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Traffic and Grid-Based Parking Lot Allocation for PEVs Considering Driver Behavioral Model

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❑Outline

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Introduction

- A recent study demonstrates that almost 27% of total energy consumption and 33% of greenhouse gas emissions in the world are related to the transportation sector.
- Replacing internal combustion based vehicles with plug-in electric vehicles (PEVs) is a promising strategy to mitigate the energy security and environmental issues, since PEVs can be charged by electricity generated by renewables as the free and clean sources of energy.
- Based on a recent study, PEVs utilization is being increased rapidly in some developed countries because of the advancement in battery technology.

Literature Review

- Previous work
  - Discuss the economic and technical characteristics of the PEVs fleet
  - Different objective functions in the literature have been considered for the parking lot (PL) placement problem that include minimum energy and power losses, maximum reliability, maximum voltage stability, and spinning reserve supply in power market.
- However, in these studies, the behavior of PEVs' drivers and their driving patterns reacting to incentives (discount on charging fee of the PEVs) and distance from the PL have not been modeled and investigated in the problem.
- In this study, a new approach for the PL placement planning problem is introduced and applied on a case study.
  - The traffic of PEVs fleet and the technical and economic aspects of the electrical distribution network are taken into consideration.
  - In other words, the PLs are allocated to the given feeder of the distribution network considering the driving patterns of the PEVs' drivers and the behavioral model of the drivers.
  - The drivers' behavior are modeled respect to the value of incentive and the amount of average daily distance of the PEVs from the PL.
  - The value of incentive is considered to motivate the drivers to charge their vehicles through the PLs.

