The assessment of PHEV energy management strategies using driving range data collected in Beijing

Cong Hou

2013.11.19

Outlines

- Introduction
- Powertrain Architecture
- Beijing Daily Driving Range
- Strategy Development
- Assessment Method
- Result and Discussion
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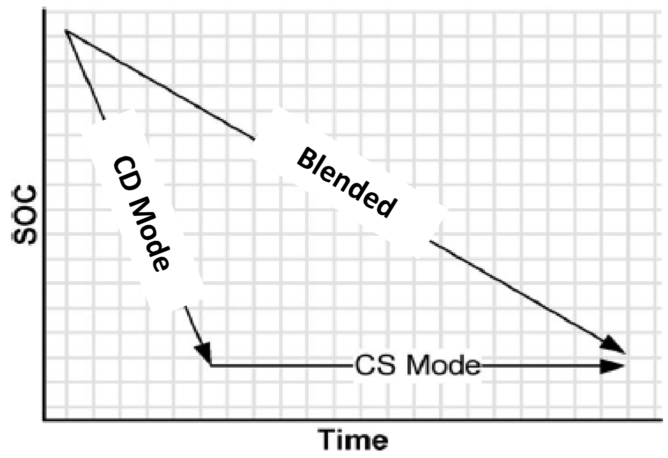
Is Blended really better than CDCS?

Introduction



Source:
S.G. Wirasingha, etc. Classification and Review of …

- N. Kim: **6% saving** by applying a PMP-based strategy.
  - *ANL, Journal of Power Sources*
- S. J. Moura: **Improved 10%** by applying a blended strategy.
  - *UM, IEEE Transactions on Control Systems Technology*
- Y. He: **Improved 14-31%** by A-ECMS strategy.
  - *Clemson, Transportation Research Part C*
- M. Zhang : **Improved 7-10%** by minimizing the loses.
  - *Chrysler, IEEE Transactions on Vehicular Technology*

Objective in common:
The fuel consumption (or energy consumption) in a SPECIFIC cycle!

Conclusion in common:
Blended is better than CDCS!

Will the conclusion still hold when considering variable trip length?

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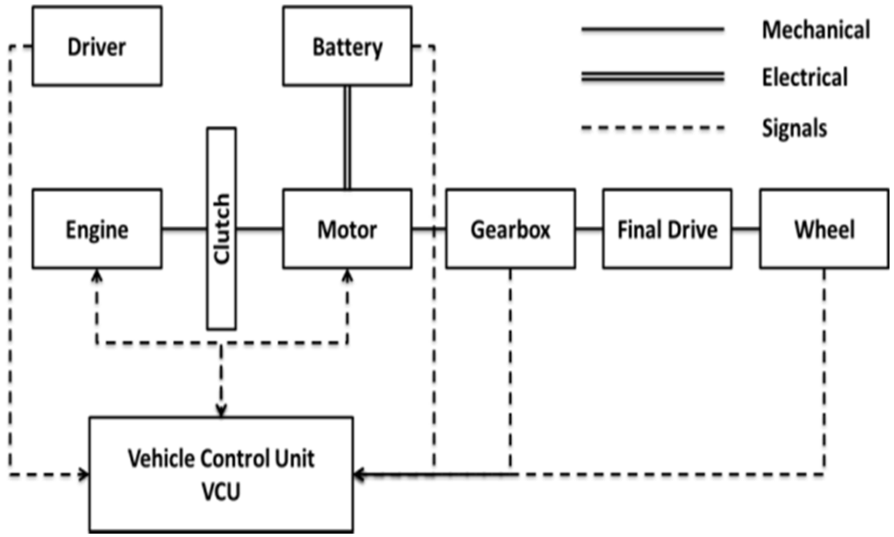
PHEV Specifications

Engine	Displacement (L)	1.5
	Max Torque (N m)	124
	Max Power(kW)	63
Motor	Max Torque (N m)	458
	Max Power (kW)	60
Battery	Cell Capacity (Ah)	12.35
	Cell Nominal Voltage (V)	3.28
	Cell Mass (kg)	0.395
	Cell Terminal Voltage (V)	2.8-3.7
	Cells in series	100
	Modules in parallel	4
Vehicle	Curb Mass (kg)	1500
	Wheel Radius (m)	0.334
	Frontal Area (m^2)	2.25
	Gear 1 Ratio	3.45
	Gear 2 Ratio	1.98
	Gear 3 Ratio	1
	Gear 4 Ratio	0.75
	Final Drive Ratio	3.63

Powertrain Architecture



Control Variable:

Torque Split Ratio

Gearbox:

Based on pedal and velocity

Clutch:

Based on engine torque requirement

Battery:

