

(d) Type B
Ex) Washing machine

(e) Type C
Ex) Computer

Model

- Driving electric vehicle
  - The battery of the electric vehicle is consumed when the electric vehicle is used at the state “Moving by car”.
  - EV is assumed to use power P_{car} when it is operated.

$$P_{car} = \frac{v}{c} \ where \ v \ = \text{average driving speed}, c = \text{energy efficiency}$$

$$U_{car}^{m} = \frac{v}{c} \times D^{m} \ where \ D^{m} = \text{driving time a day}$$

Model

- Charging electric vehicle
  - The user uses a slow charger at home and a fast charger outside.
  - Electric vehicle is fully charged the amount of electricity consumed per day.
  - User try to charge in the house as much as possible and charges the remaining amount outside.

$$U_{car}^{m} = P_{slow} \times T_{home}^{m} + P_{fast} \times T_{outside}^{m}$$

$$P_{slow}, P_{fast} = \text{power of charger}$$

$$T_{home}^{m}, T_{outside}^{m} = \text{charging time}$$

Model

- Charging EV strategies (Kamankesh, Agelidis, and Kavousi-Fard 2016)
  - Uncontrolled strategy
    - Assumed that start charging as soon as user return home after using EV
  - Controlled strategy
    - Assumed that start charging at off-peak times
    - $f(t_{start}) = \frac{1}{b-a}$ $where\ a = \max(21, t_{arrive}) \leq t_{start} < b = 24$
  - Smart schemes strategy
    - Assumed that charging start time follow a normal distribution with an average of 1:00 and a standard deviation of 3
    - $f(t_{start}) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(-\frac{1}{2}\left(\frac{t_{start}-\mu}{\sigma}\right)^2\right)}$

Case study and input data

- Data
  - The data used for research was from the 2014 Korean Life Time Survey conducted by KOSTAT.
  - Data is an individual's daily behavior and consists of a total of 53976 datasets.
  - Each data shows which activity or movement was made in which place and its details in 10 minutes

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Case study and input data

- User activity
  - In this paper each person's behavioral data was classified into nine activities as shown in (Widén and Wäckelgård 2010) and, the use of vehicles is important, so "Moving by car" and "Moving other way" has been added.

Activity	a
Away	1
Sleeping	2
Cooking	3
Dishwashing	4
Washing	5
TV	6
Computer	7
Audio	8
Other	9
Moving by car	10
Moving by other way	11

Case study and input data

- Electrical appliance
  - The use of electrical appliances to obtain electricity usage is obtained as shown in (Widén and Wäckelgård 2010).

Appliance	e	Type	a
Cold appliance	1	Constant demand	
Lighting	2	Time-dependent	2-9
Cooking	3	Type A	3
Dishwashing	4	Type B	4
Washing	5	Type B	5
TV	6	Type C	6
Computer	7	Type C	7
Stereo	8	Type C	8
Additional	9	Type A	9

Case study and input data

- Electric vehicle
  - U_{car} is amount of electricity that EV use
  - v is average driving speed of Korea
  - c is from official energy efficiency of Hyundai Ioniq which is the best-selling electric vehicle in Korea

