Time-Driven Cost Estimation Learning Model

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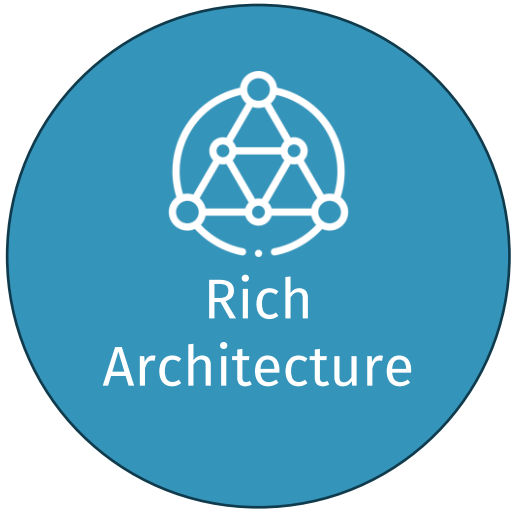
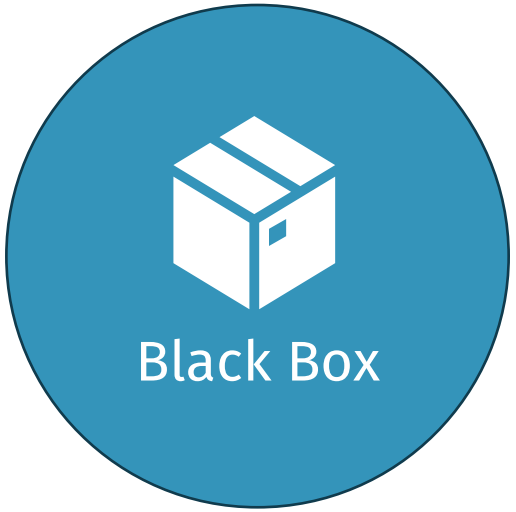
1. Problem Statement

- Artificial Neural Network (ANN) is famous for analogy-based construction cost estimation
- Generalizability makes another manufacturing cost estimation possible with some limitation