16 kWh, 400 cells, Li-Fe PO_4

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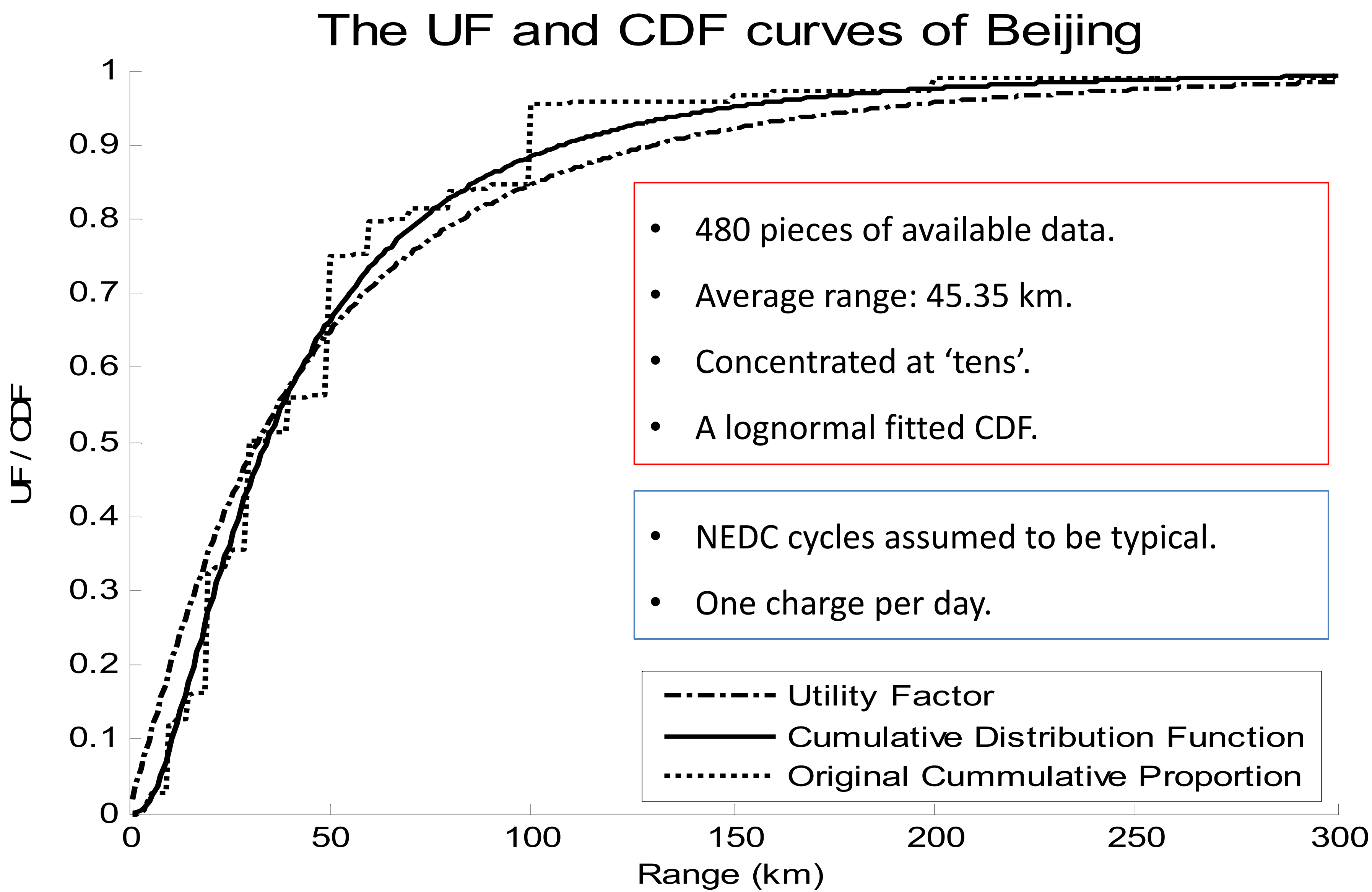
$$F(x)=\Phi\left[\frac{\ln(x)-3.5343}{0.8943}\right] \quad 0 < x < \infty$$

Beijing Daily Range



- 480 pieces of available data.
- Average range: 45.35 km.
- Concentrated at ‘tens’.
- A lognormal fitted CDF.

- NEDC cycles assumed to be typical.
- One charge per day.

Cong Hou, et.,al, Survey of daily vehicle travel distance and impact factors in Beijing, IFAC-AAC 2013, Tokyo

