Ref. Ares(2022)1115295 - 15/02/2022

[D1.3] REVIEW AND UPDATE OF THE IDENTIFIED MACRO APPLICATIONS AREAS PLAN

Project details

Project Title	**Artificial Intelligence and Big Data CSA for Process Industry Users, Business Development and Exploitation**
Project Type:	CSA
Project Acronym	AI CUBE
Grant Agreement No.	958402
Duration	24 Months
Project Start Date	September 1, 2020

Document details

WP:	**1**	**WP Leader:**	**IRIS (Beneficiary 4)**
WP Title:	Current landscape analysis: AI & BD technologies and industry applications		
Deliverable No.	D1.3.		
Deliverable Title	Review and Update of the Identified Macro Applications Areas Plan		
Dissemination level	Public		
Written By	IRIS (Beneficiary 4)		
Contributing beneficiaries	PNO (Beneficiary 1, CNR (Beneficiary 5, FRAUNHOFER (Beneficiary 3), ZLC (Beneficiary 2)		
Approved by	PNO (Beneficiary 1)		

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958402

Status	Version 1.6
Date	12/01/2022

Deliverable information

Status (F: final; D: draft; RD: revised draft):	RD
Planned delivery date	31/03/2021 (M7)
Actual delivery date	13/04/2021 (M8)
Dissemination level: (PU = Public; PP = Restricted to other program participants; RE = Restricted to a group specified by the consortium; CO = Confidential, only for members of the consortium)	PU
Type: Report, Website, Other, Ethics	Report

Document History

Version	Date (MM/DD/YYYY)	Created/Amended by	Changes
1	09/03/2021	IRIS	Preliminary version
1.1	17/03/2021	IRIS/ALL	Overall content/approach update
1.2	24/03/2021	IRIS	Updated content
1.3	29/03/2021	IRIS/CNR/PNO	Editing and update of specific sections
1.4	31/03/2021	IRIS/PNO	Editing and update of specific sections
1.5	12/04/2021	IRIS/PNO	Editing and update of specific sections
1.6	12/01/2022	IRIS/PNO	Updates to address PO comments

Detailed notes on changes made in v1.6 based on PO's comments

PAGE	CHANGES MADE
6	added extra explanation in exec. summary
9	methodology, added extra explanation
11	note regarding taxonomy
14 - 17	deleted glossary from D1.3, and it has been inserted in D1.1.

Quality check review

Reviewer (s)	Main changes
Chiara Eleonora De Marco, PNO	Document editing and overall consistency check
Ron Weerdmeester, PNO	Overall review of content, especially introduction and conclusions.
Taira Colah, PNO	Document editing and overall consistency check

Table of contents

List of abbreviations and definitions used in the document:

Abbreviation	Definition
AI	Artificial Intelligence
BD	Big Data
CPS	Cyber-Physical Systems
CSA	Coordination and support actions
DoA	Description of Action
EC	European Commission
EEA	European Economic Area
GPU	Graphics Processing Units
H2020	Horizon 2020
HR	Human Resources
IT	Information Technology
ML	Machine Learning
NLP	Natural Language Processing
SLAM	Simultaneous Localization And Mapping
SPIRE	Sustainable Process Industry through Resource and Energy Efficiency
TOE	Technology-Organization-Environment
WP	Work Package

Disclaimer

Statement for open documents & Copyrights.

1. EXECUTIVE SUMMARY

This report evaluates the work done in D1.1 and 1.2 and uses it to redefine the CUBE dimensions for process and technology, including a review and update of the proposed plan for the consolidated macro applications areas in process industry. We recall that the first deliverable D1.1 presented an overview of AI and BD technologies and their application degree in the SPIRE process industries, whereas the second deliverable D1.2 performed a sectorial analysis of industrial processes in Europe highlighting major challenges where AI and BD could play a relevant role.

The following consists of a report of a synthesis of the sectorial analysis of AI/BD technologies and industrial processes in Europe, which identifies the sectors/processes/technologies which are most active and those which are least. Furthermore, we define all the dimensions, macro-areas etc. that will guide us through the identification of best practices, potential opportunities, etc.

In contrast with the first two reports, which included literature reviews and input from projects and stakeholders, this document will perform an analysis and synthesis of the information already gathered, and reach initial conclusions that will address and establish the dimensions upon which the CUBE framework will be built. These dimensions, including AI and BD technologies, sector and macro application areas in the process industries, will be updated in the course of the project based on growing insights while the project proceeds. It will also establish the fundament, to which maturity level of process industry in the application of AI and BD will be added in WP 2, as a fourth dimension of the CUBE.

The key result of this work has resulted in an updated CUBE design, represented in the following figure:

