Bidding Agent for Electric Vehicles in Peer-to-Peer Electricity Trading Market considering uncertainty

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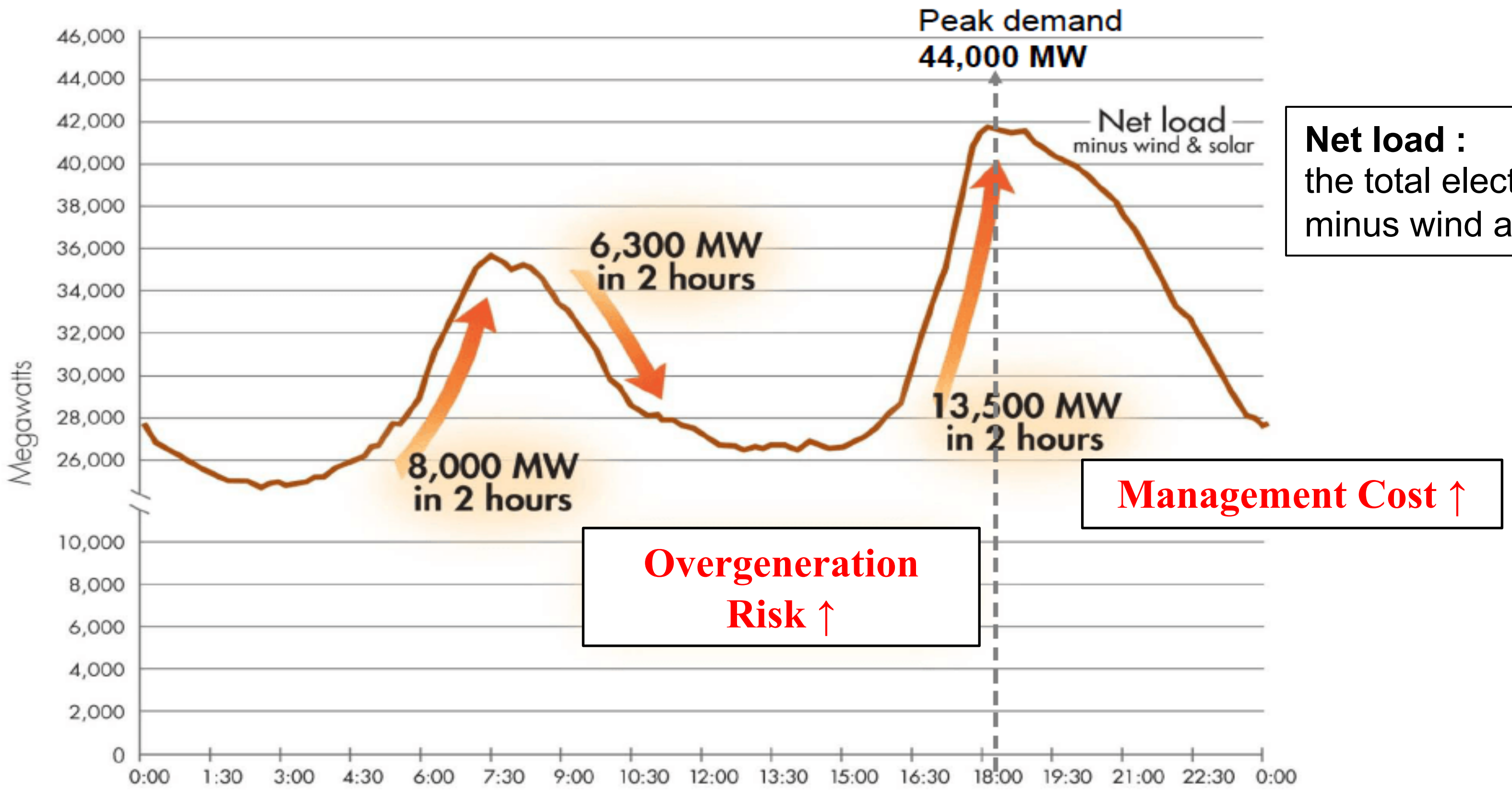
Outline

1. Background and Purpose
2. P2P Electricity Trading Market Simulator
3. EV Automatic Bidding Agent
4. Case Study
5. Conclusion

As the solar generation expands,
the electricity net demand sharply fluctuates between day and night.



Net load :
the total electric demand in the system minus wind and solar generation

Fig. 1. the duck curve shows steep ramping needs and overgeneration risk (“Fast Facts” CAISO)

P2P electricity trading market is expected to automatically level the net demand through day and night

P2P electricity trading market

- **Electricity network** that realizes **two-way trading**
- **Automatic bidding agent** will bid to the **future market**

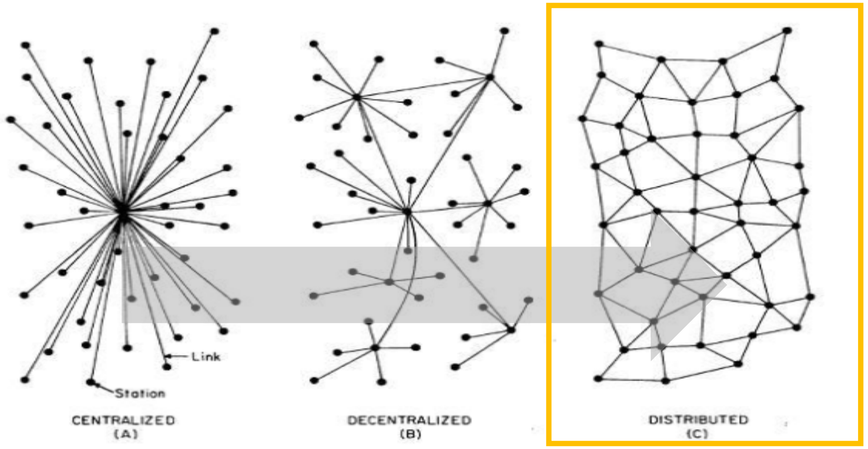


Fig.2. Trends of electricity system

Power Generation	Centralized e.g. Thermal	▶	Distributed e.g. Solar generation
Trading Flow	One-way Generator→Costumer		**Two-way** **User ⇔ User**

Battery storage users are important.

- **Electricity demand can be leveled by Market Principle**

(PV : photovoltaic)

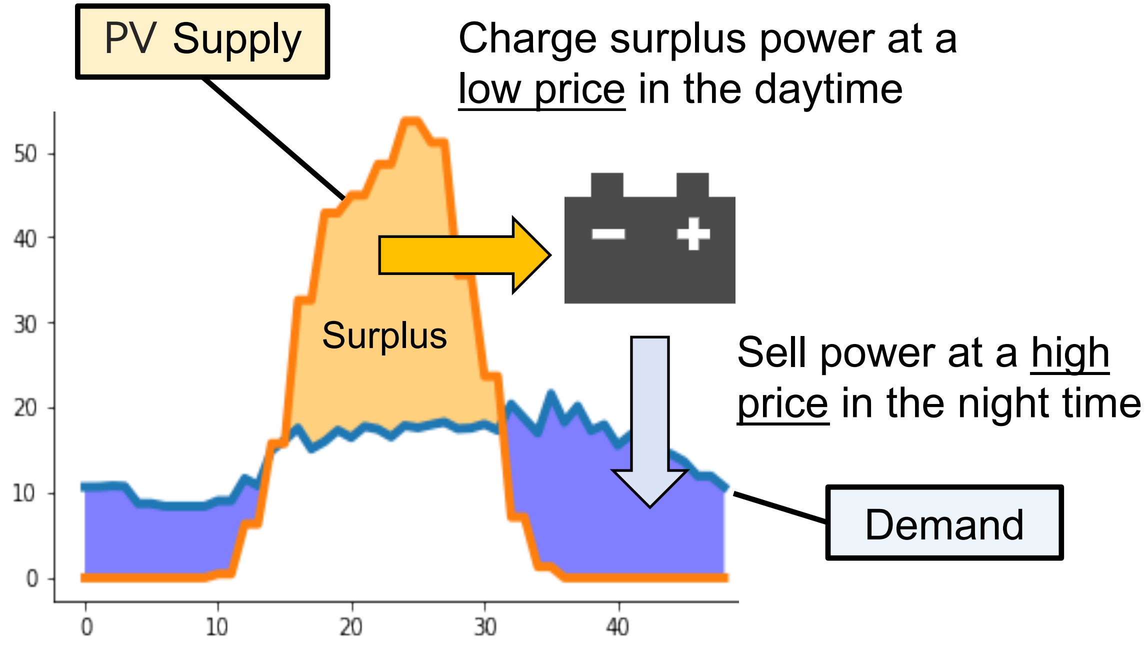


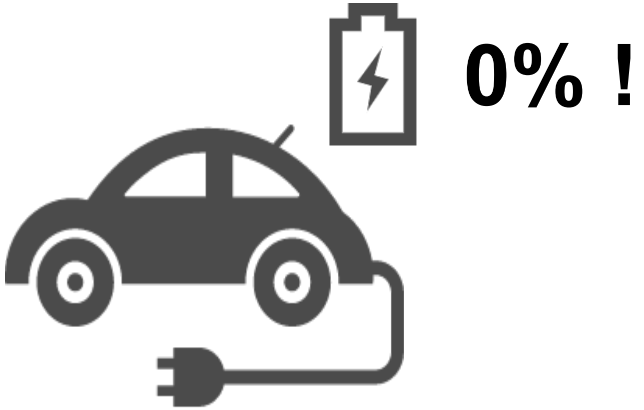
Fig.3. How the battery storage can level the net power demand

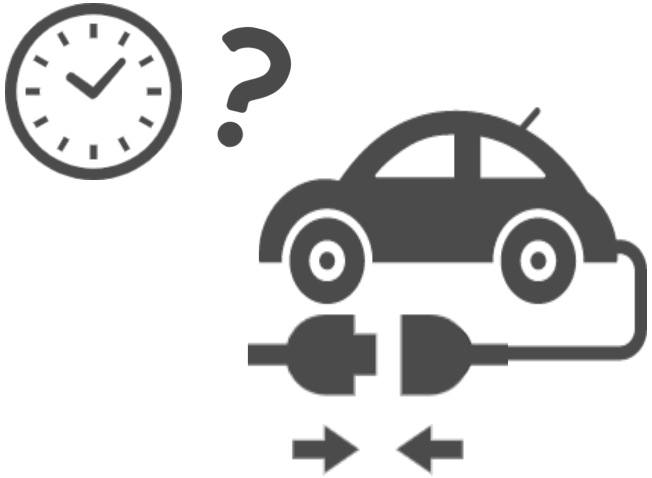
Attention is on Electric Vehicles (EV).
They are expected to participate in the P2P electricity trading market as battery storages to level the net demand.

