Powertrain Modeling and Range Estimation of The Electric Bus

Donkyu Baek*
[donkyu at cbnu.ac.kr]
School of Electronics Engineering
Chungbuk National University





Presenter



Dr. Donkyu Baek

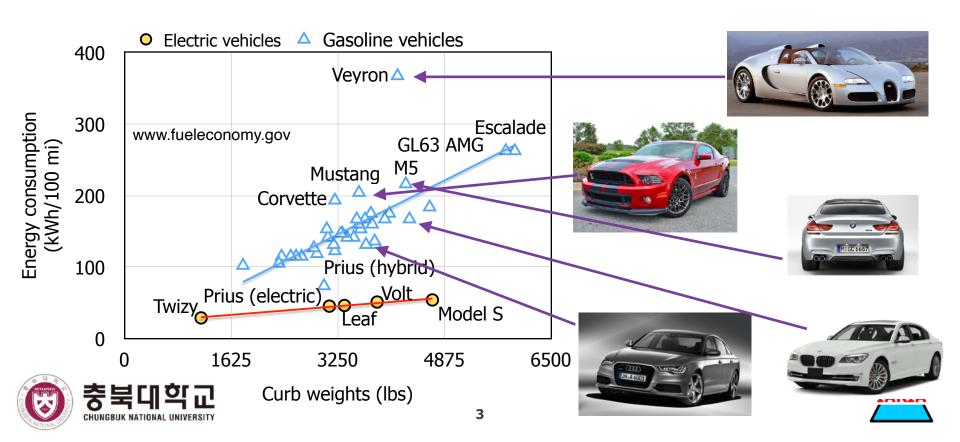
- Assistant Professor in Chungbuk National University, Korea
- Got Ph.D. in KAIST (Korea Advanced Institute of Science and Technology), Korea
- Post doc experiences
 - Mar. 2018 ~ Dec. 2018: KAIST, Korea
- Research interest
 - EV/drone powertrain modeling
 - EV/drone runtime optimization
 - EV/drone design-time optimization





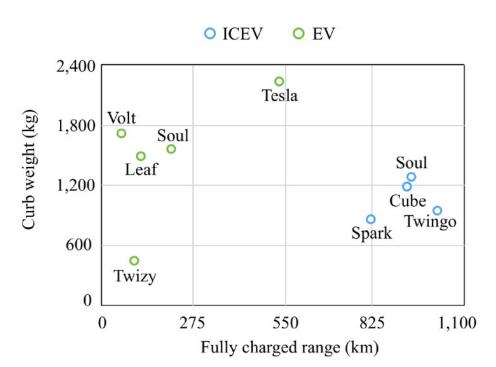
EVs Are Invading the ICEV Market

- Higher efficiency
 - Average 141 kWh for ICEVs and 20 kWh for EVs when drive 100 km
- Environmental friendliness + government promotion
- Quiet and comfort ride

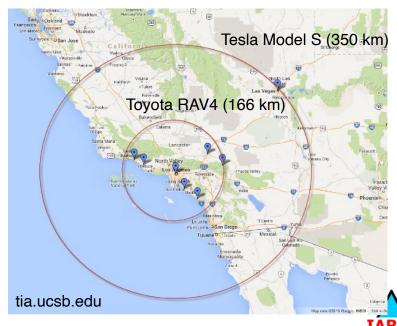


Limitation of EVs

- EVs still cannot reach the territory of ICEVs
 - Short driving range
 - 27 kWh battery pack (Soul EV) versus 514 kWh fuel tank (Soul)
 - Long charging time
 - 5 hours with level 2 and 30 minutes with level 3 battery charging systems