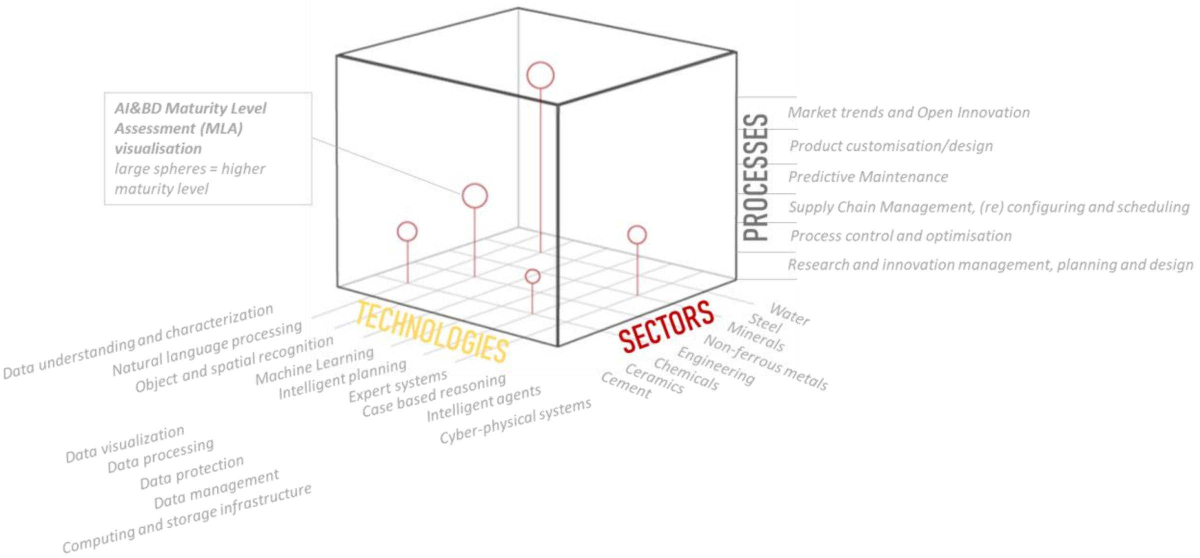

Figure 1. The updated "CUBE" design

As commented in D1.1, the original CUBE was defined in the project DoA, hence the CUBE update is the result of the research done in Deliverables D1.1 and D1.2 resulting in the new version presented in D1.3. To recap, the technology dimension was reviewed and updated in D1.1 and the process dimension was reviewed and (slightly) updated in D1.2.

This document will provide input for the upcoming Tasks 2.2 (maturity level design) and 2.3 (impact analysis) of WP2, as well as for Tasks 3.1 (maturity level assessment) and 3.2 (cross sector transferability of technologies) of WP3.

2. PROJECT INTRODUCTION

AI-CUBE seeks to enhance the understanding of different digital technologies related to artificial intelligence (AI) and big data (BD) applied in process industries for all the SPIRE industrial sectors (cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, steel, water). Therefore, a close collaboration with industry is mandatory to achieve in-depth insights into possible application areas of AI for processes, technology, sensor applicability and assessment of their level of penetration. The overall project approach is based on the development of a 3-dimensional conceptual matrix based on: 1) AI and BD technologies 2) Application areas (activities and industrial processes) 3) SPIRE sectors AI-CUBE's main goal is to define a roadmap in AI and the use of BD for the process industry and their maturity level across the industrial sectors, including guidelines for implementation. Industrial stakeholders and associations will validate the consolidated roadmap ensuring solution feasibility and benefits for the European industrial community. A crosslinked vision over process industry sectors shall facilitate cooperation and boost technologies deployment at their full potential. An in-depth consultation with industry (association, representatives, companies) will provide an overview of current AI and BD algorithms application, identifying exploitable synergies among sectors. A deep study of the application areas in planning and operations within other industrial sectors facilitates a gap analysis, propitiating knowledge sharing among processes and sectors.

It is noted that "paper & pulp" and "refineries" have been recently added by SPIRE as industrial process sectors. As this was posterior to the work on deliverables D1.1 and D1.2 and was not in the original scope of the project, they have not been studied in detail as for the existing 8 sectors. However, we may investigate later (in WP2 and WP3) how to take these sectors into consideration.

A Multi-Actor Multi-Criteria analysis will obtain a widely supported and consensus-based action plan for industrial consultation. This will allow the inclusion of a broad stakeholder community representing the main industry actors throughout all the SPIRE sectors, with which the project consortium has strong connections that will support sector integration and stakeholders' engagement.

3. OBJECTIVES OF THIS DELIVERABLE

The main objective of WP1 is to establish the current technological and industrial landscape regarding AI and BD technologies and process industry sectors in Europe, setting the basis of the following WPs work in defining mapping tools and the roadmap for AI and BD. In order to properly do so, literature reviews and consultation with relevant stakeholders will start from the very beginning of the project. Furthermore, a detailed assessment of both the technological and industrial status will allow to adjust the original implementation plan (if needed), expanding it to additional macro applications areas.

The approach and the aim of the activities carried out within Task 1.3, “Macro applications areas plan review and update”, is as follows:

By taking into consideration the information gathered in tasks T1.1 and T1.2, a plan update for the subsequent WP of the project will be outlined, focusing on the AI and BD technologies application in the different “macro” areas (or “processes”). An extended and complementary literature review will be done to assure that the following areas are adequately assessed, while any other area not identified until this moment could also be taken into consideration:

- Research and innovation management, planning, and design (e.g., new chemical synthesis strategies, health and safety assessments);
- Process control: yield and accuracy enhancement;
- Supply chain management and scheduling of connected processes, plants and/or sites (e.g., for industrial symbiosis),process flexibility;
- Predictive maintenance;
- Product customisation and product traceability.

4. METHODOLOGY AND APPROACH

AI-CUBE aims to map the state-of-play of AI and BD in different organisational core-processes, especially where AI and BD are (expected) to play a key role in the future, taking into consideration the macro-“process areas” in each of the eight SPIRE process industry sectors (e.g. RD&I, process control, SC management, predictive maintenance and product customisation and traceability).

This approach, which will underpin all actions of the AI-CUBE CSA, is visualised in the CUBE (Fig. 2), where the four dimensions are represented 1) AI & BD technologies (D.1.1), 2) SPIRE sectors, 3) Organisational core-processes where AI & BD can make a difference (D1.2), and 4) AI & BD Maturity Levels. Note that the “technology dimension” and “process dimension” were further elaborated in D1.1 and D1.2, respectively, resulting in reference taxonomies for the AI and BD technologies and the relevant processes in which those can be applied.

Note that the CUBE of Fig. 2 represents the original version (from the DoA), as point of reference, which has now been reviewed and updated as shown in Figures 1 and 8. Fig. 2 was already included in D1.1 and D1.2, and we also include it here in D1.3 to make the documents more readable and for easy reference.