EV is useful not only as a Car, but also as a Battery Storage.

EVs should be utilized to level the net demand !

However,
EV's driving should not be hindered by trading electricity, vice versa.

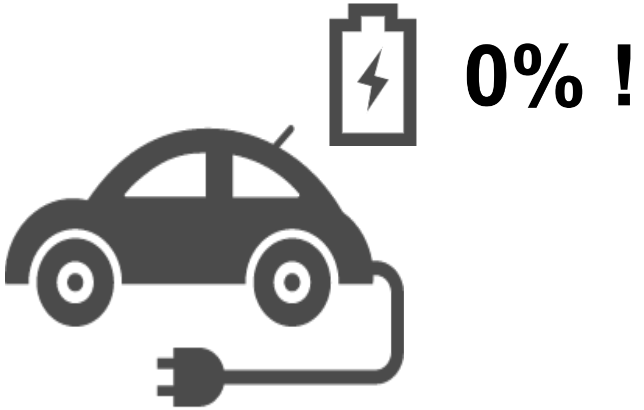


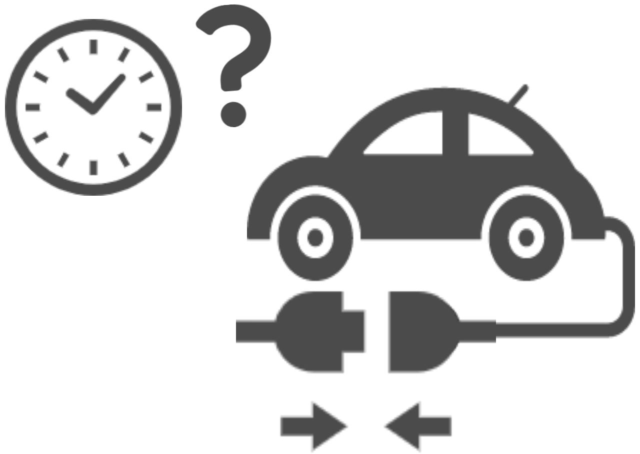


Is the remaining electricity storage enough to drive ?

Is the EV can be connected to grid in the future market time zone ?

However,
EV’s driving should not be hindered by trading electricity, vice versa.





The future driving is uncertain,
so it’s not easy to trade electricity not hindering them.

Need to design EV automatic bidding agent that work in actual world.
→ no paper addressed to the uncertainty of EV driving pattern.
(only evaluating the ideal effect)

Purpose & Approach

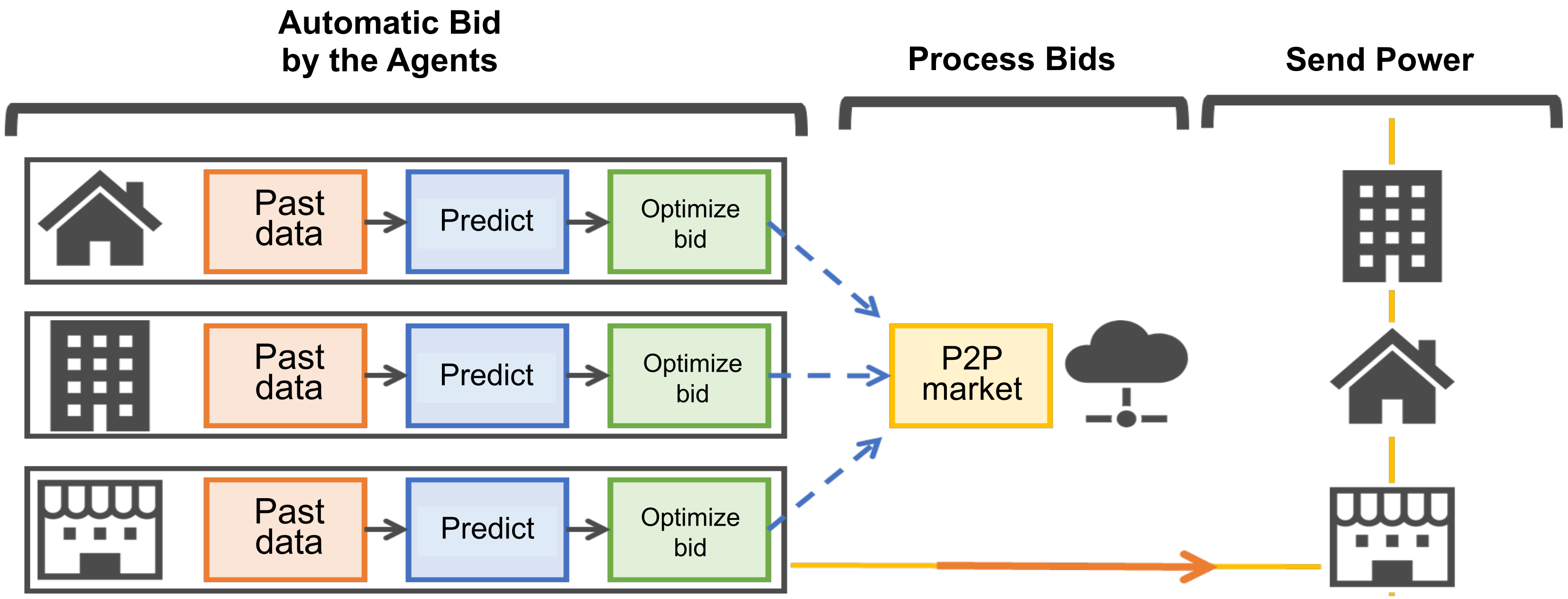
Purpose

1. Propose the design of EV automatic bidding agent, considering the uncertainty of driving pattern.
2. Evaluate the effect of the proposed EV agent, by the simulation of P2P market based on actual EV driving data.

Approach

1. Construct the P2P market simulator.
2. Design the EV bidding agent.
3. Case study based on the actual data.

How the P2P electricity market simulator works



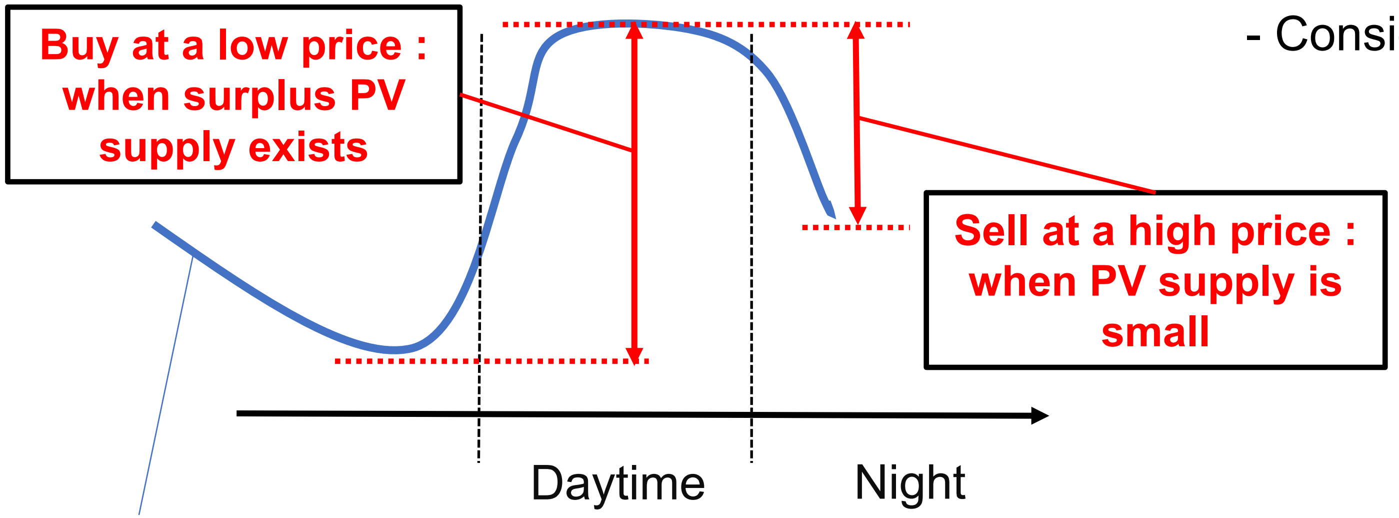
- Future market： A 24-hour futures market that deals with 30 minutes of power.
  The execution method is Continuous Double Auction.

- Bidding agent： Each participant have and automatically generates a bid.
  Agent can bid on all 48 markets that are open (24 hours/30 minutes).

Requirement Definition of EV bidding agent

Maximize profits

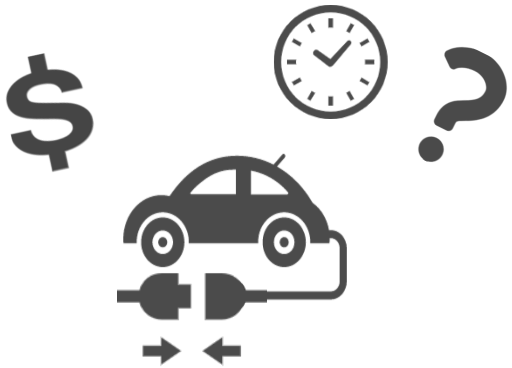
- Buy power at a low price in the daytime.
- Sell power at a high price in the night.



