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Modeling Strategic and Operational Policy Decisions for EV Sharing Platforms

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Motivation

Benefits of Electric Vehicles (EVs):

- Around 24% of CO_2 emissions are contributed to by the transportation section due to IC engine vehicles.
- EVs offer zero tailpipe emissions, better efficiency over IC engine vehicles, and reduces reliance on fuel.
- 17 countries have announced 100% zero-emission vehicle through 2050.

Adoption Issues and Motivation:

- In spite of advantages, penetration of EVs is very less (around 1% of global fleet of cars is electrified).
- Issues for adoption include
  - Range anxiety
  - Cost of EVs
  - Inadequate charging infrastructure
- Use of EV sharing platforms can help alleviate these issues.
- In India, in 2025, 17% of cars are expected to be sold to fleet owners, and the number of shared rides to increase by three times (from 2018).

Literature Review

Research stream	Study	EV-sharing platform	Station-based system	Charging levels	Traffic conditions	Vehicle dynamics	Powertrain and regenerative braking model
Performance analysis of vehicle-sharing platforms	George and Xia (2011), Roy et al. (2014)		Y				
	Chen et al. (2016), He et al. (2017), Guo et al. (2018), Loeb et al. (2018), Hua et al. (2019), He et al. (2020)	Y					
EV modeling	Shao et al. (2018)	Y				Y	
	Dandl and Bogenberger (2019)	Y		Y	Y		
	Alesiani and Maslekar (2014)	Y				Y	
	Chen et al. (2018)	Y		Y		Y	
Our work		**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

Research Questions

1. How to integrate the vehicle and network dynamics with the optimization of design parameters of EV-sharing platform?
2. How to analyze the effect of different traffic conditions on the decrease in the battery energy of the vehicle while traveling?
3. How does the consideration of powertrain and regenerative braking models impact the estimates of decrease in the battery energy of the vehicle?
4. How do partial charging and vehicle exit from the platform influence the platform's profitability?

Overall Analysis Framework

- Stage 1 - Vehicle dynamics model to calculate the energy drawn from the battery per unit distance for different traffic conditions
- Stage 2 - Open queuing network to model the EV-sharing platform and its operations
- Stage 3 - Optimization model to determine the optimal system parameters

EV Modeling

Tractive force from the powertrain (electric motor) needs to overcome 4 resistive forces:

1. Rolling resistance
2. Aerodynamic drag
3. Grade resistance
4. Inertia

Single motor drive configuration was considered in this study.

Motor modeling:

1. Ideal motor characteristics used to represent continuous torque-speed profile.
2. Efficiency map used to include motor and inverter losses.

Regenerative braking modeling:

1. Series regenerative braking for optimum braking performance chosen.
2. Braking strategy ensures ideal brake force distribution is followed, hence ensures safety.

For front-wheel drive configuration, distribution between friction brakes and motor is given by

$$F_{bf,fric}(t) = \begin{cases} 0, & F_{bf,ideal}(t) < F_{regen,max}(t) \\ F_{bf,ideal}(t) - F_{regen,max}(t), & F_{bf,ideal}(t) \geq F_{regen,max}(t) \end{cases},$$

$$F_{br,fric}(t) = F_{br,ideal}(t),$$

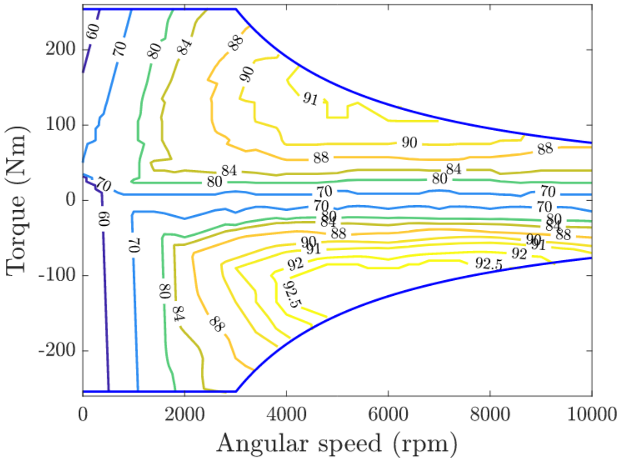
where

$$F_{regen,max}(t) = \begin{cases} -\frac{\tau_{max}(\omega(t))GR}{r\eta_t}, & \omega(t) \geq \omega_{base,cont} \\ 0, & \omega(t) < \omega_{base,cont} \end{cases}.$$

Case Study - Nissan e-NV200 Evalia

Specifications of vehicle considered:

- Light vehicle with single motor front-wheel drive configuration.
- Battery modelled using an Open Circuit Voltage vs State of charge curve and an internal resistance.
- Constant accessory power consumption of 1.4 kW considered.