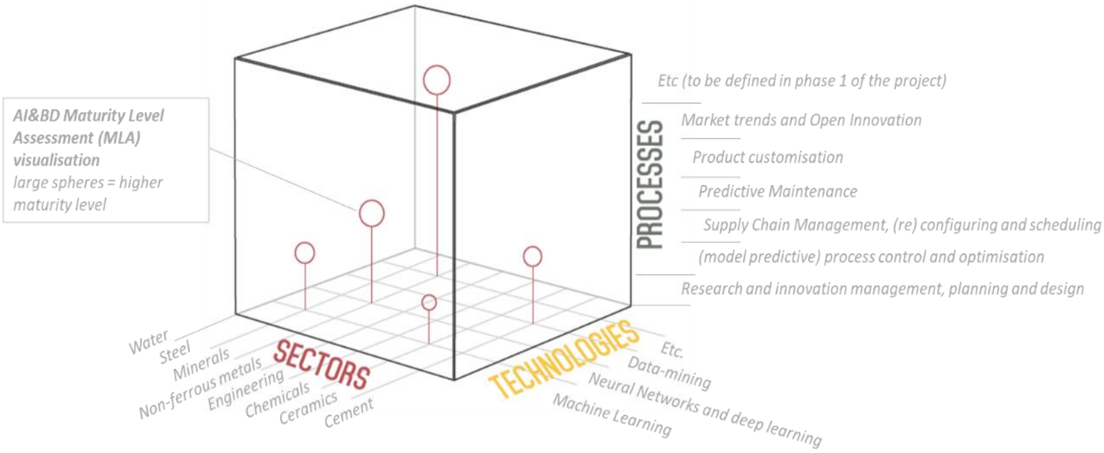

Figure 2. The original “CUBE” concept

In D1.1. we highlighted the key technologies and “heat-mapped” the macro-“process areas” where AI/BD focus is strongest in the different process industries. In D1.2. we zoomed in on the “processes” of the different process industry sectors, and highlighted the key-challenges these sectors have, where AI/BD can add value/ make a difference in the future.

Now in D1.3 we will review the “technology” and “process” dimensions of the CUBE, confirming the updated categories. Also, a glossary of definitions will be provided for each technology and process dimension, which will act as a guideline for the future work packages.

This will be concluded with the new CUBE framework definition, and laying the ground for the next steps of the project in WP2 and WP3.

5. REVIEW OF THE CUBE TECHNOLOGY DIMENSION

In the following we will start with an introduction to the “technology” dimension, followed by a "glossary" or more specific description of what it includes. In summary:

- We explain what we mean by "AI&BD technology", how we built the taxonomy in D1.1, which are the technologies that were included.
- Summary of the results obtained in D1.1
- Outline of the specific technologies that will be included in the CUBE dimension, and which ones will not and why.

Definition of Artificial Intelligence and Big Data technologies

With reference to Figures 3 and 4, a detailed taxonomy was developed for AI and BD, respectively, in which we took into consideration different existing taxonomies for AI and BD, which were then adapted as necessary, for the process industries. Hence, this gives a more practical and applied orientation, in contrast with the more academic categories which are found in other taxonomies (especially for AI).

Note that the taxonomies are hierarchical from left to right, and in the case of AI (Fig. 3) the second level is the one we have subsequently used to classify the literature search references, and evaluate their application in sectors and processes. In the case of BD (Fig. 4) we have used the first level for the same purpose. The motivation of why we went for the second level for the AI and stayed on the first one for BD, was in order to have the best representation of different relevant technologies and avoiding excessive complexity of the main categories.

One of the key criteria in choosing the categories to use (especially in AI), is identifying practical applications of the corresponding technology. Hence, in Fig. 3, the green outlined boxes to the right give examples of applications which correspond to the technologies, such as smart sensors, digital twins, predictive maintenance. In the case of the BD technologies (Fig. 4), the applications of the sub-categories seem much more self-evident (than AI).

Note that the taxonomy diagrams are repeated in D1.3 (from D1.1) for easy reference and to make the document more readable.