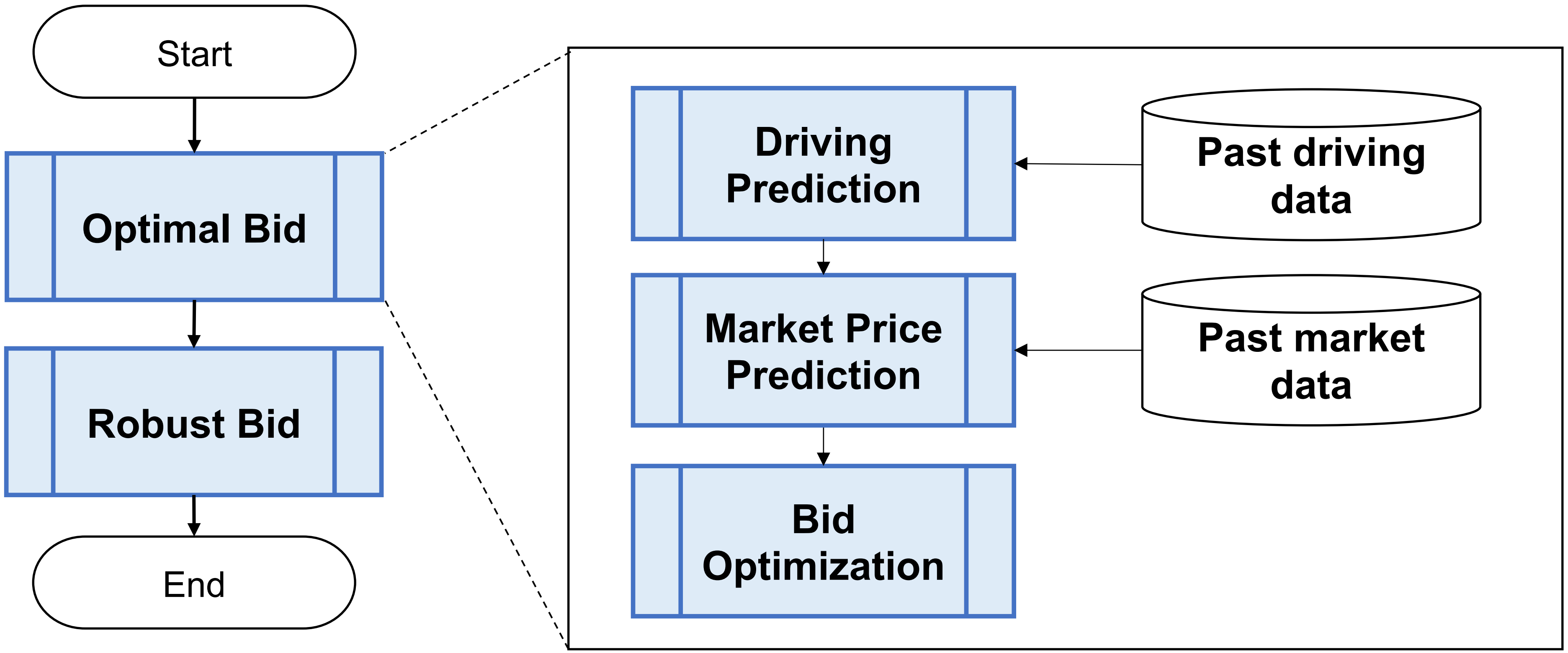
State of Charge (SOC)
= remaining storage

Robustness; consider uncertainty not to hinder future driving

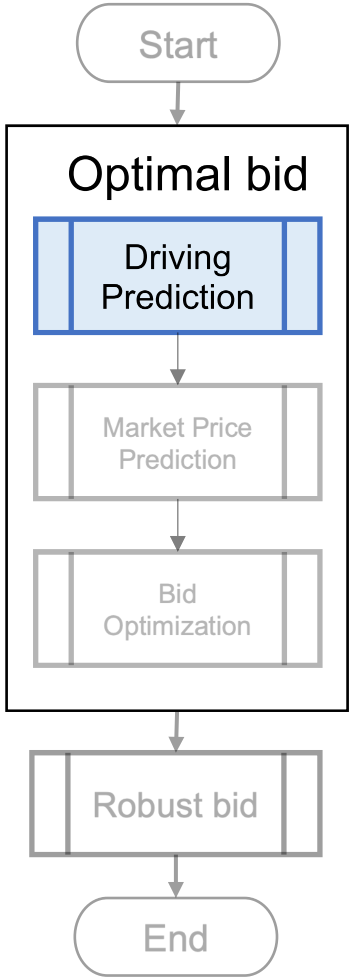
- Consider uncertainty of future driving.
- Consider uncertainty of future market price.



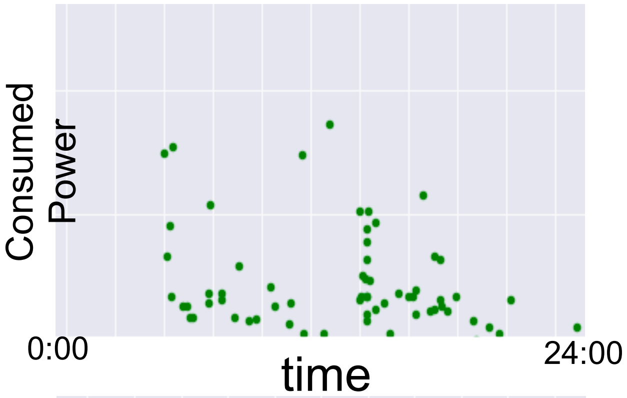
Flowchart of the proposed EV bidding agent



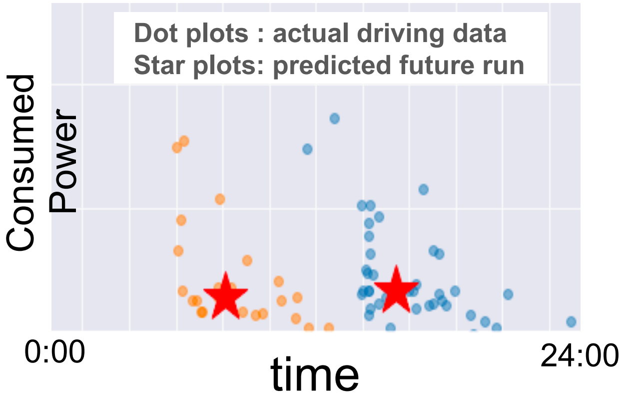
Driving Prediction



A. Driving time, power consumption



A-1.
For each past run, calculate departure time and consumed power.

