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## Review Report on the thesis titled, "Intelligent Energy-Savings and Process Improvement Strategies in Energy-Intensive Industries" submitted by Mr. Sin Yong Teng

This doctoral thesis is devoted to the optimization and debottlenecking of energy-intensive industries using artificial intelligence and data-driven methods. The thesis proposes a complete procedure for carrying out process improvement in an industrial facility. Many innovative and useful approaches were proposed in the thesis for practical implementation in the industry.

**The aim and scope of the thesis chosen by the author are,**

(i) To apply advanced artificial intelligence and machine learning techniques into process improvement projects for energy-intensive industrial systems.

(ii) To provide process optimization via artificial intelligence or data-driven methods.

(iii) To propose novel process debottlenecking procedures via artificial intelligence or data-driven methods.

(iv) To develop scientific methods, case studies, new methods as a combination for effective real-world implementation.

(v) To propose a framework to carry out process improvement with the consideration of the proposed artificial intelligence or data-driven methods.

**Contributions made in the thesis**

Author presented the contributions made to achieve the objectives listed above in the thesis in a very detailed manner, which are very significant contribution in the field of research chosen. The contributions made are listed below.

(i) Application of machine learning technique, which includes one-shot learning and neuro-evolution for data-driven single unit modelling and optimization.

(ii) Application of dimension reduction (e.g. principle component analysis, deep autoencoder) for multiple-unit multiple-objective process optimization.

(iii) Proposition of novel bottleneck tree analysis (BOTA) tool for the purpose of process capacity debottlenecking. An extended BOTA was also proposed to incorporate multi-dimensional problems via data-driven approach.

(iv) Demonstrated effectiveness of Monte-Carlo simulations, neural network and decision trees for decision-making when integrating new process technology in existing processes.

(v) Benchmarked Hierarchical Temporal Memory (HTM) and a dual-mode optimization with multiple predictive tools for real-time operational management.

(vi) Implemented artificial neural networks in the conventional process graph (P-graph) framework.

(vii) Highlight the future of AI and process engineering in biosystems via a commercial-based multi-omics paradigm.

**Organization and structure of the thesis.**

Chapter 1 provides a brief introduction of the work's background. Literature review regarding data-driven approaches were provided in Chapter 2. An overall guiding framework for process improvement was proposed in Chapter 3 which navigates readers through Chapter 4-11. For low data availability, Chapter 4 proposed a one-shot learning approach using Siamese networks and transfer learning to deal with low data availability problems. Chapter 5 demonstrates the usefulness of a progressive depth swarm evolution (PDSE) neuro-evolutionary approach to optimize a microalgae thermal reactor in achieving high conversion and low energy consumption. Chapter 6 and 7 demonstrates the usefulness of dimension reduction-based optimization for prioritization of operational variables during multi-unit process optimization. For capacity debottlenecking, Chapter 8 and 9 demonstrates a novel bottleneck tree analysis method (BOTA) that can be used with process simulation or neural network ensembles. Chapter 10 shows the effectiveness of using Monte Carlo simulations, neural network, and decision trees to carry out techno-economic analysis in the case where a new unit is considered for existing plants. Next, Chapter 11 propose the use of a neocortex inspired algorithm, Hierarchical Temporal Memory (HTM) and novel dual-mode optimization algorithm for the purpose of real-time management of a waste-to-energy plant. Chapter 12 demonstrates the novel implementation of a neural network in the P-graph framework, showing that AI and data-driven approach can be seamlessly

implemented in traditional process engineering tools. In Chapter 13, author also identified further potential in AI for bio-systems due to their uncertain nature using microalgae technologies as example.

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**Questions and comments concerning the thesis to be clarified by the Doctoral student during the thesis defence.**

1. What are the advantages of using AI and data-driven approaches (compared to traditional methods) for process improvement?
2. What is the motivation of using metaheuristic (in chapter 5) for neuro-evolution? Furthermore, what are the optimal architecture of the neural networks that were used?
3. What is the advantage of the proposed bottleneck tree analysis (BOTA) method and how does it compare to other debottlenecking methods?

**Recommendation**

Given the overall high standard of the dissertation thesis, the quality and number of original papers published in high impact international Journals by the candidate, I recommend that Mr Sin Yong Teng is awarded the degree of Doctor of Philosophy (PhD).

Sincerely,

(Ponnambalam S G)