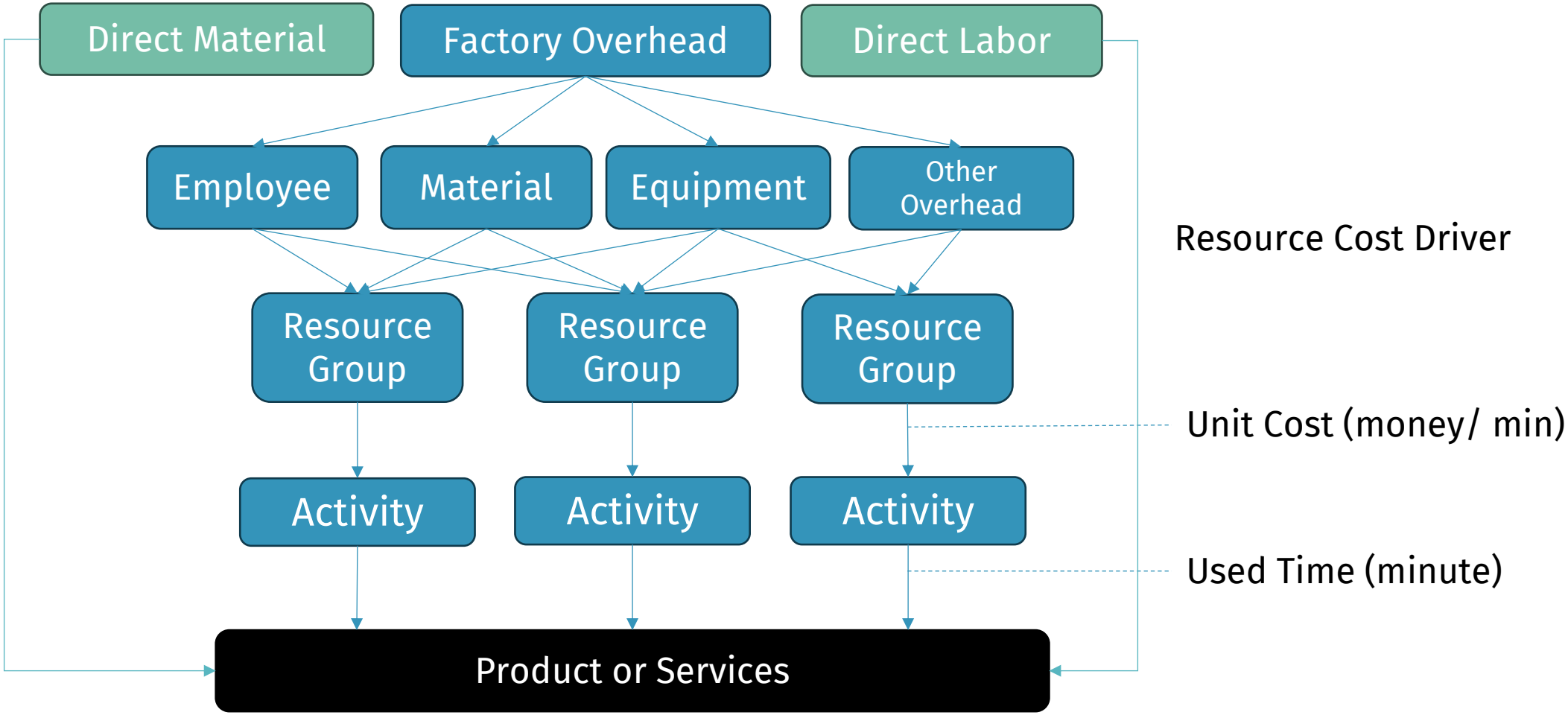


2. Objectives

- To create a glass box model in cost estimation using the idea of Artificial Neural Network and Time Driven Activity-based Costing

Picture Created by Generative AI in Microsoft Designer

3. Related Theory: Time Driven Activity-based Costing (TDABC)



Siguenza-Guzman, L., et.al. "Recent Evolutions in Costing Systems: A Literature Review of Time-Driven Activity-Based Costing." (2013) The Review of Business and Economic Literature

3. Related Theory : Time Driven Activity-based Costing (Cont.)

$$Total\ Cost = DMC + DLC + \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{k=1}^{M} t_{i,k} \times C_n$$

- DMC – Direct Material Cost
- DLC – Direct Labor Cost
- N – Amount of All Resource Pools
- I - Amount of Activity in Resource Pool
- M - Number of Events in activities
- $t_{i,k}$ - Time to perform event i in activity k
- C_n - Unit cost of resource n

Namazi, M. (2016). Time-driven activity-based costing: Theory, applications and limitations. *Iranian Journal of Management Studies (IJMS)*, *9*(3).

4. Purpose Technique : Time Driven Cost Estimation (TDCE)

- Mathematical model
- Model Architecture Design
- Learning Algorithm
- Weight Adjustment Algorithm

4.1 Mathematic Equation Modeling

- TDABC in style of ANN
- Combine labor cost with overhead cost
- Remove complexity by merging all activities and events as one activity

$$Total\ Cost = DirectMaterialCost + DirectLaborCost + \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{k=1}^{M} t_{i,k} \times C_n$$

$$DMC = \sum_{i=1}^{L} mc_i q_i$$

cost = unit cost x quantity

$$\sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{k=1}^{M} t_{i,k} \times C_n$$

Combine Direct labor to Factory Overhead

$$\sum_{n=1}^{N}\sum_{i=1}^{I} t_{i,k} \times C_n$$

Merge Events with Activities

$$\sum_{n=1}^{N} t_n \times C_n$$

4.1 Mathematic Equation Modeling (Cont.)

- Find Unit cost in minutes of labor and capital/investment cost
- Use TDABC Practical capacity model, labor will work only 80-85% of all working times
  - Daily Paid Labor

$$unit\ cost = \frac{cost}{1\ day} \times \frac{1\ day}{workhour} \times \frac{1\ hr}{60\ min} \times \frac{1}{0.8} = \frac{C_l}{48\ H_d}$$

