# Remaining useful life prediction for Lithium-ion batteries across operation conditions by CORAL

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## Abstract

Unsatisfying data integrity and heterogenous data distribution are the main problems for echelon (ladder) utilization(EU) of Lithium-ion batteries (LiBs).

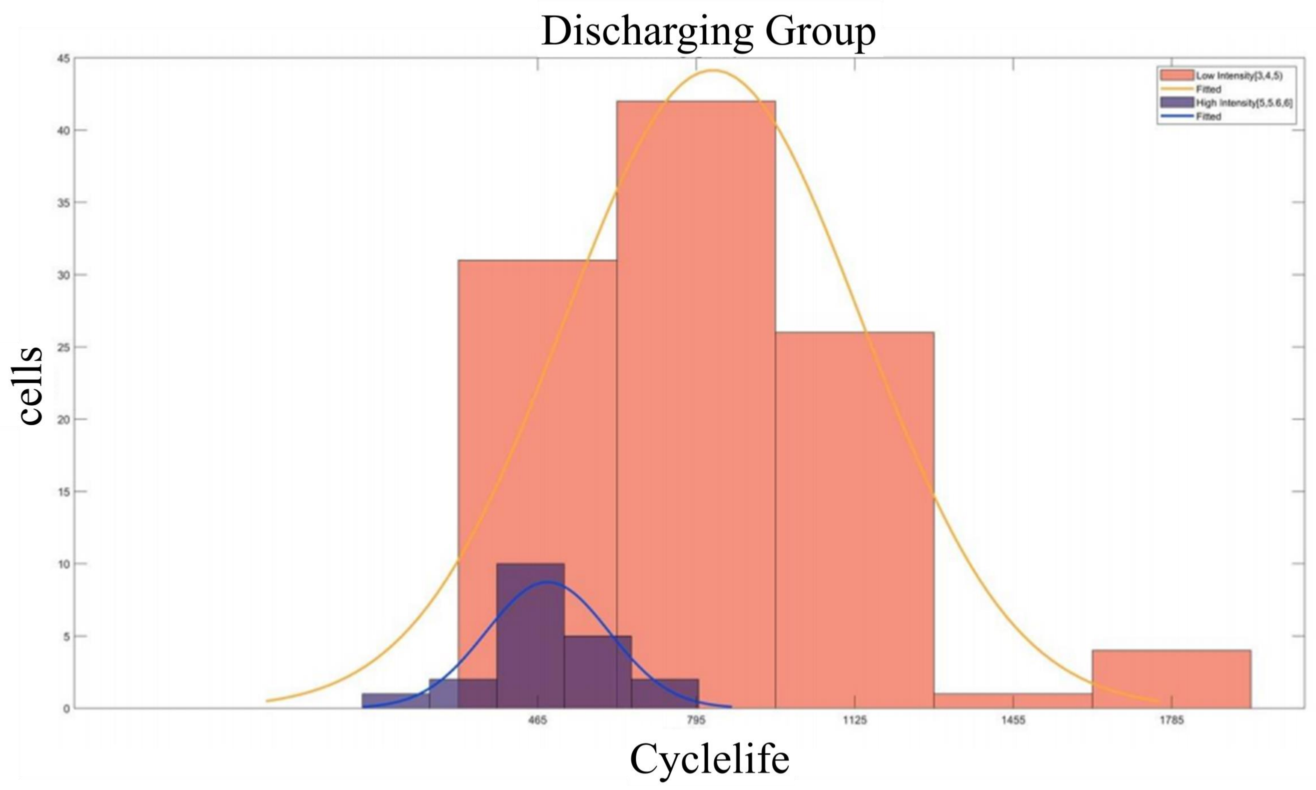
Here we propose **a transfer learning (TL) model with feature embedding based on multi-layer-perceptron (MLP)** and first define the transferability for EU as the Wasserstein distance across operation conditions (OCs). The accuracy of proposed TL model is 91%.

This work would accelerate the development of EU and new knowledges towards efficient, state estimation and RUL prediction methods in the future.