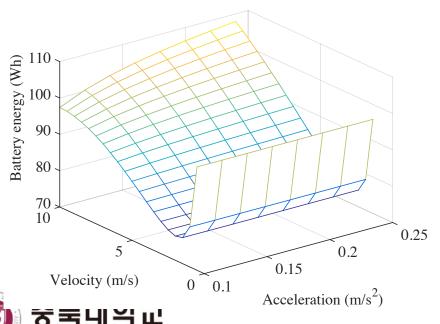
Driving ranges from Los Angeles

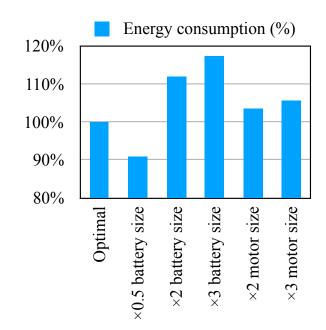




Energy-Efficient EV

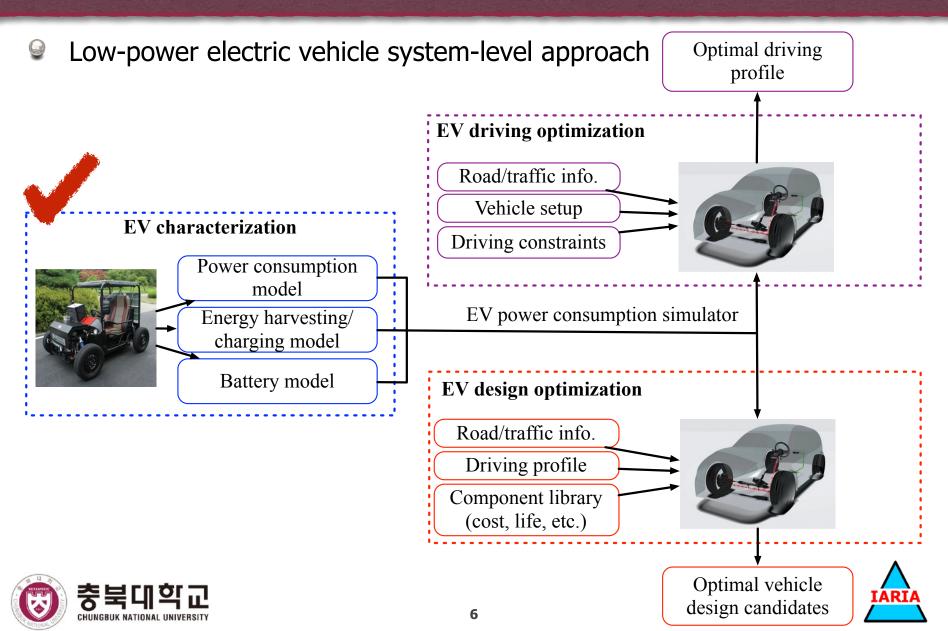
- Energy consumption is reduced by 50% with optimal driving and by 20% with optimal vehicle design
- Then, how to find the optimal vehicle driving and design?





