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ARTIFICIAL INTELLIGENCE in EU PROCESS INDUSTRY A VIEW FROM THE SPIRE cPPP

I. Summary

- **Artificial intelligence technologies have large potential** to assist the EU Process Industry to achieve disruptive transformations **that strengthen its global competitiveness** as well as contributing to a **carbon-neutral economy and to circular-economy solutions**.
- However, the **Process Industry sector is currently lagging behind in some fields of AI-utilisation**. AI technologies are developing very fast while adoption in our industries is often challenging. **Support for R&I actions to speed-up the adoption of AI-technologies by Process Industries is needed NOW**.
- Specific AI solutions for Process Industry companies will create **a larger demand for highly digitally skilled human operators** who will develop, monitor and manage AI-based operations. **Investments in digital education and skills** is therefore a very important priority.
- Under Horizon2020, several **SPIRE projects have focused on areas such as advanced process control and scheduling, process and catalyst design and digital platforms for industrial symbiosis.** It is time to make a further major step forward. Under Horizon Europe, **SPIRE aims at contributing to the EU strategy on Artificial Intelligence by including ad-hoc SPIRE calls targeting AI applied to Process Industry reality and by collaborating with the relevant digital Partnerships to jointly develop solutions and maximise impact in our society.** SPIRE is already in discussions with them, and SPIRE is open to explore the best joint initiatives (e.g. MoUs, joint calls, events etc.) to maximise impact through industrial implementation of AI.
- Horizon Europe and Digital Europe **investments in AI should be as integrated as possible** to ensure they both provide interest and incentives for the process industry **to create their future productivity increases in the EU and for the EU**. Research and deployment should be possible in a system integrated way seamlessly **over the boundaries of different funding mechanisms, instruments, and initiatives** so that industrial companies, universities and research institutions can execute their transformation as impactful, holistically and efficiently as possible.

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II. The roots of an invasive use of AI in Process Industry

Artificial Intelligence (AI) is today one of the most hyped technologies. It has become strongly relevant in many aspects of our lives from natural language processing to navigation and trading in stock exchanges. AI refers to systems or applications which can make decisions and can take actions without being explicitly programmed to do so, based on data collection, usage analysis and other observations. **AI is not one universal technology, it is rather an umbrella term that includes multiple technologies such as machine learning, reasoning, computer vision and natural language processing (NLP) that, individually or in combination, add intelligence to applications.** The broadness of the technology portfolio, its rapid pace of change, and the increasing power of the proposed solutions will find within the process industries a significant field of implementation, leveraging some very specific characteristic of these industries.

<u>Process industry is seen as an old industry, but it faces new challenges. Amongst them:</u>

- An ever-increasing world level competition, which must be fought by EU leadership, and a fast and efficient innovation process to generate market-minded solutions;
- Its involvement in building the materials-loops of the circular economy, which will create the (previously) never-met needs to be industrially linked with downstream users as well as with the upstream operators who will provide the materials to be recycled;
- The development of eco-design methodologies with customers, increasing the exchange of information between actors and transforming what a product should be, i.e. not only a material but also the data file containing the information to use it (the materials' digital passport);
- The opportunity to develop innovative materials generating the data that will be used to improve the life cycle of the final products;
- The ability to define new business models, once markets switch from materials consumption to "materials rental" concepts, or from product delivery to service achievements;
- The transformation of its plants into units that will be fully optimised, smart, innovative and integrated in their environment and surroundings.

It should be remembered that - for decades - the process industry has developed automation of its plants and processes, providing the databases that can be explored in data intensive AI solutions. But the Process industry relies also on other capabilities:

- Structured knowledge, through a strong corpus of sciences and technologies, well described and structured, in literature, patents, publications, with the ability to define the classification of concepts (the ontologies) to represent them. The ever-increasing amount of knowledge to be used and the disappearance of experts in some of the "basic sciences" are challenges that also need to be tackled, for the Process Industry to continue to master one of its key assets;

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- Individual as well as collective know-how, mainly in industrial operations, as plant workers have developed a delicate understanding of the processes and equipment they use. The loss of this pragmatic expertise is also a significant threat.

At the crossroad of the challenges and the capabilities listed above, digital technologies and more specifically AI solutions are compulsory tools to be adapted, developed, implemented. But this implementation will have to consider the specific challenges of Process Industry, i.e. its pace in renovating and replacing its equipment and infrastructure and the need to have secure and safe transitions as this industry is critical to Europe and responsible for managing hazardous processes, etc.