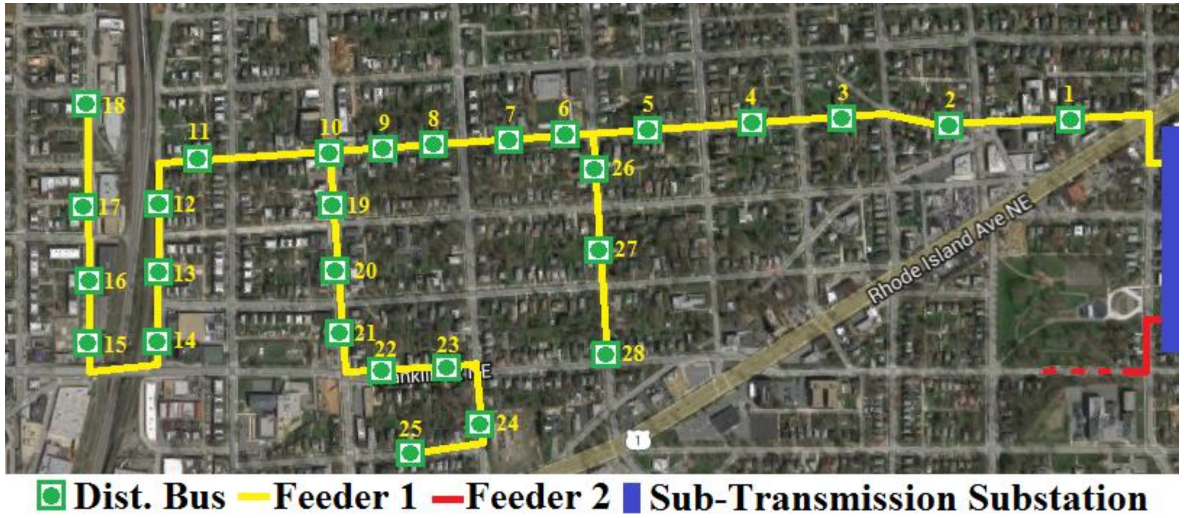
Proposed Technique

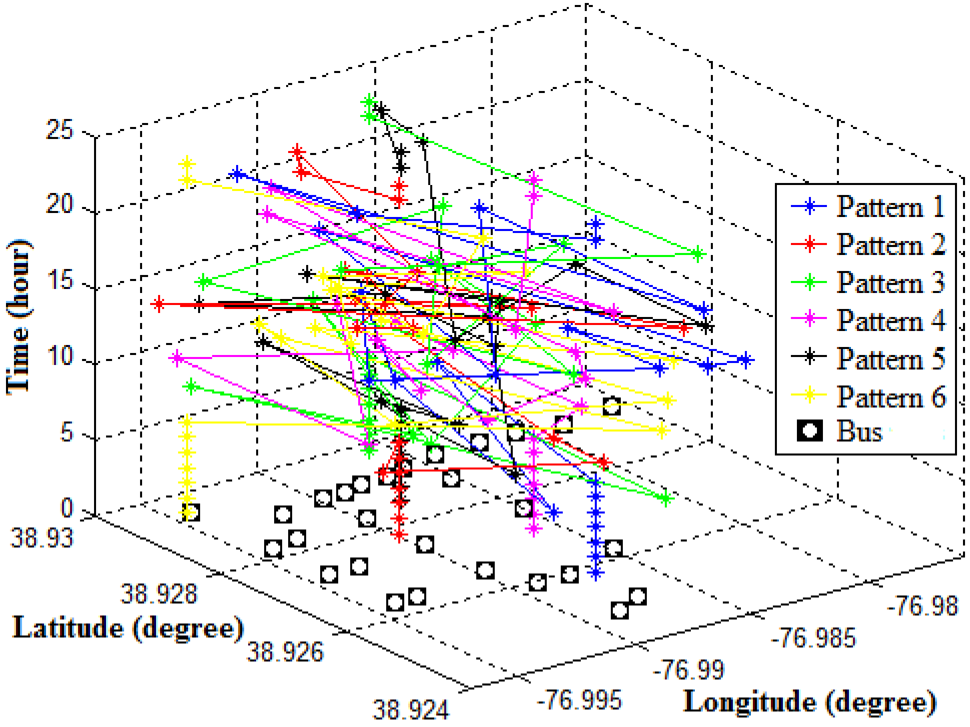
❑ **Modeling Driving Patterns of the PEVs Fleet**

➢ In order to figure out the driving pattern of a PEV or a group of PEVs, the position data of PEVs are recorded at every hour of a typical day.

➢ By knowing the hourly position data of every PEV, the route and the driving pattern of the PEV can be determined.

➢ Fig. 2 shows the hourly space-time driving patterns of the PEVs (Patterns 1-6) from our synthetic data.





Proposed Technique

- By knowing the driving pattern of the PEV, the amount of average daily distance of the PEV from every bus of the feeder ($\overline{\eta_{e,b}}$) can be calculated using the hourly position data of the PEV ($x_{e,t}^{PEV}, y_{e,t}^{PEV}$) and the bus ($x_b^B, y_b^B$), as in (1).
- The value of $\overline{\eta_{e,b}}$ will be applied for determining the reaction of the PEV respect to the value of incentive (ξ_{Model}) introduced to motivate the driver to charge his/her vehicle through the suggested PL.
- Drivers usually prefer to park in a nearby place

$$\overline{\eta_{e,b}} = \frac{1}{24} \times \sum_{t=1}^{24} \sqrt{\left(x_{e,t}^{PEV} - x_b^B\right)^2 + \left(y_{e,t}^{PEV} - y_b^B\right)^2}, \forall e \in \{1, \dots, N_{Tot}^{PEVs}\}, \forall b \in \{1, \dots, Nb\} \qquad (1)$$

Proposed Technique

- By knowing the driving pattern of the PEV, the state of charge (SOC) of the PEV can be approximated, since the SOC of a PEV has a direct relation with the amount of distance that it travels in a day.
- The value of SOC of the PEV is used to determine the amount of power and energy demands of the PL.
- The value of SOC of a PEV at every hour of a day (t) can be determined using (2).
- kWh_{km} is the amount of energy (in kWh) that the PEV needs to travel about 1 km and C_e^{PEV} is the capacity of battery of PEV.