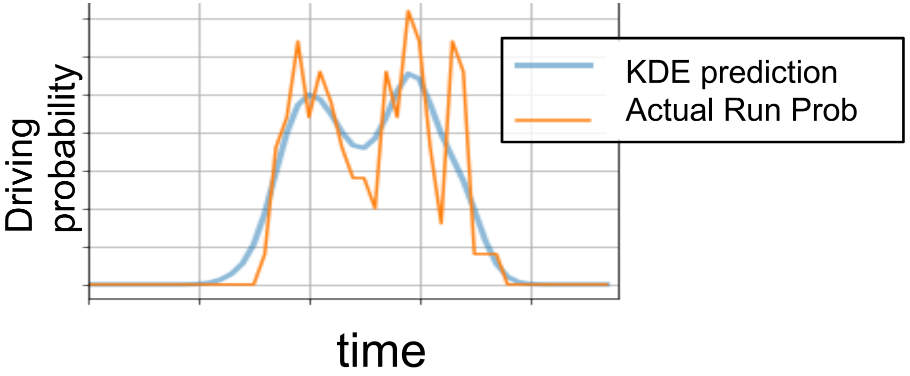


A-2.
Do clustering for departure time.
（K = number of runs per day）

A-3.
Median of each cluster is prediction

B. Driving Probability

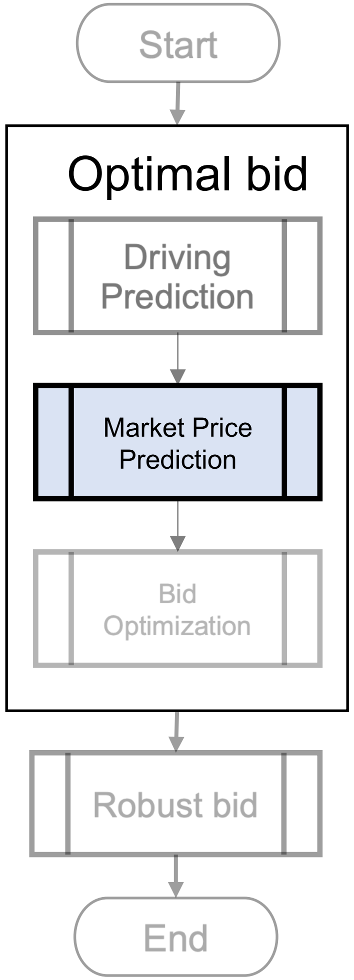
→ Considering uncertainty of driving



B-1.
For each past run, calculate running probability

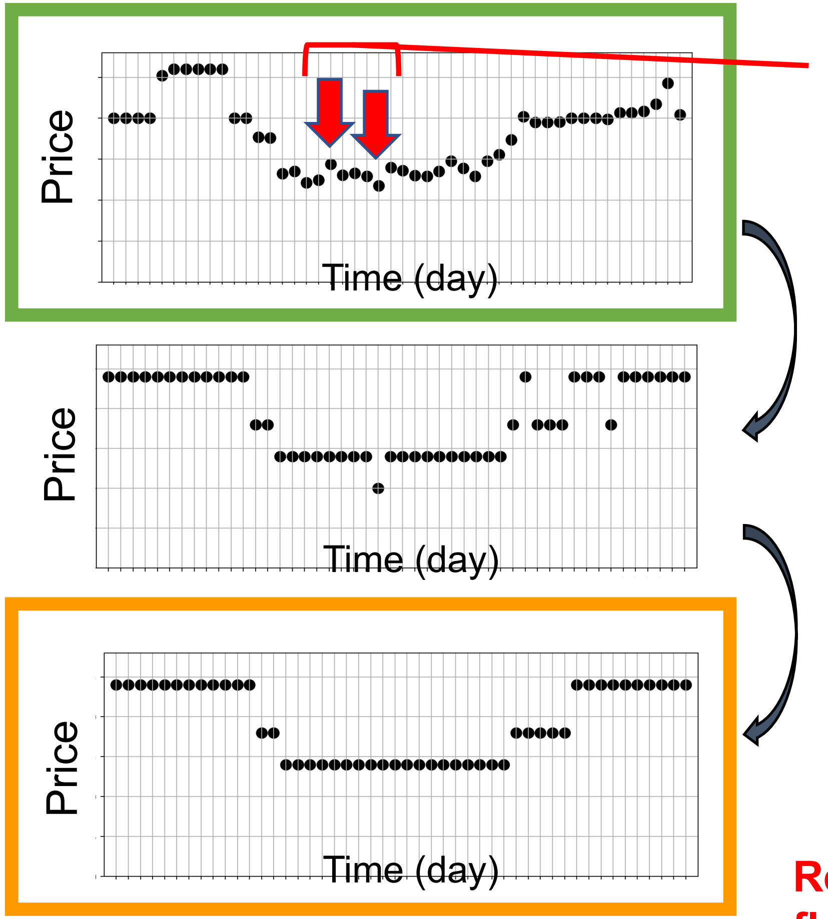
B-2.
By Kernel Density Estimation(KDE), predict the future driving probability

Market Price Prediction



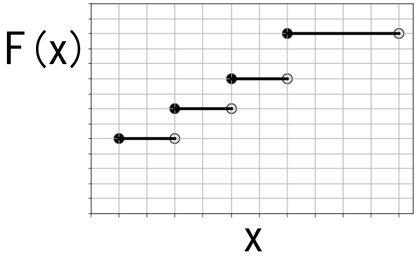
Day 0 :
Actual Market Price
(average of each time zone)

Day 1 :
Predicted Market Price
(each time zone)



Aiming for small price fluctuations is highly uncertain and can easily lead to losses.

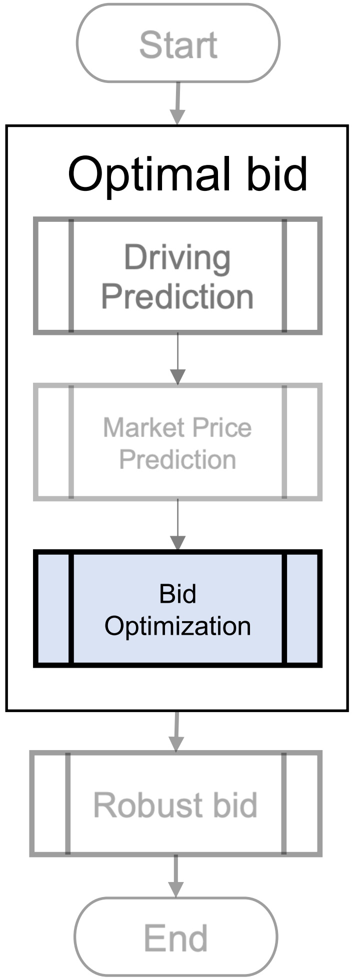
Apply Step Function



remove of outliers

Reflects only the global fluctuation of price

Bid Optimization by the Linear Programming method :
optimize bid amount for each future market



Consider Uncertainty !

(1) Expenditure
→ Maximize Profits

(2) Penalty for the bid when driving probability is high.

Objective function

$$\min. \sum_{i=mn}^{mn+48} [\{buy_i - sell_i\} * pred\_price_i + C * \{buy_i + sell_i\} * \{run\_prob_i + \varepsilon\}]$$

(1) ← From Market Price Prediction

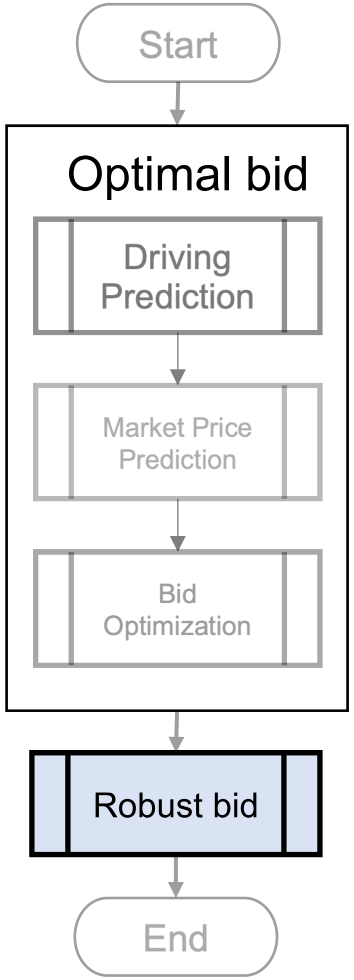
(2) ← From Driving Probability Estimation

Constrains

s.t.	$soc_{i+1} = soc_i + buy_i - sell_i - cons\_pred_i + contracted_i$	Relations between variables
	$buy_i = 0, sell_i = 0 \quad (if\ \ run\_pred_i = true)$	Don't bid at the predicted driving time
	$soc_i \geq soc\_lower\_limit_i$	SOC should be above the lower limit
	$soc_i \leq soc\_higher\_limit_i$	SOC should be under the higher limit

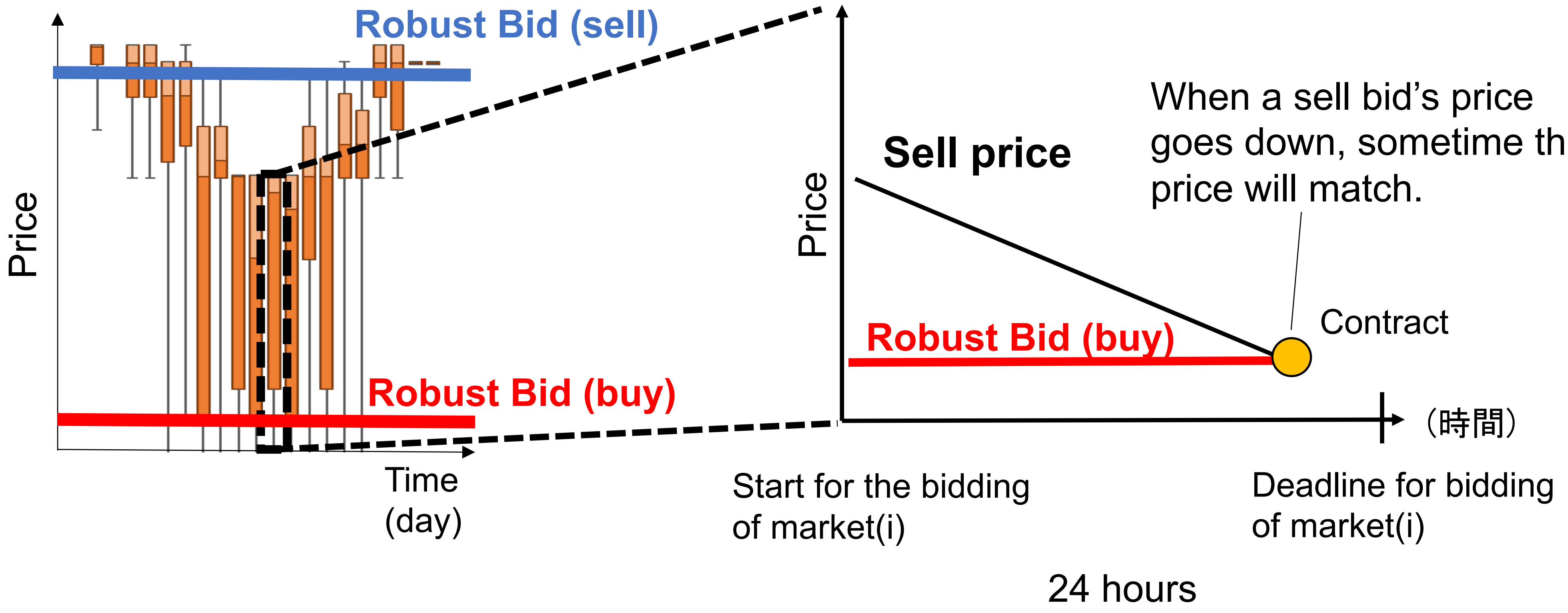
→ Bid Price would be around the predicted market price (linearly changes as the time gets closer to the time zone of the market(i).

Robust Bid :
it is passive, only contracts when it's a lucky condition.

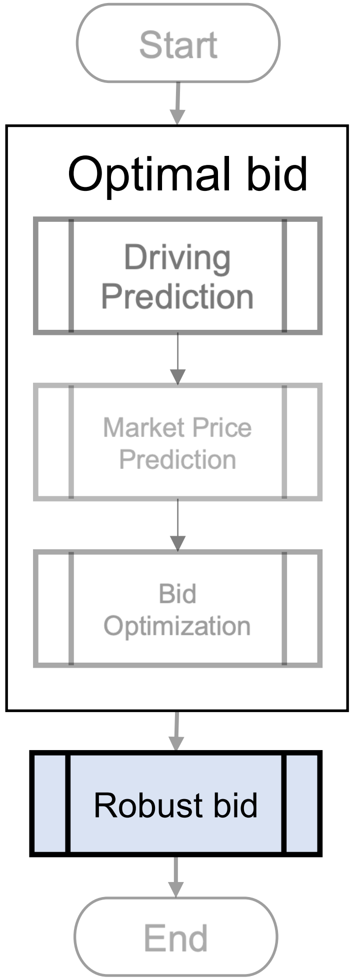


- Buy if the price is lower than a certain set price
- Sell if the price is higher than a certain set price

Even if it's not the time of "optimal" bid, it'll be possible to buy when the market price is low, and sell when the market price is high.