What is going on elsewhere? Every year CB insights publishes a report on the top 100 most promising AI or artificial intelligence-based start-ups that are challenging the old and legacy-based systems in almost all the sectors of the economy including the manufacturing and process industry. These are companies that are at the forefront of disrupting existing market trends and have caught the attention of investors big time[1]. In the year 2018 alone, AI based start-ups received almost $10 billion in funding, up 72% from the previous year[2]. While there is a strong interest in implementing AI across sectors in Europe, a recent MIT study reported that 40% of AI companies in Europe do not use AI at all[3]. Similar views were echoed by the consulting firm, Ernst and Young Inc. in a report that said only a meagre 4% of the 275 European companies they interviewed had implemented any kind of AI technology in their processes[4].

Nevertheless, **given the huge potential for transformation that AI can bring to Process Industry**, which plays a pivotal role in the European economy, and given the cascading effect of value creation that any improvement in the Process Industry provides to all the downstream users, **it is vital to support the adoption of AI technologies by all the actors in the Process Industry**. The current state of the art of AI deployment, as well as the barriers met, and the many improvements or disruptions that AI can bring to the Process Industry are described briefly below.

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[1] https://www.cbinsights.com/research/artificial-intelligence-top-startups/
[2] https://www.bloomberg.com/news/articles/2019-01-08/vcs-plowed-a-record-9-3-billion-into-ai-startups-last-year
[3] https://www.technologyreview.com/f/613078/about-40-of-europes-ai-companies-dont-actually-use-any-ai-at-all/
[4] https://pulse.microsoft.com/uploads/prod/2018/10/WE_AI_Report_2018.pdf

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III. AI and its expected impact on Process Industry

AI is part of the digitalisation of industry. It will not only have technical, social and economic impact. It will also make plants and operations in process industries more resource and energy efficient, warrant safety and risk management, secure product quality, contribute to significant CO_2 emissions reductions, orchestrate the pathway to a carbon-neutral economy, optimise internal and external supply management, and transform the European job market.

As a very important part of digitalisation, **Artificial Intelligence technologies have the potential to assist process industry companies to achieve disruptive transformations both in performance and in value generation.** [5] Rapidly emerging AI technologies are likely to have a huge impact on the value chains and profit pools within those chains that will have far-reaching implications for the structure of the entire industry and how it currently operates. AI has the potential to improve many aspects of today's business models (customer experience and interaction, plant operations, administration, research and development etc.) and to open new avenues to innovative products and more competitive and customised service offerings.

Artificial Intelligence is used to describe machines that mimic "cognitive" functions that humans associate with other human minds, such as "learning" and "problem solving". AI represents a group of digital technologies that includes machine learning, reasoning, computer vision/speech recognition and autonomous/self-organised operations and can help to improve many other fields such as predictive analytics, advanced process automation, robotics and mechanical automation, among many other examples.

AI has quickly become relevant in private- and business-to-consumer contexts, and it has the potential for a significant impact on Process Industries. Observing AI's powerful and fast evolving capabilities, the process industries imagine a digital-supported future that leads to maximised resource and energy efficiency, digitally-enabled circularity, symbiosis between all sectors and to products produced without waste in processes with minimal downtime.

AI will impose disruption not only on operational tasks such as production, plant maintenance or sales, but also on industries' administrative, managerial and even on scientific tasks in the R&D stage. AI is expected to reduce the human workload across many areas of employment, **however in the short- and medium- term, it will create a larger demand for highly digitally skilled human operators who** will develop, monitor and manage AI-based operations.

AI has the potential to significantly change many industrial processes like product development, plant and supply chain operation:

a. Impact on human/operators

- With better availability of information, operators and plant controllers can make improved decisions.
- Provides the scope to gain new and better insights through improved use of existing

[5] Accenture, «Artificial Intelligence and Blockchain, Insights and Actions for the Chenmical Industry", 2019

data which otherwise would overwhelm humans. For instance, an average chemical plant has 5,000 to 10,000 pieces of static and rotating equipment, each sending condition data such as pressure, temperature, flowrates and speed of rotation every few seconds — generating as much as 50 terabytes of information per year. In other industries, e.g. the steel sector, the number of sensors is similar, but the speed of the processes is much higher requiring data gathering every few milliseconds with more than 500 terabytes of information per year could be generated.