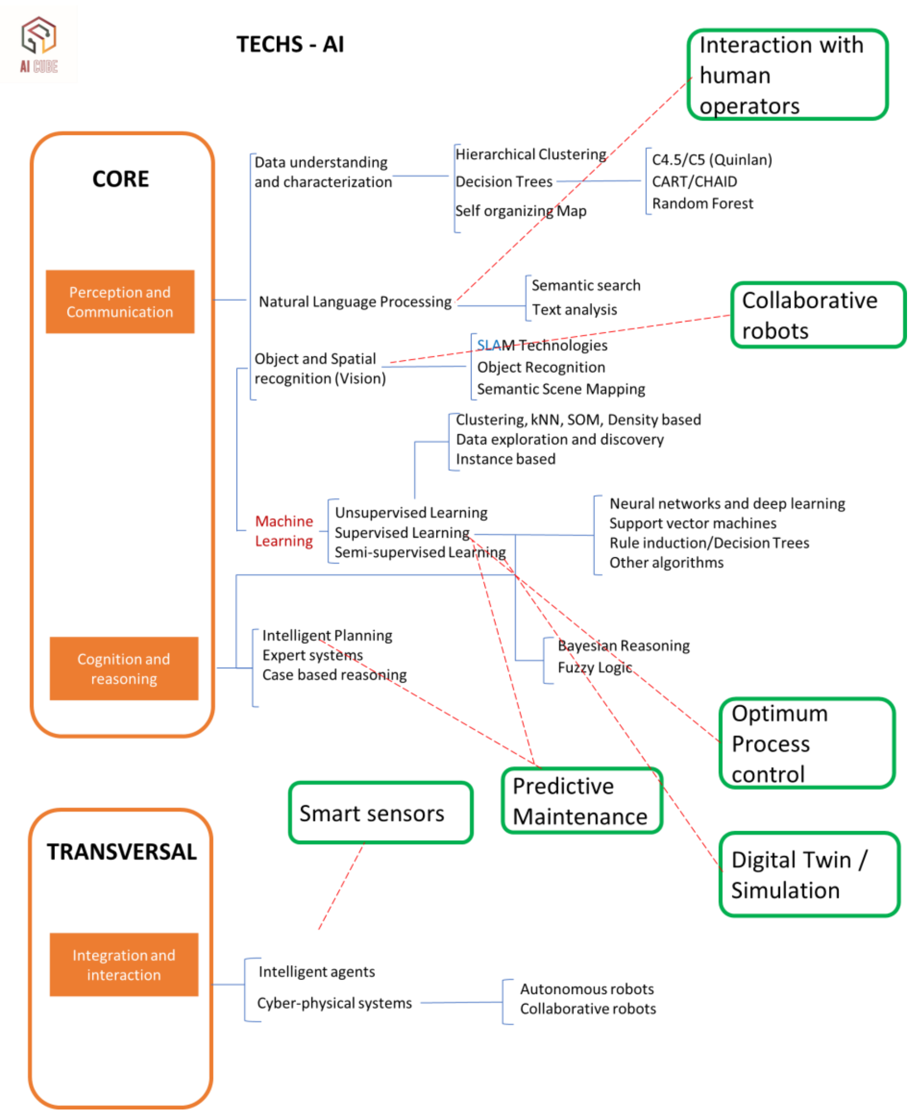

Figure 3. Artificial Intelligence Taxonomy

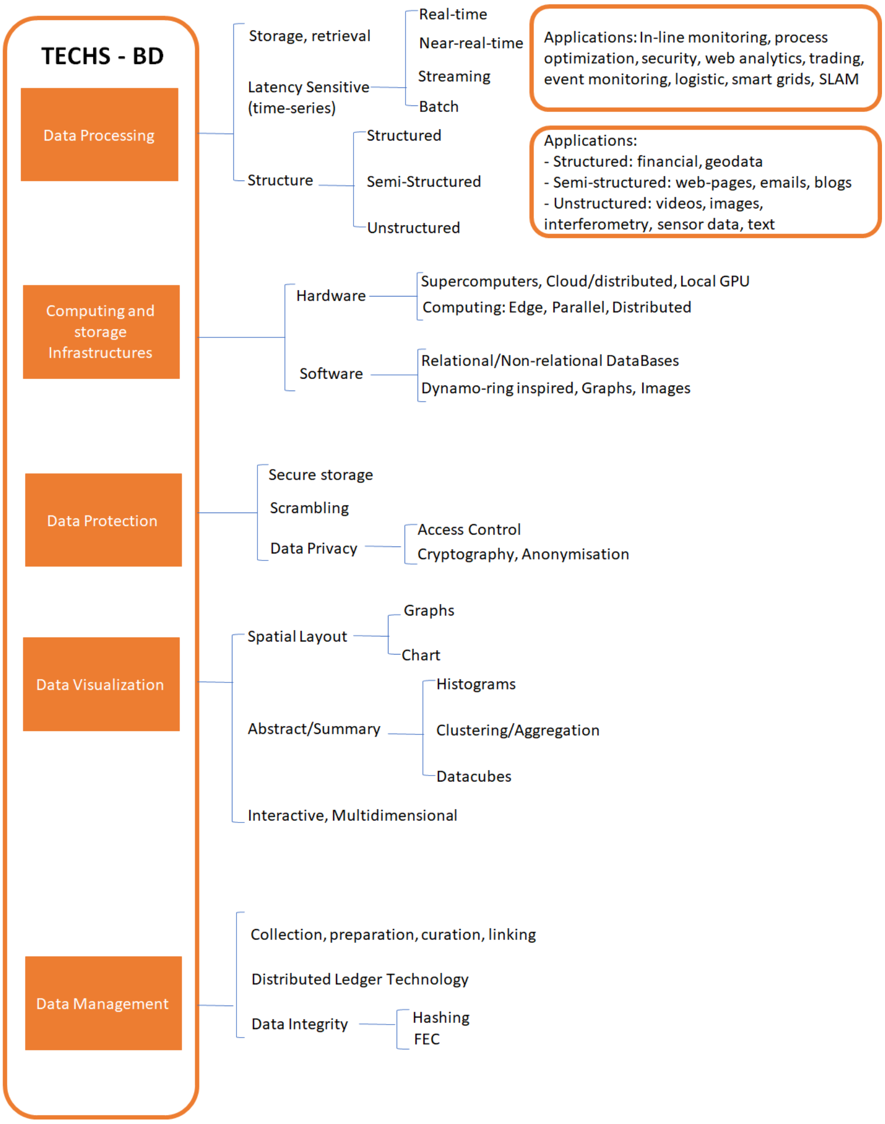

Figure 4. Big Data Taxonomy

5.1 SUMMARY OF THE RESULTS OBTAINED IN D1.1

Table 1 shows the “heat map” of the number of references found in the literature searches for technologies with respect to sectors. It can be seen that the “hot” technology category is machine learning with a particular concentration in the chemicals and minerals sectors. Categories with the least references are “data understanding and characterization”, “data protection” and “computing and storage infrastructure”.

Table 1. “Heat map” sectors vs technologies.

	Data understanding and characterization	Natural language processing	Object and spatial recognition	Machine learning	Intelligent planning	Expert systems	Case based reasoning	Intelligent agents	Cyber-physical systems	Data visualization	Data processing	Data protection	Data manage-ment	Computing and storage infrastructure
Cement				4		3	1		1	2	2		1	
Ceramics			2	4	4	2	1	1	2	1	4		2	
Chemicals	8		1	10			1		1		2		3	3
Engineering	1	8		5	1	4	4	4	8	1		1	5	3
Minerals	2	1	4	14	4	1	1	2	1	1	1	1	3	2
Non ferrous metals				7		2	1		1	1	3		1	
Steel		2	5	8		7	1	2	5		2		2	
Water		1	1	7	1			1	1	2	2		3	
	HEAT MAP													
	>9	high												
	4-9	medium												
	0-3	low												

On the other hand, Table 2 shows the “heat map” of the number of references found in the literature searches for technologies with respect to processes. It shows a particular concentration of references for machine learning, data processing, expert systems and object and spatial recognition. Likewise, the least references are found for data protection and natural language processing, for example. As mentioned for Table 1, the search results may be biases by keyword selection and focus (for example, there may be in practise much more activity in data protection but it is not reflected in published references).

Table 2. “Heat map” processes vs technologies.

	Data understanding and characterization	Natural language processing	Object and spatial recognition	Machine learning	Intelligent planning	Expert systems	Case based reasoning	Intelligent agents	Cyber-physical systems	Data visualization	data processing	data protection	Data manage-ment	Computing and storage infrastructure
(Model predictive) process control and optimization	2	1	10	25	7	11	5	1	8	4	12		6	3
Market trends and open innovation	4	2		5				1					1	1
Predictive maintenance		2	2	5		2	2	2	5				1	1
Product design/custom		3	1	10		4	2		4	2	2		3	
Research and innovation management, planning and design	5			8	1			1		1	2	1	7	2
Supply chain management (re) configuring and scheduling		4		6	2	2	1	5	3	1		1	2	1
	HEAT MAP													
	>9	high												
	4-9	medium												
	0-3	low												

Figure 5 shows the histogram of frequency of AI technology references found in the literature (last 5 years). Machine learning is clearly the top category, followed by cyber-physical systems and object and spatial recognition. The categories with least references are intelligent agents and case based reasoning.