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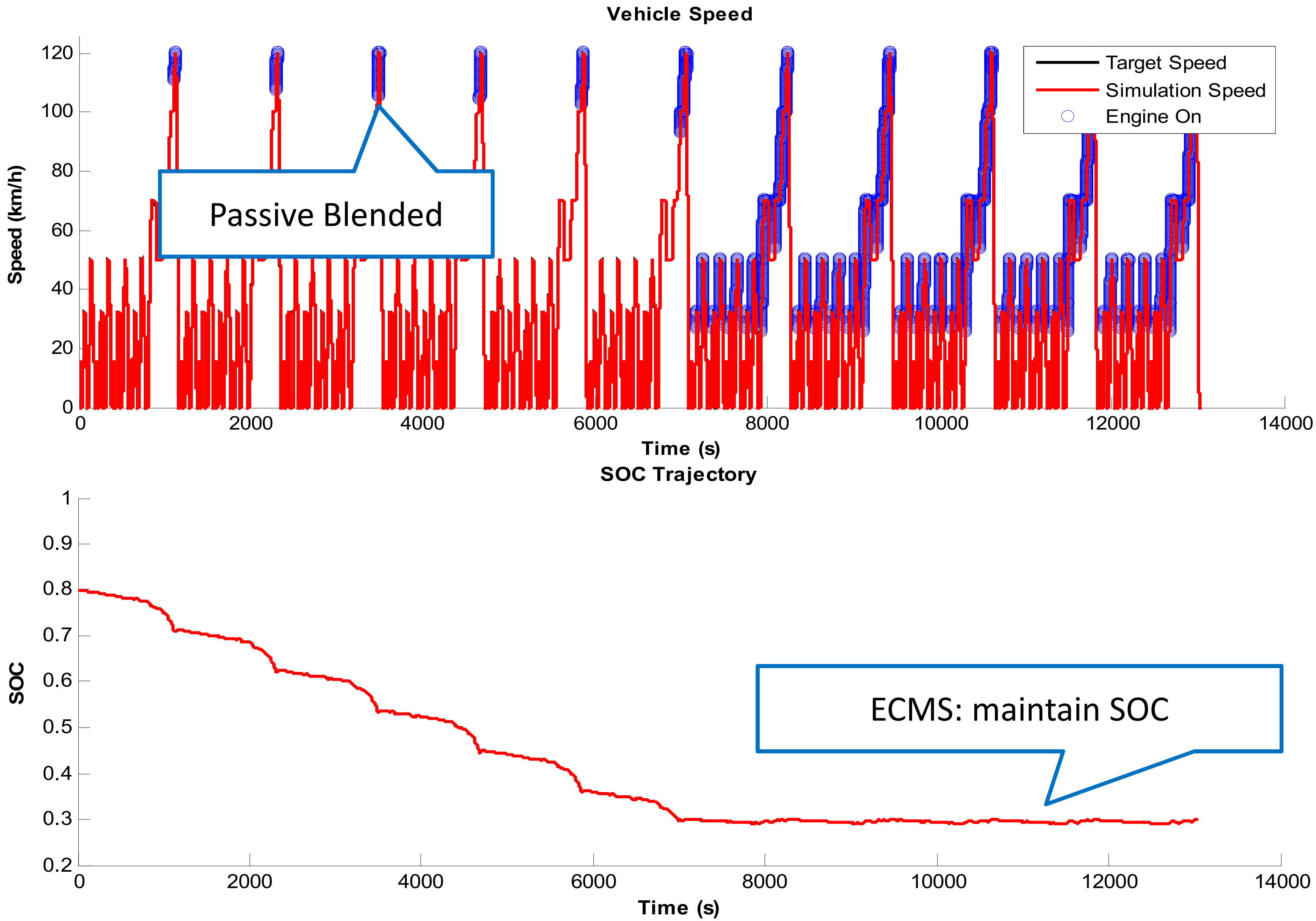
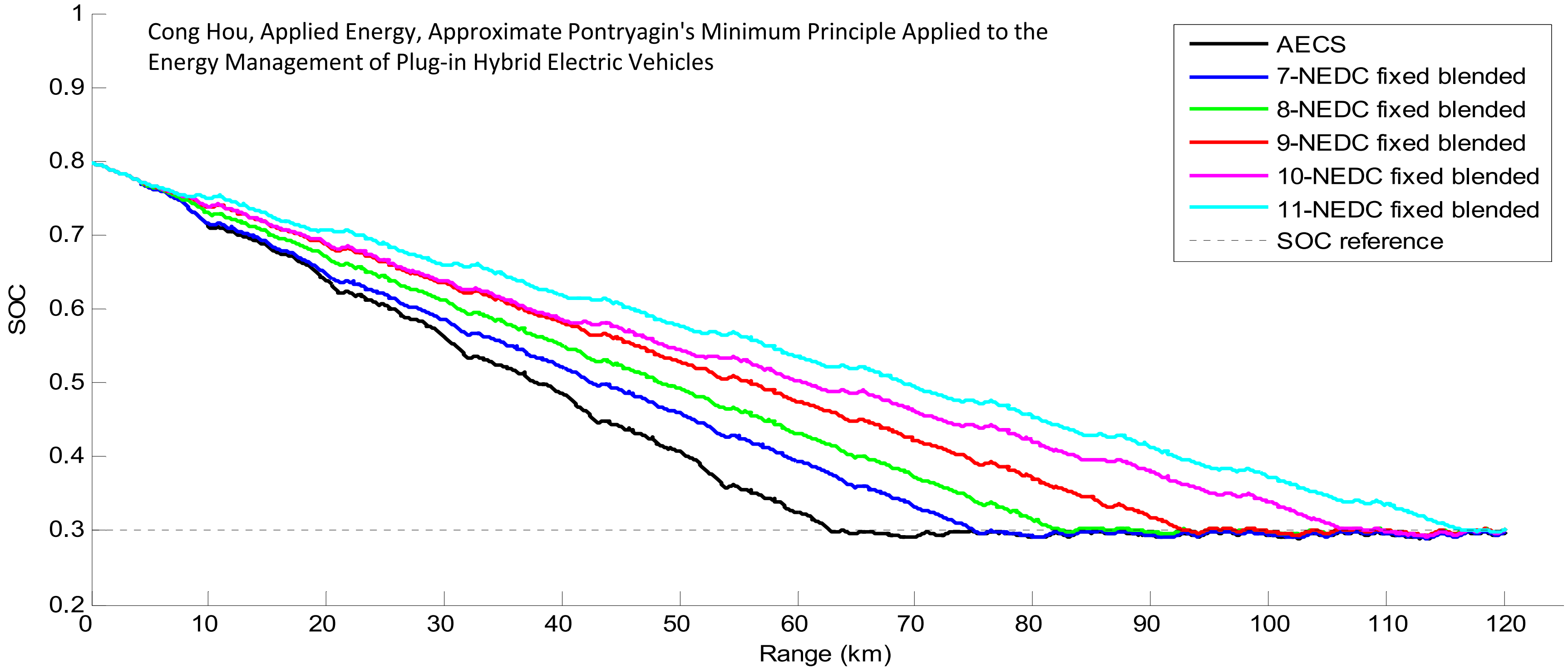
AECS | Fixed Blended | Adaptive Blended | Strategy Development



