DEVELOPMENT OF CEDM DIGITAL TWIN TO SUPPORT OPERATOR ACTIONS

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Outlines

- ✓ **Introduction**
- ✓ **CEDM Digital Twin**
- ✓ **Algorithms**
- ✓ **Results**
- ✓ **Conclusion**

INTRODUCTION

- Information management in control room is a critical task for operators.
- Data monitoring and decision making puts heavy mental load and cognitive demands on operators.
- Improving operator performance will help to increase plant safety, availability and reliability.
- Digital technology with data-driven modeling enable fast processing, and analysis for better real-time and informed decision making.
- Digital Twin is one of the promising techniques in the digital technology era.
- Digital Twin concept is applied to Control Element Drive Mechanism (CEDM), as it's the most critical systems in NPP.

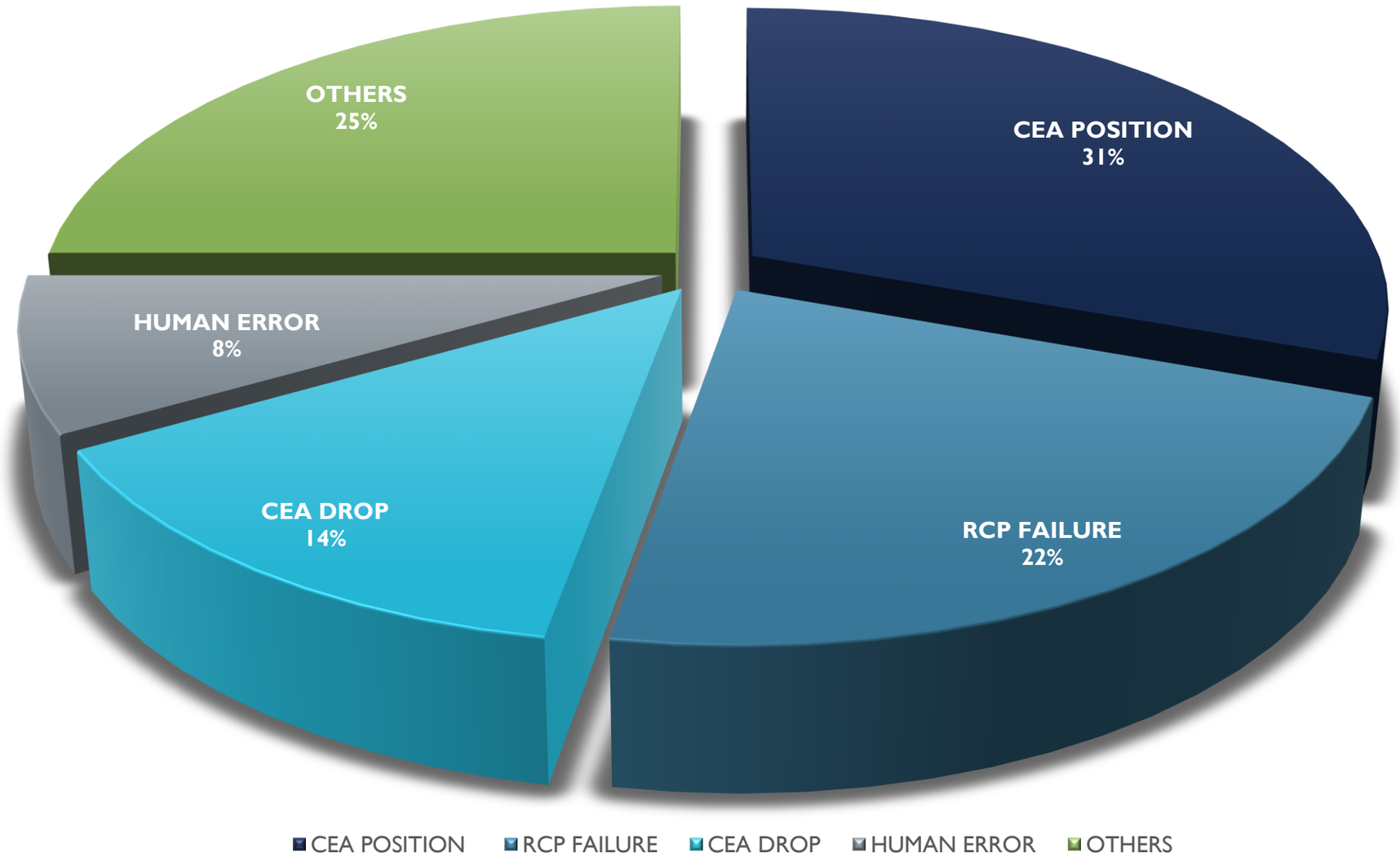
Introduction

- Digital Twin could be considered as adaptive modeling of a complex physical system, it is the computerized counterpart and virtual representation of a physical system across its lifecycle.
- Digital Twin could be represented as a digital structure of information of a physical object, product lifecycle management (PLM)
- The Digital Twin was defined formally at first by NASA to reflect the behavior of air vehicle.
- Then, the definition of DT expanded to be applied in a generic system or product.
- Digital Twin technology can result in higher accuracy, efficiency and gains economic benefits in the all lifecycle of the product due to:
  - The availability of communication technologies and cheap sensors
  - Artificial Intelligence (AI) and Machine Learning (ML) increasingly great success, in particular, Deep Learning (DL)
  - Presence of the new developments of computational hardware

[1] Rasheed, O. San, and T. Kvamsdal, "Digital Twin: Values, Challenges and Enablers From a Modeling Perspective," in IEEE Access, vol. 8, 2020.
[2] Grieves, Michael; Vickers (2017). Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems.