  - Monthly Paid Labor

$$unit\ cost = \frac{cost}{1\ month} \times \frac{1\ month}{workingday} \times \frac{1\ day}{workhour} \times \frac{1\ hr}{60\ min} \times \frac{1}{0.8} = \frac{S}{48 D_m\ H_d}$$

  - Capital Cost

$$unit\ cost = \frac{cost}{lifetime\ (year)} \times \frac{1year}{12\ month} \times \frac{1\ month}{workday} \times \frac{1\ day}{hourwork} \times \frac{1\ hr}{60\ min} = \frac{C_C}{720 \times D_m \times LT \times MH}$$

4.1 Mathematic Equation Modeling (Cont.)

$$total\ cost = \sum_{i=1}^{I} C_{m_i} q_i + \left(\frac{1}{48\ H_d} \sum_{j=1}^{J} C_{l_j} + \frac{1}{48 D_m\ H_d} \sum_{k=1}^{K} S_k + \frac{1}{720 D_m} \sum_{l=1}^{L} \frac{C_{C_l}}{LT_l MH_l} \right) \cdot t$$

Material

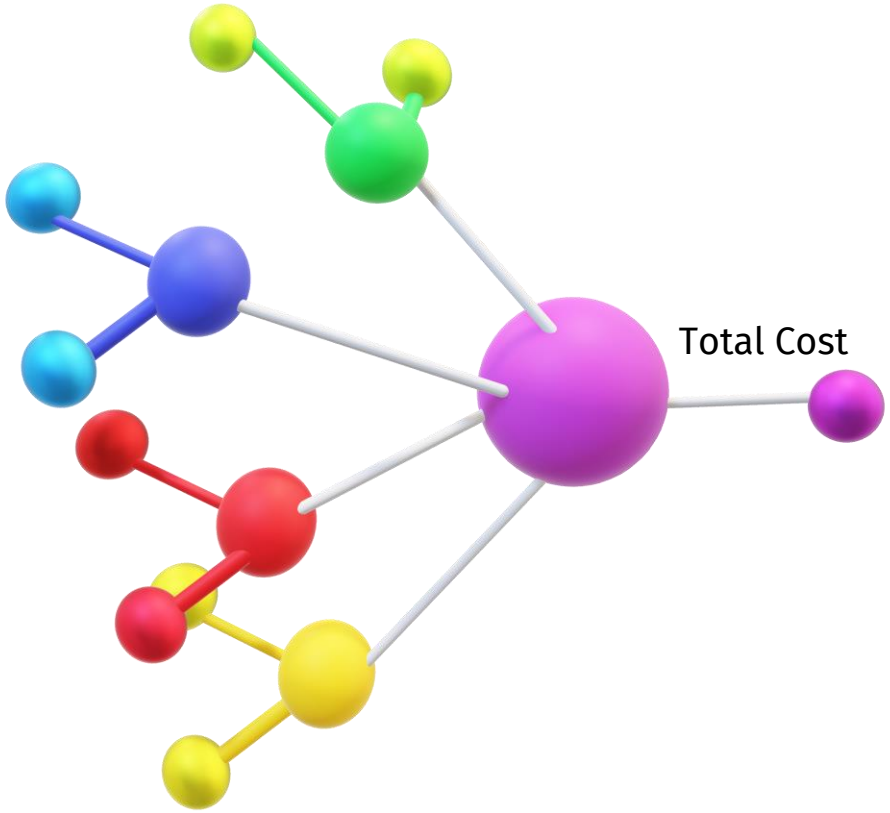
Daily Paid Labor

Monthly Paid labor

Capital Cost

4.2 Architecture Design and Learning Algorithm