## Problem Statement

OC settings: (1) medium Discharging Intensity

(2) high Discharging Intensity




A cycle life distribution shift under different OCs

## Results

### 1. Features Extracted

(1) min dQ, (2) var dQ, (3) average charging time

(4) average charging time delta, (5) intercept, (6) slope

(7) min IR , (8) max IR, (9) dif IR

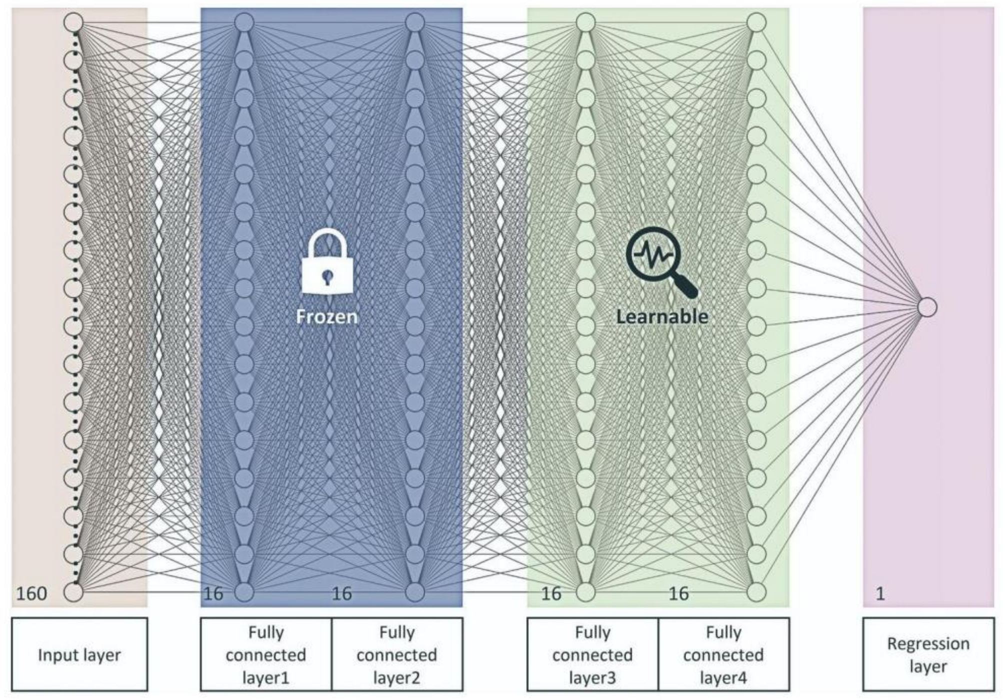
(10) integral of temperature by time.

