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Novel PSE applications and knowledge transfer in joint industry - university energy-related postgraduate education

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ABSTRACT

The field of Process Systems Engineering (PSE) is undergoing a renaissance through the integration of artificial intelligence (AI) and machine learning (ML). This transformation is driven by the vast availability of industrial data and advanced computing power, enabling the practical application of sophisticated ML models. These models enhance PSE capabilities in design, control, optimization, and safety. The progress of ML and ever-present data collection address previously intractable problems, particularly in system integration and life-cycle modeling. ML-powered predictive algorithms are augmenting traditional control systems, showing potential in supply chain optimization and increasing operational resilience. Additionally, ML-driven fault prediction and diagnostics are enhancing process safety systems, allowing for predictive maintenance and minimizing risks of accidents. A case study of the collaboration between the University of West Attica and Helleniq Energy through the MSc program in Oil and Gas Process Systems Engineering showcases the practical application of advanced technologies and knowledge transfer, emphasizing the importance of blending AI with traditional PSE education.

Keywords: Artificial Intelligence, Machine Learning, Education, Knowledge Transfer, Oil and Gas.

INTRODUCTION

The field of process systems engineering (PSE) has long been characterized by a deep theoretical foundation. Pioneers like George Stephanopoulos [1] and David Himmelblau [2] laid the initiative. A lot of other researchers have laid the groundwork, exploring the potential of early artificial intelligence (AI) concepts to model and optimize complex industrial processes. However, these ambitious ideas often outstripped the available computing power and the quantity and quality of data. The models were constrained, not by theory, but by practical limitations. Today, the situation is dramatically different. The confluence of vast industrial data repositories and highly accessible cloud computing has created a fertile ground for the practical application of sophisticated machine learning (ML) models augmenting PSE modelling capabilities. This is driving a renaissance in PSE, transforming how we approach design, control, optimization and safety within the process industry.

The Dawn of Data-Driven Process Systems Engineering

The maturation of ML, combined with ubiquitous data collection, allows for previously intractable problems to be addressed. The most intractable problem in PSE is the integration of systems in a life-cycle model of the process.

In PSE, the focus is shifting to two key areas:

1. Advanced Control and Optimization
2. Fault Detection and Diagnosis or Enhanced Process Safety and Reliability

A description of this trend as expressed by academia can be found in [12], [13].

Advanced Control and Optimization

Traditional control systems, typically implemented on Distributed Control Systems (DCS) and Advanced

Control Systems (APC) using real-time operating systems, are being augmented by ML-powered predictive algorithms. These algorithms, often implemented as neural networks and deep learning architectures, can handle the complexities of large-scale systems more effectively than classical methods. While full plant-wide optimization remains a challenge, progress is being made in areas such as supply chain optimization. This is supported by research and industrial adoption, showing a clear potential to boost efficiency, reduce costs and increase operational resilience. Academic institutions (see for example [5]) are actively researching supply chain optimization using ML, seeking to understand how algorithms can predict demand, optimize production scheduling and manage inventory effectively. This area showcases a clear transition towards more intelligent manufacturing and is currently being implemented on pilot scales within various industries.

Reluctance of market participants has resulted in applications which have different origins towards autonomy (mostly arbitrary and team driven).

In the area of Reinforcement learning controls there are examples of:

1. Off-line reinforcement learning optimization (AIO) by IMUBIT (www.imubit.com)
2. Other similar to IMUBIT partial efforts toward real time AI augmented optimization (YOKOGAWA- KBC, ASPENTECH, C3.AI etc.) depending on the application.
3. Online gain adapting controllers by Honeywell, ExxonMobil and Yokogawa.

Information currently can be obtained mainly by their patents and traced back to theory as the descriptions are usually very detailed and can be easily compared with Google Reinforcement Learning (RL) models or among them all [8], [9], [10], [11].

It is very much of a coincidence indicating the difficulty of the problem that Anderson controller described in [2] is also tested today by some companies like Honeywell and Yokogawa in laboratory environments.

Of course, this list is by no means exhaustive but gives the dynamics of the problem, i.e very few companies are involved because of the difficulty of the subject but the development thrives in this area (there are patents and products). Note that development is mostly associated with academia for all the above companies.