A-PMP Method:

$$H(x(t),u(t),p(t),t) = \dot{m}(u(t),t)\text{-}p(t)\cdot\frac{V_{oc}(x)\text{-}\sqrt{V_{oc}{}^{2}(x)\text{-}4P_{batt}(u(t))R_i(x)}}{2R_i(x)Q_{batt}}$$

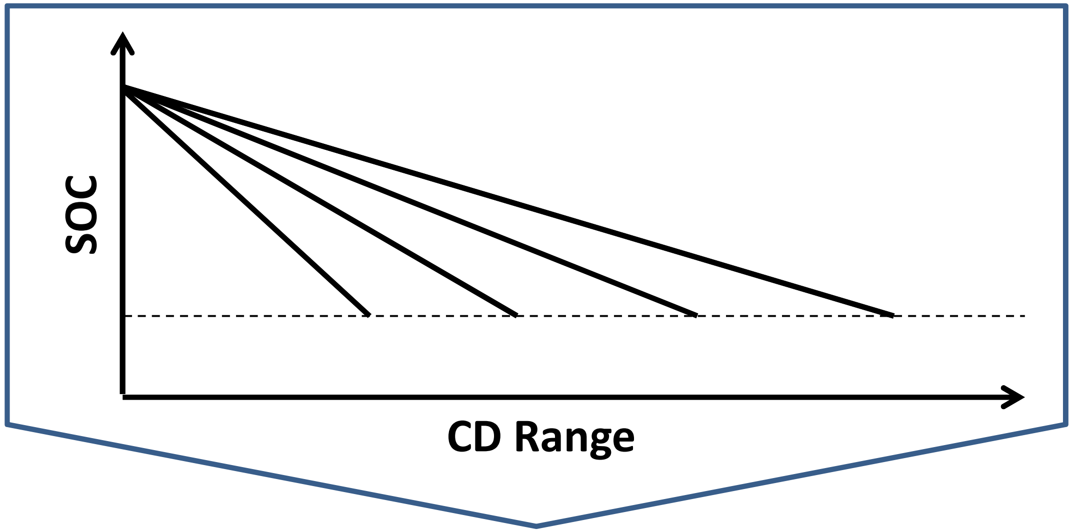
$$u^*(t) = \arg\min\{H(x,u,p,t)\} \quad \dot{p}^*(t) = -p(t)\frac{\partial(H(x,u,p,t))}{\partial x}$$



1. Determine the trip length → 2. Let trip length equal to CD range → 3. Look up for the corresponding co-state initial → 4. Implement A-PMP with the correct co-state initial

Theoretically,
No CS stage exists!