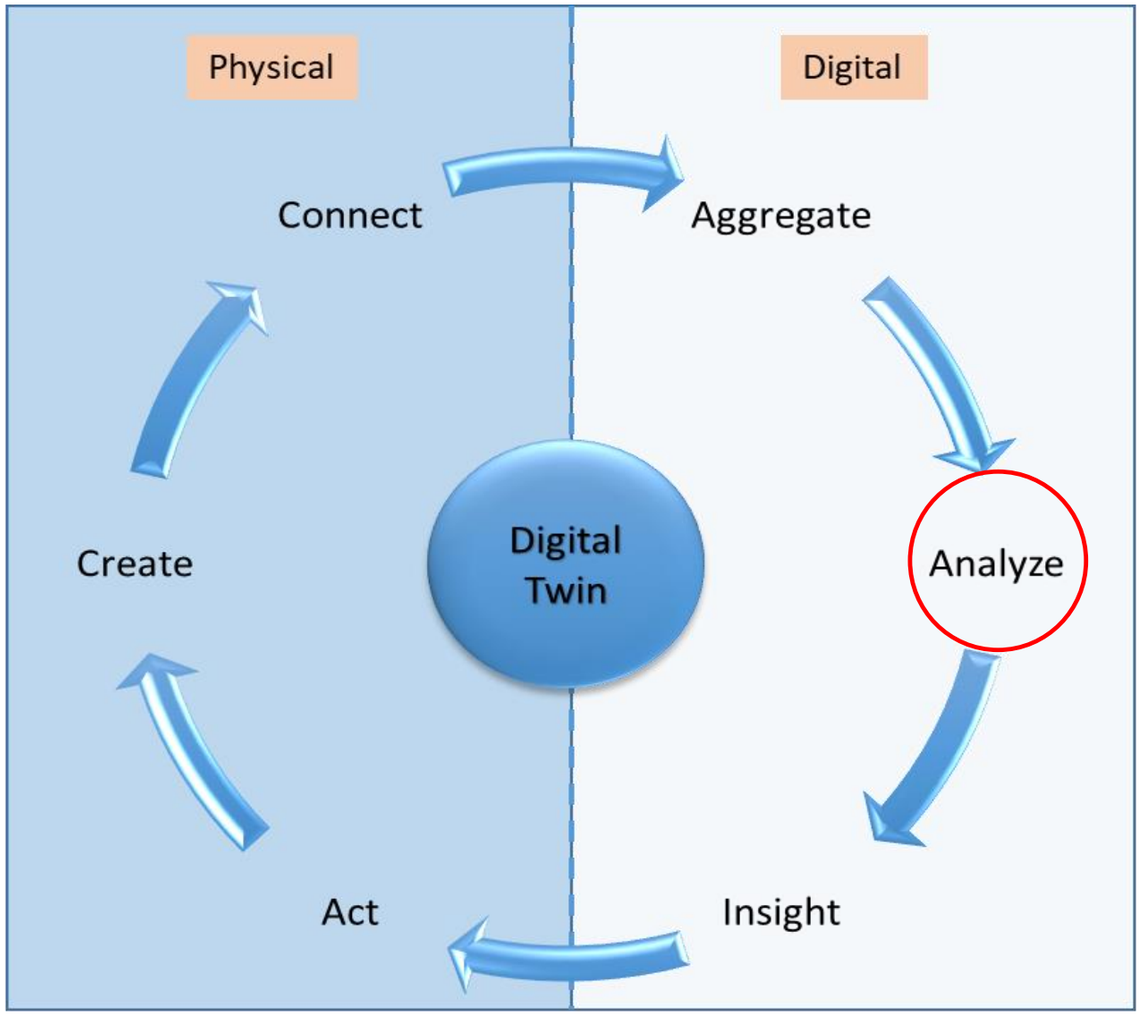
Introduction

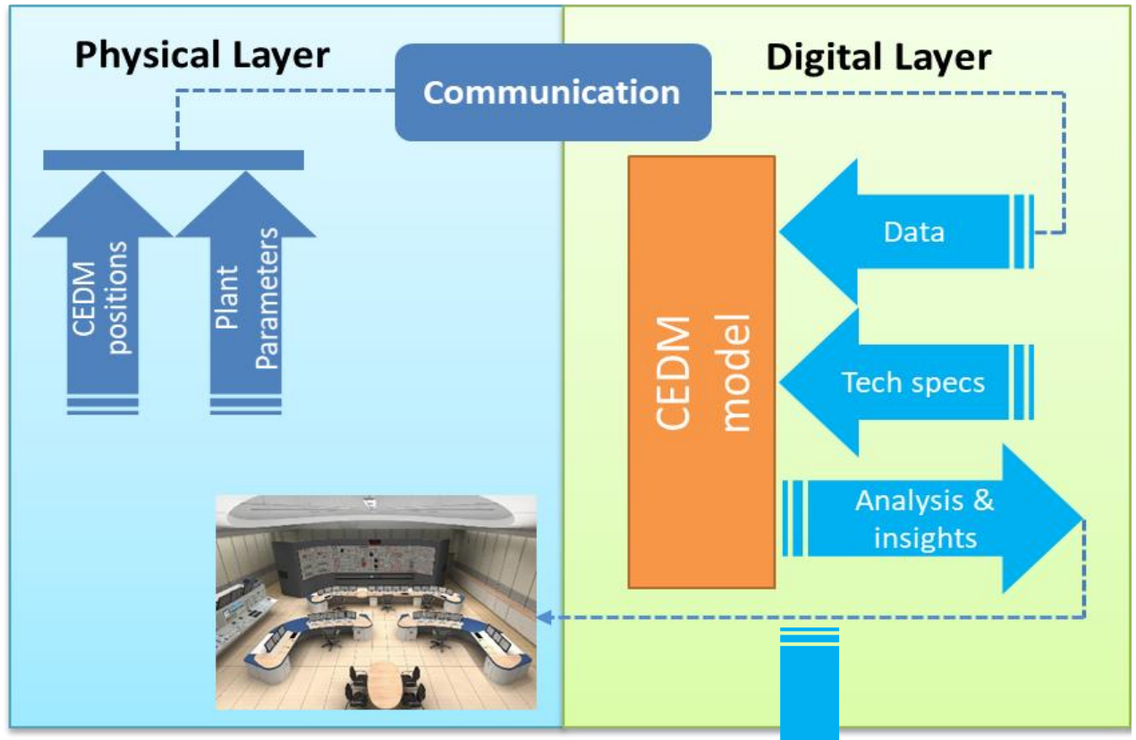
- **REACTOR TRIP OCCURRENCES**



[3] KINS. Korea Institute of Nuclear Safety. Operational Performance Information System for Nuclear Power Plant. Available at: https://opis.kins.re.kr/opis?act=KEOPISMAIN.