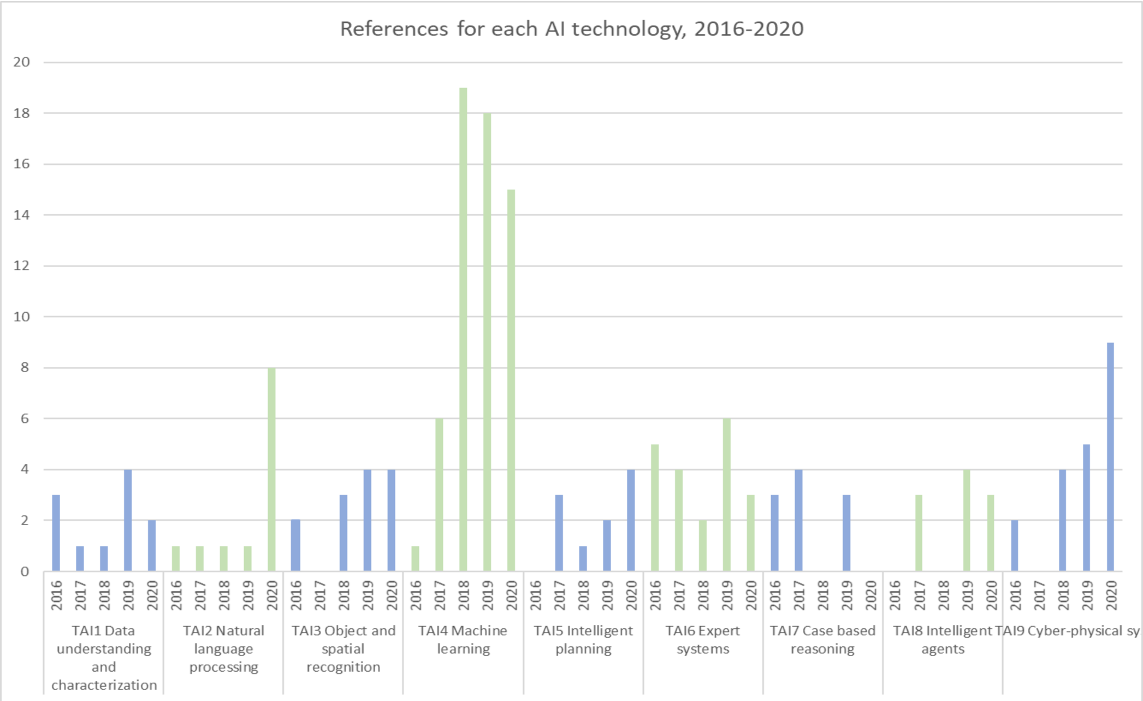

Figure 5. Literature references found per AI technology: 2016-2020

Figure 6 shows the histogram of frequency of BD technology references found in the literature (last 5 years). The top categories are data management and data processing, whereas the bottom category is data protection.

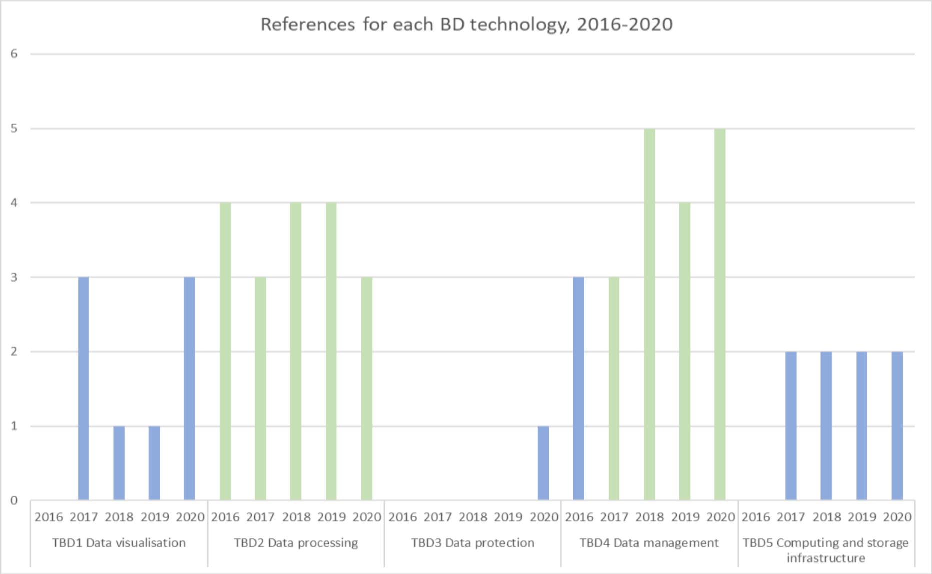

Figure 6. Literature references found per BD technology: 2016-2020

6. REVIEW OF THE CUBE PROCESS DIMENSION

In the following we will start with an introduction to the "process" dimension, followed by a "glossary" or more specific description of what it includes. In summary:

- We explain what we mean by "processes", how we chose and evaluated the processes in D1.2, which are the processes that were included.
- Summary of the results obtained in D1.2
- Outline of the specific processes that will be included in the CUBE dimension, and which ones will not and why.

Definition of "processes"

A process is defined as a major activity by a company as part of its value chain. They can be considered in chronological order, from the initial abstract conception of an industry, through to its physical processing and its distribution to consumers. Hence, in this scheme, we could consider product design/research and innovation as the first step, followed by marketing to consolidate a customer base to make the business viable, then process control applied to the core "production" activity, maintenance to keep the production infrastructure up and running, supply chain to get the product to the consumers, and again research/innovation to review the value chain and loop back as necessary to product design. In the process industries, "product" is a very generic term and makes sense when referring to, for example, "iron ore" (mining), "drinking water" (water), and so on. **So it would appear that conceptually, with our chosen process categories, we are covering the whole value chain for the process industries. We also note that the choice of processes takes into account their relevance for the use and application of digital technologies.**

Definition of sub-classes for processes

Different studies have proposed classifications for business processes and the value chain. For example, Chen et al. (2015), defined the technology–organization–environment (TOE) framework to map big data analytics usage of organizations. On the other hand, Hau et al. (2018), mapped the value chain onto AI technologies and adoption levels. Also, the review by Toorajipour et al. (2021) mapped the supply chain subfields onto AI technologies. These and other publications have provided input to define the subclasses which are listed in Table 3 for each main process category.