Trip Length = CD Range



Corresponding Co-state Initials

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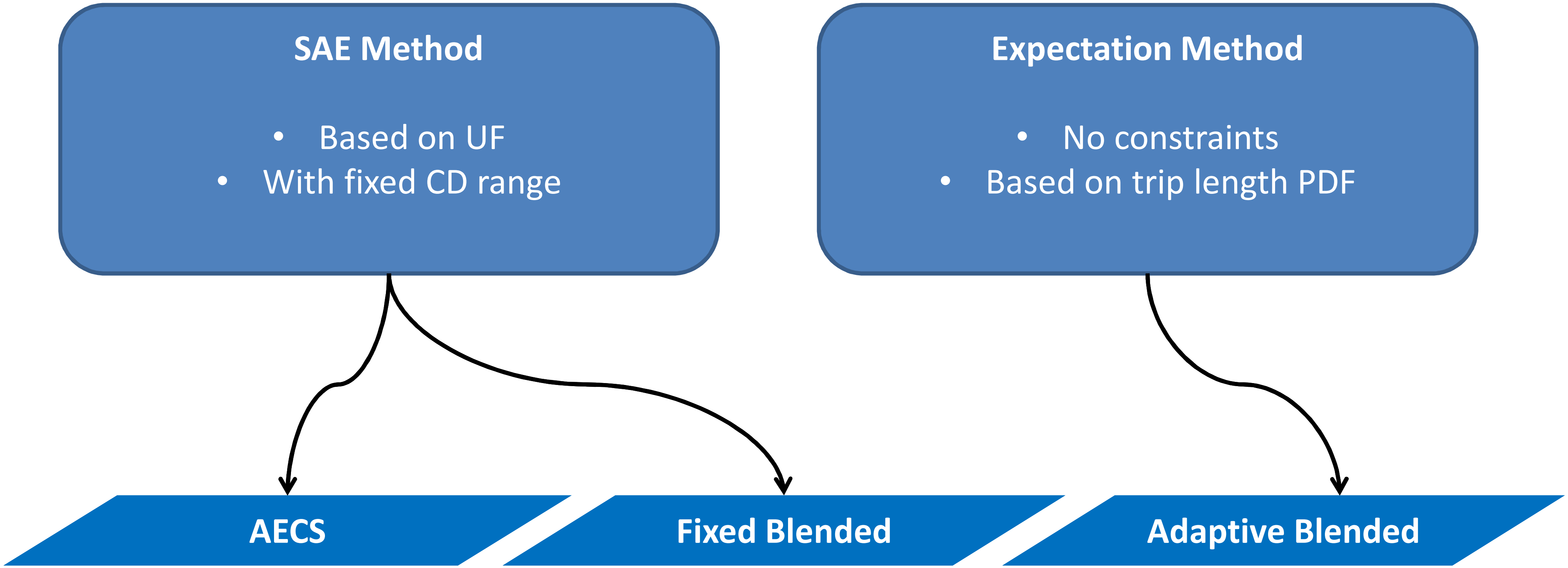
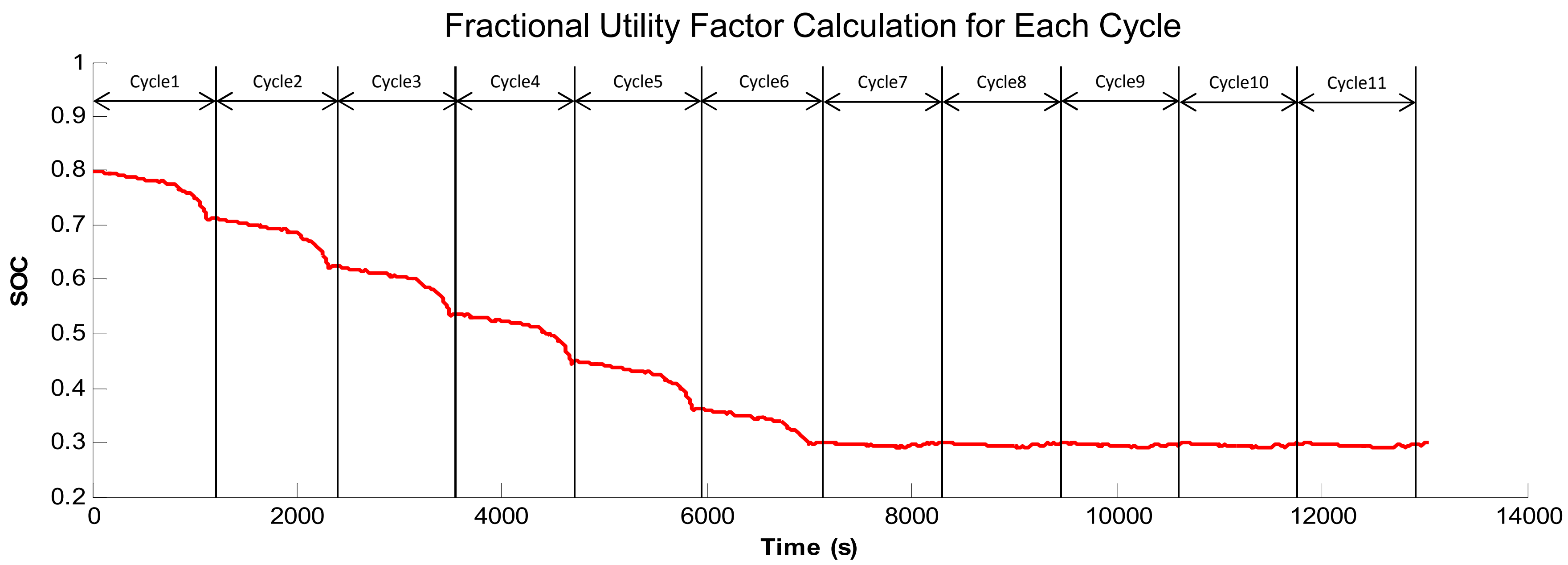
Assessment Methods

- **AFC: Average Fuel Consumption (L/100km)**
  average in terms of different trip lengths.

- **FSR: Fuel Saving Rate (%)**
  relative to the corresponding HEV (the performance of CS stage)



SAE Method



$$AFC = \sum_{i=1}^{lastCDcycle} [(UF(i * D_{cycle}) - UF((i-1) * D_{cycle})) * FC_{CDi}] + [1 - UF(R_{CDC})] * FC_{CS}$$

Cycle No.	1-NEDC	2-NEDC	3-NEDC	4-NEDC	5-NEDC	6-NEDC	7-NEDC	8-NEDC	9-NEDC	10-NEDC	11-NEDC
Cycle UF	0.2054	0.1668	0.1282	0.0975	0.0747	0.0579	0.0455	0.0361	0.0290	0.0236	0.0194