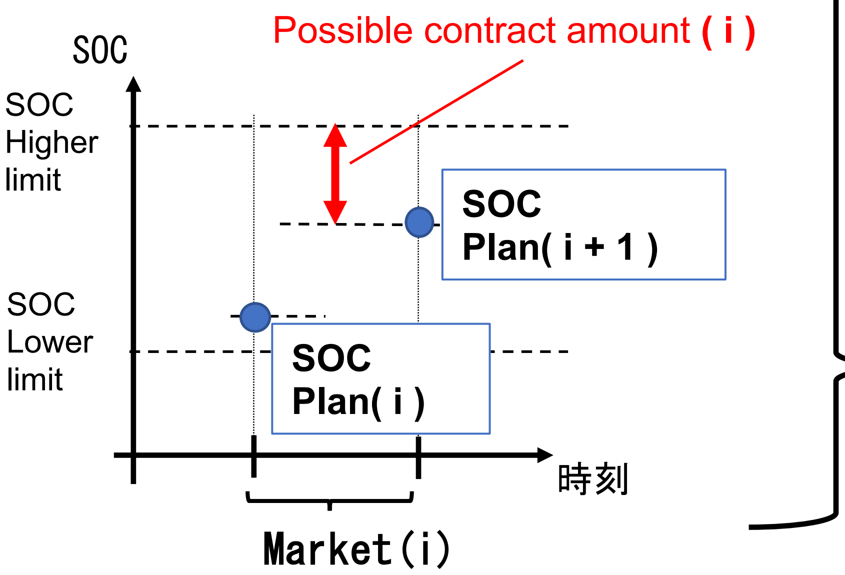


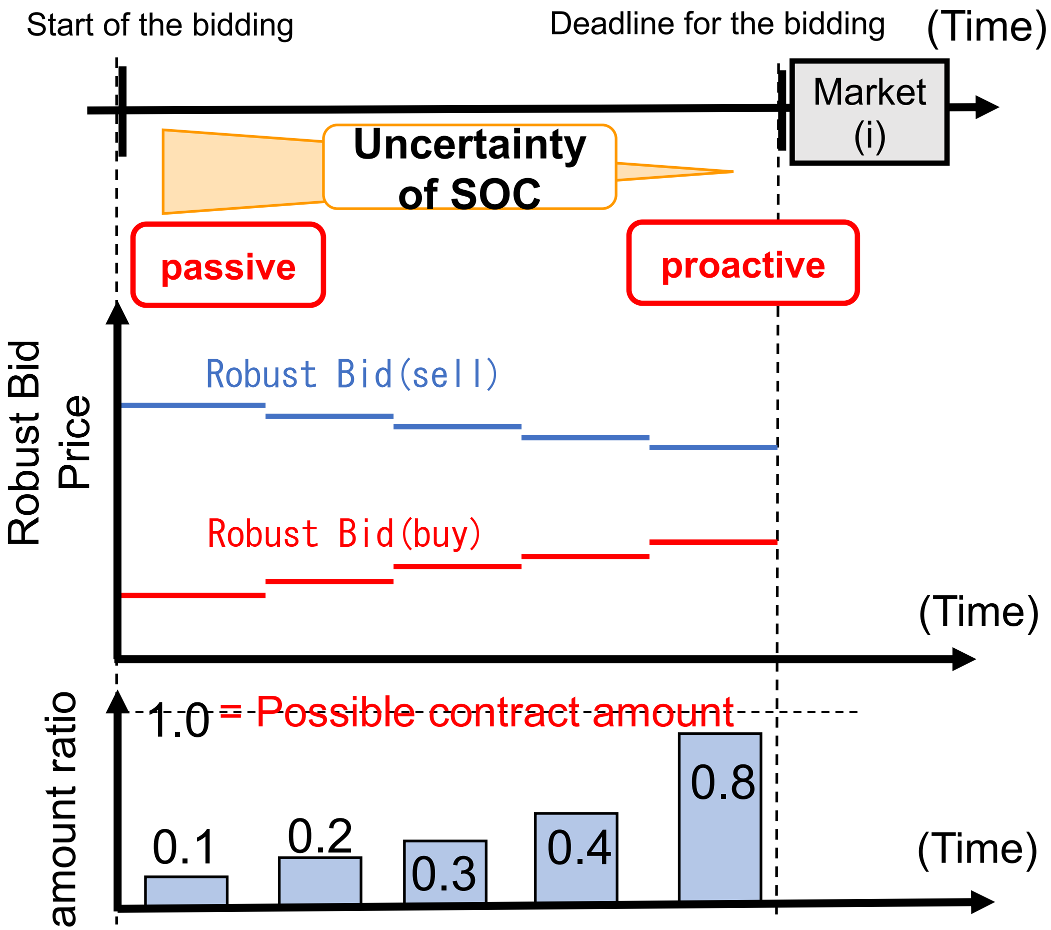
Robust Bid : It's not limitless.
Should not exceed the battery storage, lack of power.



Possible contract amount

→calculate based on the result of optimization phase



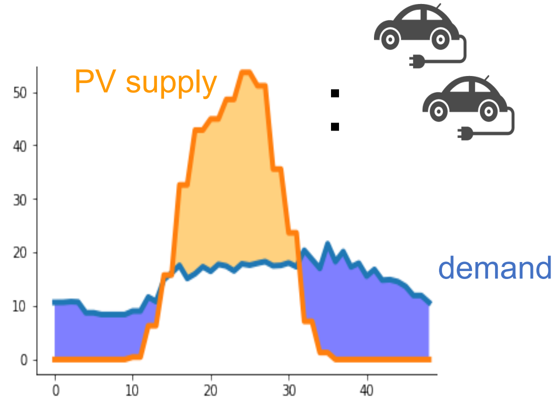


Case Study

	span	House Agent	PV Agent	Total demand [kWh/day]	Total supply [kWh/day]	Electric power system	EV	EV/Surplus Ratio	Item(2) of the minimization formula
Case1	7days	2	2	720	720	1	27	100%	X
									O
Case2	7days	10	10	550	530	1	①20	100%	O
				615	615		②20		
				530	530		③20		
				576	576		④20		
				533	533		⑤20		
				526	526		⑥20		
				546	546		⑦20		
				550	550		⑧20		
				499	499		⑨20		
Case3	7days	4	4	1299	1299	1	27	55%	O
				1157	1157			62%	
				1015	1015			71%	
				873	873			83%	
				731	731			100%	
				588	588			125%	
				446	446			166%	
				303	303			250%	
				159	159			500%	

EV/supply ratio

$$\frac{\sum_{EV} BatteryStorage\_i}{\sum_{Day} SurplusPowerAmount}$$



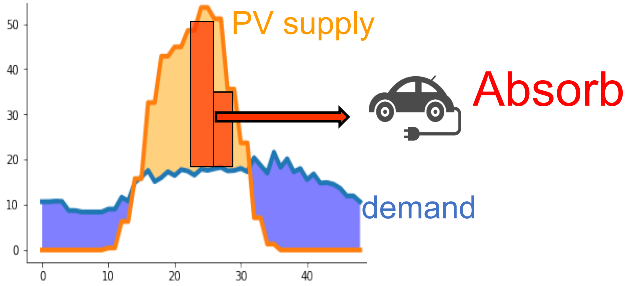
Metrics

EV Profits

$$\sum_{EachContract=i}(SellPrice_i \; - BuyPrice_i) \; - \sum_{MissedContract}(ContractAmount \; * PenaltyPrice)$$

Surplus Power Absorption Rate

$$\frac{\sum_i AbsorbedPowerByEV_i}{\sum_{Day} SurplusPowerAmount}$$



If EV/surplus Ratio >= 100%,
Ideally, Surplus Power Absorption Rate = 100%

II

If EV battery storage is more than PV surplus,
Ideally, all surplus power would be absorbed by EVs.

Case 1

We compared the existence of item(2) of the objective function in Optimization Phase.
→ see, whether considering driving probability works.

(1) Expenditure
→ Maximize Profits

(2) Penalty for the bid when driving probability is high.

Objective function

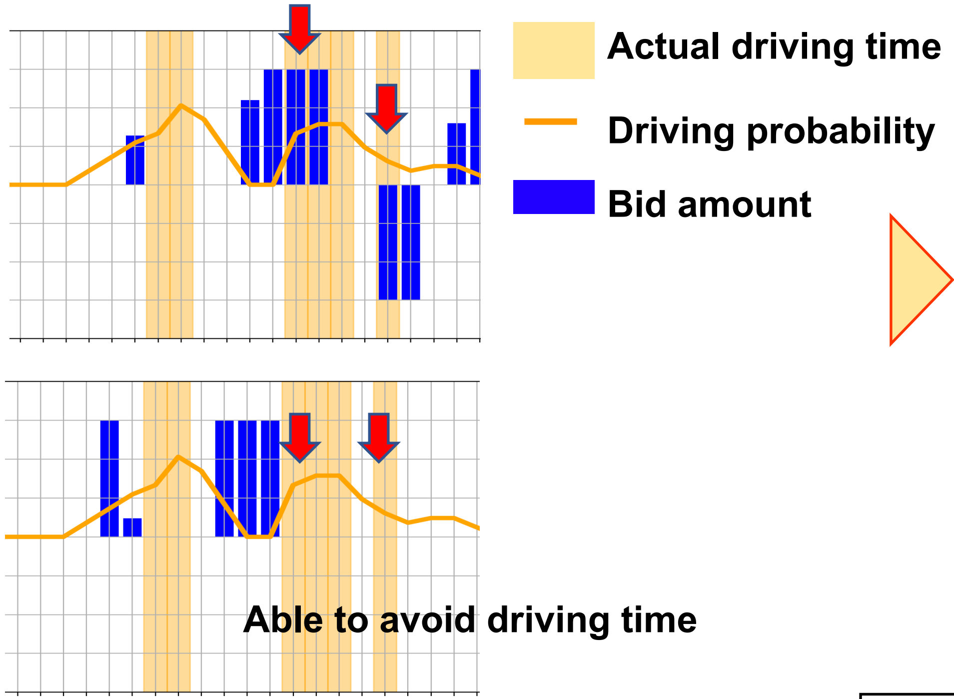
$$\min. \sum_{i=mn}^{mn+48} [\underbrace{\{buy_i - sell_i\} * pred\_price_i}_{(1)} + \underbrace{C * \{buy_i + sell_i\} * \{run\_prob_i + \varepsilon\}}_{(2)}]$$