$$SOC_{e,t}^{PEV} = 1 - kWh_{km} \times \sum_{t=1}^{t} \sqrt{\left(x_{e,t}^{PEV} - x_{e,t-1}^{PEV}\right)^2 + \left(y_{e,t}^{PEV} - y_{e,t-1}^{PEV}\right)^2} \times \frac{1}{C_e^{PEV}}, \forall e \in \{1, \dots, N_{Tot}^{PEVs}\}, \forall t \in \{1, \dots, 24\} \quad (2)$$

Proposed Technique

❑ Modeling Behavior of the Drivers as a Function of Incentive and Distance from the PL

- In addition to the value of discount on charging fee (γ), the average daily value of distance of the PEV from the location of PL ($\overline{\eta}$) is considered.
- A linear function is assumed between ξ_{Model} and $\overline{\eta}$, as can be seen in TABLE I.
- By considering these two parameters (incentive and distance), ξ_{Model} will be a three-dimensional spatial surface.

TABLE I: The percentage of drivers that charge their PEVs through the parking lot as the mathematical functions of discount on charging fee (%).

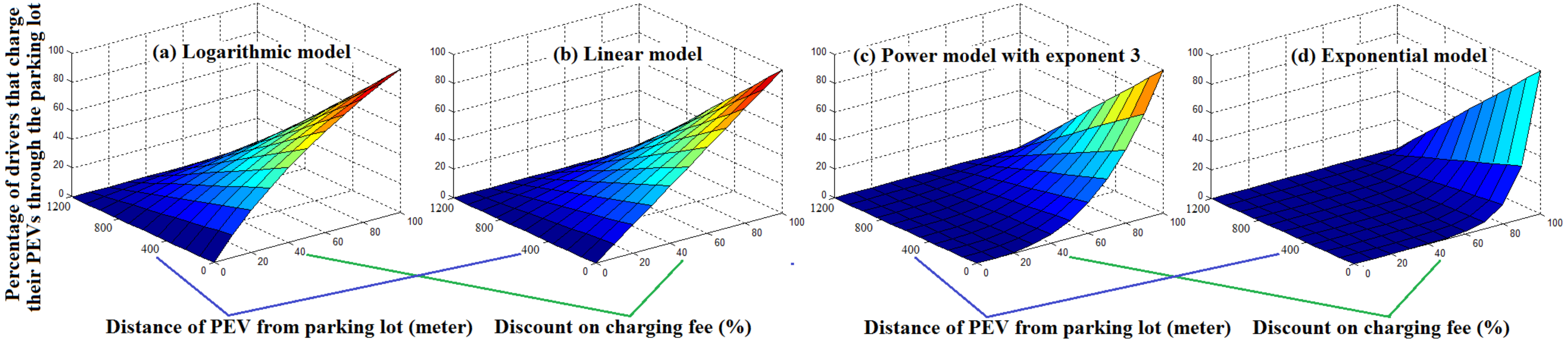
Mathematical model	Percentage of drivers that charge their PEVs through the parking lot
Power model	$\xi_{Pow} = 100 \times \left(\frac{\gamma}{100}\right)^n, n\epsilon\{0.3,3\}$
Linear model	$\xi_{Lin} = \gamma$
Logarithmic model	$\xi_{Log} = 100 \times ln\left(\frac{\gamma}{100} \times (exp(1) - 1) + 1\right)$
Exponential model	$\xi_{Exp} = 100 \times exp\left(M \times \left(\frac{\gamma}{100} - 1\right)\right), M \gg 1$

TABLE II: The percentage of drivers that charge their PEVs through the parking lot as the mathematical functions of discount on charging fee (%) and distance from the parking lot (meter).