$$U_{car} = \frac{v}{c} = 4.973kW$$

$$v = 31.33km/h$$

$$c = 6.3km/kWh$$

$$P_{slow} = 7kW$$
$$P_{fast} = 50kW$$

Case study and input data

- Electricity rate
  - Timeslot

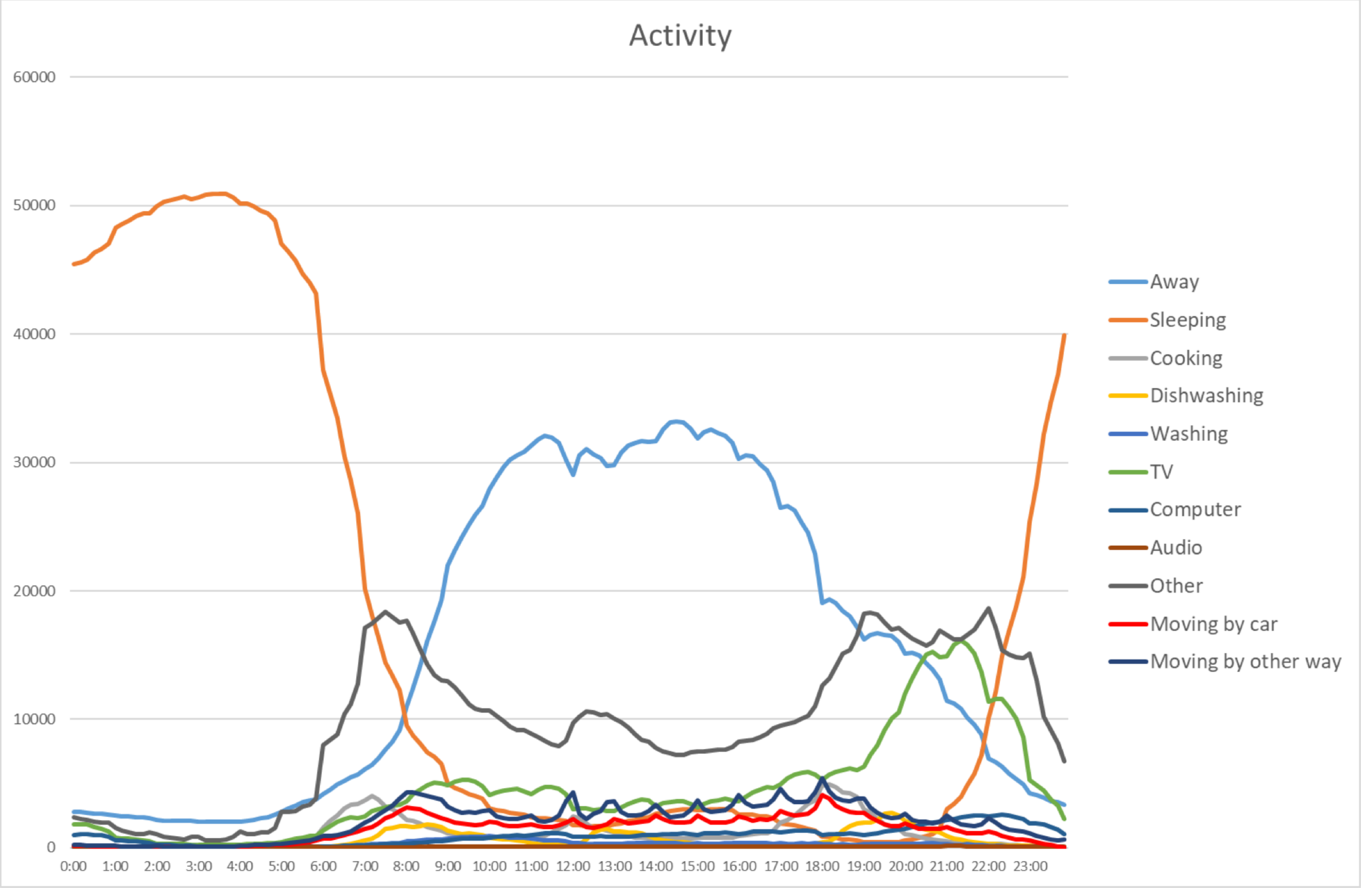
Time period	Summer (Jun. ~ Aug.)	Spring / Fall (Mar.~May. / Sep.~Oct.)	Winter (Nov. ~ Feb.)
off-peak load	23:00 ~ 09:00	23:00~09:00	23:00~09:00
mid-load	09:00~10:00 12:00~13:00 17:00~23:00	09:00~10:00 12:00~13:00 17:00~23:00	09:00~10:00 12:00~17:00 20:00~22:00
peak-load	10:00~12:00 13:00~17:00	10:00~12:00 13:00~17:00	10:00~12:00 17:00~20:00 22:00~23:00

  - Price (KRW / kWh)

Time period	Summer	Spring / Fall	Winter
off-peak load	57.6	58.7	80.7
mid-load	145.3	70.5	128.2
peak-load	232.5	75.4	190.8
Fast charging	173.8 (discounted from 313.1 by subsidy)		