In the following, we have defined a set of (level 1) processes, supported by the literature searches and analysis completed in D1.1 and D1.2. However, we think it is also important to keep an open mind and flexibility for future WPs 2 to 4, so that if necessary, the current processes can be updated and/or adapted to the new, more detailed information from the interactions with industry stakeholders, workshops and surveys. Also, in Table 3 we show a second level taxonomy where the main process category (first column) has a higher level of abstraction, and the subprocesses (second column) are aligned with the main processes of the current categories we have defined and used in D1.1 and D1.2.

Table 3 – Mapping of main process categories to sub-processes

PROCESS	SUB-PROCESS
Market trends and Open Innovation	Sales
	Customer Relationship Management
	Consumer Behaviour Analysis
	Market Scenario Analysis
	Demand Management and Forecasting
Product customization/design	Product/Service Design and Customization
	New Product/Service Introduction
	Design
Predictive maintenance	Predictive Maintenance
Supply chain management	Procurement
	Production
	Storage
	Distribution
	Reverse Logistics
	Network Design
	Logistics Systems (replenishment/distribution) design
	Supplier Relationship Management
	Contract Management
	Sourcing Analysis
	Resource allocation/utilization and scheduling
	Process Redesign
Process control and optimization	Process and Equipment Monitoring
	Quality control and monitoring
	Process Redesign
Research and innovation management, planning and design	Scenario Based Analysis: Optimization/Simulation
	HR Management
	Risk Management
	Collaborative/Joint Innovation Platform Development
	Process Redesign

To finalize the main categories, we have added some additional information to “predictive maintenance” to include other maintenance and data driven related services. To “product customization” we have added “design”, and we have simplified the title of the category “Process control and optimization”.

6.1 GLOSSARY OF THE PROCESS CATEGORIES

The following definitions provide the glossary for the Process categories which make reference to the mappings given in Table 3.

Market trends and Open Innovation – A company must have an awareness of market trends in order to adapt their products/services to future demands and customers. This requires obtaining information (strategic and tactical) and data from internal and external sources which needs to be then interpreted in a usable / actionable manner. *For example, a chemical manufacturer must be aware of the evolution and innovations occurring in the chemical industry, and in the finished products, such as recyclability.* Open innovation is closely related to market trends as it deals with using key information from both within a company and beyond the individual organization. Tapping into knowledge and assets available from other companies, along with any other relevant data, aims at improving internal innovation that will lead to external innovations in line and synchronized with the market evolution. On the one hand, external data is brought into companies to be utilized and innovated upon, and on the other hand, internal technology, know-how or data goes out to other companies to be improved. **In terms of the potential for applying new technologies, it is clear that marketing data analysis and trend identification is a key aspect of data exploration and modelling.** With reference to Table 3, the sub-processes included in the macro area of "Market trends and Open Innovation" that would benefit from the application of AI&BD are: Sales, Customer Relationship Management, Consumer Behaviour Analysis, Market Scenario Analysis, Demand Management and Forecasting.

Product design/customization – product design is the basic activity of conceptualizing, creating, and evolving products that solve a customer's/user's problems or address specific needs in a given market. To be successful it requires an understanding of the end-user customer, the person for whom the product is being created. Product customization is closely related to design, and can be defined as "producing in response to a particular customer's desires." It is relevant to make the distinction between variety and customization – the objective of the latter is to fulfil individual customer's needs, whereas variety refers to offering a wider choice from which the customer is able to choose. Hence, customization is intended to add increased customer perceived value to a product. *For example, a ceramics producer will have different production lines for different types of product: industrial/construction use (e.g. earthenware, stoneware, tiles) or domestic use (e.g. porcelain, pottery), and so on.* **In terms of the potential for applying new technologies, it is clear that digital design tools can potentiate creativity and finding innovative and competitive products.** With reference to Table 3, the sub-processes included in the macro area of "Product design/customization" that would benefit from the application of AI&BD are: Product/Service Design and Customization, New Product/Service Introduction, Design. The original macro-area was originally defined as "product customization" and after the literature review we identified the importance of "product design" so this was added to the name.

Predictive maintenance – consists of a series of actions and techniques which are applied to detect possible failures and defects of machinery in the early stages, to prevent these failures causing major failures and stoppages at a later date. This will have as objective to maintain a certain level of service in the given process industry. Typically this requires the capture of a lot of data from sensors of the machines (temperature, pressure, vibration, wear indicators, etc.) as well as information from periodic reports and planned maintenance (e.g. replacement times indicated by manufacturers guidelines). **In terms of the potential for applying new technologies, it is**

clearly a key potential field for big data processing and data modelling of data from the sensors and other data/information. *For example, smart infra-red sensors can identify over-heating of components of machinery which would not be discernible to the human eye.* With reference to Table 3, the macro area of “predictive maintenance” has just one sub-process (for application of AI&BD) with the same name. Although this macro-area could be considered a type of technology/technique, it is also more importantly present as a process and activity in all industry sectors.

Supply chain management (re)configuring and scheduling - supply chain management is the process of planning, executing and controlling the operations of the supply network with the purpose of meeting customer needs as effectively as possible. Complex requirements, deadlines and restrictions are often conflicting/overlapping, **hence data models and intelligent planning can help to find optimum configurations which obtain an equilibrium between different prioritized (e.g. time) requirements and commitments.** *An example requiring complex rescheduling would be in the case of industrial symbiosis, i.e., the circular economy, in which wastes or by-products of an industry or industrial process become the raw materials for another.* With reference to Table 3, the sub-processes included in the macro area of “Supply chain management (re)configuring and scheduling” that would benefit from the application of AI&BD are: Procurement, Production, Storage, Distribution, Reverse Logistics, Network Design, Logistics Systems (replenishment/distribution) design, Supplier Relationship Management, Contract Management, Sourcing Analysis, Resource allocation/utilization and scheduling, Process Redesign.