- Accelerate human/operators learning.
- Enable the human workforce to be more effective and efficient—as well as more creative. For example, by use of augmented reality (AR) and AI technologies real time feedback on processes can be displayed in their AR glasses[6].
- Automate repetitive, transactional and judgment-related tasks.
- Reduce human involvement in physical tasks in dangerous working environments.
- Improve the operators' working conditions by simplification of human-machine interface with complex processes.
- Transfer and formalise operators' knowledge and best practices.

b. Impact on Process/Product R&D&I

- Predictive analytics based on internal and external data can be used to help design experiments and interpret results.
- Achieve superior product quality by faster and better innovation cycles using data-driven R&D systems, data-driven R&D through in-silico experimentation and advanced lab automation[7].
- Better analysis of the performance of previous products for the improvement of future products based on lifecycle data.
- Data analytics in material design and simulation in order to accelerate new and customised product development. For instance, the chemicals manufacturing giant, BASF has already setup a pilot plant that allows consumers to customise their product requirements [8].
- Achieve more flexible and more customer-driven production of customisable goods, ultimately with the help of other technologies, leading to a dramatic change in the value-chain.

[6] https://www.coresystems.net/blog/cool-virtual-and-augmented-reality-gadgets-for-field-service
[7] https://www.lexology.com/library/detail.aspx?g=4bd8371b-e31a-4fe1-8d03-914c6bfc0e80
[8] https://www2.deloitte.com/insights/us/en/focus/industry-4-0/chemicals-industry-value-chain.html

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c. *Impact on Plant and Plant Operations*

- Significant efficiency improvements, even in production processes that have been already optimised for decades in process industries. For example, steelmaking is as challenging an activity as chemical production. It traditionally requires highly experienced workers to constantly adjust the conditions of the steel production facilities, while carefully managing the addition of coal, iron ore and various alloying elements. The use of AI in a steel plant could increase output by a significant percentage, while simultaneously reducing fuel costs.
- Reduced energy consumption through machine learning based optimisation, improved spot vs. contracting mix for energy sourcing, intelligent coupling of production plants/sites with renewable energy grids.
- Dedicated digitally supported and dedicated teams of operators, pooled for larger plant clusters, to handle problems and unexpected events.
- Data scientists, process engineers and production managers supervise autonomous plants and use real-time digital-twin simulation to optimise operations constantly towards higher energy and resource efficiency and better product quality.
- Production data is fully and seamlessly available for R&D and customer service activities.
- Intelligent Digital Twins will be combined with Software Agents to communicate with each other and become powerful techniques to solve several types of complex optimisation tasks. This can be a significant step in the direction of self-organisation of industrial production.
- First-time-right production will contribute to increased throughput and yield.
- Tedious, routine-based manual work becomes obsolete, and safety and quality reach unprecedented high levels.
- AI augments supervision activities such as maintenance routines, helping to reduce plant downtime and to increase overall plant lifetime, but also reducing superfluous and often routine maintenance activities and component spare part replacements.
- Supporting the optimisation of the whole production chain and avoiding sub-optimisation of single processes.
- Integrated management of production by commonly analysing process, product and maintenance information.
- Support for holistic coordination and optimisation of new and conflicting operational objectives or goals.

d. *Impact on Value Chains*

- Create new services and flexible and customer-tailored offerings.
- Develop a much deeper understanding of customers' experience and behaviour and better identify new applications/markets for existing and new products.
- Conduct highly targeted, proactive sales with AI-based customer-specific forecasting and demand sensing, which could make it possible to ship goods even before the customer places orders so customers will never run out of the product.
- Better demand forecasting will reduce storage requirements and look-up value.
- Products as a service.
- Realisation of industrial symbiosis by tight coupling of production units (streams of materials and/or energy) through simulation of operating conditions of all involved plants of all participating companies, also across SPIRE sectors.

e. *Impact on organisation in factories and in companies*

This is a quite crucial matter for many companies, as AI can impact marketing and product design cycles, or even dramatically change the value cycle, as well as changing the production environment and organization, etc. In addition, trust is quite an issue when deploying AI based solutions, hence a wide range of human and social sciences issues will need to be addressed.

IV. State of play of AI use in Process Industries

In recent decades, Process Industry companies have invested heavily in data capture and storage technology, such as operational intelligence systems for asset data or systems for customer and market-related data. As of today, many companies have applied advanced but rather 'standard' data-analytics driven by applied 'human intelligence' and 'human experiences' to extract insights and take decisions from these data-pools. Recently, process industries have become aware of AI and its potential to extract more knowledge out of this deluge of data.