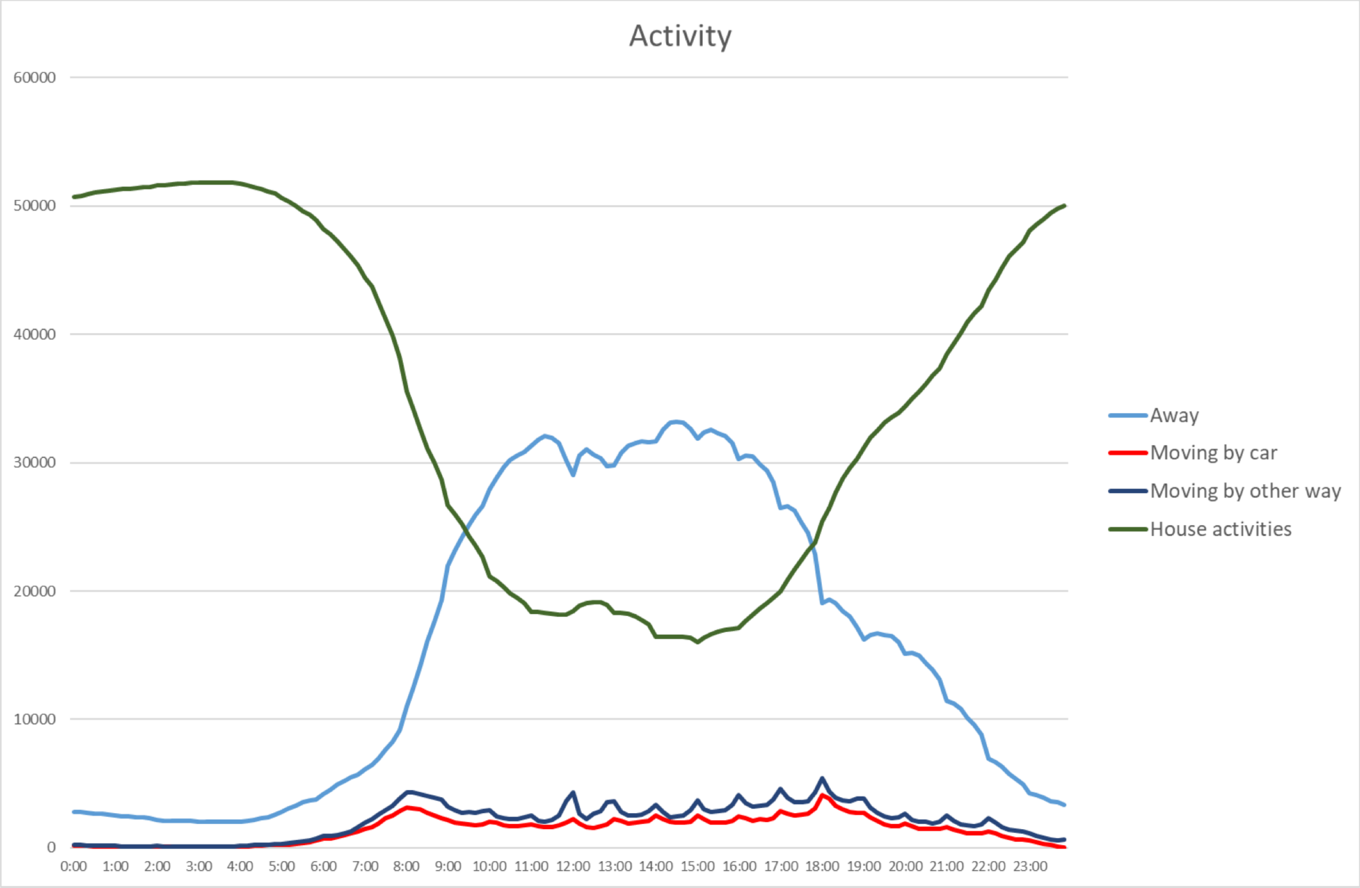
Result

- Activity at each time
  - Number of user in each activity



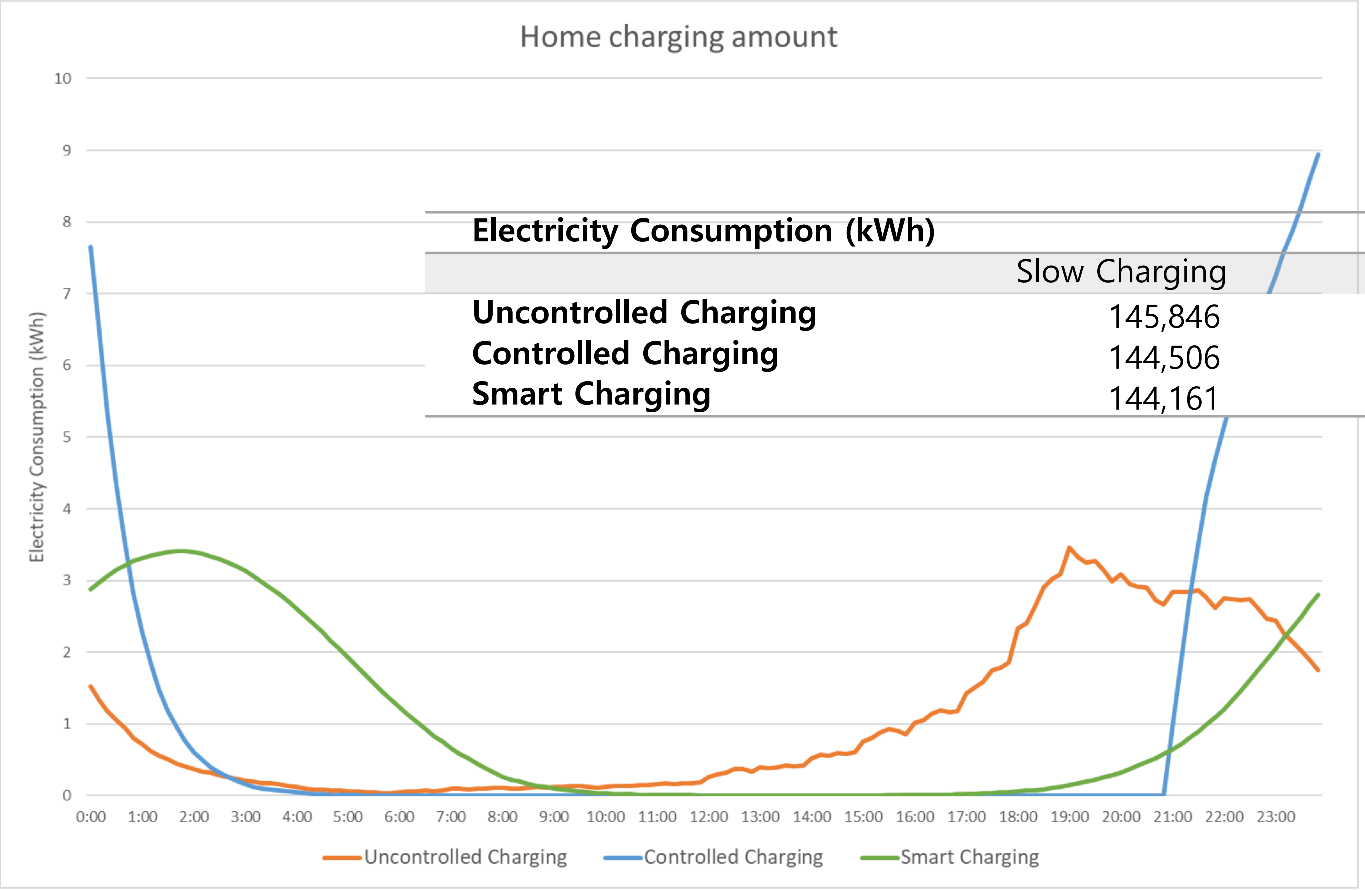
Result

- Activity at each time
  - House activities and Moving



Result

- Home charging amount
  - Charging amount is a lot in the evening time when uncontrolled charging



Electricity Consumption (kWh)		