CEDM Digital Twin

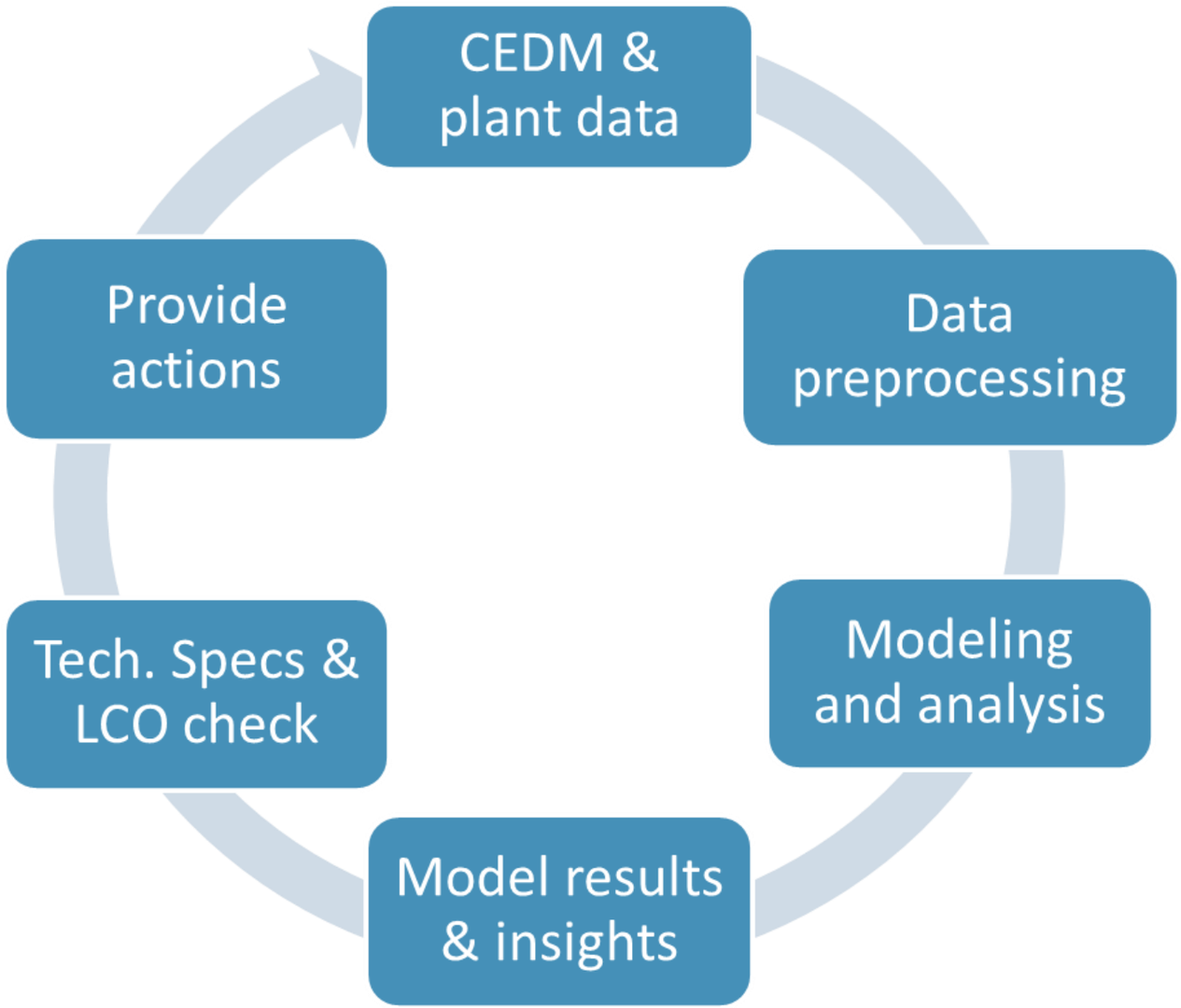




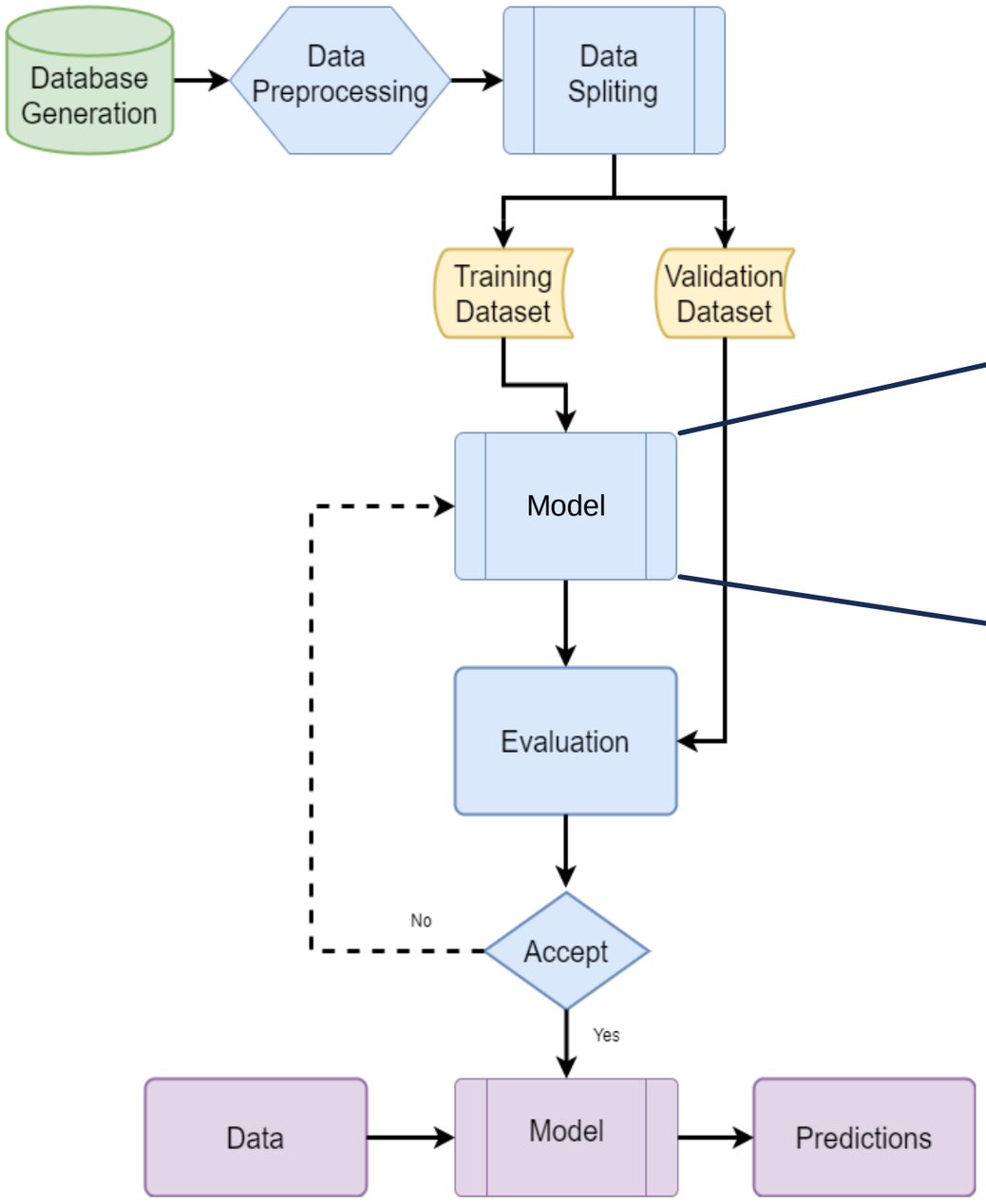
Operator decision support
- **Reduce analysis time**
- **Provide Required actions**
- **Ensure Safety & Operability**