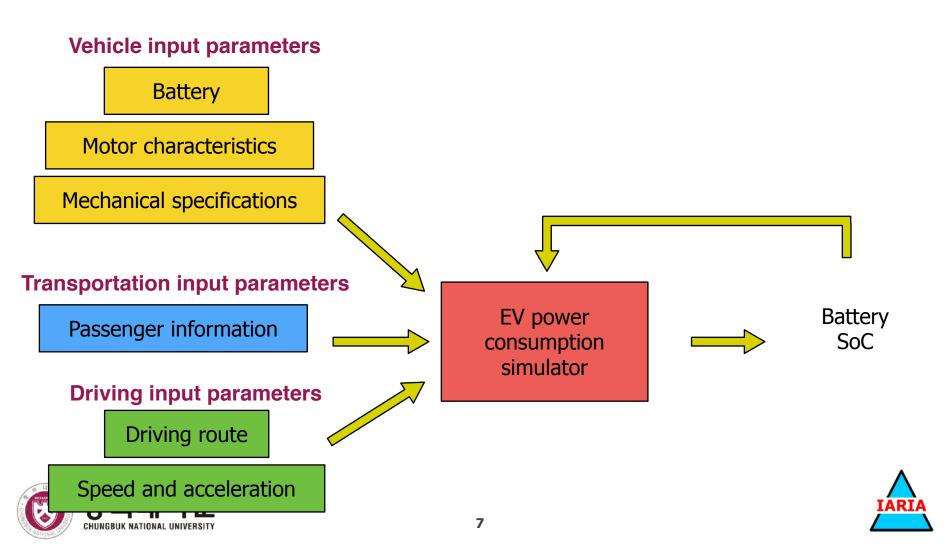


System-Level Approach for EV Optimization



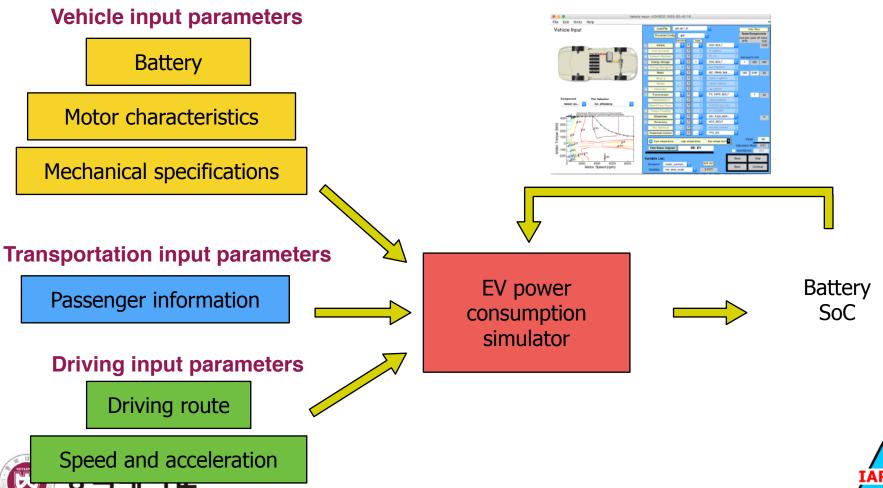
IT Technology Inspired EV Design Framework

Electric vehicle power consumption simulation



IT Technology Inspired EV Design Framework

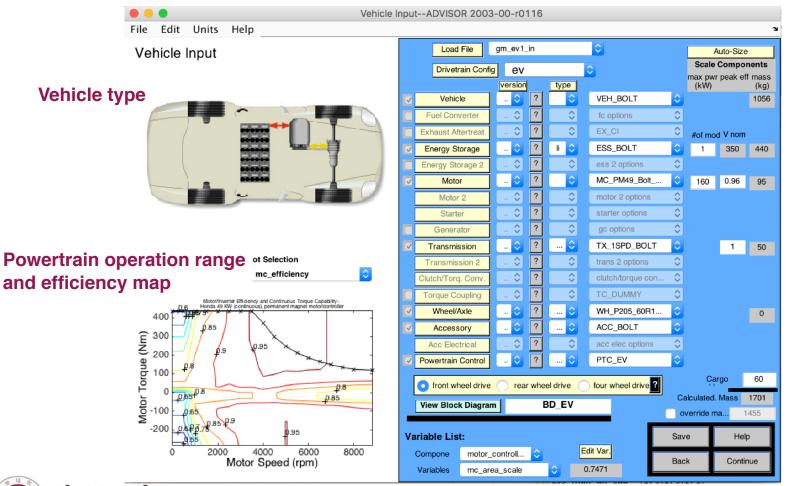
ADvanced VehIcle SimulatOR (ADVISOR) works well to estimate
 1) vehicle powertrain and 2) battery SoC



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IT Technology Inspired EV Design Framework

ADvanced VehIcle SimulatOR (ADVISOR)



Input parameters





ADVISOR is a fast simulator BUT not proper to run in the inner loop of the optimization algorithms

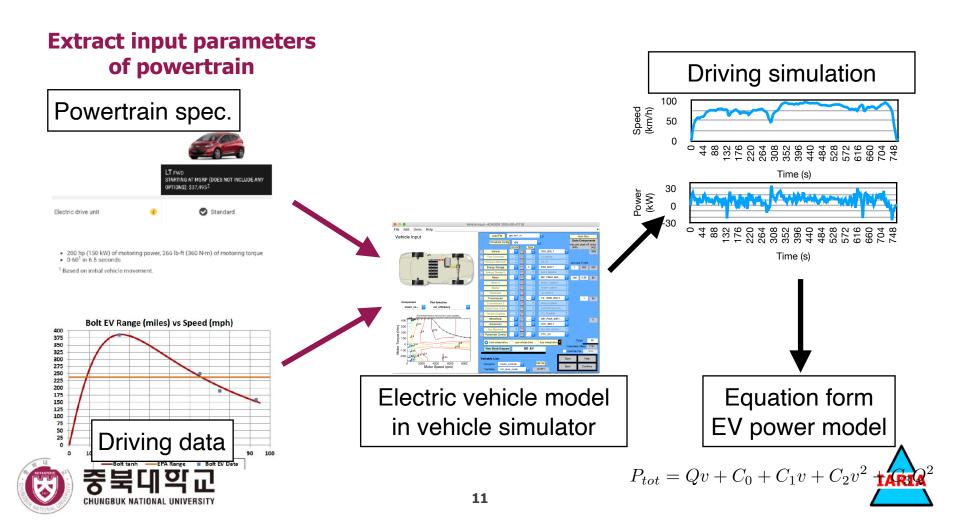
Vehicle input parameters Battery Not acceptable for online loop-based Motor characteristics optimization methods Mechanical specifications **Transportation input parameters** EV power Battery Passenger information SoC consumption simulator **Driving input parameters** Driving route