Mathematical model	Percentage of drivers that charge their PEVs through the parking lot
Power model	$\xi_{Pow} = (a_1 \times \overline{\beta} + a_2) \times 100 \times \left(\frac{\gamma}{100}\right)^n, n\epsilon\{0.3,3\}$
Linear model	$\xi_{Lin} = (a_1 \times \overline{\beta} + a_2) \times \gamma$
Logarithmic model	$\xi_{Log} = (a_1 \times \overline{\beta} + a_2) \times 100 \times ln\left(\frac{\gamma}{100} \times (exp(1) - 1) + 1\right)$
Exponential model	$\xi_{Exp} = (a_1 \times \overline{\beta} + a_2) \times 100 \times exp\left(M \times \left(\frac{\gamma}{100} - 1\right)\right), M \gg 1$

Proposed Technique

- The percentage of drivers that charge their PEVs through the PL.



Proposed Technique

The number of PEVs that charge their vehicles through the parking lot (N_{Model}^{PEVs}) is determined using (3) that depends on the percentage of discount on charging fee (γ), the total number of PEVs in the area (N_{Tot}^{PEVs}), and the average daily distance of the PEVs from the locations of parking lots ($\overline{\beta}$).

The hourly demand of parking lot (D_t^{PL}) in Mega Watt (MW) is approximated applying (4).

$$N_{Model}^{PEVs} = \xi_{Model} \times N_{Tot}^{PEVs} \qquad (3)$$

$$D_t^{PL} = \sum_{e=1}^{N_{Model}^{PEVs}} \left(1 - \frac{SOC_{e,t}^{PEV}}{100}\right) \times \frac{C_e^{PEV}}{1000} \qquad (4)$$

Proposed Technique

- **Optimization problem (PL planning problem of a DSICO)**
  - Aims to minimize total cost for deploying the parking lots
- Inputs:
  - All the technical and economic parameters of the problem
  - All the technical data of the electrical distribution network
- Outputs:
  - Optimal location of parking lots
  - Optimal value of incentive

Problem Formulation

- **Objective Function**
  - The objective function of problem is minimizing total cost of the local DISCO over the operation period (Ny) by installing PLs in the optimal locations of a feeder of the given electrical distribution grid.

$$OF_{Ny} = min\left\{Cost^{INV} + \widetilde{Cost}_{Ny}^{MAINT} + \widetilde{Cost}_{Ny}^{INC} + \widetilde{Cost}_{Ny}^{EL} + \widetilde{Cost}_{Ny}^{EENS}\right\} \quad (5)$$

  - *Investment cost*

$$Cost^{INV} = C^{INV} \times N_{Model}^{PEVs} \quad (6)$$

  - *Maintenance cost*

$$\widetilde{Cost}_{Ny}^{MAINT} = \sum_{y=1}^{Ny} C^{MAINT} \times N_{Model}^{PEVs} \times (F^{PWV})^{y}, F^{PWV} = \frac{1 + IFR/100}{1 + ITR/100} \quad (7)$$

  - *Incentive cost*

$$\widetilde{Cost}_{Ny}^{INC} = \sum_{y=1}^{Ny}\sum_{d=1}^{365}\sum_{t=1}^{24} D_{t,d,y}^{PL} \times \frac{\gamma}{100} \times \pi^{E} \times 10 \times (F^{PWV})^{y} \quad (8)$$

  - *Energy loss cost*

$$\widetilde{Cost}_{Ny}^{EL} = \sum_{y=1}^{Ny}\sum_{d=1}^{365}\sum_{t=1}^{24}\sum_{br=1}^{Nbr} R_{br} \times \left|I_{y,d,t,br}\right|^{2} \times MVA^{BASE} \times \pi^{E} \times 10 \times (F^{PWV})^{y} \quad (10)$$