CEDM Digital Twin

- **Misalignment detection as part of CEDM Digital Twin**



Artificial Intelligence Model Development

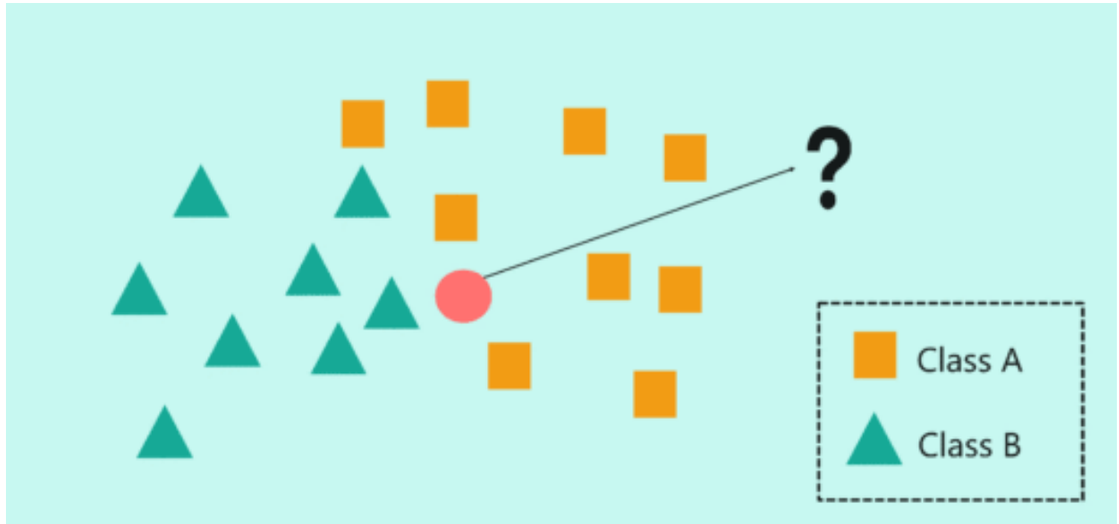


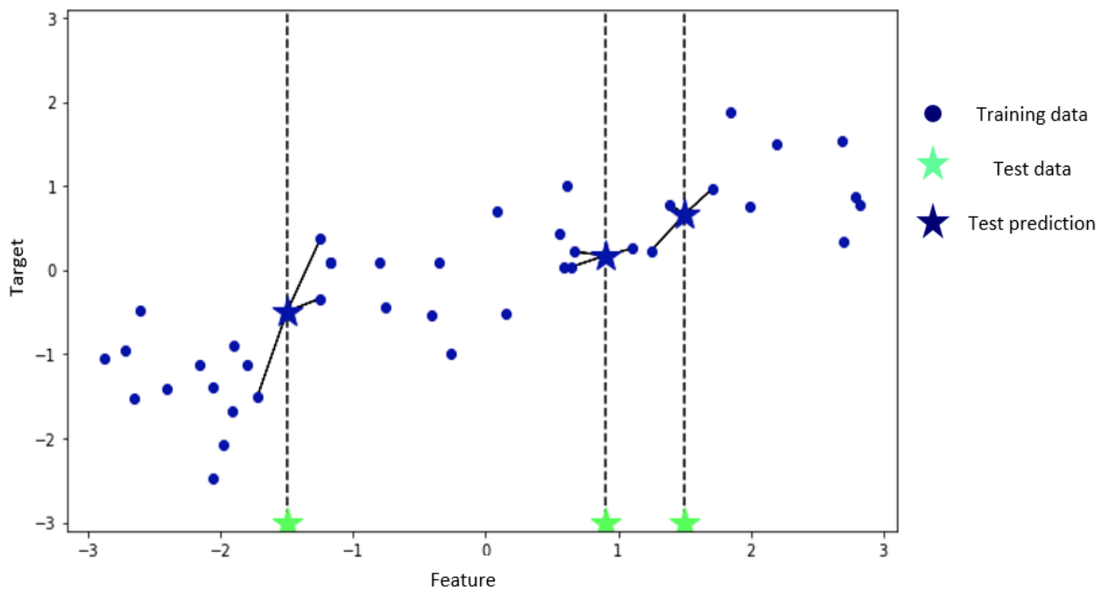
- **Machine Learning**
  - K-Nearest Neighbor (K-NN)
  - Decision tree (D-Tree)
  - Support vector machine(SVM)

[4] Gomez-Fernandez M, Higley K, Tokuhiro A, Welter K, Wong WK, Yang H. 2020. Status of research and development of learning-based approaches in nuclear science and engineering: A review. Nucl Eng Des. 359:110479.