Specification	Meaning	Value
M_{laden} (kg)	Mass of the fully laden vehicle	2250
$M_{unladen}$ (kg)	Mass of the fully unladen vehicle	1592
L (mm)	Wheelbase	2725
$l_{f,laden}$ (mm)	Distance of CG from the front axle center for the fully laden vehicle	1429.12
v_{max} (km/h)	Maximum longitudinal vehicle speed	123
r (mm)	Tyre rolling radius	310.75
E_{rating} (kWh)	Energy rating of the fully charged battery	40
n_{cells}	Total number of cells	192
Q_{cell} (Ah)	Rated cell capacity	56.3
R_{int} (Ω)	Internal cell resistance	0.002
P_{cont} (kW)	Continuous power rating of the motor	80
τ_{cont} (Nm)	Continuous torque rating of the motor	254
ω_{max} (rpm)	Maximum angular speed of the motor	10000
$\omega_{base,cont}$ (rpm)	Continuous base angular speed of the motor	3008
GR	Gear ratio of the final drive	9.301
h_{laden} (mm)	Height of CG from the ground for the fully laden vehicle	800
C_d	Coefficient of drag	0.35
A_f (m^2)	Frontal projected area	2.8043
ρ (kg/m^3)	Mass density of air	1.225
η_t	Transmission efficiency	0.95
f_r	Coefficient of rolling resistance	0.01

EV Model Validation and AVL CRUISE Results

Model Validation:

- Vehicle simulated using the World Harmonized Light Vehicle Test Procedure.
- Energy consumption obtained with EV model (= 0.2633 kWh/km) matched closely the quoted value by Nissan (= 0.2591 kWh/km).

Traffic conditions considered:

Traffic condition	Drive cycle	Parameters			
		s_{cycle} (km)	t_{cycle} (s)	$v_{max,cycle}$ (km/h)	$v_{avg,cycle}$ (km/h)
Low	HWFET	16.45	765	96.40	77.57
Medium	UDDS	12.07	1369	91.20	31.50
High	ECE-15	1.013	195	50	19

Results from AVL CRUISE:

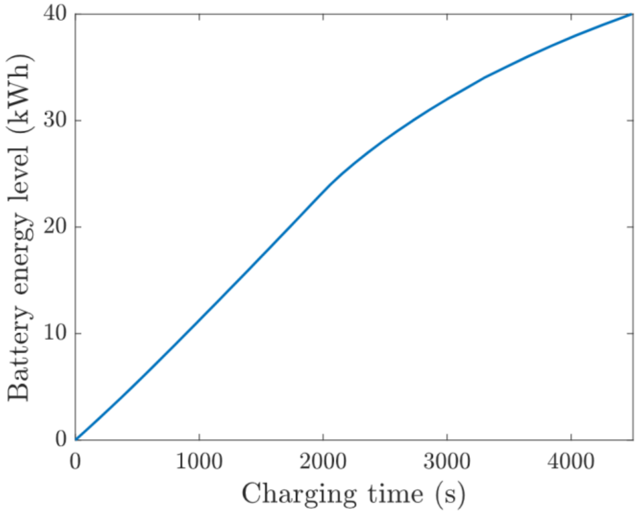
$\Delta E_{battery}$ over HWFET, UDDS, and ECE-15 are 0.2375, 0.2725, and 0.2771 kWh/km.

Comparison with simplified EV model:

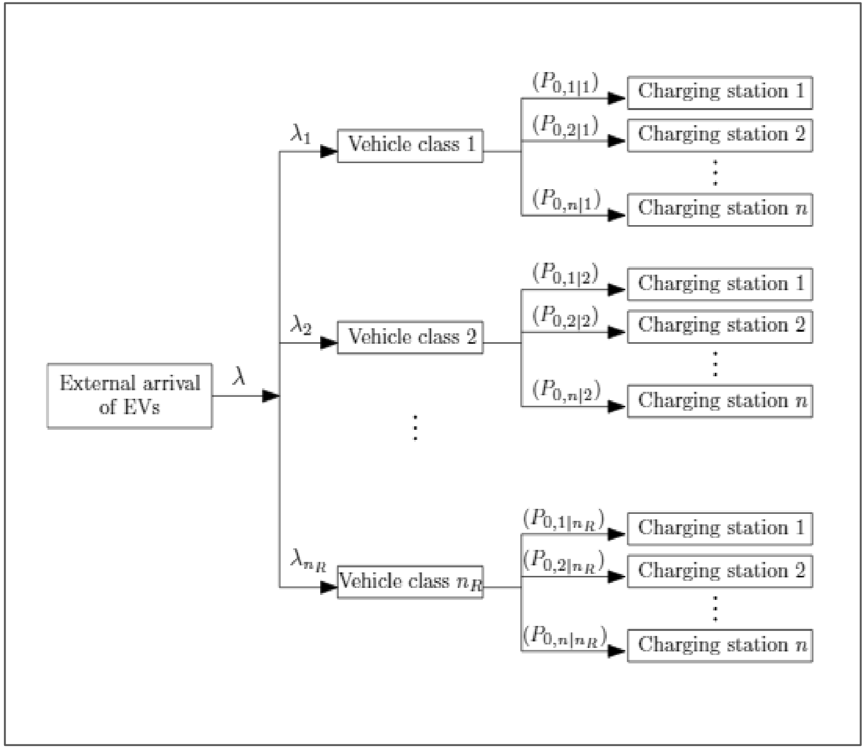
- Net efficiency factor of 80%.
- 20% regenerative braking factor.