Process control and optimization - is the discipline of adjusting a process to maintain or optimize a specified set of parameters without violating process constraints. Different control loops are responsible for controlling different parts of the process, such as maintaining a temperature, level, or flow. This requires real-time sensors which generate data which is analysed in real time. *For example, a viscosity sensor will monitor a dissolution process to detect when the next phase can begin. Then a data model will predict the viscosity trend curve under equal conditions at a given time step during the process.* Other applications are, for example, yield and accuracy enhancement. **Digital twins are a solution for modelling and simulating complex processes, thus avoiding expensive trial and error calibration, for example.** With reference to Table 3, the sub-processes included in the macro area of “Process control and optimization” that would benefit from the application of AI&BD are: Process and Equipment Monitoring, Quality control and monitoring, Process Redesign.

Research and innovation management, planning and design – is defined as making sure the necessary resources (human, physical, and financial) are in place and are effective for a required research and innovation plan and requirements. Hence the first step is to define what is the research and innovation (scientific/industrial) to be done, and this will require evaluating complex information from different sources, including awareness of the leading edge and best practises for a given discipline, sector, process, product or service. This will typically result in a medium to long term investment. **Hence many of the digital technologies can play a role here, such as data management, intelligent planning, data visualization, cyber-physical systems, data understanding and characterization, natural language processing, and so on.** With reference to Table 3, the sub-processes included in the macro area of “Research and innovation management, planning and design” that would benefit from the application of AI&BD are: Scenario Based Analysis: Optimization/Simulation, HR Management, Risk Management, Collaborative/Joint

Innovation Platform Development, Process Redesign. Note that “research” is considered as “applied research”. Also, “planning research” is differentiated from “logistics planning” and “design research” is differentiated from “product design”.

6.2 SUMMARY OF THE RESULTS OBTAINED IN D1.1/1.2

Table 4 shows the “heat map” of the number of references found in the literature searches for processes with respect to technologies. It can be seen that the “hot” process category is process control with a strong concentration in five sectors and a lesser frequency for cement, engineering and non-ferrous metals.

Table 4. “Heat map” processes vs technologies.

	Market trends and open innovation	Product design / customization	Predictive maintenance	Supply chain management (re) configuring and scheduling	(Model predictive) process control and optimization	Research and innovation management, planning and design
Cement		5		1	8	
Ceramics		2		2	17	2
Chemicals	7			2	13	7
Engineering	4	12	10	10	6	3
Minerals	3	1	4	3	19	8
Non ferrous metals		4		1	9	2
Steel		7	8	6	13	
Water				3	10	6
	HEAT MAP					
	>9	high				
	4-9	medium				
	0-3	low				

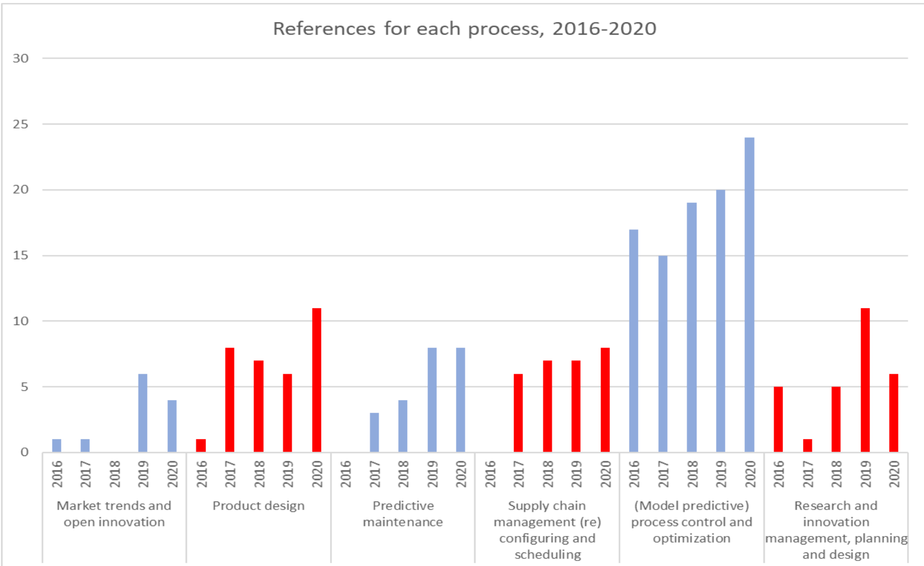

Figure 7. AI and BD literature references found per process: 2016-2020

Please refer to D1.1, Sections 5 and 6 for comments and evaluation of the "International" references vs the EU references.

Figure 7 shows the histogram of frequency of AI and BD technology references found in the literature (last 5 years) per process. The top categories are process control, supply chain and product design, though predictive maintenance has risen significatively in the last 2 years. The category with least references is "market trends". Table 5 shows a summary by CUBE sectors and processes, of related needs and challenges, together with the potential AI/BD applications which are considered applicable. Table 5 was also included and discussed in detail in D1.2 and is shown here for easy reference.

Table 5 – Summary by (CUBE) sectors and processes, issues and potential AI/BD applications

Sector	Process	Needs/Challenges	Corresponding AI/BD technologies
Water	(Model predictive) process control and optimization Predictive maintenance Research and innovation management, planning and design	Needs: waste water processing, clean water processing. Challenges: complex processing chain, large processing volumes, yield.	Machine learning, Data understanding and characterization, Expert systems, Cyber-physical systems.
Steel	(Model predictive) process control and optimization Supply Chain Management	Needs: efficient furnace operation and smelting. Challenges: High energy consumption, risk to humans, quality control, logistics, Value Chain.	Machine learning, Cyber-physical systems, Intelligent planning.
Minerals	(Model predictive) process control and optimization Predictive maintenance	Needs: efficient milling of raw material, mining/extraction, scheduling/planning, security, automation, remote monitoring. Challenges: high energy consumption, security and human safety,	Machine learning, Data understanding and characterization, Intelligent planning, Cyber-physical systems (SLAM Self Driving Vehicles)
Non-ferrous metals	(Model predictive) process control and optimization Predictive maintenance	Needs: furnace, smelting, scrap quality control, logistics. Challenges: high energy consumption, risk to humans,	Machine learning, case based reasoning, Cyber-physical systems