	Slow Charging	Fast Charging
Uncontrolled Charging	145,846	1,826
Controlled Charging	144,506	3,167
Smart Charging	144,161	3,511

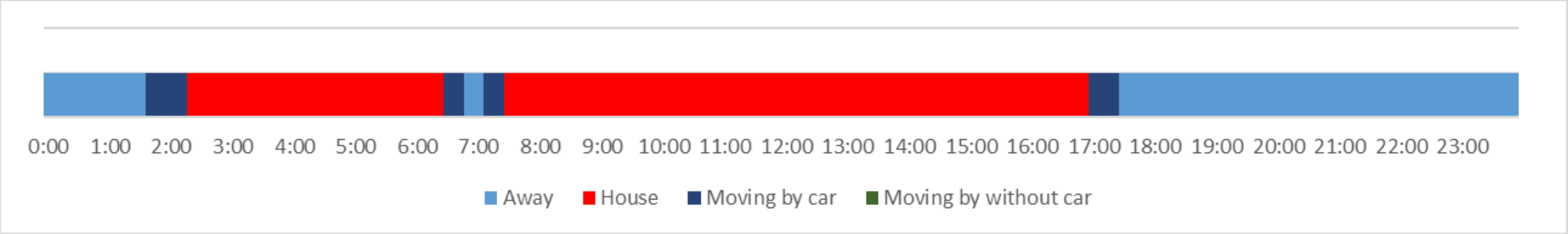
Result

- Ratio of the optimal strategy
  - Most of people choose smart charging
  - Smart charging is relatively small in Spring and Fall, it is because peak-time and non peak-time price has little difference