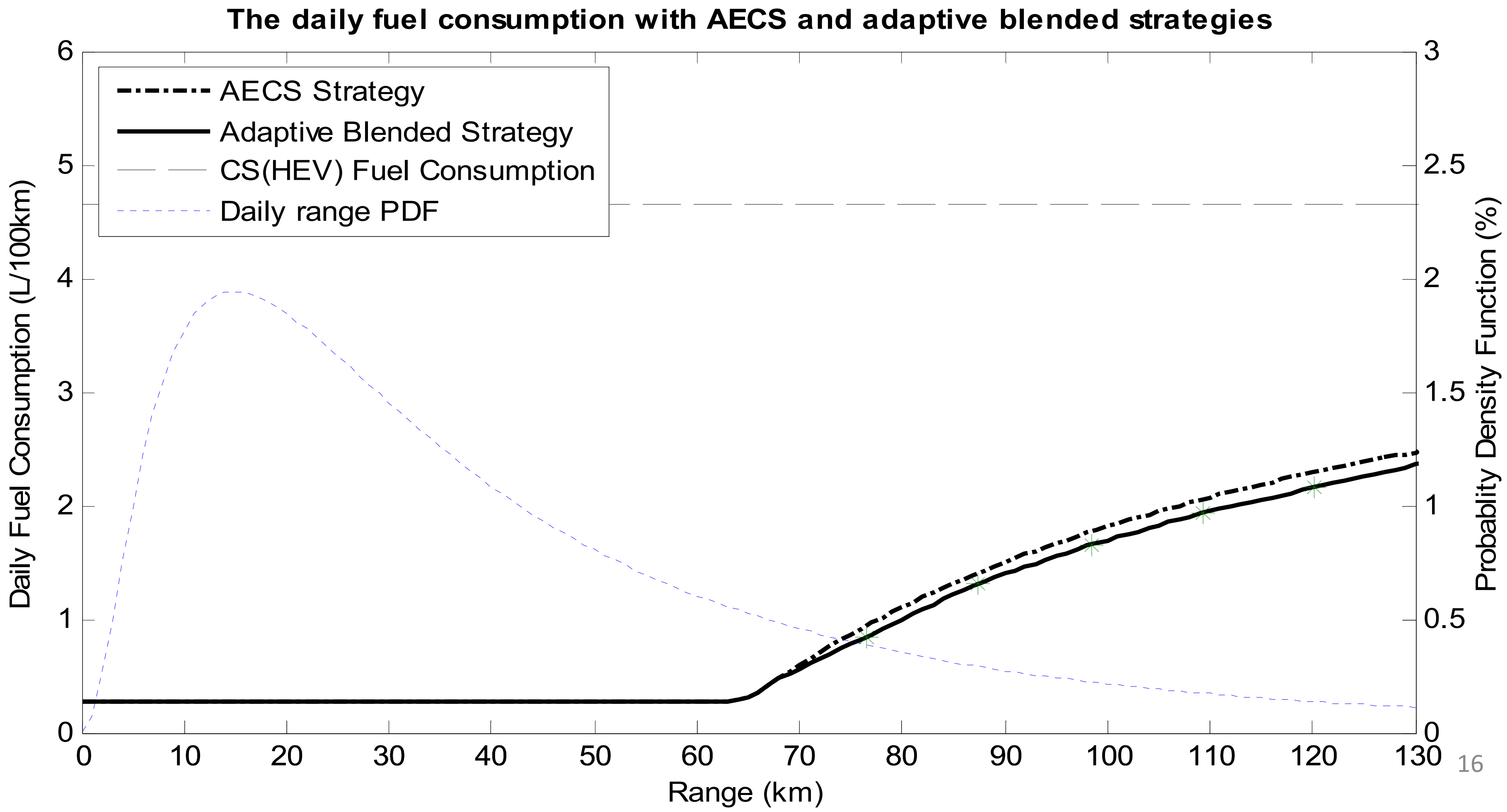
Lumped Utility Factor Calculation

$$FC = UF(R_{CDC}) * FC_{CD} + [1 - UF(R_{CDC})] * FC_{CS}$$

Expectation Method

$$AFC = \frac{TF}{TR} = \frac{E[DF(x)] \cdot N}{E[x] \cdot N}$$

$$AFC = \frac{\int_0^{+\infty} x \cdot dfc(x) \cdot f(x)dx}{\int_0^{+\infty} x \cdot f(x)dx}$$