  - *Expected Energy Not Supplied (EENS) cost*

$$\widetilde{Cost}_{Ny}^{EENS} = \sum_{y=1}^{Ny}\sum_{br=1}^{Nbr} \lambda_{br} \times \left(\tau^{FL}\sum_{b=1}^{Nb} LNS_{y,b}^{FL} + \tau^{FR}\sum_{b=1}^{Nb} LNS_{y,b}^{FR}\right) \times \pi^{ENS} \times (F^{PWV})^{y} \quad (12)$$

Problem Formulation

- *Security Constraints*

- *Loading limit of the branches:* magnitude of the apparent power flowing through the branch must be less than the allowable magnitude of the apparent power of the branch.

$$|MVA_{br}| \leq |\overline{MVA}_{br}|, \forall br \in \{1, \ldots, Nbr\} \quad (13)$$

- *Voltage magnitude limits of the buses:* Magnitude of voltage of each bus must be within the allowable minimum and maximum limits.

$$(1 - \sigma^V/100) \times |\bar{V}_b| \leq |V_b| \leq (1 + \sigma^V/100) \times |\bar{V}_b|, \forall b \in \{1, \ldots, Nb\} \quad (14)$$

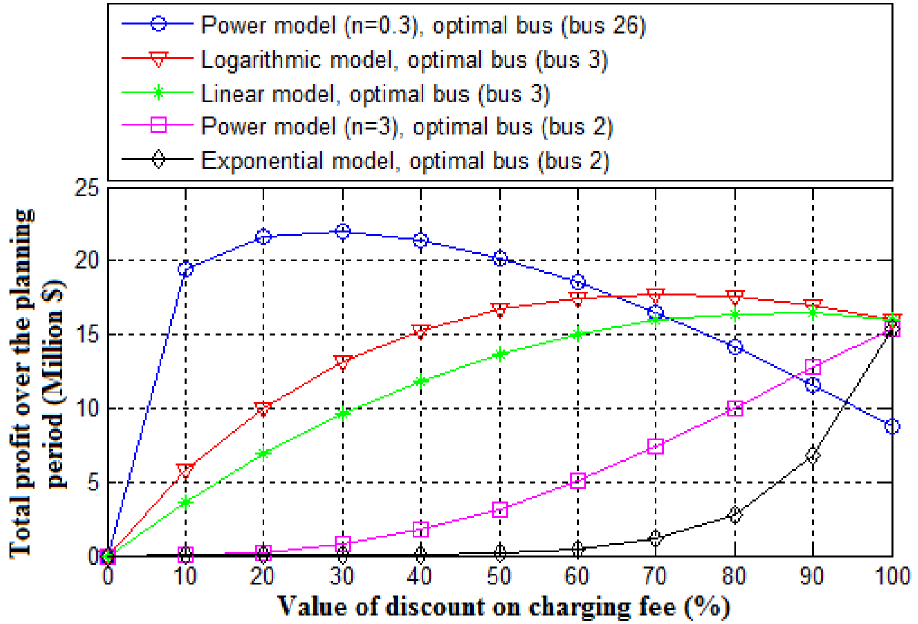
Problem Simulation

TABLE IV
THE DETAILED RESULTS OF OPTIMAL PL ALLOCATION CONSIDERING DIFFERENT BEHAVIORAL MODELS FOR THE PEVS FLEET.

-	Pow.	Log.	Lin.	Exp.
Optimal discount (%)	30	70	90	100
Optimal bus for PL	26	3	3	2
Optimal size of PL	756	542	617	686
Energy loss (Million MWh)	2.7745	2.7772	2.7592	2.7432
EENS (Million MWh)	0.1342	0.1344	0.1343	0.1342
Investment cost (Million $)	1.6636	1.1928	1.3593	1.5104
Maintenance cost (Million $)	1.0612	0.7608	0.8670	0.9634
Cost of discount (Million $)	6.346	10.617	15.557	19.206
Energy loss cost (Million $)	589.91	590.48	586.66	583.26
EENS cost (Million $)	142.73	142.87	142.80	142.73
Maximum profit (Million $)	21.963	17.755	16.433	16.002