Leaders in the Process Industries need to be thinking about whether, how, and where they should be investing in AI-based technologies. This means understanding the available AI technologies and analysing existing and potential technical/business processes, staffing models, data assets, and markets to identify ways that AI can be used to improve quality, speed, and functionality, as well as to drive top-line revenue growth. It should be remembered that AI is not only restricted to learning from data, but it covers also many aspects of intelligent reasoning, based on simple rules or more complex semantic descriptions. Furthermore, AI must be combined with different existing technologies like 1st principle models to reach a new level of powerful solutions for optimisation or automation tasks.

Even though the process industry has been active in the past, new and affordable IT techniques developed over recent years have led to new interest of industrial companies in these technologies.

However, **the Process Industry sector is currently lagging behind in some fields of AI utilisation** compared to frontrunners like the communication industry or social networks. Adopting new technologies, especially in process industries, requires sound planning, which is time consuming. Companies have long histories in optimising their production and the life span of investments can be decades, meaning that, unfortunately, changes cannot be made rapidly.

In many real applications of AI in Process Industry we are facing the problem of having not enough data for the given tasks, which may be surprising for somebody unfamiliar with the industry. Here more "*smart data*" or "*small data*" techniques are necessary that could be realised by adapting existing "*big data*" solutions to the specific needs of Process Industries.

In addition, safety and environmental regulations require strict governance; in the field of AI especially the topic of cybersecurity must be considered. In processing, short-term benefits are expected to come mostly from process- and process chain automation and productivity-based solutions. In the mid-term, more complex processes can be automated as intelligent automation offers considerable potential, and predictive maintenance and optimisation applications further boost performance.

In Process Industry, the use of AI is now supporting decision making by analysing information from several different data sources and proposing an action based on that synthesis. Industry has already identified problematic issues here concerning transparency of the decision-making process and responsibility for the decision. There is no clear transparency for AI decision processes and no clear understanding about the responsibility, if a decision fails.

At the same time companies must deal with the "point of inflated expectation" within the technology hype cycle: many new players offer 'new' IT technologies to the market and many promises are made but the lack of specific success stories together with several failures/not successful AI trials often hamper fast industrial AI implementation. **There is a high potential to speed-up the process from R&I to large-scale industrial implementation through orchestrated European innovation programmes bringing together Process Industries with the digital industries, academic research and highly innovative SMEs across Europe.**

Another aspect of high importance must be mentioned: if future intelligent systems are based much more on data than today, much more effort is needed to ensure that all the data used are highly reliable. That is not an easy task in the existing industrial environment with many challenges like the high number of different types of sensors, complex IT networks, sometimes still needing inputs from human operators, and many interfaces to computers systems, for example on different levels of process automation.

a. Current areas of AI applications in industries

In the industrial sectors represented in A.SPIRE, the following general application areas can be identified up to now: modelling of static and dynamic systems while coping with uncertainty; detection of causality and correlation (e.g. of quality defects); realisation of smart sensors (e.g. in the field of vision, as inputs for higher level systems like PLC-controllers); intelligent plant and process monitoring; online process control and optimisation; supervisory control such as through-process product quality control; control of industrial robots ensuring their capability for collaborative work together with human operators; Decision Support Systems for repetitive tasks which require higher level cognitive operations (e.g. situation awareness) in combination with complex data processing tasks and; last but not least, applications in predictive maintenance.

All these applications are oriented to the technical processes and their control and optimisation. Furthermore, there are applications which do not differ from other industries such as manufacturing industry and which deal, for example, with process mining of business processes or machine learning techniques to analyse future behaviour of customers based on intelligent analysis of information sources like the World Wide Web. However, the required processing of raw data, or even of information, refers to specific ontologies and issues.

b. *Forms of AI relevant for process industries*

The above-mentioned application areas are driven by AI technologies which do not differ from AI applications in other technological fields, such as other industrial areas or telecommunication or social networks, for example. Nevertheless, there are significant differences, not in the technologies themselves, but more in the preparation of the necessary input information like data or knowledge, and in the way to implement them in a complex environment for online purposes. The most commonly used AI technologies are the different forms of machine learning such as supervised (e.g. deep learning neural networks or random forest of decision trees or Support Vector Machines, etc.), unsupervised (e.g. clustering techniques like SOM/DBSCAN or dimension reduction techniques like AutoEncoder), and reinforcement learning (e.g. Deep Q Network or Q-Learning, etc.). Furthermore, all the techniques of machine-based reasoning should be mentioned here, like Expert System Technologies (rule-based knowledge description in combination with inference mechanisms) or other knowledge driven techniques like Ontologies (semantic knowledge descriptions) also in combination with inference machines. An emerging technology is Multi-Agent-Systems, which can help to solve different kinds of optimisation problems in complex environments because they can be excellently adapted to the needs of the highly distributed systems used in industrial production.