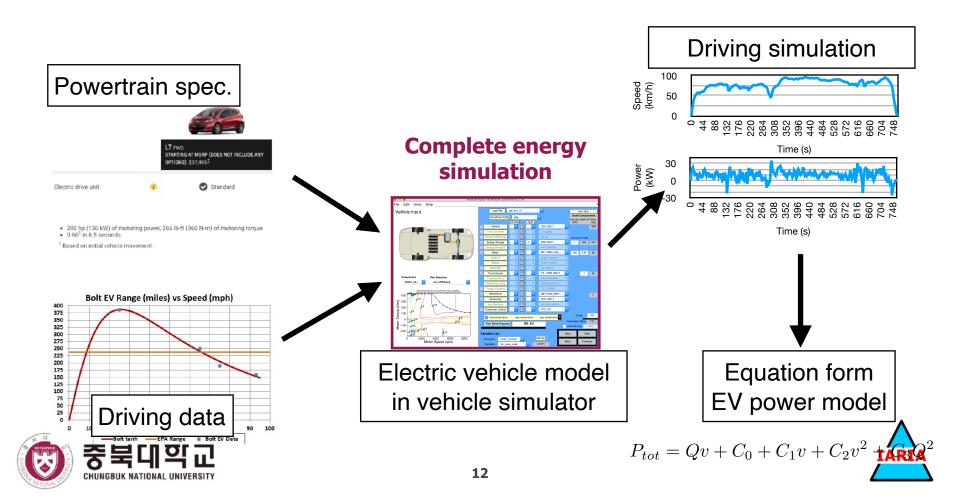
Speed and acceleration

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Need to implement very simple but accurate power model using ADVISOR



Need to implement very simple but accurate power model using ADVISOR



Vehicle Simulator Model

- BYD K9 bus of 18 tons curb weight
- We implemented a new sub-model of each vehicle component
- Estimate motor efficiency based on driving experimental results

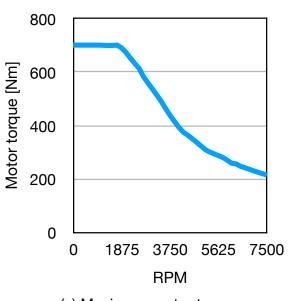


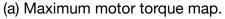


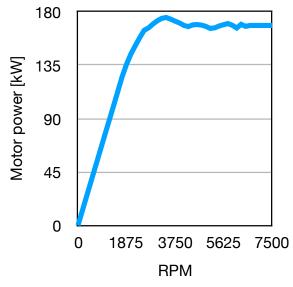
Vehicle Simulator Model

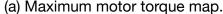
- Motor
 - Includes two brushless permanent magnet synchronous motors
 - Maximum 350 Nm and 90 kW performance
- Performance (by ref. experimental results)
 - 43 mile per hour top speed
 - 6.5 second 0–100 km/h time
- Gearbox
 - 17.7:1

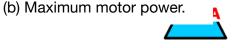
Extract detailed motor torque map based on performance experimental results







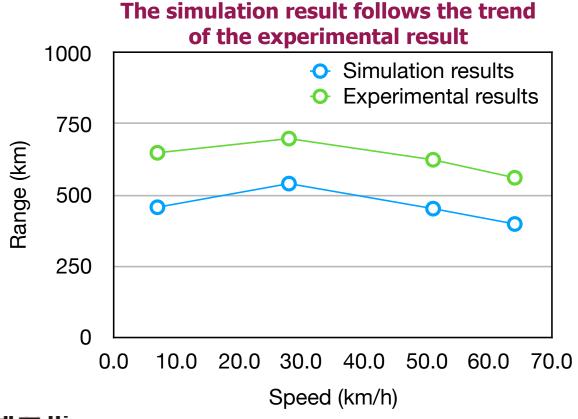




"Federal Transit Bus Test," The Larson Institute, Tech. Rep., 2014.