Case 1 : result

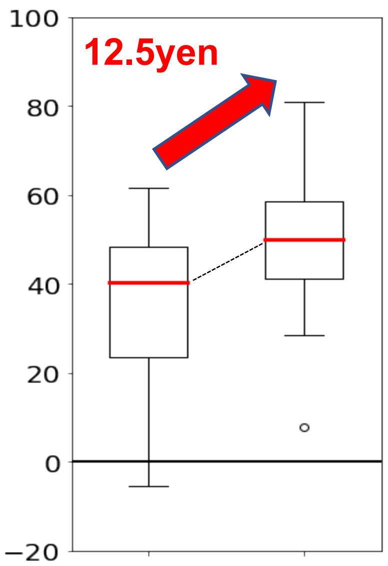
It was more possible to avoid transaction during the driving time.

EV's profit and Surplus Power Absorption Rate improved.

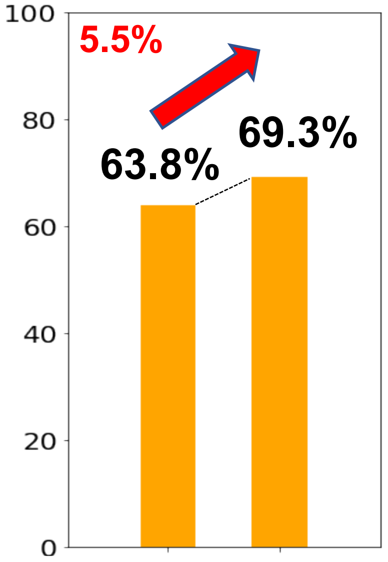
Item (2)	
	×
	○



EV's Profits [yen/week]
(for 1kWh of battery)

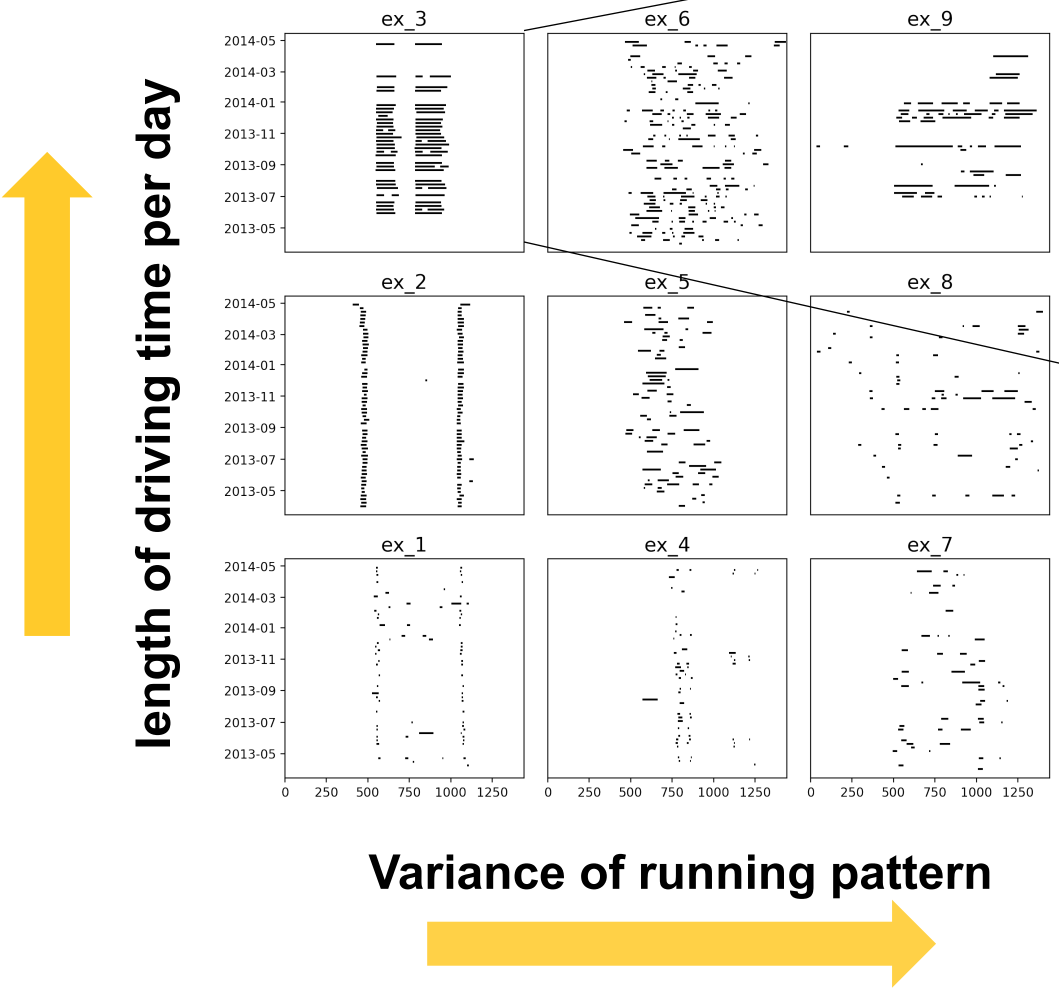


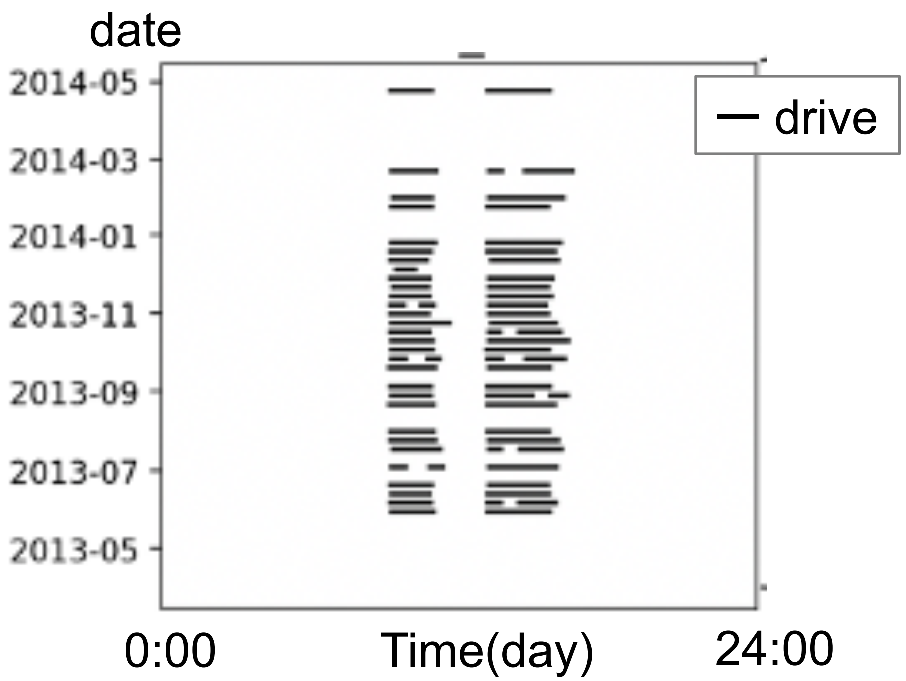
Surplus Power
Absorption Rate [%]



Item(2)	×	○	×	○

Case 2



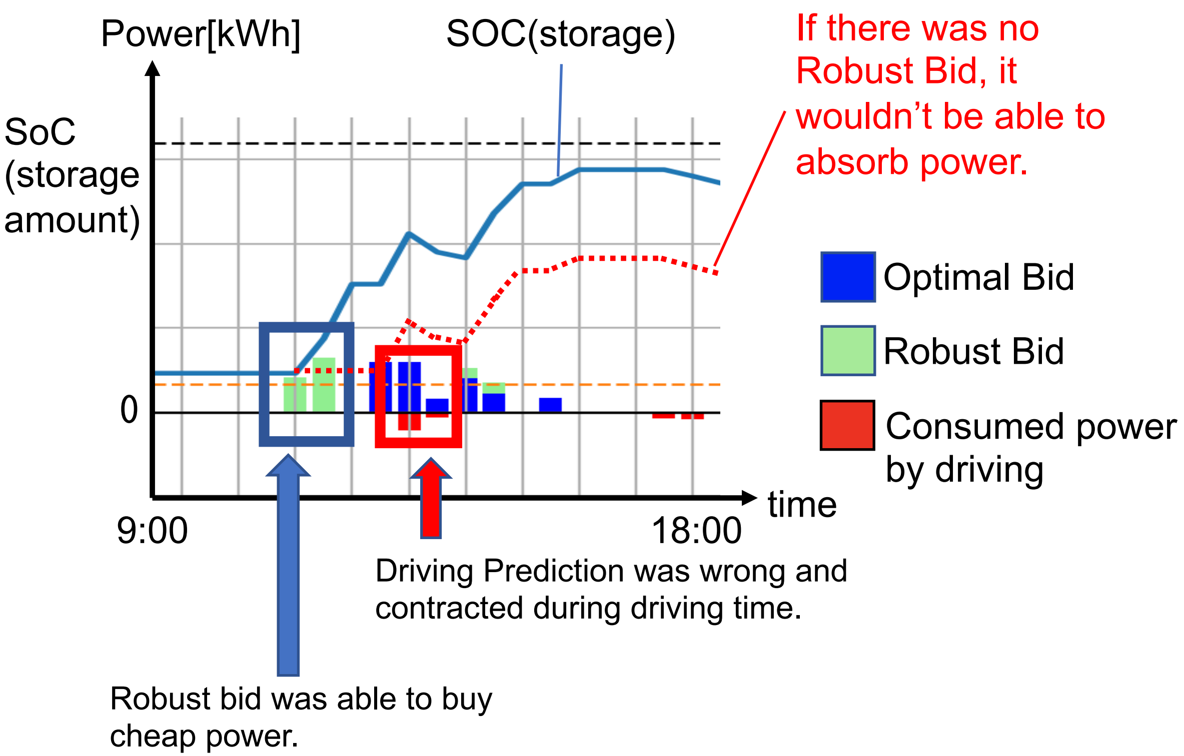


We compared the EVs of different driving patterns.