For process industries, it is important is to be able to combine different AI methods with more classical ways of modelling (like 1st principal or statistical models) or other IT techniques.

c. *Data/information sources and data/information collection methods and practices*

All AI methods are highly dependent on the necessary input information. This information is in many cases a large amount of data but could also be several forms of knowledge like rules or semantic descriptions of knowledge domains. The ways and means to collect all this information and to store it in a suitable way are of high importance for the success of all AI technologies.

Here it should be mentioned that process industries are working in a “brown field” environment (as opposed to “green field” applications which means in a new-build factory), which means that existing plant, control and IT-systems cannot easily be replaced completely by new solutions. Therefore, interfaces between new systems and existing equipment are necessary. Keywords in this field are SCADA, MES-MOM, ERP, ISA95/IEC62264, Data Warehouse, Data Lakes, Cloud Computing, Edge Computing, noSQL, and Streaming technologies, etc.

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In combination with the data and information collection, the problems of the amount, quality and reliability of data must be mentioned. In this sense, the demands of process industries are extremely high because any kind of wrong decisions related to little or poor data could lead to unstable production processes with unforeseeable and potentially dramatic consequences. **Appropriate solutions to handle situations of poor data quality in an industrial environment do not exist today and are one of the main research-needs for the future.**

d. Other relevant aspects

Finally, it needs to be mentioned that up to now, typically only case specific solutions have been developed and implemented while no systematic approach exists to develop solutions for different types of problem and to roll out these solutions subsequently to all possible application examples. This is strongly connected to the project-based implementation of AI solutions with the consequence that no systematic long-term maintenance, update and re-check of the deployed AI solutions after the project end is undertaken.

V. Existing Barriers and Threats to the use of AI

Alongside all the positive aspects of the application of AI technologies in Process Industries, it should not be neglected that there are barriers and threats that need to be overcome before AI applications can be implemented successfully. The following lists intend to categorise the various barriers and threats:

a. Technical

- Some AI methods are based on large amounts of data and these data must be highly reliable, therefore data generation (e.g. by sensors), **data robustness, data quality**, and data access need to be improved further in process industry.
- As said before, some AI methods need large amounts of data to work properly. Process Industries are facing the problem that, in many cases, not enough data are available to apply machine learning techniques in a suitable way. New technologies must be developed which are able to work with a significantly lower amount of data to produce similar results. We have to come from **"Big Data techniques"** to **"Smart Data methodologies"** combining process modelling and AI learning.
- One step more: In many cases, even "Smart Data" are not available due to the difficulty of generating data points; for instance, when it requires building physical prototypes for testing, or complex simulations that may take days to run. In these cases, it is desirable to be able to start building models with very few data points, here called **"Small Data"**, and continue learning as new data become available. In the best cases, the model itself can suggest what is the most efficient next trial, as is the case in Gaussian Processes/Kriging. The 'continue learning as new data becomes available' part (online learning) is also quite interesting, as it helps with some of the issues pointed out in this document such as deployments that are not updated, lack of generic solutions, etc.

- Data engineering foundational work is still ongoing (networks, data model, data security).
- Quality of data sources feeding into AI is often still not high enough, further digitalisation efforts and data integration of the processes are needed.
- Lack of relevant data (AI implementations usually show that the most needed information is usually not available or unreachable), which new powerful sensors are necessary.
- Evolution from ISA95 to RAMI4.0 and beyond, problem of non/less-digitised brownfield-equipment and legacy-assets.
- Lack of automated solutions (from data quality/validity checks and preparation to knowledge extraction and implementation).
- Complexity of hybrid systems which incorporate AI and other ICT approaches, quite often in cyberphysical-systems.
- Interoperability issues across various hybrid systems in heterogeneous environments.
- Human system interactions at various levels and steps, which may become critical to safe plant operation.

b. Company internal

- Difficulty in convincing management of the benefits of AI, given the difficulty in estimating the business benefits *a priori* (e.g. unclear benefits, lack of examples, business models, lack of control, lack of understanding of what AI really is - including its limitations).
- Security aspects and vulnerability of companies using AI.
- Fear to share data, loss of control of decision making to algorithms, fear of jobs losses.
- Company leadership not acquainted with all the possibilities of AI.
- Limited willingness to adopt new technologies, company culture not ready for digitalisation.
- Unrealistic expectations (the hype around AI).
- Lack of a guarantee about the accuracy and final usefulness of AI-solutions.
- Lack of appropriate knowledge/internal skills within the process industry.
- Lack of interdisciplinary knowledge (combining industry domain knowledge and AI).
- Organisational (e.g. strategy, processes, and leadership towards implementation of digital).