K-Nearest Neighbors (K-NN)

- K-NN can be used both in classification and regression problem.
- Lazy learner, i.e., it uses all training samples at runtime and hence slow for large datasets
- Simple and easy to understand
- Robust to any irrelevant information (noise)

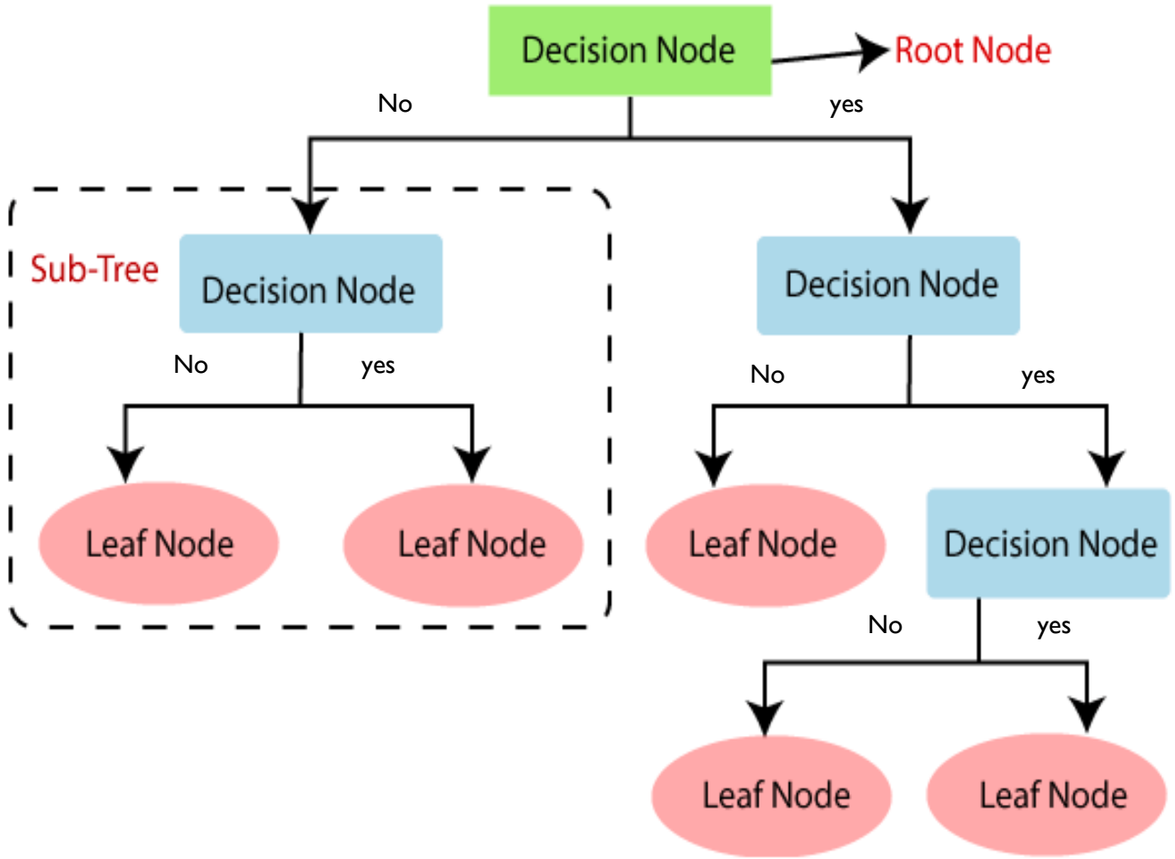




[5] Sadegh Bafandeh Imandoust and Mohammad Bolandraftar. Application of knearest neighbor (knn) approach for predicting economic events: Theoretical background. International Journal of Engineering Research and Applications, 3(5):605–610, 2013.