Vehicle Simulator Model

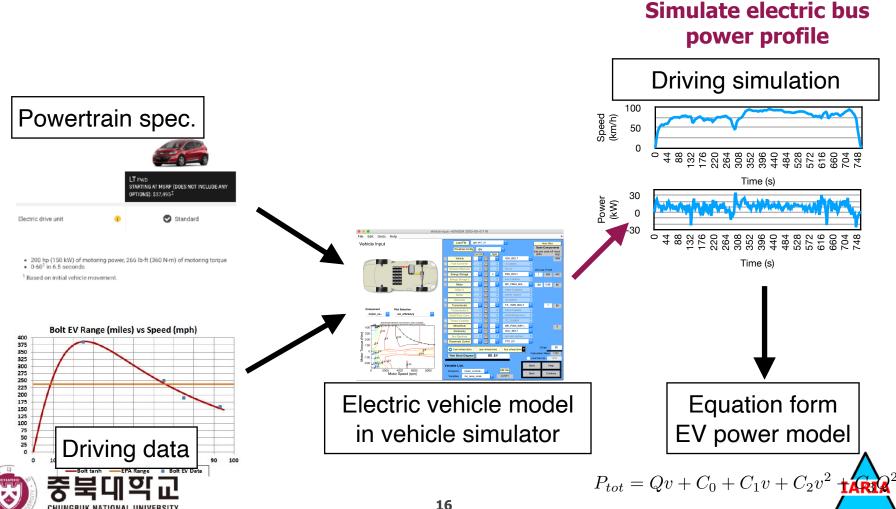
- 320 kWh battery capacity
- Average 250 km driving range (by ref. experimental results)







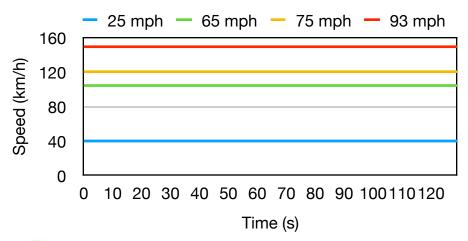
Need to implement very simple but accurate power model using **ADVISOR**



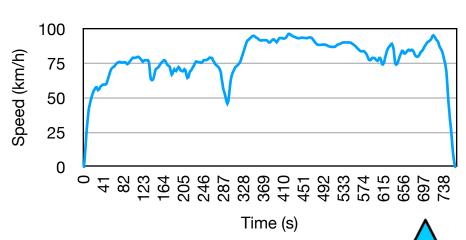
EV Power Characterization -should be updated

Extract simulation results from ADVISOR

Constant speed driving profile

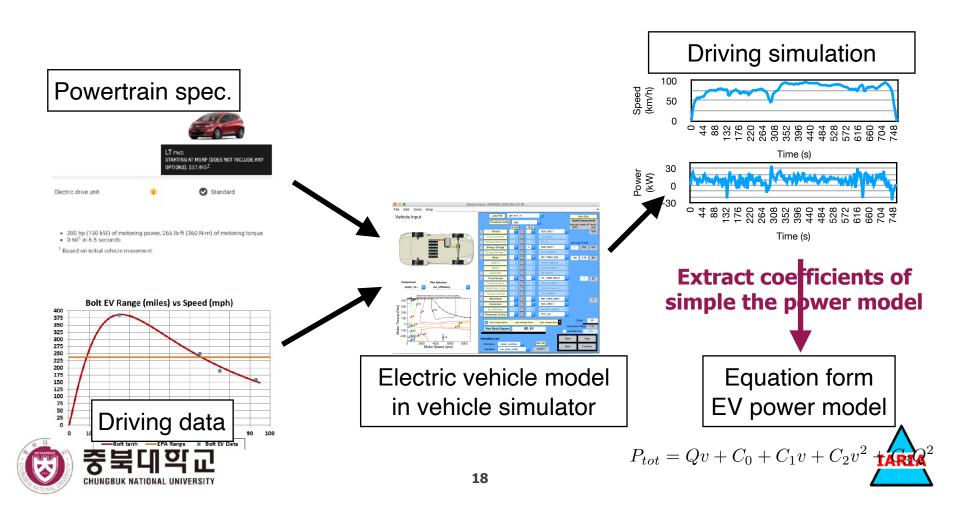


Benchmark driving profile





Need to implement very simple but accurate power model using ADVISOR

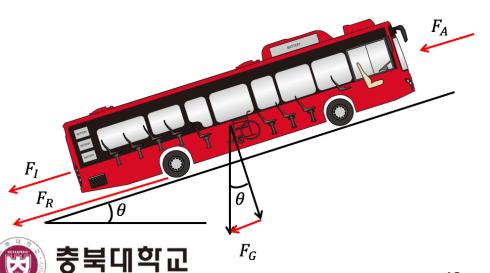


EV Power Characterization

- EV power model
 - Dynamics by resistances acting on a vehicle
 - Motor energy loss includes copper loss, iron loss, friction, and windage loss