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- Communication gap between computer science and process industry, difficult to implement solutions without coupling methodology and domain knowledge.
- Data- & AI-algorithm governance.
- Validation of AI algorithms (lack of ability to reverse engineer).
- Cybersecurity requirements will become an extremely important issue in the future, because systems will increasingly work through very complex IT solutions.
- Training of staff.

c. Economic

- Lack of funding.
- Unclear benefits to the industry as final user (marketing and expectations often differ from the achievable results). Appropriate public funding is needed to de-risk implementation decisions on digital solutions.
- Cost/benefit ratio ('off the shelf AI' is not common, each problem usually requires an individual and very specific, carefully adapted solution).

d. Standardisation and related topics

- Quality Assurance of AI.
- IP of ever evolving techniques/algorithms, patents.
- Lack of standardised solutions, lack of commercial building blocks.
- Interoperability will have to be considered.

e. Others

- Educational (e.g. skills, retraining of employees whose jobs are changed/substituted).
- Ethical (e.g. purpose of using AI, clarity of responsibilities, accountability, public image and proper customer dialog and acceptance).
- Legal (e.g. data sharing agreements, privacy & data protection, liability/responsibility of actions/decisions performed by AI algorithms).
- GMP (good manufacturing practices) restrictions.
- Industrial AI is different from other commercial AI applications (higher standards for safety, reliability, accuracy, robustness).
- There is a communication gap between computer-science and the process industry. On the other hand, it is difficult to implement AI solutions without coupling AI methodology and domain knowledge.

- Data opening, use of external data, and how to do it: in many cases companies have to work together with external data providers (public and private) while developing AI solutions, because it will not be possible to rely exclusively on the data provided internally.
- Data governance and data ownership: this will become an important issue in several industries, especially if cooperation with external stakeholders becomes necessary to produce the database on which AI algorithms can operate.

VI. Opportunities and Outlook - Future Trends in AI and Application of AI

The main task in the Process Industry for the next years is to find the right applications of **AI technologies which bring the most benefits in terms of reducing energy consumption, reduction of environmental pollution, realisation of a full circular economy, cost reductions and product quality improvements**. Some examples in this field could be the realisation of intelligence in distributed systems based on software agent networks and combined with suitable process modelling technologies; the elimination of subjective decisions wherever possible by intelligent decision support systems; AI on time series with cyclic changes; the optimisation of collaborative robots (e.g.: human-robot collaboration in industrial tasks) regarding safety mechanisms and planning; improved process situation awareness by more powerful image recognition techniques; and better diagnostic/prognosis based on historical data for preventive maintenance and energy optimisation.

Furthermore, there are some more general issues to be addressed such as better explainable and trustable AI solutions, the automatisation of AI development, deployment and management, and a much higher autonomy for AI based systems.

a. Research needs:

As well as the field of AI applications and the more general aspects mentioned above, many specific research fields can be identified to help process industry realise powerful future AI applications.

Some examples include:

- Research in the field of *data quality* and *data reliability* (how much can we trust the data we are looking at?)
    - Including numerical precision of sensors (ongoing).
    - Trustworthiness of data and its quantification.
- Upcoming "Data provenance" and "data lineage"
    - Carries trustworthiness to the next stage.
    - Asks "where does the data come from; what changes did the data go through?"