Fault Detection and Diagnosis or Enhanced Process Safety and Reliability

Process safety systems, implemented on Programmable Logic Controllers (PLCs) and also known as Interlock or Emergency Shutdown Systems, are now being enhanced with ML-driven fault detection and diagnosis. Most of industrial applications are given as ad-hoc cases for special equipment e.g. furnaces, compressors, mixers or individual unit emergency s/d. Details can be found in [6] on the internet. While still ad-hoc, a systematic Abnormal situation management system is of paramount importance as described for example in [7]. Comparison in [7] of 7 methods with 10 criteria concludes that no one can serve more that 70% of the criteria and no criterion can be served by more than half of the methods. This adds to theoretical complexity as much as safety requirements add to the implementation of the methods. For example, explainability criterion clearly can be fulfilled by expert systems but not by neural networks. Alternatives to these criteria are still evolving.

Fault Detection and Diagnostics (FDD) in reliability is especially impactful in asset performance management, where ML is used to predict failures in rotating machinery and other critical assets. Predictive maintenance allows companies to take proactive measures, minimizing the risks of accidents and avoiding production losses by maintenance planning. ML algorithms learn from sensor data (vibration, temperature, pressure) to identify patterns indicating potential failures, enabling preventive maintenance interventions. This is vital for preventing catastrophic events and ensuring a smooth production process.

Currently there are vast alternatives for predictive maintenance applications and large machinery equipment provide ML software as a standard part of their machines (for monitoring by both client and manufacturer). Still reinforcement learning equipment switching is not provided yet to the clients.

Most market participants employ ML for advice to operations with statistical ML methods, providing ML libraries (in edge i.e. field computers) with particular case studies.

An important field for continuous plants is the ML augmented procedural automation standards (ISO 106) and implementations which automate the step-wise procedures required in starting-up and shutting-down.

The Challenges of Interdisciplinary Integration

While the potential benefits of ML in PSE are clear, several significant challenges hinder its widespread adoption. These challenges mainly concern education at any level (undergraduate, postgraduate, continuing). This problem has been already pinpointed e.g. in [4] by defining a partial role of a “process data scientist”. Also, in [3] where it is noted that there is a tendency to rush off and teach courses that are cookbook-style offerings, where students learn to mechanically apply different software packages without a deeper understanding of the fundamentals knowing not only how to apply but also why to apply.

Currently with a relatively narrow industrial application environment a bonus starting point is also “where to apply" with industrial applications guiding theoretical analysis efforts with a dynamic curriculum.

The integration of PSE with ML and data engineering presents a triple challenge:

1. Understanding Process Systems Engineering Fundamentals: The first challenge resides in the complexity of PSE itself, requiring a deep understanding of chemical, physical, and thermodynamic principles. This alone is a demanding discipline. Students need a robust foundation in process modeling, simulation and control theory to grasp the notion of industrial processes.

2. Mastering Machine Learning Techniques: ML, while powerful, is also a complex discipline that requires familiarity with statistical modeling, algorithm design and optimization. This understanding is paramount for applying ML correctly and understanding its limitations, ensuring that ML is being used in a suitable way and not only as a black box.

3. Developing Data Engineering Skills: The sheer volume of data generated by modern industrial processes demands a proficiency in data engineering. This involves skills in database management, cloud computing, data preprocessing, data architecture and data governance. Without the ability to effectively handle and structure data, advanced ML algorithms cannot reach their full potential.

These are three distinct disciplines, each with its own language, frameworks and modes of thinking. To fully leverage the power of ML in PSE, there needs to be a convergence of these disciplines, and reframing of classical engineering principles to incorporate the new methodologies. This requires a shift in education methodologies, moving past siloed subjects and into an integrated approach.

A similar shift is expected from an industry point of view because of low inventory of both experience and head count. Both represent hurdles which can be surpassed by educational means only and beyond classical business measures per se.

The Need for Rapid Adaptation

The pace of technological change demands that the PSE field adapts quickly. While new generations, are adept at hands-on learning and readily embracing new technologies, seasoned engineers may find this transition overwhelming. The ability of companies and academia to adapt to the changes of incorporating the new technologies and the development of novel talent will be the main factors for the survival of businesses in the coming years.