EV physical power consumption

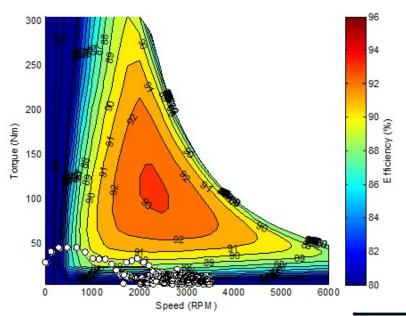
$$P = F\frac{ds}{dt} = Fv$$
$$= (F_R + F_A + F_G + F_I + F_B)v$$



Motor energy loss

$$Q = P/\omega = (\alpha + \beta sin\theta + \gamma)mr$$

$$P = C_0 + C_1 v + C_2 v^2 + C_3 Q^2$$



EV Power Characterization

EV power model

EV power consumption model

$$Q = P/\omega = (\alpha + \beta \sin\theta + \gamma)mr$$
$$P_{tot} = Qv + C_0 + C_1v + C_2v^2 + C_3Q^2$$

EV power harvesting model

$$P_{regen} = \varepsilon T v + \zeta$$

 $F_{RB}(regen.\ brake\ resistance) = constant$





EV Power Model Validation

EV power model

EV power consumption model

$$P_{EV} = rac{P_{trac}}{\eta_{EV}}$$

$$P_{trac} pprox (\alpha + \beta sin\theta + \gamma a + \delta v^2) mv$$

$$\eta_{EV} = rac{P_{trac}}{P_{trac}} + k_c T^2 + k_i \omega + k_w \omega^3 + C$$

$$P_{tot} = Qv + C_0 + C_1 v + C_2 v^2 + C_3 Q^2$$

EV power harvesting model

$$P_{regen} = \varepsilon T v + \zeta$$

EV power model parameters

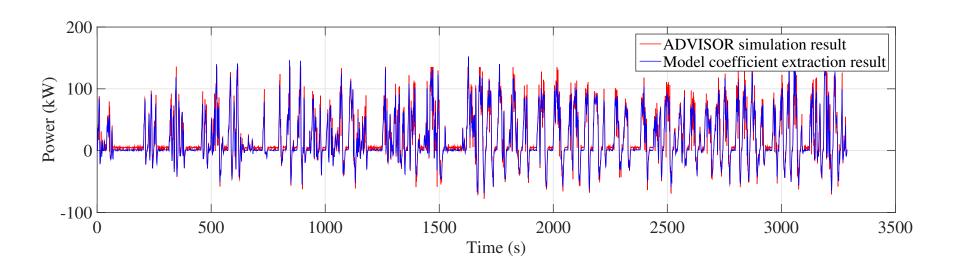
α	0.098	β	9.7562	γ	1.2016	δ	0.0001
C_0	1000.0	C_1	1378.2	C_2	0.00001	C_3	0.000015
ϵ	0.4095	ζ	2178.5				