        - Provenance (closed track record) of changes to the data.
        - Digital ledger technologies such as *blockchain* or *tangle* are some promising candidates for realising data provenance.
- Convergence of data analytics and business intelligence (BI): In process industries, there is a gap between process data and business relevant analytics. These gaps need to be closed. Applications sitting on live data will feed business intelligence in real-time.
- Significant opportunities in model-based reinforcement and related approaches with respect to process industries.
- Adoption of methods from Natural Language Processing (NLP) including Long-Short Term Memory (LSTM) and Generative Adversarial Networks (GAN) approaches.
    - "ProcessAlexa"
        - Application scenario 1
            - Process perturbation happens;
            - Operator tells "ProcessAlexa" where he wants to look;
            - "ProcessAlexa" listens and uses NLP to automatically display relevant data.
        - Application scenario 2
            - Same as in scenario 1, but now a secondary machine learning (ML) unit learns what questions are being asked by the operator;
            - It builds up a knowledge base of common questions and correlates it semantically with the description of the perturbation;
            - This feed input into any semantic reasoning algorithm.
- Overcoming MIT "trio of challenges" for ML: Language, Context and Reasoning
    - RETE Algorithm.
    - Distributed context reasoning.
    - Application in process industries:
        - Today: Ontologies can store semantic information and are based on triplet structures which are stored in "RDF Triplet Stores"; existing reasoning algorithms evaluate and perform inference on this information.
        - Of greater interest for industry: A problem occurs, the reasoner launches on existing ontology but recognises that there is some piece of information missing.

The system now tells the operator which type of information is needed, e.g. by experiment.

- Machine learning control (MLC)
  - Incorporation of sophisticated 1st-principle models, while enriching these models with probabilistic information from data, gathered by means of ML.
  - Learn the "easiest, most robust and efficient" model that successfully does the control job.
  - Ubiquitous ML and MLC.
- Collaborative AI/ML
  - From single aggregate control, process industry will go towards final-product-centric control, where plant-wide ML learns and trains sub-ML codes to optimise the overall process chain.
  - From communicating and collaborating agents with models (developed by humans) development will move towards collaborating agents with embedded AI/ML capability. These smart agents will convolute.
- Multi-objective optimisation by using different AI approaches, to ensure the true trade-offs between different solutions is known, decisions are appropriately made, and solutions are efficient (in the Pareto sense). Many problems in the industry have opposing goals, and often any scaling is a coarse simplification (e.g. manufacturing cost vs. service level).
- Distributed optimisation, e.g. by networked agents' architecture, to reach true globally optimal decisions.
- Optimisation under uncertainty, in the form of robust optimisation, stochastic optimisation, and reasoning with probability models. Uncertainty must be handled in many cases where data are the basis for AI methods, for example if 1st principal models are applied in the environment of predictive control systems. Including that uncertainty in the optimisation process can protect against the effects of variability and prediction deviations. The optimisation of the mix of spot and contract energy purchase falls under this area.
- Combination of AI with more conventional modelling solutions: strategies are necessary to create in a more systematic way the ideal combination of different types of technologies such as statistical models, 1st principal models, semantic or rule-based knowledge, and other AI based methods.

b. Needs for a capable workforce:

To integrate AI and all advantages of digitalisation into industry, it has been estimated that a typical €10 billion turnover, 15,000-employees chemical company might need approximately 500 to 1500 full-time employees with a digital skill set (data-scientists/engineers with IT skills etc.). **These skills are difficult to recruit and will become even scarcer as demand increases.**

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VII. Planned investments

It is very difficult to get information from Process Industry companies about planned investments and corresponding ROIs. Firstly this is because many companies now decide to invest in digitalisation in general and do not explicitly differentiate between digitalisation and AI. Another aspect relates to European and National Anti-Trust Laws that do not allow companies to describe planned future investments if they are highly connected to their business models and anticipated economic benefits. In general, according to various studies, the chemical industry directs a large share (>25%) of their digitalisation budget into the exploration of new technologies including AI and blockchain.

On the other hand it is possible to look to national strategies in the field of AI and here some countries have been selected to demonstrate their particular approaches:

Example Finland:

Artificial intelligence is a very hyped technology and has already made in-roads in to almost every sector of the Finnish economy ranging from retail to manufacturing and the financial sector. Embracing AI technologies will have a significant impact on the Finnish economy. A recent study by Microsoft reported that a successful adoption and promotion of AI technologies could result in an additional $20 billion boost in Finland's GDP by 2023[9]. Several companies have already implemented AI and Internet of Things (IoT) technologies in their operations and have realised improvements in their business operations. For example, Metso[10] a leading organisation offering sustainable processing and supply of resources for process and manufacturing industries, has successfully implemented AI for 1) improved mining process stability, 2) optimised business operations with constraints, and 3) maximised uptime for equipment availability and usage. **StoraEnso,** a leading Finnish company that provides renewable solutions for packaging using biomaterials and paper, today uses AI to predict failures ahead of time to reduce downtime[11]. **Borealis Polymers Ltd** is a company based in Porvoo-Finland, which produces ethylene and other petrochemical products. The company has used machine learning and advanced analytics for advanced process control that has led to a consistent increase in their profit of approx. $12.5 million per annum for over a decade[12].