Evolution of similar systems like APC may predict that AI will mature in the next decade (50 years as other PSE systems).

Having noticed that, it is also clear that the arguments expressed for AI in [1] in 1986 are still valid:

1. Limited by complexity 1986 – Still a problem in 2025
2. Limited by computing power 1986 – Still a problem for combinatorial or factorial size processes in PSE.
3. Limited by data (Industry is not mature) 1986 – still a problem but Digital transformation is underway, and data quality is an issue followed by data marketing problems.
4. Not existing market pull (conceptually successful, implementation and workflow limited) 1986 – Still a problem if AI hype is removed but cloud facilitates development. ML for PSE might help but General AI for PSE is rather not yet. AutoML slowly evolves to be an option for ad-hoc model building.
5. High hanging fruits for the period 1986– Multivariable Predictive Control took over the low hanging fruits 1995-2005 – Still a problem in 2025 to maintain MPC apps and a new high hanging challenge is integration of MPC with Scheduling and Supply chain Optimization on a theoretical and practical ground.

The rapid adaptation of AI by the companies and academia is required because of the momentum of Digital transform. As an example of such efforts, currently, a change management project supports the digital transformation of the Helleniq Energy Group, introducing an extensive training program for engineers and technical personnel. More than 12k manhours training in 2023 and approximately 30k manhours training for 2025, are spent for several digital transformation tools applications (Asset Management, Digital OPS/HSE, HC Supply Chain, Energy Management Cyber Security etc.). This momentum was not present in the distant 1986 or even 2016 and presents a large factor of evolution.

Still, the development of theory is not yet complete and Autonomous plants are a distant vision.

Future Trajectory: Plant-Wide Intelligence

The future of AI in PSE lies in the development of intelligent plant-wide optimization and fault detection and diagnosis models.

A partial example is discussed in [5] where academic and industrial experience have put reinforcement learning methods in chemical plant scheduling. Operations continue with these models for years already.

These systems will leverage ML to optimize every aspect of the production process, from resource allocation to energy management and maintenance, and provide real-time diagnostics, enabling highly reliable operations.

A CASE STUDY IN COLLABORATION: ACADEMIA AND INDUSTRY PARTNERSHIP

The Master of Science Postgraduate Program (MSc)

"MSc in Oil and Gas Process Systems Engineering" began its first cycle in April 2019. The MSc is implemented by a scientific team from the Department of Mechanical Engineering at the University of West Attica (UNIWA), who have significant and long-standing experience in reputable postgraduate programs in the energy field, with the support of Hellenic Petroleum and, until recently, the Aspropyrgos Municipality.

The Program, which awards a Master of Science - MSc in Oil and Gas Process Systems Engineering, focuses on:

- Industrial systems and hydrocarbon processing (H/C),
- Production, storage, supply chain of liquid and gaseous hydrocarbons, and
- Optimization of processes and production planning/control of hydrocarboNIns.

The MSc is a full-time program, lasting four (4) academic semesters, equivalent to 120 ECTS, and includes:

- Attendance of ten courses (out of 13 offered in total),
- Completion of a research master's thesis, and
- Completion of a two-month internship in an industry or organization.

Currently, one hundred students are being trained, while many of the MSc instructors come from Helleniq Energy Group: over twenty subject matter experts - production and process engineers with PhD teaching courses such as Basics of Refinery Operations, Process Safety, Natural Gas Processing - Transportation and Distribution, Supply Chain Management in Oil and Gas Industries, Optimization and Decision Making in Oil and Gas Process Industry, etc. This is a unique competitive feature as it transfers genuine knowledge and valuable real-world experience to the MSc students. This is especially pronounced during their thesis preparation, where the collaboration becomes even closer with the allocation of industrial research subjects to be investigated by the students.

From the highly successful course of the Postgraduate Program so far, it is concluded that there are excellent prospects for further development. In the next steps, the Postgraduate Program will design fully English-taught courses to meet the educational needs of company executives and hydrocarbon organizations abroad. Today the Course is bilingual, with teaching to be carried out in Greek but the Assignments, Dissertation and most of the educational material to be in English. Additionally, already implemented activities that will be further strengthened in the Program include scheduled lectures by field experts, as well as selected high-specialization and know-how seminars. The program runs exclusively with the physical presence of students and instructors/professors. However, recent COVID experience had inspired the preparation of e-learning material. Therefore, some of the highly specialised or wide interest courses may also be carried out in distant mode, allowing wider participation from executives of hydrocarbon companies and local municipalities.