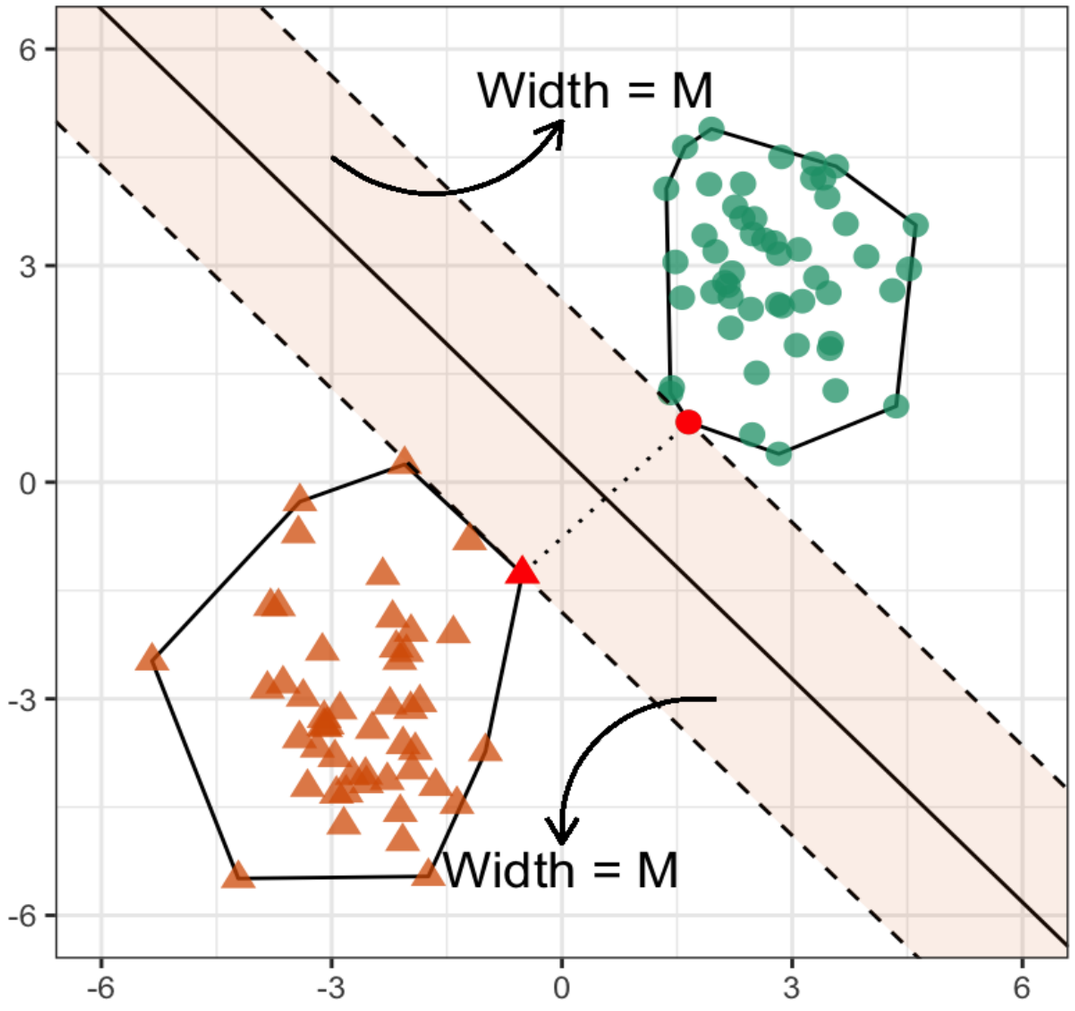
Decision Tree

- It can be used for both Classification and Regression problems.
- Easy to Understand, Interpret, Visualize.
- Non Parametric Method.
- There is less requirement of data cleaning compared to other algorithms