Finland launched a national programme for exploiting AI technologies in 2016. The programme has sketched an AI strategy for Finland emphasising use of AI technologies in manufacturing and process industries. In the first phase, major funding for basic research was allocated by the Academy of Finland. In the second phase, an RDI programme governed by Business Finland, worth €100 million, was launched. In the third phase, an AI accelerator was started by the technology industry organisation TT. Process industry firms have embraced AI technologies by hiring experts, partnering with AI technology companies and organising hackathons[13].

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9 https://info.microsoft.com/WE-AzureDS-CNTNT-FY18-04Apr-17-UncoveringAIinFinland-MGC0002305_01Registration-ForminBody.html

10 https://www.metso.com/blog-hub/mining-minds/intelligent-minerals-processing-powered-by-ai-and-iot/

11 https://pulse.microsoft.com/uploads/prod/2018/10/WE_AI_Report_2018.pdf

12 https://www.napconsuite.com/reference/100m-more-profit/

13 https://www.tekoalyaika.fi/en/

Example Slovenia:

a. **Slovenian national strategy on AI**

The preparation of the Slovenian national strategy on AI is coordinated by the Ministry of Public Administration. The strategy will be aligned with the European coordinated plan on AI and OECD recommendations. Currently, the draft version of the strategy is being verified by a group of experts. The Slovenian goal is to establish an effective system to support AI research and deployment activities. Moreover, artificial intelligence is planned to be one of the priority areas of the Slovenian presidency of the Council of the European Union in the second half of 2021. The implementation of the Slovenian AI strategy will focus on three main areas: strengthening technological and industrial capacities in the AI field, responding to socio-economic changes, and ensuring an appropriate ethical and legal framework. The national strategy on AI will specifically address policies and tools to: 1) strengthen and systemically reorganise interconnection of AI stakeholders, 2) revise education and training aspects to improve human resources, 3) increase financial support and promote AI research in the public and private sector, 4) prepare the economy and society for change, 5) improve data capabilities, 6) use AI to strengthen security, 7) raise the trust of individuals in AI, 8) ensure an appropriate ethical and legal framework, 9) increase the use of artificial intelligence in the public sector, 10) strengthen international cooperation on AI, and 11) monitor the development and use of artificial intelligence.

b. **Slovenian Smart Specialisation Strategy**

Slovenia's Smart Specialisation Strategy (S4) was adopted in 2015 with three priority areas and nine areas of application. The latter acted as a springboard for establishment of nine Strategic Research and Innovation Partnerships (SRIP) in 2017, which bring together companies, research institutions, education institutions and civil society with the state acting as their partner. The state is providing its support in priority areas through RTDI, infrastructure, public procurement, and pilot projects. Under the S4 domains there is currently available support to promote research and development activities of companies with the aim to support the development of new or improved products, processes or services in the priority areas of the S4 (€74 million from 2018-2022). There are also available incentives for development and innovation activities which pilot/demonstrate new or improved products, processes or services in a real environment (€56 million from 2019-2022). These actions intend to promote innovation actions of the companies, shorten time from idea to market, strengthen the competitive position of companies and their positioning in existing and new value chains, and to increase private sector investment in research and innovation.

AI-case studies and initiatives from SPIRE-sectors (Examples from public company press-releases, non-exhaustive):

Evonik and IBM are set to co-develop a cognitive Evonik-specific Chemical and Life Science Knowledge Corpus based on analysis to identify relationships in unstructured data.

Cementos Molins revolutionised its highly traditional operations through the application of artificial intelligence.

BASF applies artificial intelligence in materials research to accelerate product and process research. Full artificial intelligence systems are still limited to a few, relatively simple, decisions whereas elements of artificial intelligence are applied widely. Decisions that are made by artificial intelligence include design of experiments and assessments of application tests.

Solvay research activities generate huge volumes of data from both the company's numerous labs across the world and external sources. Using AI tools will enable the creation of high-quality data assets that can be turned into smart recommendations that are viable in the real world. Solvay has invested in Noble.AI, a leading developer of software that helps R&D organisations speed up their innovation efforts.

A.SPIRE PAPER

Editors: *Martin Winter (CEFIC) and Harald Peters (BFI)*

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For further information, please contact: info@spire2030.eu