With the expansion of Helleniq Energy Group's activities into other energy fields (RES, green hydrogen production) and its pioneering role in energy issues beyond Greece, joint actions with the laboratories of UNIWA, which also have a long history and specialization in modern energy issues, can be expanded.

This article highlights the ongoing collaboration between the Helleniq Energy, the largest energy company in Greece and a leading university UNIWA. This partnership is facilitating the transfer of knowledge in the practical implementation of advanced technologies through postgraduate and potential doctoral programs. These programs will enhance the understanding of novel AI implementation within the process industry.

The collaboration provides real-world industrial data for testing and implementation, promoting the education of students by offering a unique insight to the real application of the academic taught principles and enabling faster adaptation for the industrial partners.

This type of collaboration acts as a catalyst, accelerating the implementation of innovative AI solutions within industry, while also enabling a deeper theoretical understanding for all sides involved.

Practical aspects of the case study

The artificial intelligence has been introduced in both UNIWA and Helleniq Energy with a pace corresponding to Helleniq Energy Digital Transformation so that firm steps are presented to the students as a supplement in particular courses. A faster pace would be possible but was deemed overwhelmingly evolving and difficult to bottle in a comprehensive course. A significant feature of the process is that AI is a bridge between fossil fuels technology and green fuels technologies enabling the persistence of the latter reducing costs and improving efficiency which enables energy transformation. So, digital and energy transformation go hand in hand and AI is augmenting capability down this path.

Furthermore, and in addition to initial efforts, a course in AI is planned with considerations from all involved subjects. The MSc program evolves and targets AI-augmented contemporary industrial needs.

AI lectures in MSc program: already in place

Methods for exploiting and utilizing the readily available data are presented in various modules of the MSc course. The most extensive and systematic amalgamation of conventional engineering approaches with novel data-driven techniques, is found in the “Advanced Process Control and Digital Transformation” module, that contains lectures, tutorials, as well as a reverse MATLAB PC-lab, which is split between control systems synthesis and analysis, and ML methodologies. Namely, although the module focuses on real-world control systems, both classical and advanced, it also entails lectures on measurements and real-world data-cleaning, ML (supervised, unsupervised, reinforcement learning), ensemble methods and actual case studies. A couple of reverse labs are on supervised learning and reinforcement learning. The agile methodology is introduced, to break the project into phases and emphasize on the continuous collaboration and improvement, by following a cycle of planning, executing, and evaluating. The goal of this approach to teach Process Control through a modern prism, is to provide students with practical skills and foster real-life intuitions.

Current efforts focus involve a number of seminars on the subject at hand:

1. A Seminar on the application of statistical modeling in maintenance. A predictive maintenance (and asset management in general) related subject outline, the theory and ML methods used as well as the target and scope of Industrial applications. The predictive maintenance applications of Helleniq Energy are discussed as examples of applications.

2. One Seminar on the application of reinforcement learning in Control and Scheduling applications with an outline of the methods used. These two areas of PSE have distinct scientists in both academia and industry and completely different understanding depending on the origin, be it control or scheduling. Again, examples of blending and unit operations (FCC unit) of Helleniq Energy are used from the control point of view with examples in MATLAB. In the future the Scheduling point of view will be incorporated.

3. A Seminar after supply chain and process design courses for supply chain integration. The focus is on historical evolution of machine learning especially in PSE but also recent advances, Process monitoring examples, emphasis on better quality inference with ML, reinforcement learning theory and current use in the industry, fault detection and diagnosis not only in predictive maintenance but in all process, equipment rotating or static and finally operating procedures (start-up, shutdown)

4. A seminar focused on non-technical aspects of AI as it is applied in Refinery unit optimization. For non-technical people reading the press, there is a lot of simplifications and analogies for AI and ML which are misleading. Also, General AI in PSE or even AI is rather just an intention yet (2025). A grounded fact is ML for PSE. So, there is a need of specifying where and how existing systems are augmented and how the augmentation would produce benefits without the need for programming or Machine learning fundamentals.