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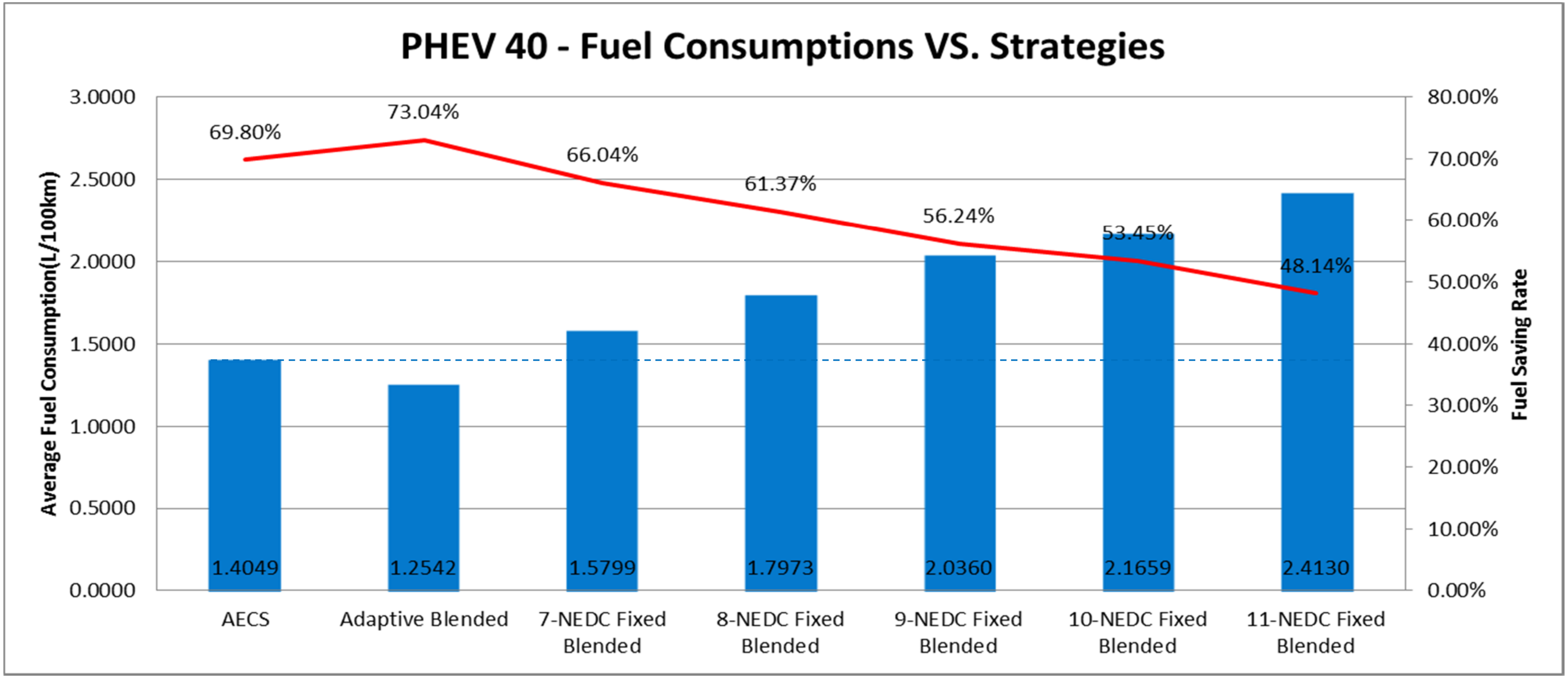
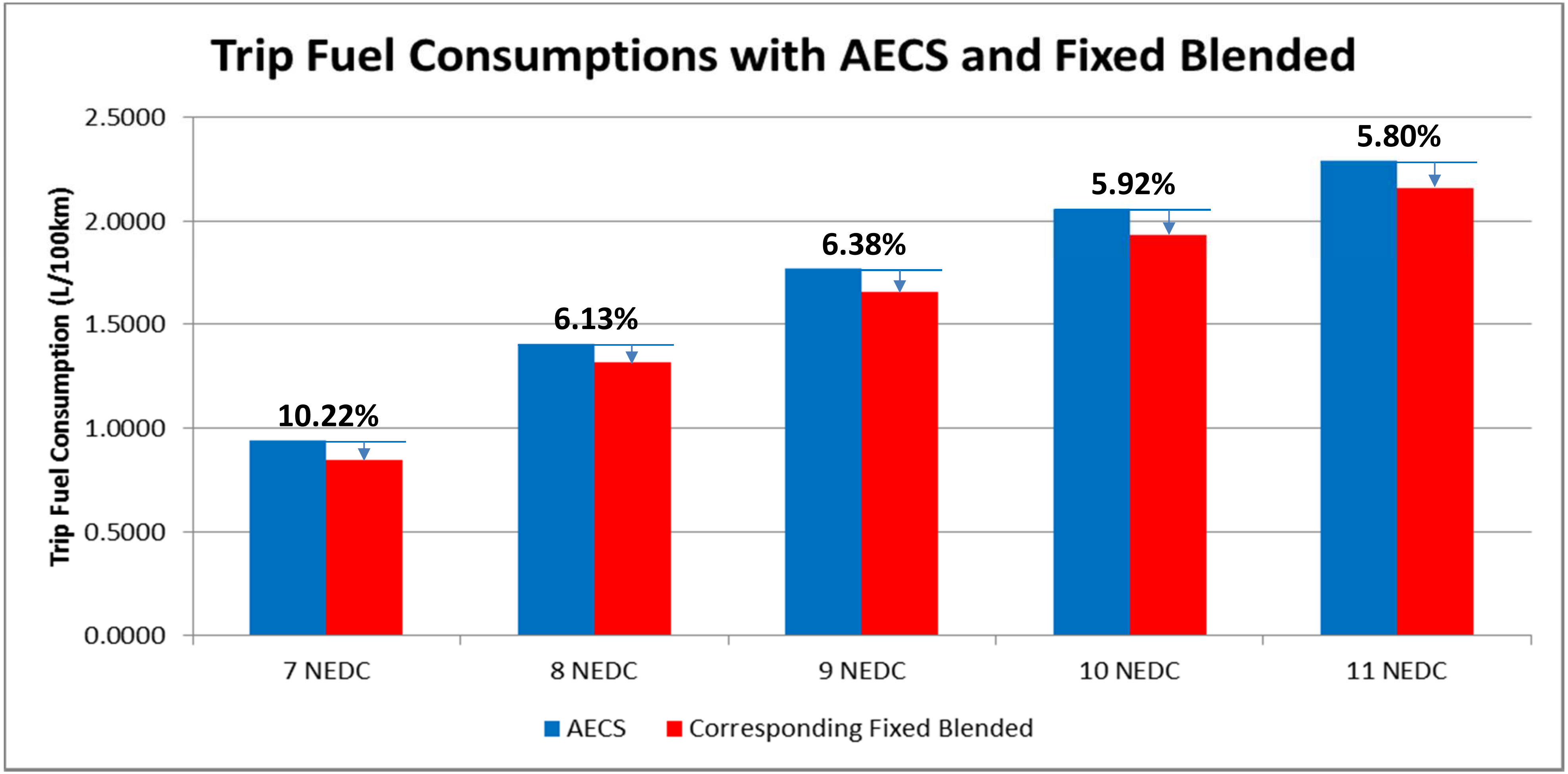
General Results