EV Power Model Validation

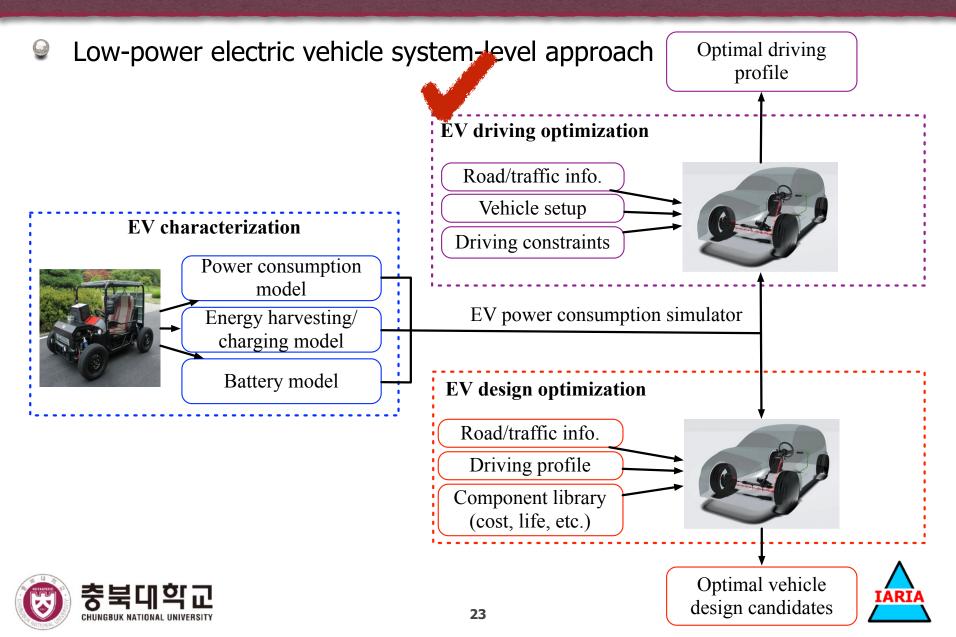
Normalized root-mean-square (RMS) deviation: 9.12%





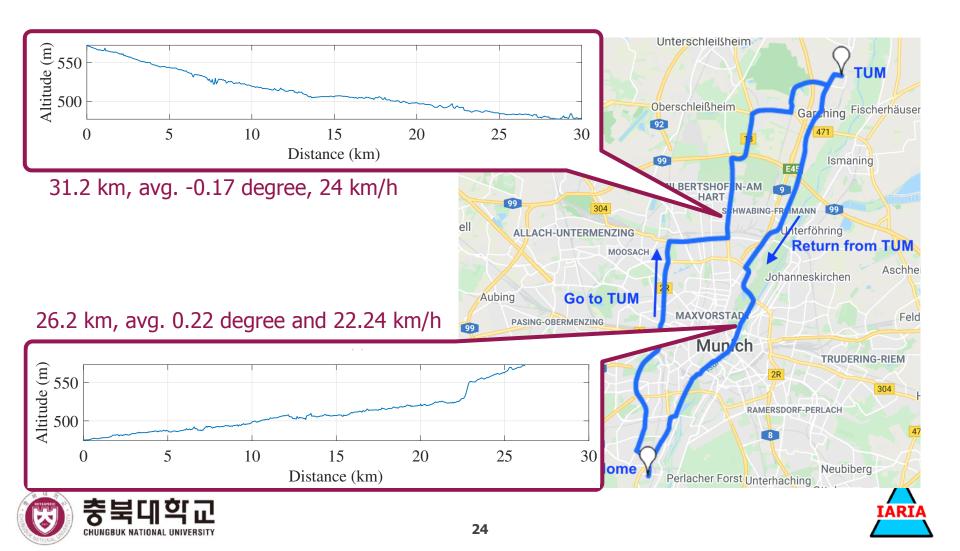


System-Level Approach for EV Optimization



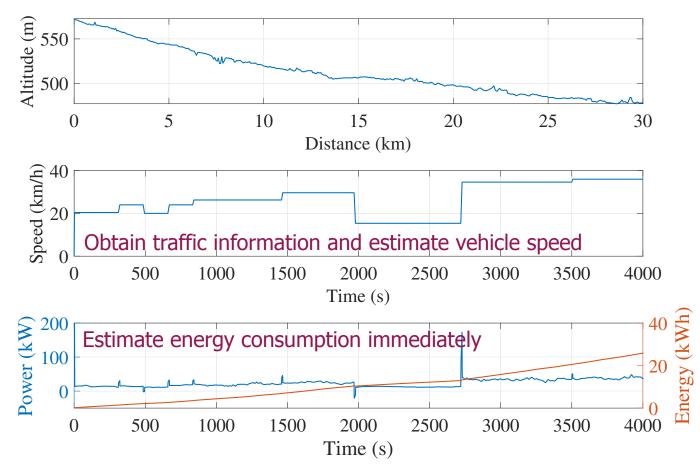
Case Study 1: Fast Driving Energy Estimation