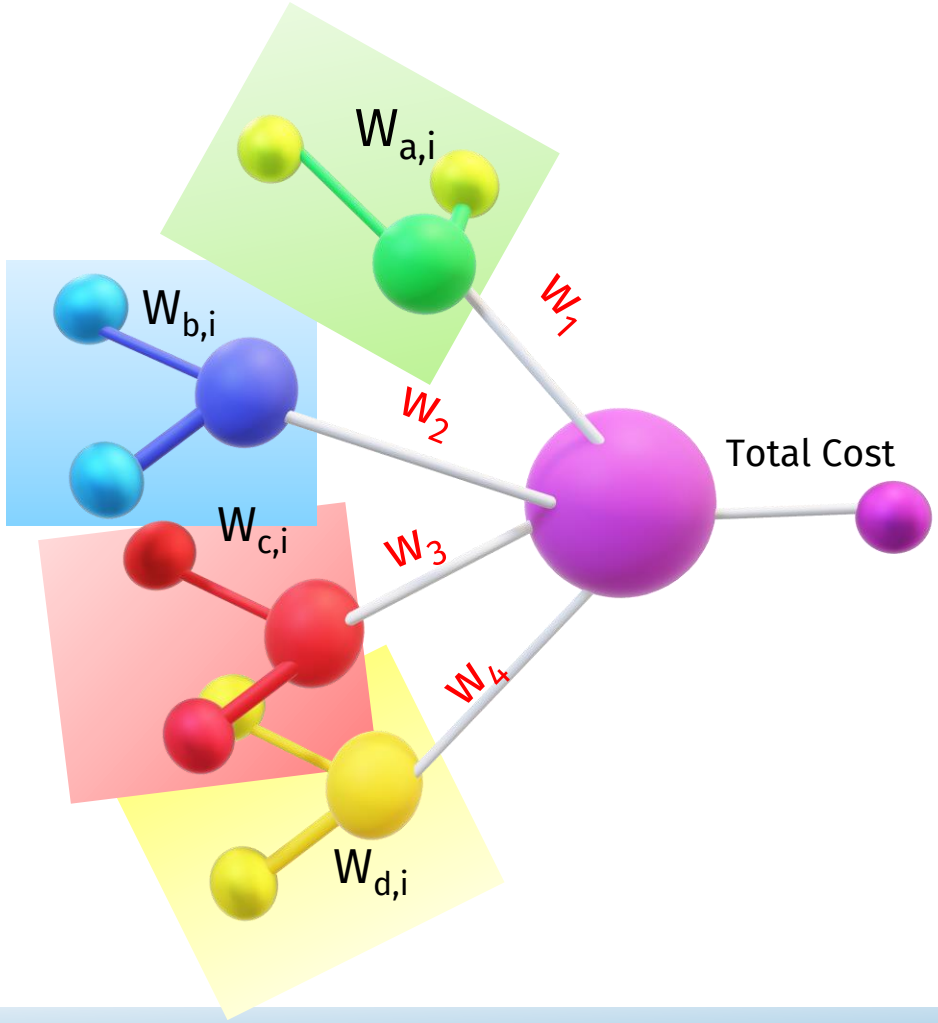
- Add the hidden weight to represent the actual situation of manufacturing



$$
\begin{aligned}
&total\ cost \\
&= \sum_{i=1}^{I} C_{m_i} q_i \; + \frac{1}{48\ H_d} \sum_{j=1}^{J} C_{l_j} t \\
&+ \frac{1}{48 D_m\ H_d} \sum_{k=1}^{K} S_k t \\
&+ \frac{1}{720 D_m} \sum_{l=1}^{L} \frac{C_{C_l}}{LT_l MH_l} t
\end{aligned}
$$

4.2 Architecture Design and Learning Algorithm (Cont.)

- Add the hidden weight to represent the actual situation of manufacturing



$$
\begin{aligned}
&total\ cost \\
&= w1 \sum_{i=1}^{I} C_{m_i} q_i \cdot wa_i + b_a \quad + w2 \frac{1}{48\ H_d} \sum_{j=1}^{J} C_{l_j} t \cdot wb_i + b_b \\
&+ w3 \frac{1}{48 D_m\ H_d} \sum_{k=1}^{K} S_k t \cdot wc_i + b_c \\
&+ w4 \frac{1}{720 D_m} \sum_{l=1}^{L} \frac{C_{C_l}}{LT_l MH_l} t \cdot wd_i + b_d + b
\end{aligned}
$$