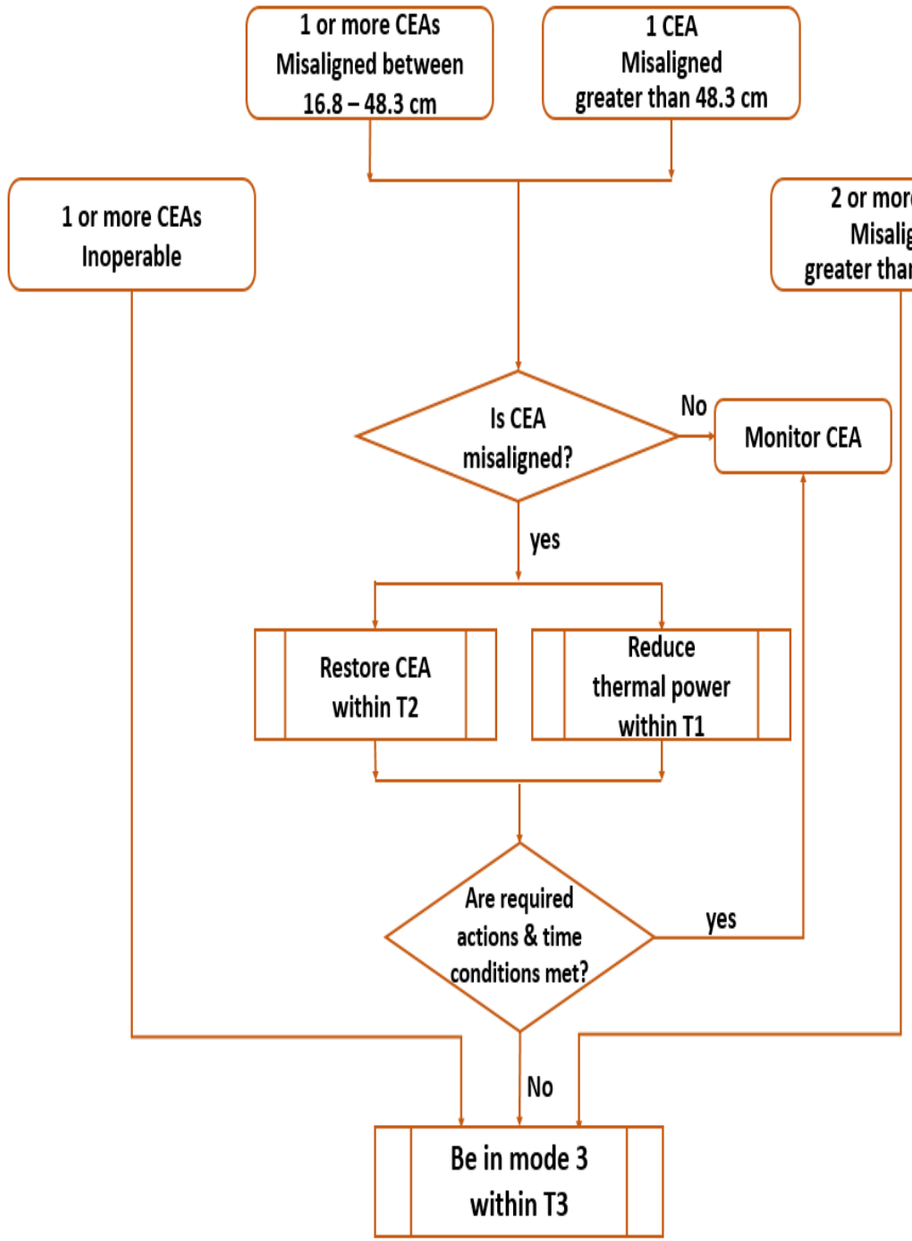
Support Vector Machine

- Solves both Classification and Regression problems.
- A small change to the data does not greatly affect the hyperplane and hence the SVM. So the SVM model is stable.
- SVM takes a long training time on large datasets.
- Algorithmic complexity and memory requirements of SVM are very high.



[6] Y. Lei, Intelligent fault diagnosis and remaining useful life prediction of rotating machinery. Elsevier Inc., 2016.

Misalignment Detection



Extracted Actions from LCO

ACTION 1: A.1 Reduce THERMAL POWER in accordance with

Figure 3.1.4-1.

AND

A.2 Restore CEA Alignment.

1 hour

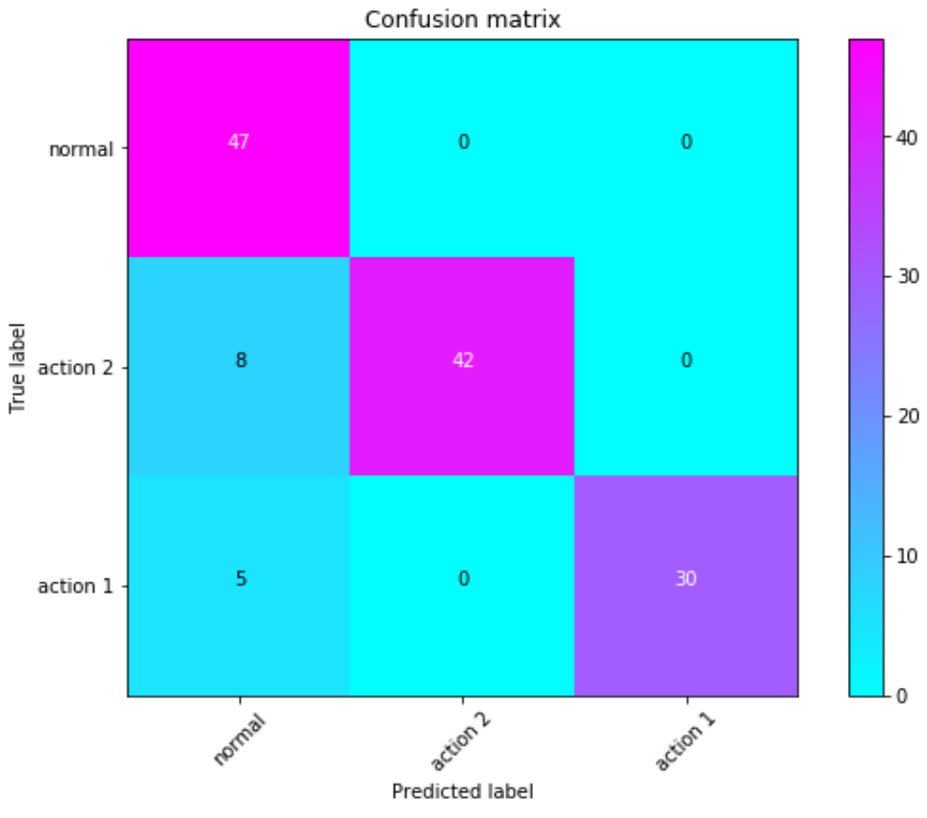
2 hours

ACTION 2: B.1 Be in MODE 3.