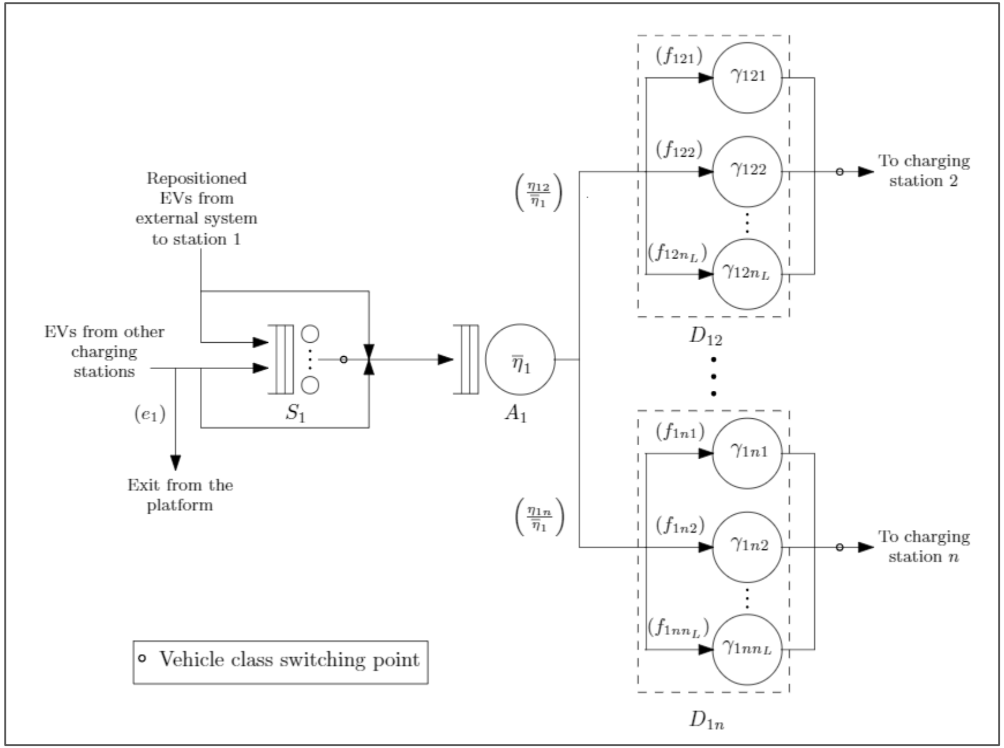
$\Delta E_{battery}$ over HWFET, UDDS, and ECE-15 are 0.2233, 0.2605, and 0.2593 kWh/km.

Battery energy vs charging time:



Queuing Network of the EV-sharing Platform





Optimization Model for Setting Policy Parameters

- Mixed-integer nonlinear optimization problem (MINLP)
- Decision variables:
  - Number of chargers at each charging station
  - Distribution of external arrival of EVs to different charging stations
  - EV queue length for charging
  - EV queue length for trip assignment
  - Queuing node utilization
  - EV flow rates between different queuing nodes