4.3 Weight Adjustment

- Back Propagation using Gradient Descent both model level and element level

Model Level Gradient

$$\frac{\partial E}{\partial w_1} = \frac{\partial E}{\partial y} \cdot \frac{\partial y}{\partial w_1} \text{ By Chain rule}$$

$$= M\acute{SE} \cdot \frac{\partial\left(w1\left(\sum_{i=1}^{I} C_{m_i} q_i \cdot wa_i + ba\right) + \cdots + b\right)}{\partial w_1}$$

$$= M\acute{SE} \cdot \left(\sum_{i=1}^{I} C_{m_i} q_i \cdot wa_i + ba\right)$$

$$w_{1,new} = w_{1,old} - \alpha\left(M\acute{SE} \cdot \left(\sum_{i=1}^{I} C_{m_i} q_i \cdot wa_i + ba\right)\right)$$

Element Level Gradient

$$\frac{\partial E}{\partial w_{a_i}} = \frac{\partial E}{\partial y} \cdot \frac{\partial y}{\partial w_{a_i}} \text{ By Chain rule}$$

$$= M\acute{SE} \cdot \frac{\partial w1\left(\sum_{i=1}^{I} C_{m_i} q_i \cdot wa_i + ba\right)}{\partial w_{a_i}}$$

$$= M\acute{SE} \cdot \left(C_{m_i} q_i\right)$$

$$w_{a_i,new} = w_{a_i,old} - \alpha\left(M\acute{SE} \cdot C_{m_i} q_i\right)$$

α is a model learning rate

5. Experimental Result

- Experimented with Python 3.10.6
- Train a model with 70% of simulated datasets and test them with the rest 30%
- Measure the error in
  - Mean Square Error (MSE)
  - Root Mean Square Percent Error (RMSPE)

5.1 Datasets

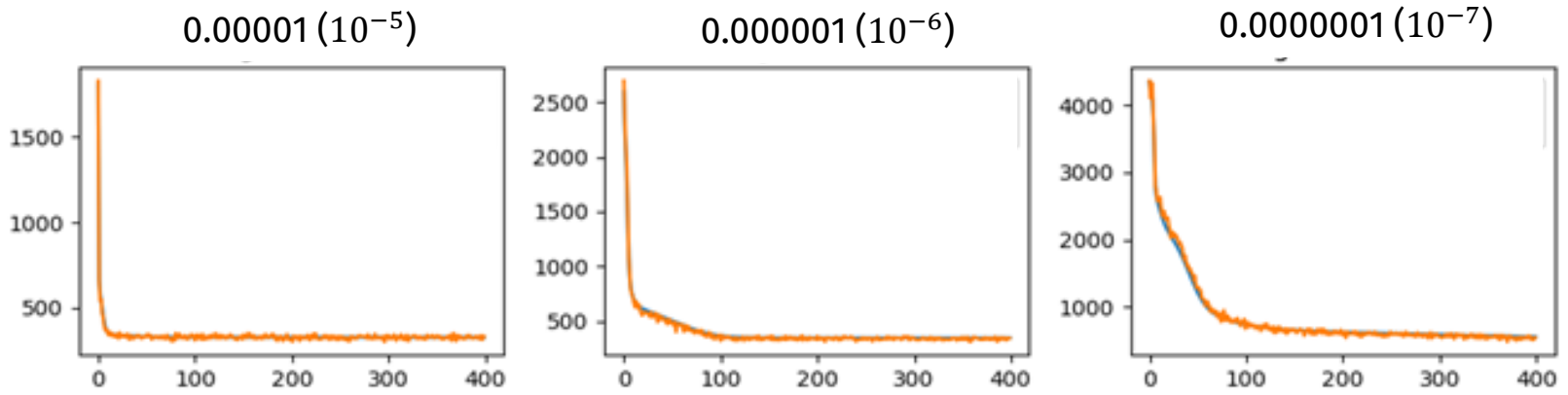
- Simulate 2 datasets with different complexity levels
- Actual cost in Dataset 1: 32.03 – 48.98, Dataset 2: 20.05 – 97.94 THB