- **Does the fixed blended WORK?**
- **What makes the AFC with the fixed blended strategies so HIGH?**

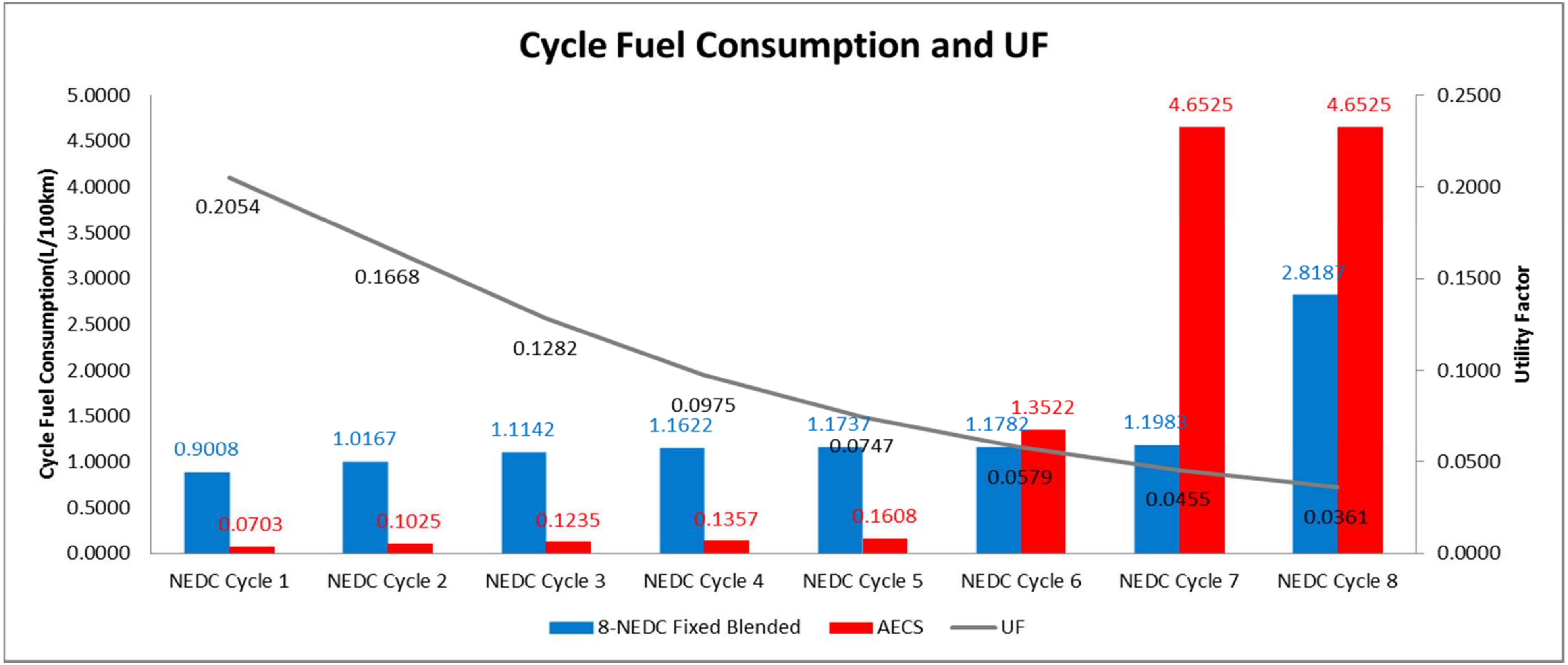
Does the fixed blended WORK?



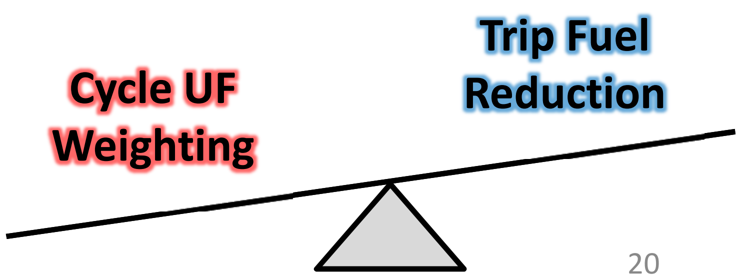
- The fixed blended strategies DOES reduce the fuel consumptions for specific trips.
- The fixed blended strategies ALSO reduce the fuel consumptions for the trips longer than the specific trips, as they share the same ECMS strategy for CS stage control.

What makes the AFC so HIGH?

Results and Discussion



- **Fixed Blended**: Uniformly distributes the fuel.
- **AECS**: Aggressively consumes electricity, then fuel.
- The high UFs in the early cycles make the high AFC.



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Conclusions

1. According to the assessment, with the same components, the lowest AFC is 1.2542 L/100km, with the adaptive blended strategy; and the highest AFC is 2.4130 L/100km, with one of the fixed blended strategy.

2. For the studied powertrain architecture applied in Beijing, the AECS is the best strategy unless the blended strategy is adapted to the driving range.

3. The AFC, instead of the specific trip fuel consumption, should be taken into consideration when optimizing the energy management strategy for a PHEV.

Thank You!

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