AI in MSc program evolution: Enrichment with AI courses

A plan for a course in "ML applications in PSE in Oil and Gas" which will not replace references inside particular courses but rather setup a basic understanding of breadth and depth of ML applications. Several other courses are known in the academia including that of V. Venkatasubramanian [3]

The plan involves the following considerations:

1. Preparatory course: Two courses are proposed by V. Venkatasubramanian [3] namely undergraduate and postgraduate. To cover for the scenario of continuing education students, a two-month preparatory course with basic elements (ML methods, PSE subjects and uses) in the postgraduate (MSc) will replace and enhance the current seminar covered subjects. A special focus on all three elements (PSE, ML Programming, Data Engineering) will be characterizing this effort.

2. An elective course will cover applications of AI in PSE expanding all the subjects of preparatory course and focusing in current (growing) applications in Industry as well machine learning (see for example Kumar and Cerrillo [4]) as outlined in the following:

a. Machine Learning subjects for Process Monitoring, Advice and Predictions

i. Classification techniques
ii. Regression techniques
iii. Ensemble Learning, Boosting, Random Forests
iv. Deep Neural Networks
v. Deep Belief Networks and Classifiers

b. Reinforcement Learning, theory, applications and offline/online RL agents for control and scheduling integration.

c. Applications in PSE

i. Optimization of Unit operations and Blending
ii. Fault Detection and Diagnosis in rotating equipment
iii. Fault Detection and Diagnosis in process equipment
iv. Procedural automation augmented with AI
v. Scheduling and Control integrated and augmented with AI
vi. Quality and Quantity Inferentials augmented with AI.
vii. Large Language models as operator/engineering and predictive maintenance advisors

These courses are under review for the next year starting with the preparatory course but current status of AI in the industry and academia forces their introduction as soon as possible. It is well understood that as applications are evolving, a dynamic curriculum should be anticipated and a process in the curriculum for its improvement should be built in.

CONCLUSIONS

Paradigm of Continuous Improvement Culture: Continuous process performance improvement and optimization

The "MSc in Oil and Gas Process Systems Engineering", is a Paradigm of Academia and Industry Partnership in Greece and EU, providing sustainable and continuous improvement culture in both industry and university [14].

The MSc Program is well designed to enhance the academic program of West Attika University, but also to support the sustainable development and operation of the Helleniq Energy Group business areas, covering continuously and in an advanced way the educational needs of its Technical Personnel.

The long-lasting expertise acquired in the Oil & Gas sector, is transferred to the academia through the pool of knowledge of its experts and their valuable contribution.

Technical experts of almost all the business units of Helleniq Energy Refineries, actively support the program with lectures, industrial case studies and thesis work supervision.

It is of paramount importance in this point to emphasize that the inspiration of AI and ML introduction in the Aspropyrgos Refinery of Helleniq Energy SA has been provided by the detailed, enthusiastic and thorough investigation of the state of the art in these issues that has been carried out for the successful implementation of an intensive highly specialised course in the above MSc Course, delivered by one of the authors of the present paper and embraced from the whole team and the management of the company.

Furthermore, one more invaluable reciprocal benefits of the MSc Course should be recalled, namely the high quality of the education that is provided to the technical personnel of the company, as well as the development – through the Course of excellent quality instructors that will in their own turn educate the rest of the company's technical personnel.

During its six years of operation the PG Course has been educating 120 professionals, mostly working in the hydrocarbons field. Almost 40 of them have already graduated and have advanced their career in petroleum and natural gas industries. On the other hand, the knowledge acquired form the graduates has been implemented through the implementation of advanced methods and tools for the design, operation and optimization of the processes and supply chains.

To conclude, the convergence of ML, cloud computing, and vast datasets is revolutionizing process systems engineering. The challenge lies in integrating these new tools and skills into the core of the PSE discipline, thus creating a new kind of engineer. This will require cross-disciplinary education, industry-academia partnerships, and a commitment to embracing the potential of AI to unlock unprecedented levels of efficiency, safety, and sustainability in industrial operations. The ability to adapt is going to be paramount for the industry and academia..

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