Data	Dataset 1			Dataset 2		
	Amount	Mean	S.D.	Amount	Mean	S.D.
Duration (Min)	2,000.00	4.48	1.76	2,000.00	5.99	3.34
Actual Cost (THB)	2,000.00	40.55	4.97	2,000.00	51.83	19.56
Material Amount (THB)	14,007.00	25.56	47.32	13,026.00	81.08	115.29
Material Cost (THB)	14,007.00	0.57	0.39	13,026.00	0.65	0.46
Daily Labor Cost (THB)	2,678.00	424.78	25.00	1,762.00	404.06	126.57
Monthly Labor Cost (THB)	1,336.00	12,000.00	0.00	2,256.00	27,135.74	12,554.15
Capital Cost (THB)	1,025.00	10,590.00	0.00	529.00	5,238.85	3,047.42

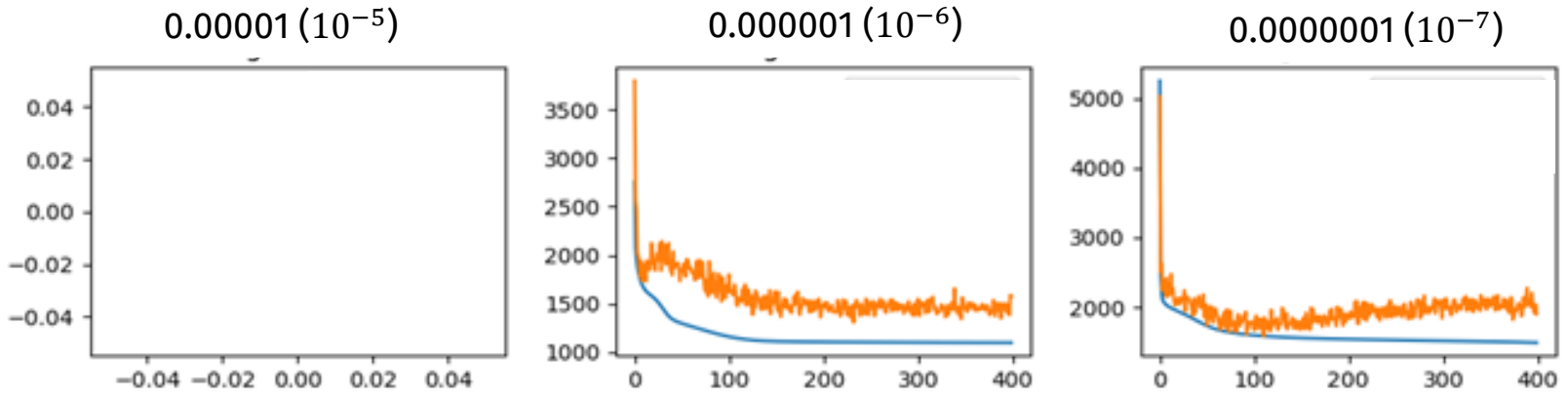
5.2 Result

- Training and Validation Errors in each Iteration

Dataset 1



Dataset 2



5.2 Result (Cont.)

- Result after 400 iterations of training with learning rate 0.0000001 (10^{-7})

Dataset	Dataset 1	Dataset 2
Loss (MSE)	529.20	1,365.07
Validation Loss (MSE)	471.12	1,557.81
% Loss (RMSPE)	29.33	38.97
Example on Actual Cost data		
Range (THB)	32.03 – 48.98	20.05 – 97.94
Mean (THB)	40.55	51.83
Predicted (THB)	22.64 – 63.35	12.24 – 136.11
Error (THB)	9.39 – 14.37	7.81 – 38.17

5.3 Discussion

- Strong
  - Specially designed for cost estimation
  - Clear structure and explainable
- Weakness
  - Rough model structure
  - Incomprehensive sample data or Incomplete nature understanding

6. Conclusion and Future Work

- This research creates the TDCE model which is a glass box cost estimation model based on TDABC and ANN
- The Model is clear and explainable
- The model produces a prediction result with an error of 25-40 %
- The model has some problem on resolution level and sample data nature
- Future work is to evaluate and fine-tune with real-world data

Any Questions ?