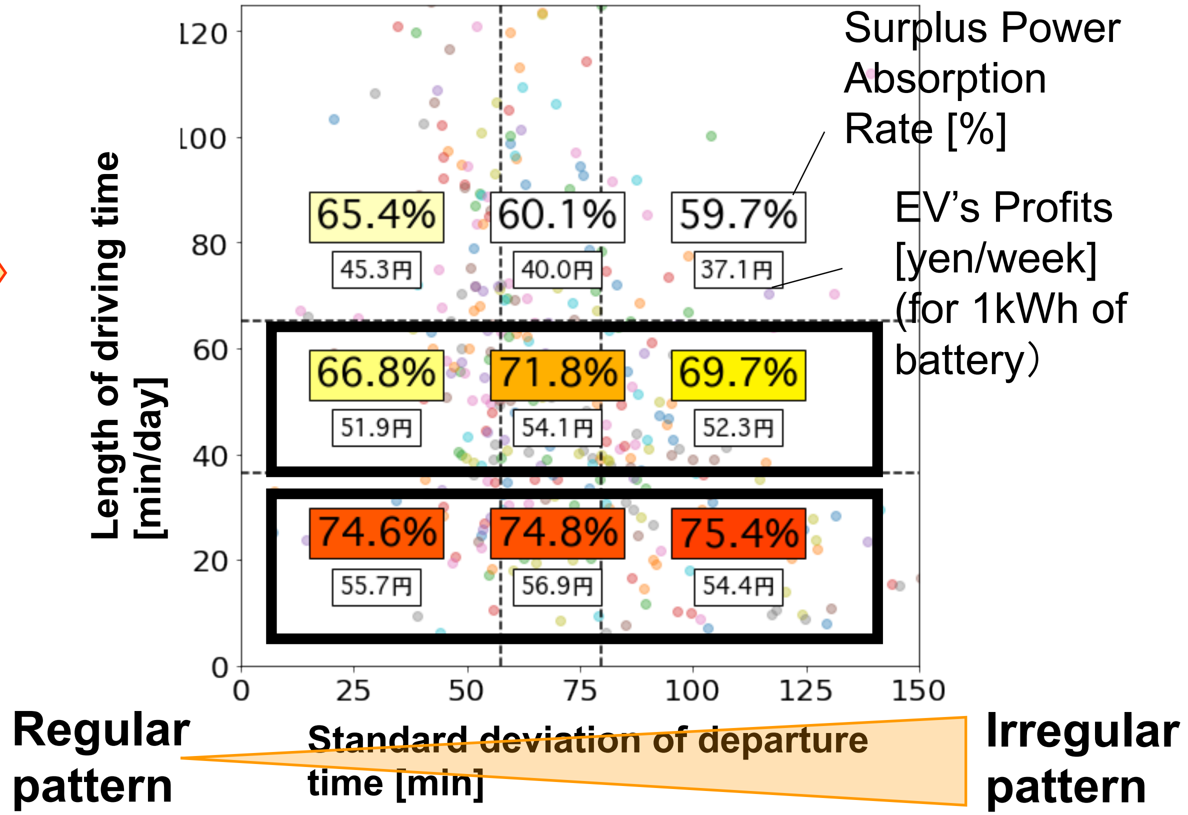
See how the proposed EV agent works for different types of EV.

Case 2 : result

Even if the driving prediction is wrong, Robust bid can absorb power if there exists cheap surplus supply.

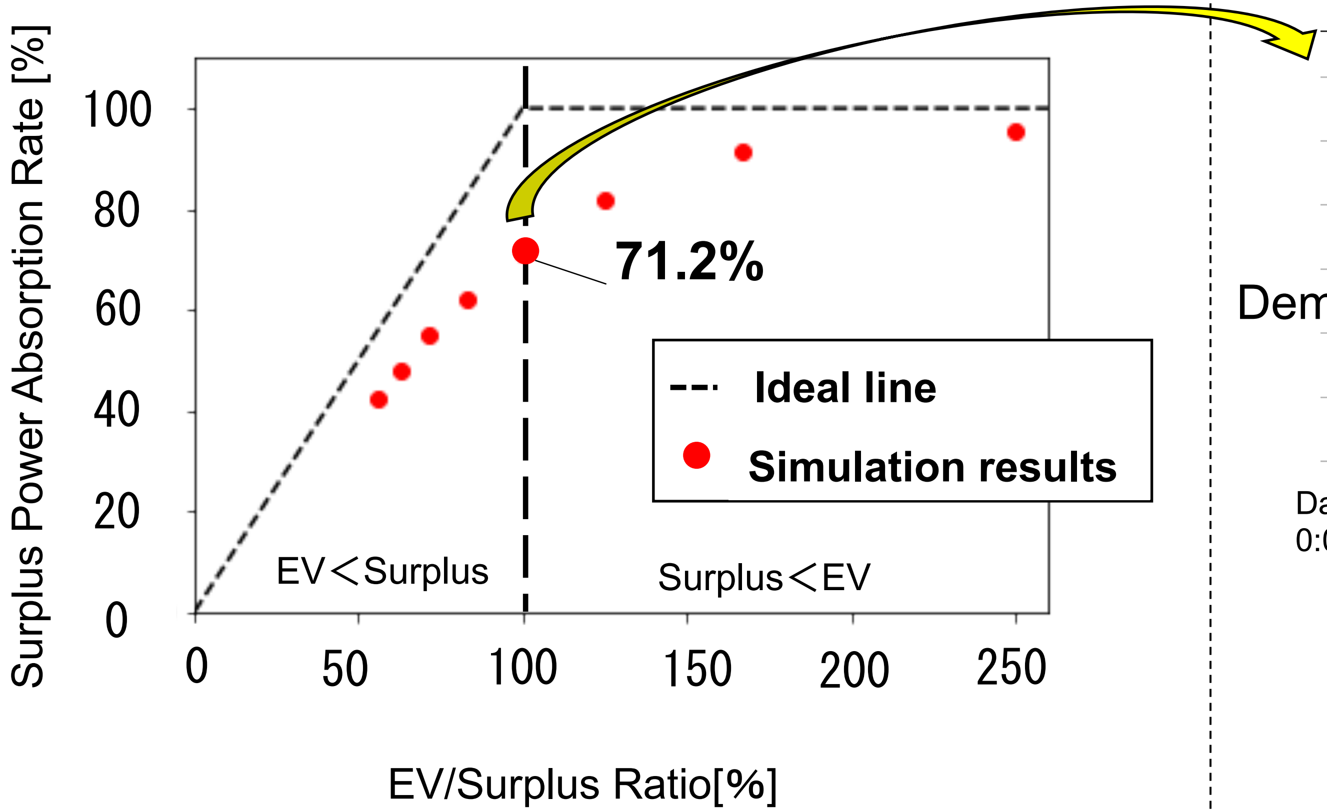


Even if the driving pattern is irregular, it was able to realize nearly the same Profits and Surplus Power Absorption Rate.