	Uncontrolled Charging	Controlled Charging	Smart Charging
Summer	5.77%	9.91%	84.32%
Spring / Fall	6.13%	17.81%	76.06%
Winter	6.30%	8.37%	85.33%
Total	6.10%	12.69%	81.21%

Result

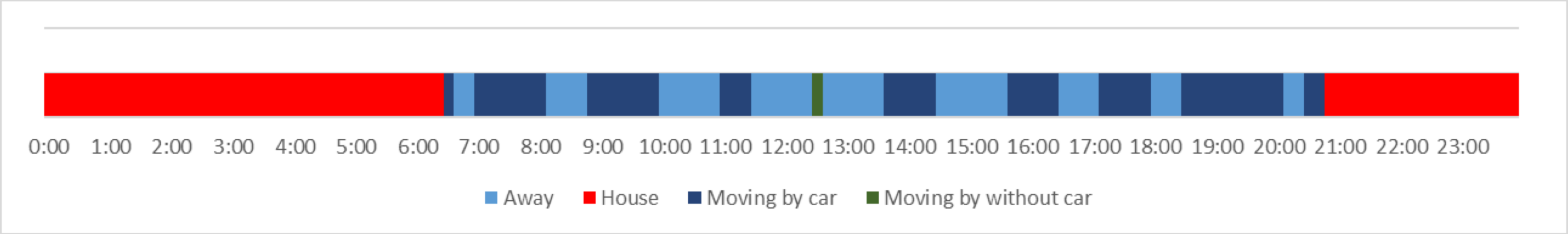
- User whose optimal is uncontrolled charging strategy
  - Who use EV little and return back home early



Charging Strategy	Price
Uncontrolled Charging	599
Controlled Charging	843
Smart Charging	680

Result

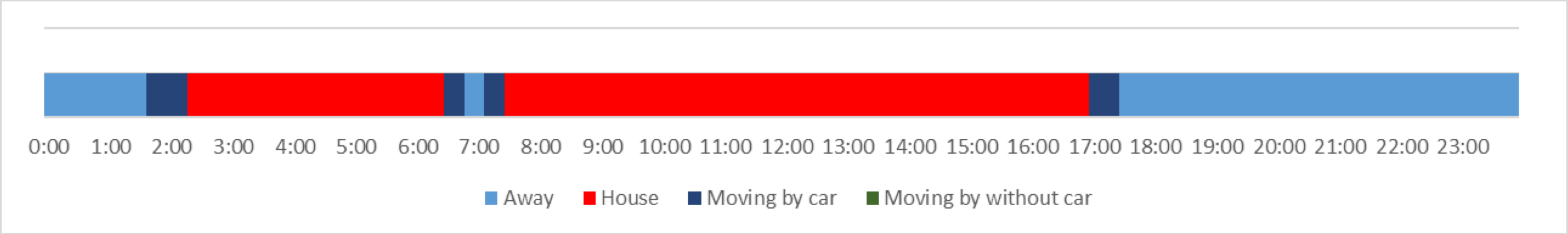
- User whose optimal is controlled charging strategy
  - Who use EV a lot and return back home late



Charging Strategy	Price
Uncontrolled Charging	2820
Controlled Charging	1720
Smart Charging	1845

Result

- User whose optimal is smart charging strategy
  - Who use EV normally and return back home at evening



Charging Strategy	Price
Uncontrolled Charging	1667
Controlled Charging	1218
Smart Charging	1049