6 hours

Misalignment Detection

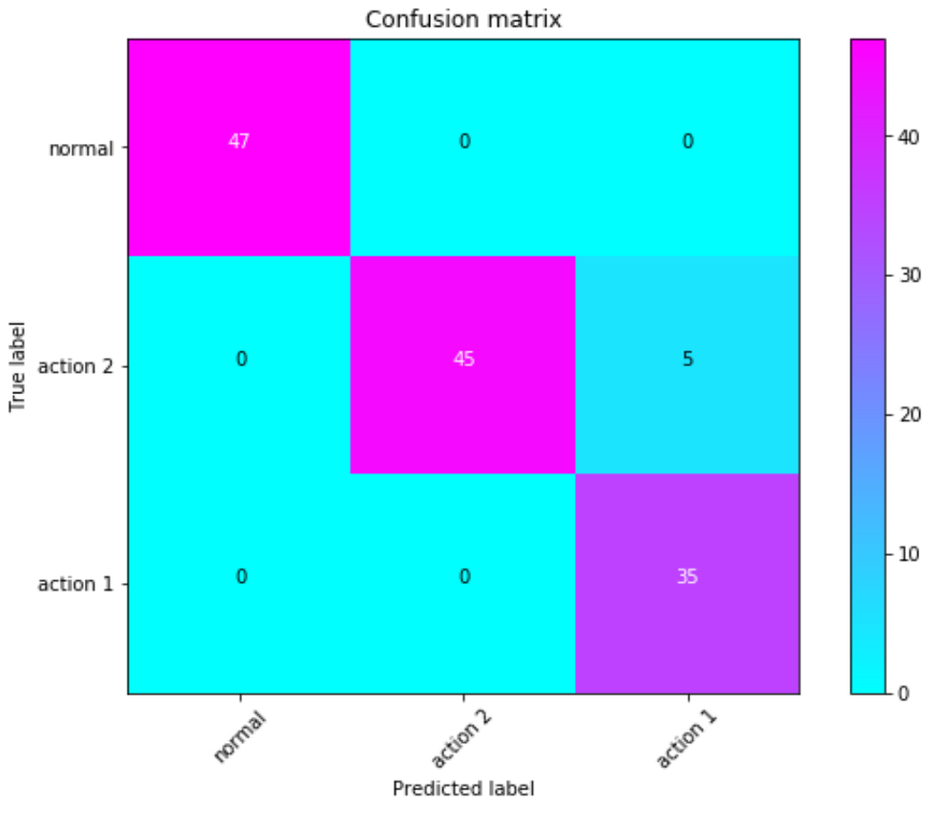
➢ **Support vector classification (SVM)**



	precision	recall	f1-score	support
1	0.78	1.00	0.88	47
2	1.00	0.84	0.91	50
3	1.00	0.86	0.92	35
accuracy			0.90	132
macro avg	0.93	0.90	0.90	132
weighted avg	0.92	0.90	0.90	132

Misalignment Detection

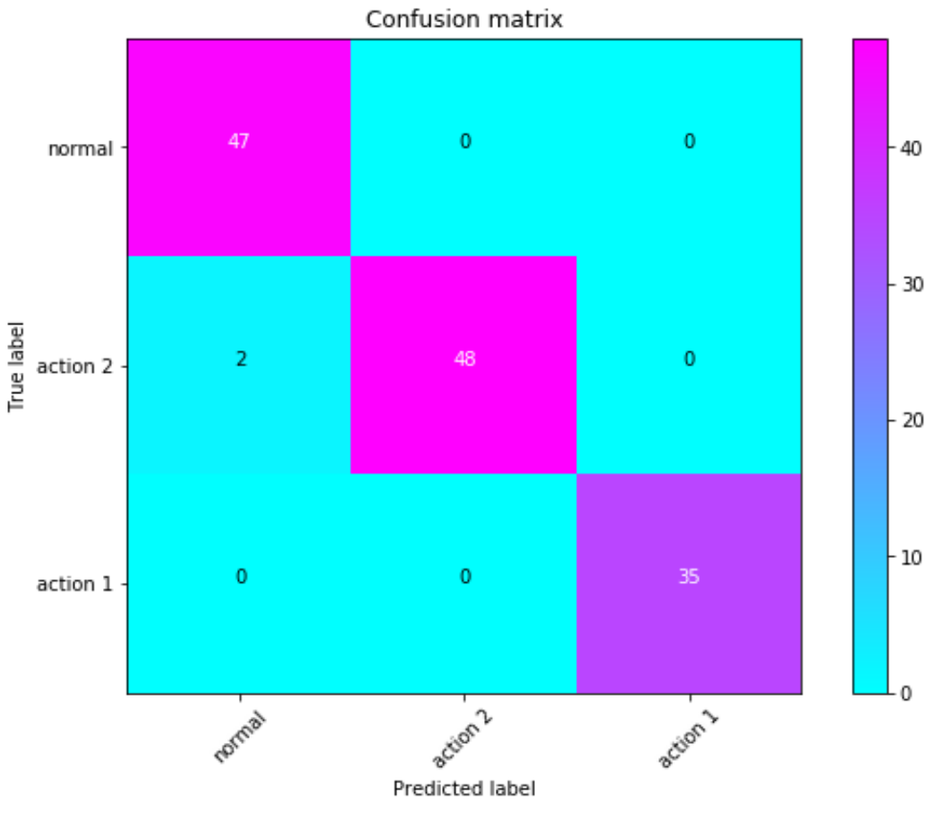
➢ **Decision tree classification (D-Tree)**



	precision	recall	f1-score	support
1	1.00	1.00	1.00	47
2	1.00	0.90	0.95	50
3	0.88	1.00	0.93	35
accuracy			0.96	132
macro avg	0.96	0.97	0.96	132
weighted avg	0.97	0.96	0.96	132

Misalignment Detection

➢ **K-Nearest Neighbor classification (K-NN)**



	precision	recall	f1-score	support
1	0.96	1.00	0.98	47
2	1.00	0.96	0.98	50
3	1.00	1.00	1.00	35
accuracy			0.98	132
macro avg	0.99	0.99	0.99	132
weighted avg	0.99	0.98	0.98	132

Conclusion

- Research in Digital Twin is still in its infancy, especially in nuclear field.
- Digital Twin concept application on CEDM system is introduced in this work.
- Digital Twin concept introduces a fast analyzer for CEDM and plant data and a quick recommender system to support the operator in decision making.
- Data processing modeling of sensed CEDM positions are performed using ML algorithms as apart of CEDM Digital Twin.
- The K-Nearest Neighbors algorithm gave the best performance with the highest accuracy.
- Digital Twin could be used in many other systems in NPP.
- The CEDM Digital Twin can be improved by including CEDM PHM for better informed decision making.

References

[1] Rasheed, O. San, and T. Kvamsdal, "Digital Twin:Values, Challenges and Enablers From a Modeling Perspective," in IEEE Access, vol. 8, 2020.

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[6] Y. Lei, Intelligent fault diagnosis and remaining useful life prediction of rotating machinery. Elsevier Inc., 2016.

THANK YOU