### 2. Pretraining MLP model

Baseline1, only use Medium Discharging Intensity data

### 3. Fine tuning

Baseline2, Medium Intensity + small High Intensity



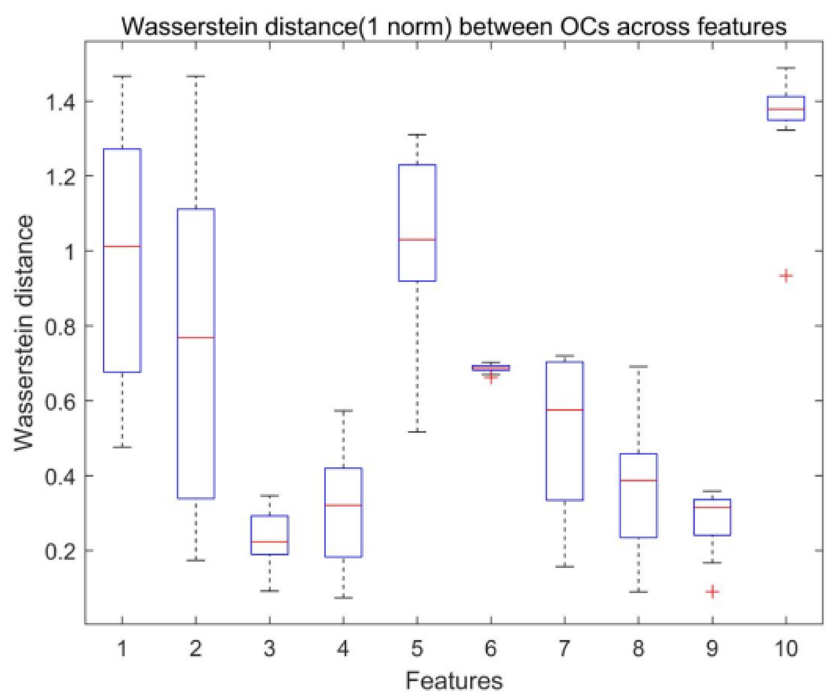

The schematic of MLP based fine tuning Discharging Intensity data

### 4. Domain adaption (DA)

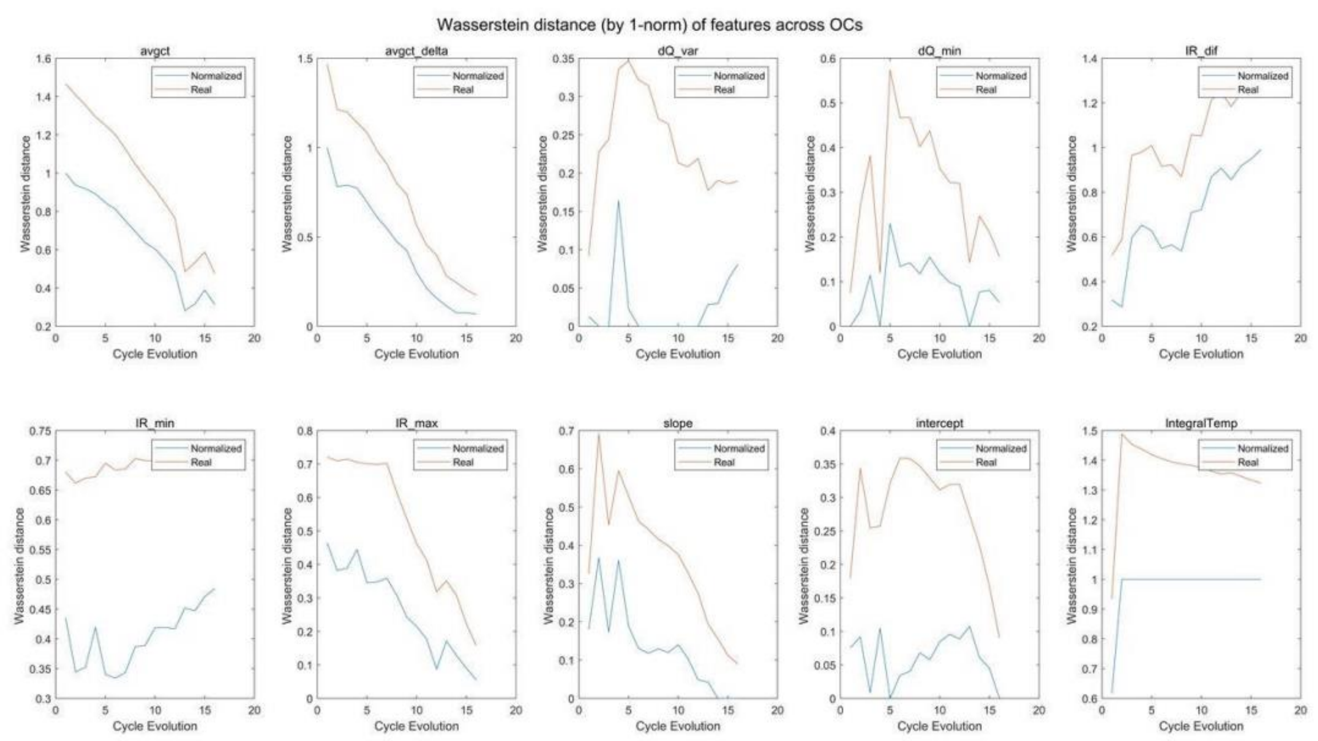
Correlation alignment (CORAL), a feature based DA method is adopted to align the features in source domain and target domain into an encoded feature space.