EENS: expected energy not supplied

Problem Simulation



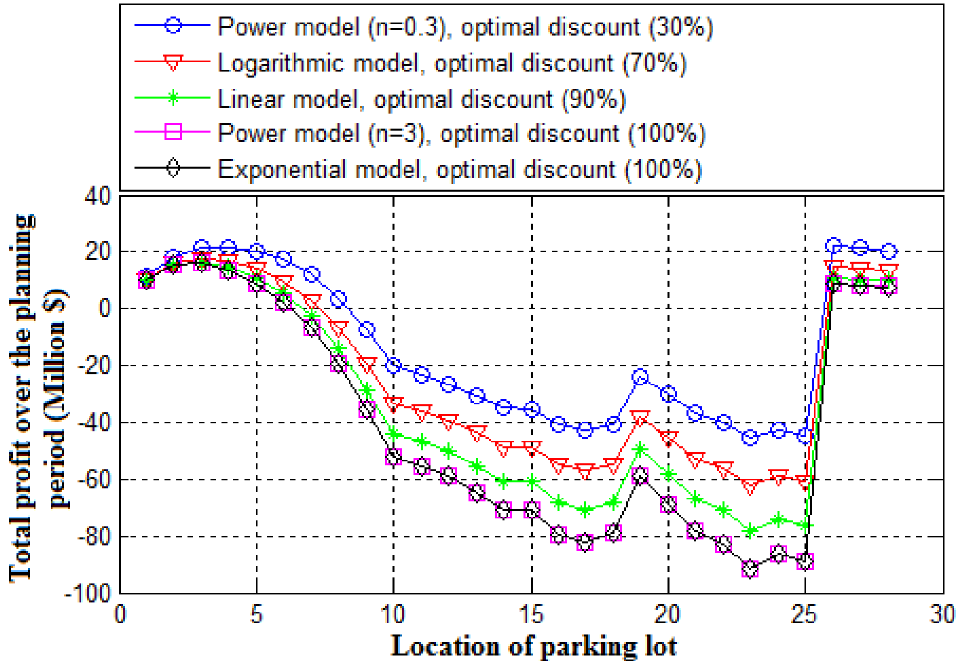


TABLE V

THE RESULTS OF OPTIMAL PL ALLOCATION CONSIDERING DIFFERENT DRIVING PATTERNS FOR THE PEVS (DRIVERS' BEHAVIOR MODEL IS POWER MODEL).

Driving pattern of the PEVs	Optimal discount (%)	Optimal bus for PL	Maximum profit (Million $)
Default (100 PEVs for each pattern)	30	26	21.963
All PEVs have pattern 1	40	3	23.772
All PEVs have pattern 2	30	26	16.427
All PEVs have pattern 3	40	3	39.864
All PEVs have pattern 4	30	26	16.914
All PEVs have pattern 5	40	3	21.956
All PEVs have pattern 6	30	5	18.567

TABLE VI

THE RESULTS OF OPTIMAL PL ALLOCATION CONSIDERING DIFFERENT TYPE FOR THE PEV (DRIVERS' BEHAVIOR MODEL IS LINEAR MODEL).

Type of PEV	Optimal discount (%)	Optimal bus for PL	Maximum profit (Million $)
Default (Nissan Leaf BEV)	90	3	16.433
Chevy Volt 2012 PHV	80	3	11.470
Toyota Prius 2012 PHV	60	3	1.947

Conclusion

- It was noticed that the drivers' behavioral model and drivers' driving patterns can remarkably affect the outcomes of the planning problem including the optimal size and location of the PLs, optimal value of incentive, and maximum profit of the local DISCO.
- However, previous works for this problem fail to consider these factors.
- In this work, we considered these factors in solving the problem.
- Our numerical study confirmed the influence of these factors and the effectiveness of our approach.

Thank you!

Questions & Comments?

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