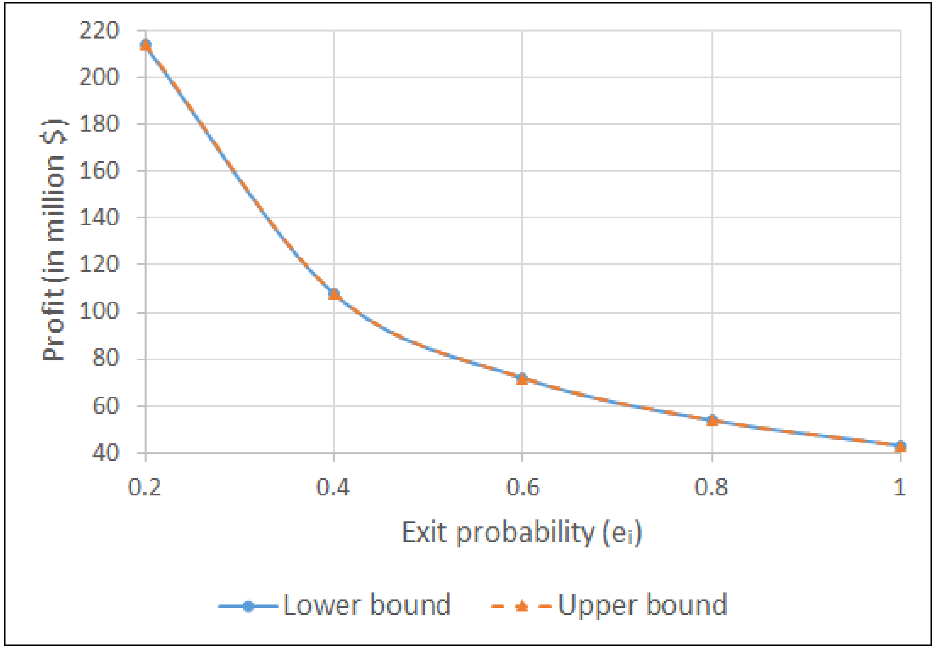
Optimization Model for Setting Policy Parameters

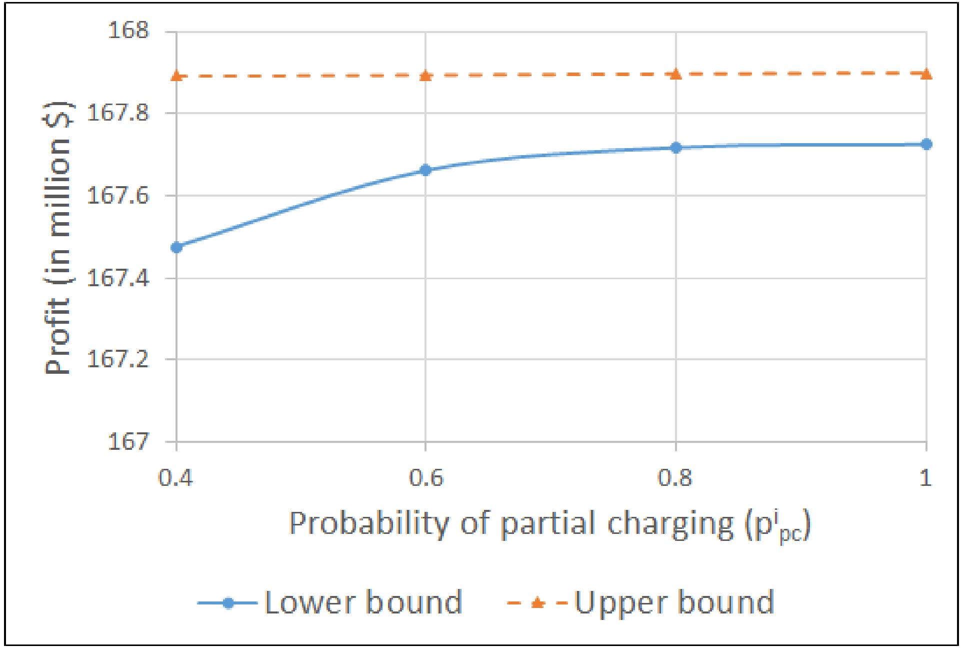
- Objective function: Maximize the platform’s annual profit
  - Revenue from customer trips
  - Charger installation cost
  - Waiting cost of the EVs at charging stations
  - Repositioning cost of the EVs to charging stations
- Constraints:
  - Sum of fractions of repositioned EVs of a particular vehicle class to different stations is 1
  - Flow-balance constraints at the queuing nodes
  - Queuing node utilization constraints
  - Queue length constraints
  - Capacity constraints for the charging station

Solution Method and Results

- MINLP is nonlinear and non-convex due to integer variable and fractional constraints with multi-linear cubic and quadratic terms.
- Constraint for the decision variable - EV queue length for charging is causing multi-linear cubic terms.
- Bound-based heuristic
    - Overestimate the decision variable to obtain the lower bound of the optimal profit
    - Underestimate the decision variable to obtain the upper bound of the optimal profit
- The optimality gap between the lower and upper bounds from the heuristic, is found to be less than 0.5%.

Managerial Insights





Contributions and Future Directions

- We propose an integrated analytical framework to address the operational and infrastructural challenges faced by an EV-sharing platform.
- We provide a bound-based heuristic to solve a mixed-integer nonlinear optimization model with fractional constraints and multi-linear cubic terms.
- Our analysis provides various operational insights for the policy makers of the EV-sharing platform.
- Possible extensions:
  - Heterogeneous EV fleet with different vehicle loading conditions
  - A more specific and realistic vehicle speed profile by collecting real time data
  - Joint determination of optimal partial charging probabilities and target energy level for partial charging along with the number of chargers

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Thank You!

Questions/Comments?