$$\min_{A} \| A^T C_S A - C_T \|_F^2 \qquad W_P(F_S, F_T) = \left( \inf_{\gamma} \int_{r \times r} |x-y|^p \, d\gamma(x,y) \right)^{\frac{1}{p}}$$

**What to transfer** With high transferability (low distance value)

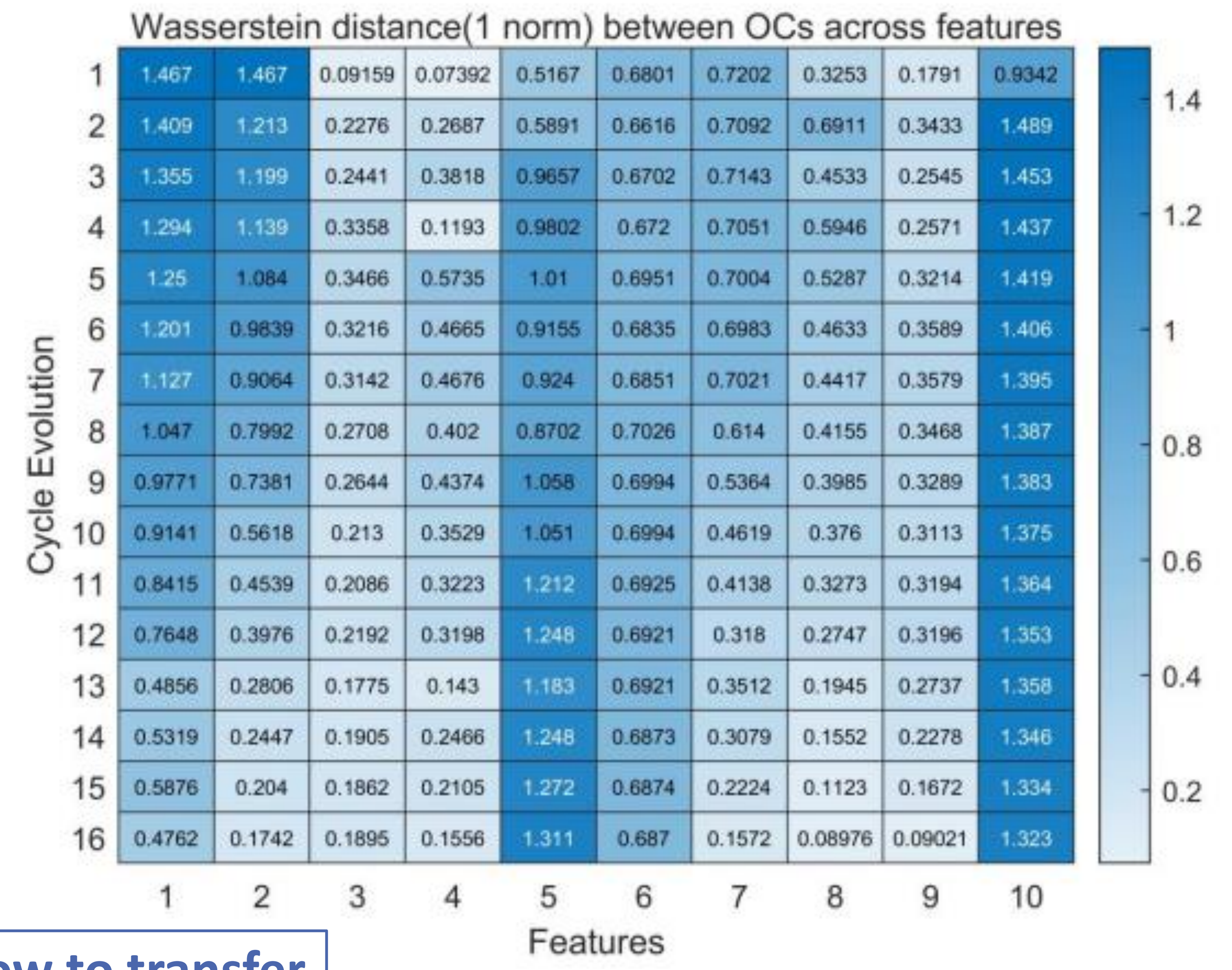



Kantorovich-Wasserstein distance measure between the high cycle rate condition and the medium cycle rate condition for the selected 10 features. When the distance value is small, the transferability of selected features is higher.