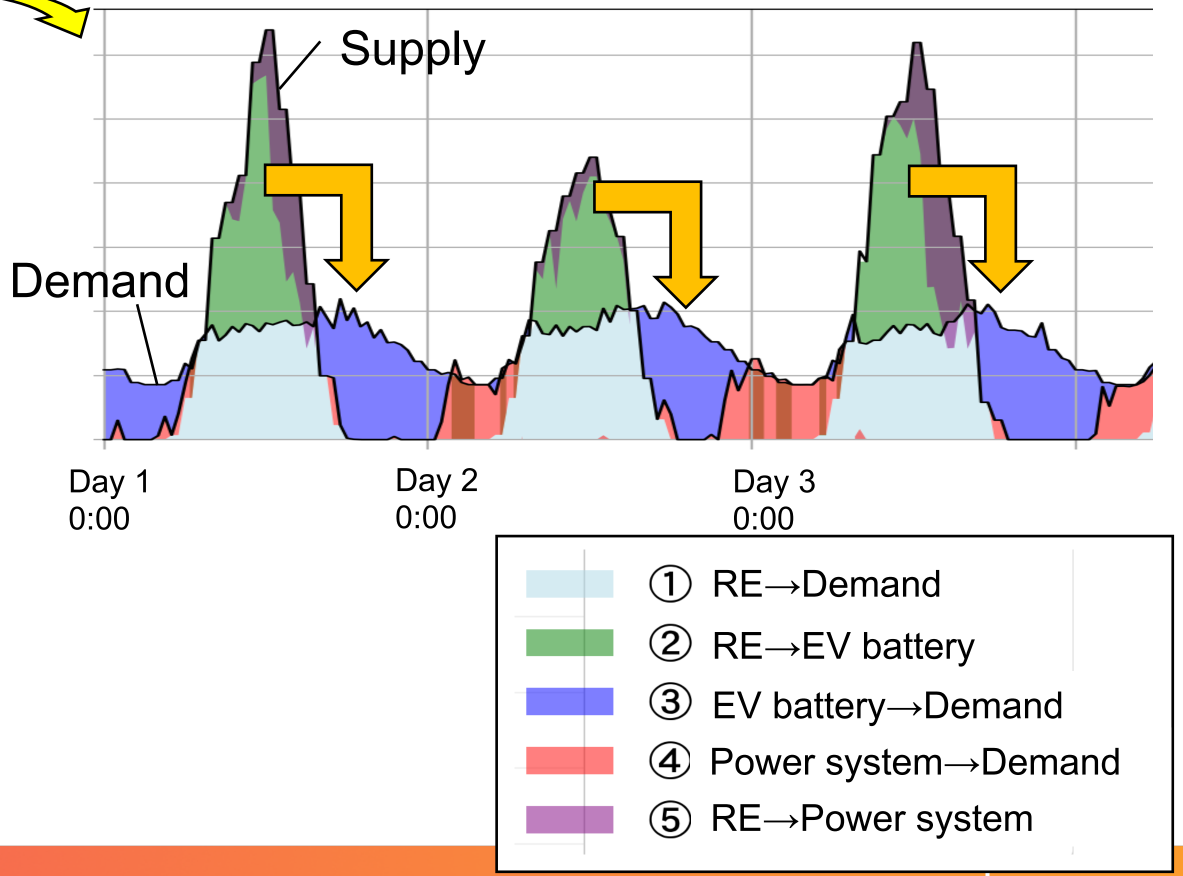


Case 3 : result

Changed EV/Surplus Ratio.
→ Result : When EV/surplus Ratio = 100% → Surplus Power Absorption Rate = 71.2%



The result where the power moved.



Conclusion

1. We proposed a design of EV bidding agent that considers the uncertainty.
   - By considering the driving probability, EV profits and Surplus Power Absorption Ratio improved.
   - Combination of Optimal Bid and Robust Bid seemed to worked well for EVs of irregular driving pattern.

2. About 70% of the EV storage capacity was able to utilize as battery storages leveling the net demand.

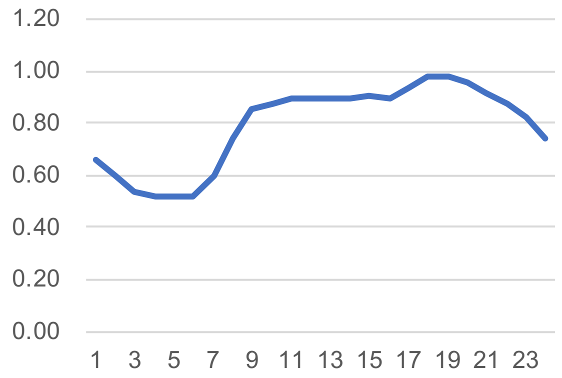
3. Even considering the future uncertainty, it was shown that there are importance and incentive for EVs to participate in the P2P electricity trading market.

Appendix

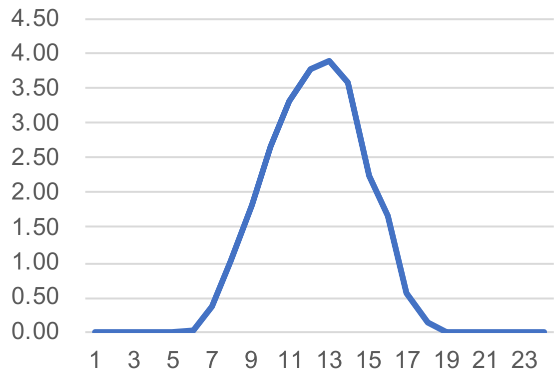
Data Examples

Agent	Household	PV	EV
Example	see below	see below	see below

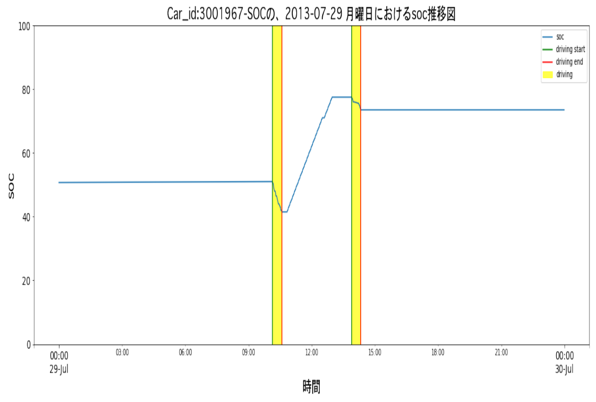
Household



PV

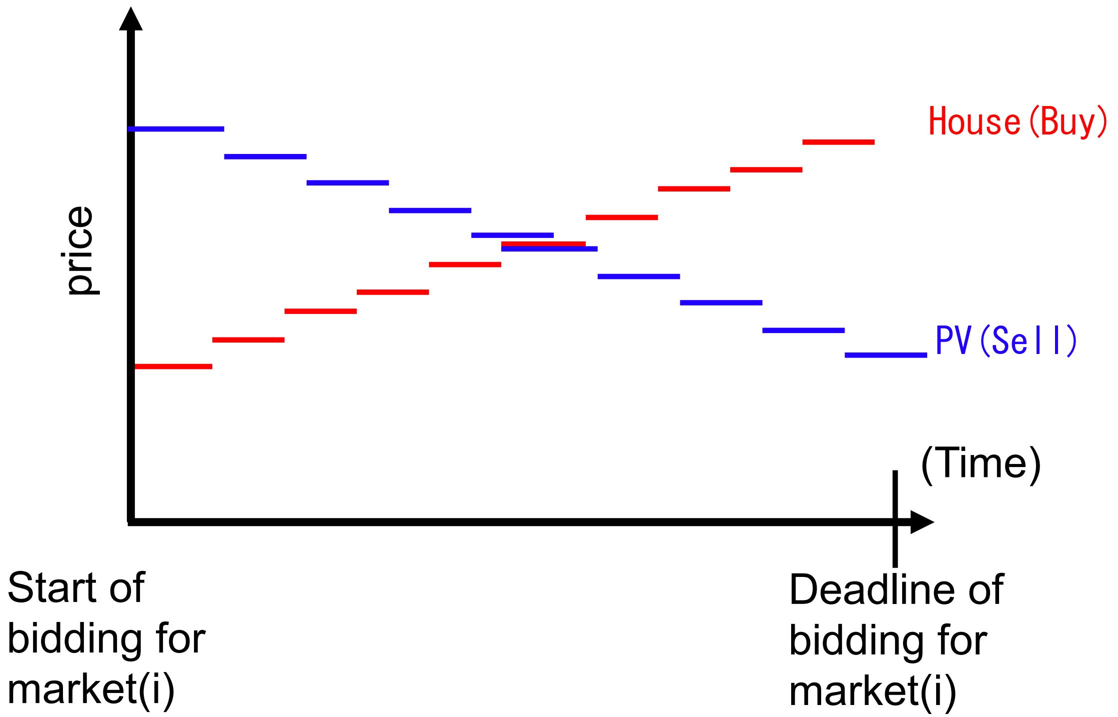


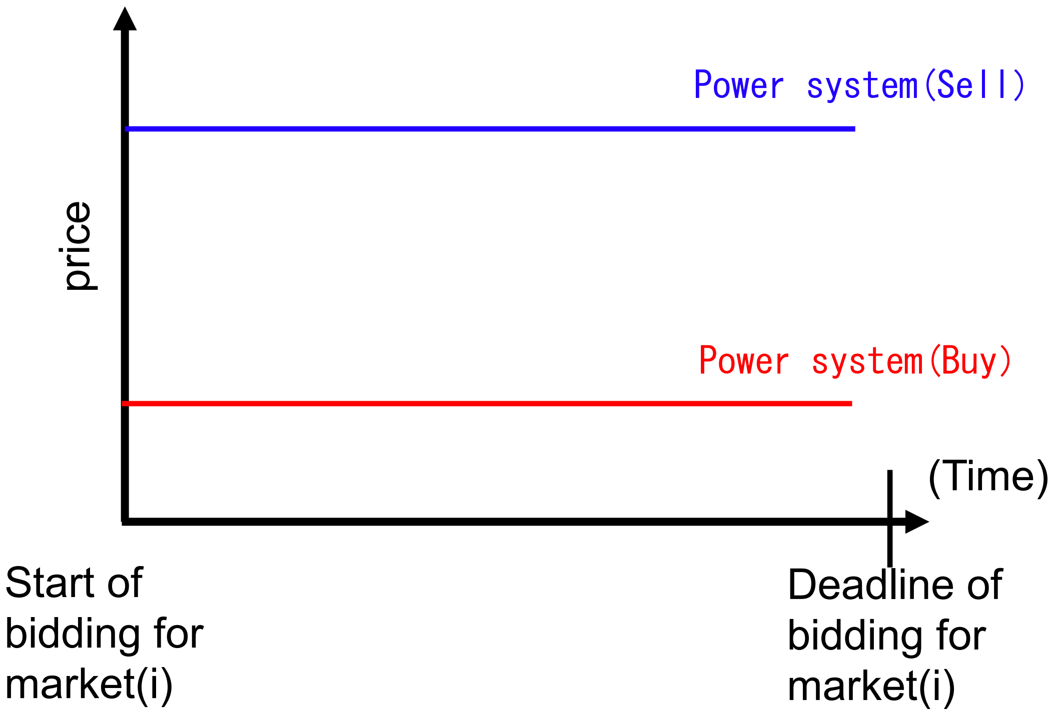
EV



Appendix

House Agent, PV agent, Power system Agent's Strategy :
changes the bidding price(i) linearly as the time gets closer to the time zone of the market(i).





Appendix

Example of
how is the optimization of bids.

Appendix

Example of Price fluctuation and contracted amount (7days).