Benchmark route information



Case Study 1: Fast Driving Energy Estimation

Estimate power consumption in online manner

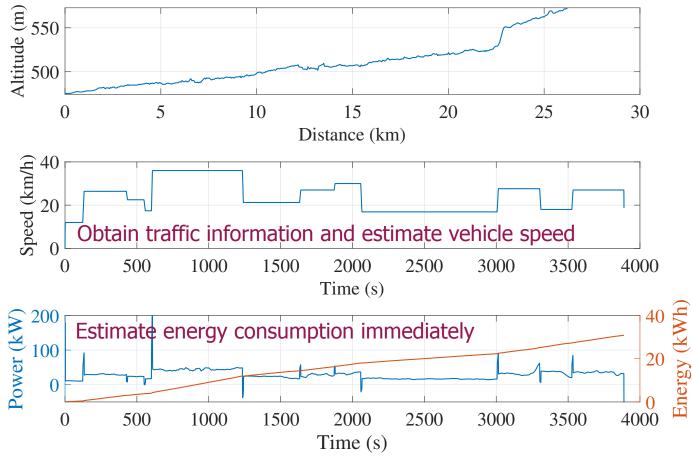






Case Study 1: Fast Driving Energy Estimation

We can pick the best way using the up-to-date traffic information

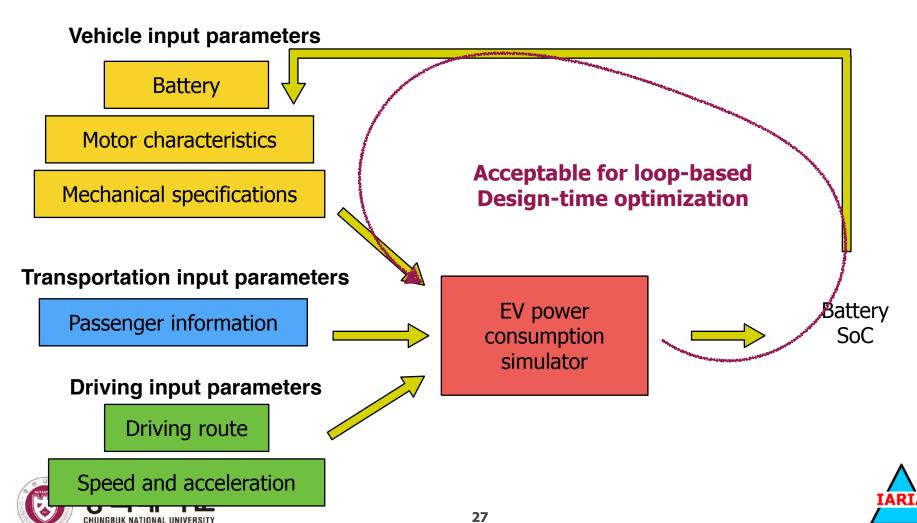






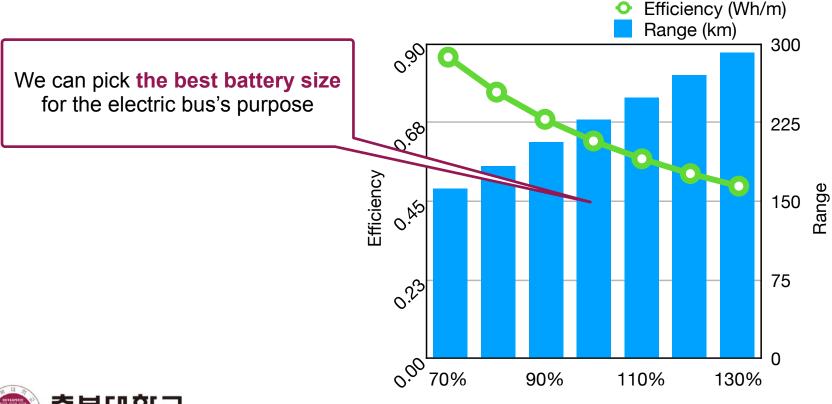
Case Study 2: Battery Size Analysis

The optimal battery size is derived using the iteration-based problem solver



Case Study 2: Battery Size Analysis

- Estimate below for the same driving profile
 - Driving range
 - Energy consumption and driving efficiency (Wh per meter)







Conclusion

- Electric bus powertrain modeling
 - Conventional vehicle estimator is accurate but slow for online estimation or optimization problem
 - We suggest fast but accurate powertrain modeling
 - Extract vehicle component parameters
 - Use simulation results
 - Extract coefficients of powertrain model
- Case studies with the fast powertrain model
 - Estimate power/energy consumption online manner
 - Show the range/energy/efficiency by the battery size
 - Fast powertrain model can be utilized for the various area!