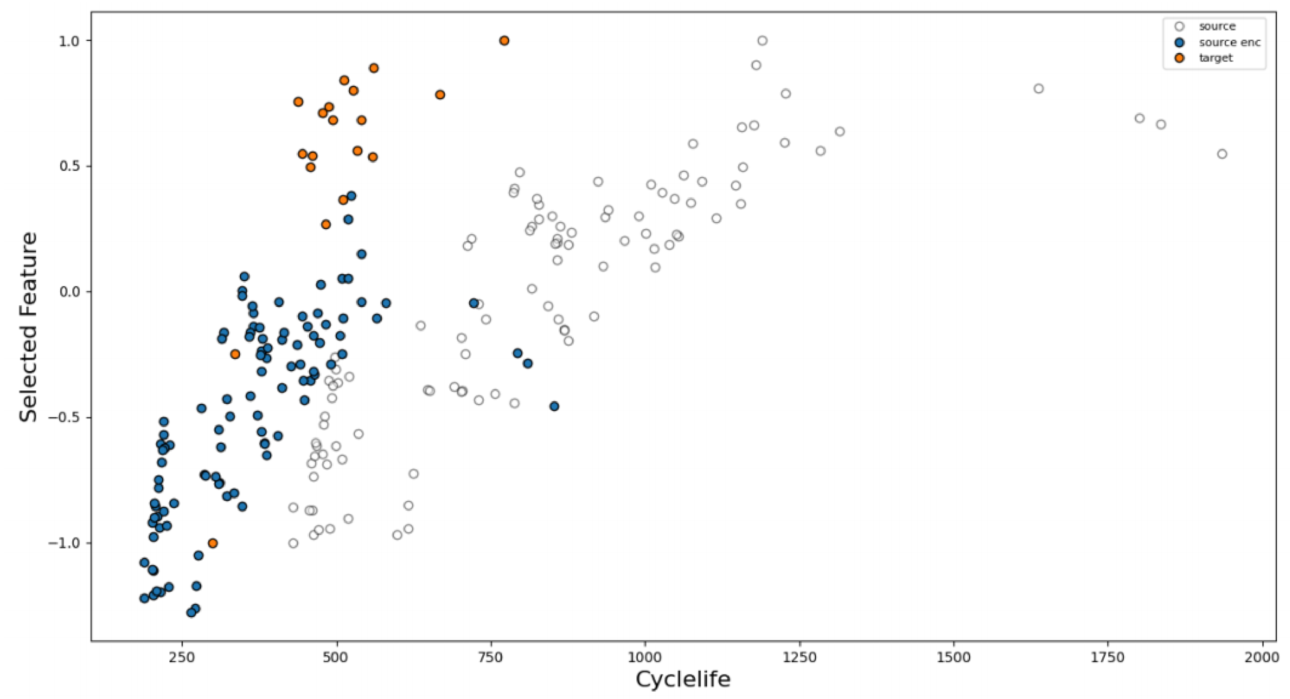

**When to transfer**

The transferability against cycle evolution number determines when to transfer.




**How to transfer**

Use optimal transport algorithms such as CORAL.




## Conclusion

1. After Domain adaption, the performance of the model is better.

| OC | MAE | MSE | RMSE | Err(%) |
|---|---|---|---|---|
| Baseline2 | 67.8589 | 9419.9873 | 90.5153 | 14.1475 |
| CORAL | 42.7514 | 3333.896 | 53.8341 | 8.2736 |

2. Features with smaller Kantorovich-Wasserstein distance are more likely to be universal features.