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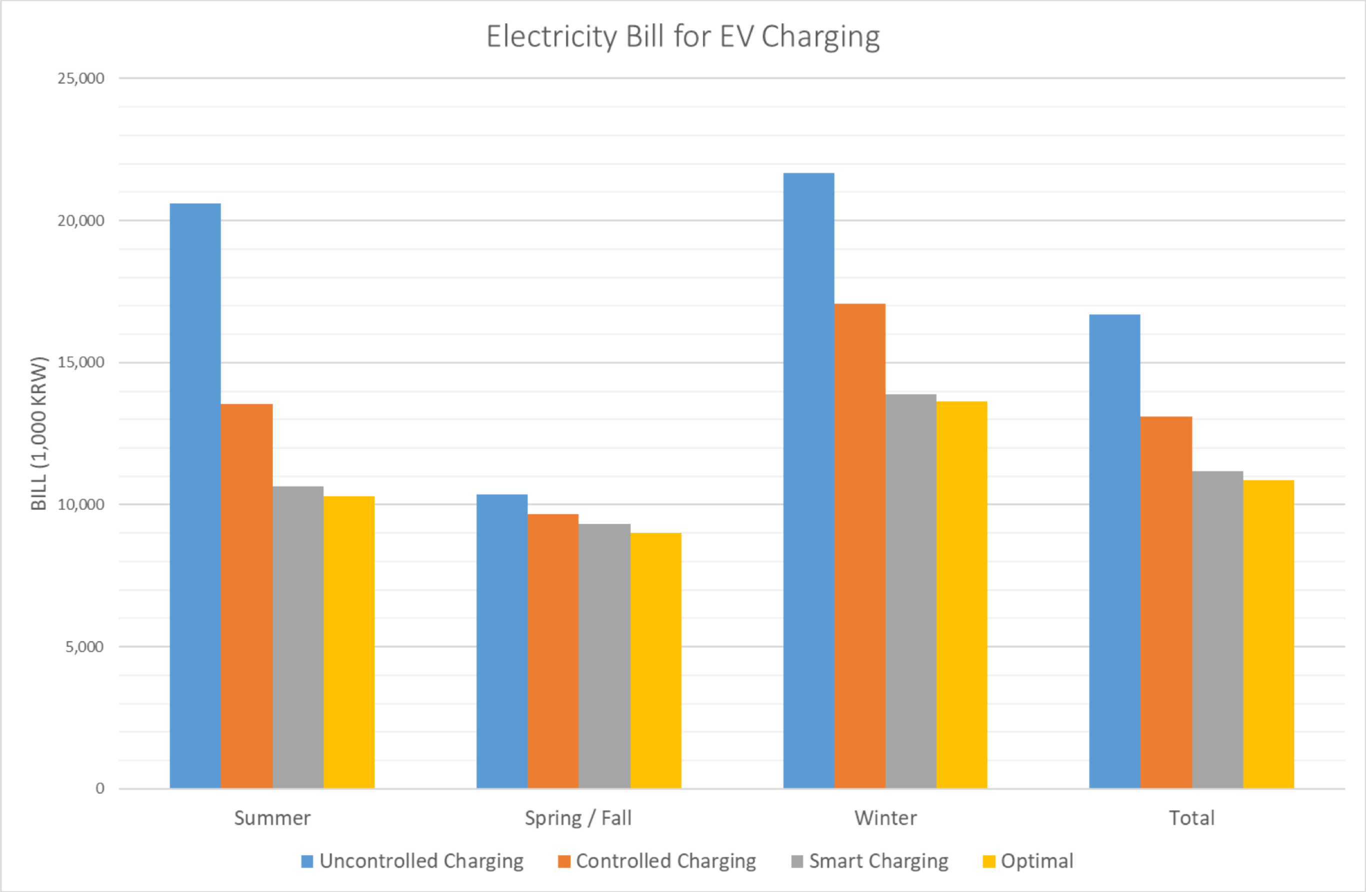
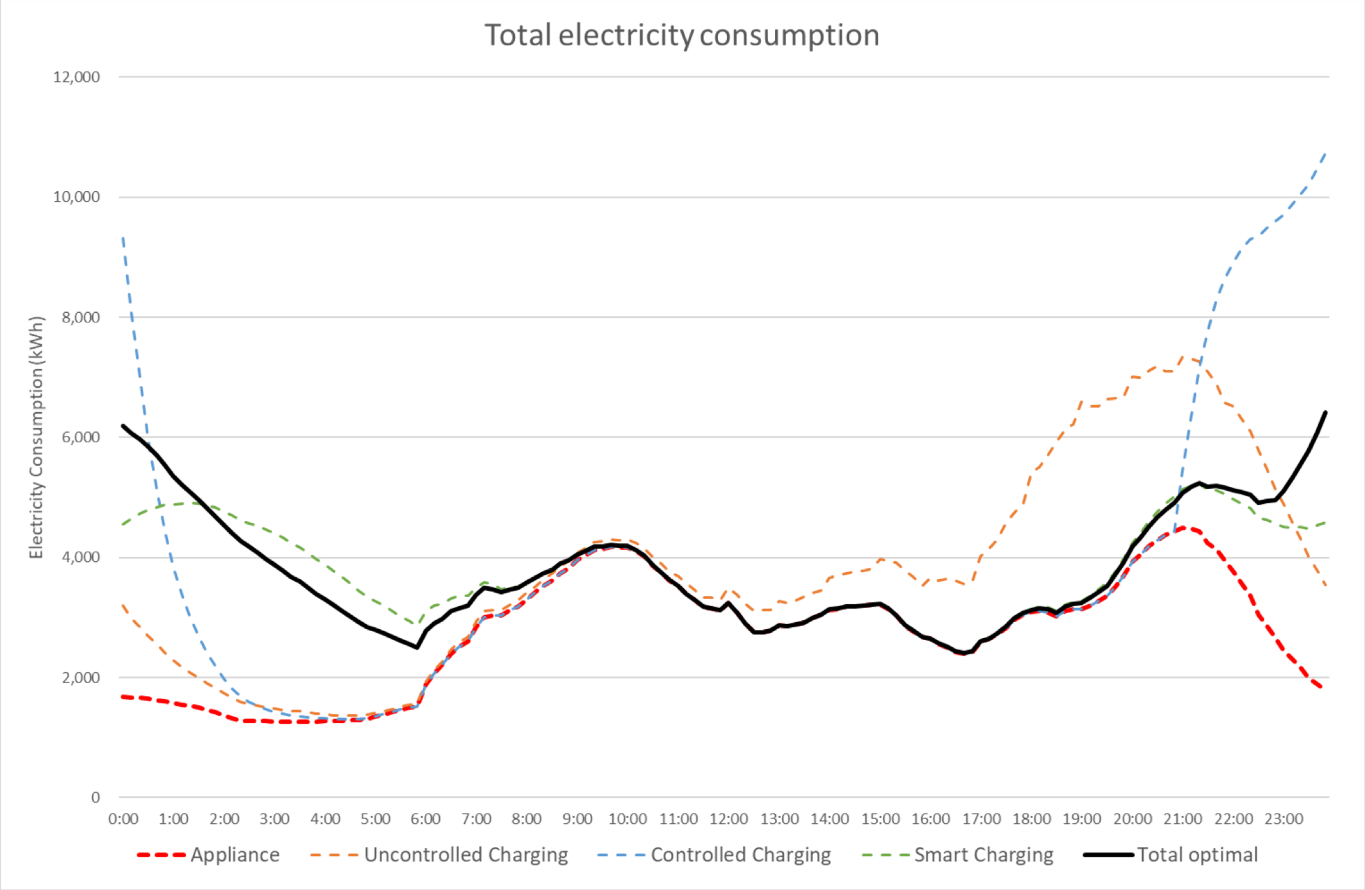
Result

- Total Electricity Bill for EV Charging
  - Summer and Winter has large difference



Result

- Total electricity consumption
  - Optimal strategy use most electricity for charging at night time



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Result

- Peak-to-average-ratio
  - Smart charging strategy and optimal charging strategy has lower PAR than uncontrolled charging strategy and controlled strategy.

	PAR
Appliance only	1.63
Uncontrolled charging	1.95
Controlled charging	2.85
Smart charging	1.39
Total optimal	1.70

Conclusion

- The electricity amount for EV charging is predicted from user behavior data
- Optimal charging strategy depends on behavior pattern
- Electricity bill of the household is reduced when every user chose their own optimal charging strategy than the case where the user's charging strategy is uncontrolled or all choose same strategies.
- PAR was lowered when user choose own optimal charging strategy than uncontrolled Charging
- In the future research,
  - model to select more individualized strategies such as different parameters for each person rather than setting the parameters of the three charging strategies as fixed values
  - select optimal charging strategy through interaction between electric vehicle users.

THANK YOU

Q & A