Engineering	(Model predictive) process control and optimization Predictive maintenance Supply Chain Management	Needs: quality assurance, predictive maintenance, sensor data capture. Challenges: fault detection, data quality.	Machine learning, Data understanding and characterization, Cyber-physical systems, Object and spatial recognition, Intelligent planning.
Chemicals	Supply chain management (re)configuring and scheduling (Model predictive) process control and optimization Research and innovation management, planning and design Supply Chain Management	Needs: optimum conversion of materials. reliability, production planning, continuous sensor-based monitoring process control logistics, goods shipments tracking. Challenges: waste avoidance, process complexity.	Machine learning, Data understanding and characterization, Intelligent planning, Expert systems, Cyber-physical systems.
Ceramics	Product customization/design Supply chain management (re)configuring and scheduling Model predictive) process control and optimization Research and innovation management, planning and design	Needs: optimum raw material processing, firing, finishing. Challenges: high energy consumption, reduction of defects (cracking/foaming)	Machine learning, Data understanding and characterization, Intelligent planning.

Cement	Predictive maintenance (Model predictive) process control and optimization Product design Research and innovation management, planning and design Supply chain management	Needs: optimization of kiln, firing, material processing, predictive maintenance, predict process behavior, supply chain, remote operation. Challenges: high energy consumption,	Machine learning, Data understanding and characterization, Intelligent planning, Cyber-physical systems.

7. THE CUBE FRAMEWORK

Figure 8 shows the result of our CUBE framework (using as a basis the preliminary one defined in the proposal DoA). There are 6 processes and 14 technology categories (9 for Artificial Intelligence and 5 for Big Data). The SPIRE sectors have of course been maintained as constant. As mentioned in the last part of Section 6 of this document, we will keep flexibility towards any possible updates as WP2 to 4 progress and new information becomes available from interaction with Stakeholders and the Expert group.

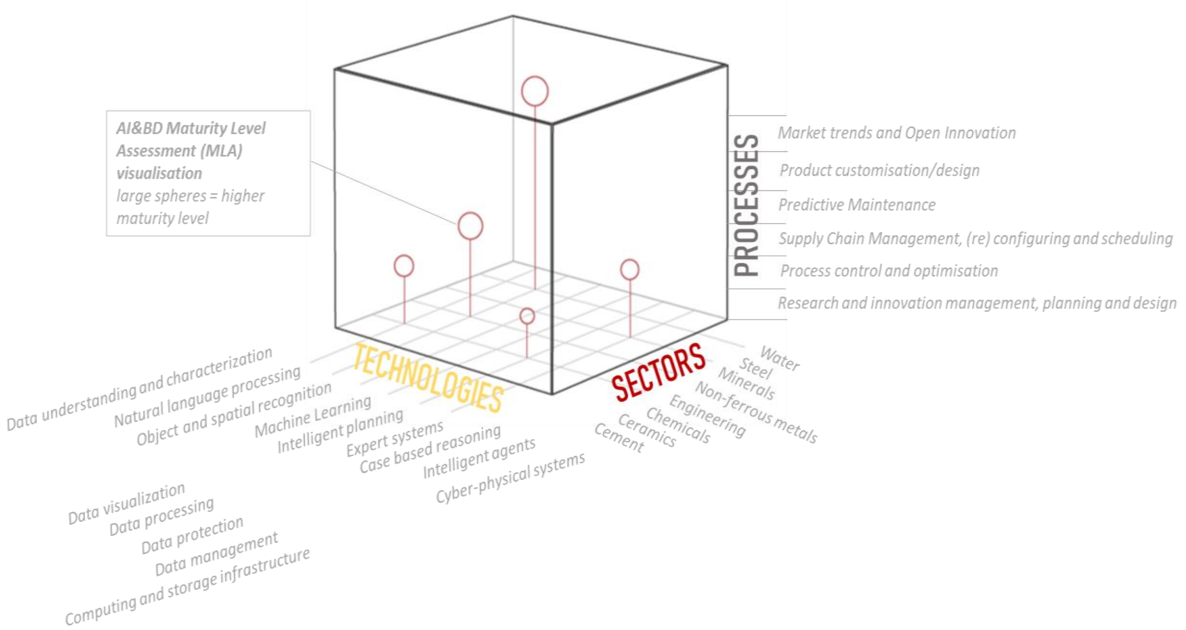

Figure 8. The CUBE framework.

The literature searches resulted from the collaborative work of different people, exploring different sectors/technologies/process. In order to mitigate the risks related to potential biases and multiple researchers, common search terms and criteria were discussed and agreed upon. As well as identifying under-represented categories, we have also identified potential "overload" of others, such as technology machine learning. This could imply we need to subcategorize this further (e.g. only data driven, data driven + a priori knowledge, supervised, unsupervised, deep learning, ...). This could also be a consequence of authors (of the references themselves) using machine learning as a generic “catch all” term with a certain lack of rigor. However, overall, the latest heat maps seem to be quite informative and make sense, though we can identify a few possible inconsistencies which may be due to the information capture technique.

Another issue is that the progressive adoption of AI/BD has different key drivers in the industry eco-system. There is also the very important inertia driven by the interests of the Information Technology industry to push new hardware and software. Key players include large IT companies and consortiums which are closest to industry (such as IBM, Palantir, Siemens, Hewlett Packard, Datalogic, Fujitsu, Samsung, ...) as well as the Telecommunications Industry which is now building AI functionalities into its real time network infrastructures (e.g. load balancing, re-routing, cryptography, data compression, ...). These major players co-exist with smaller specialized AI/BD firms and consultancies, which may be industry (e.g. Mining - Outotec) or process specific (e.g. predictive maintenance and process control - IRIS, Diribet). Also, the computer hardware industry is a key driven lead by Intel, ARM, and Nvidia, among others, to process specialized chips and solutions (e.g. for SLAM technology for self-driving and autonomous vehicles) and GPUs, which are currently driving the Blockchain and Crypto-currency movements.

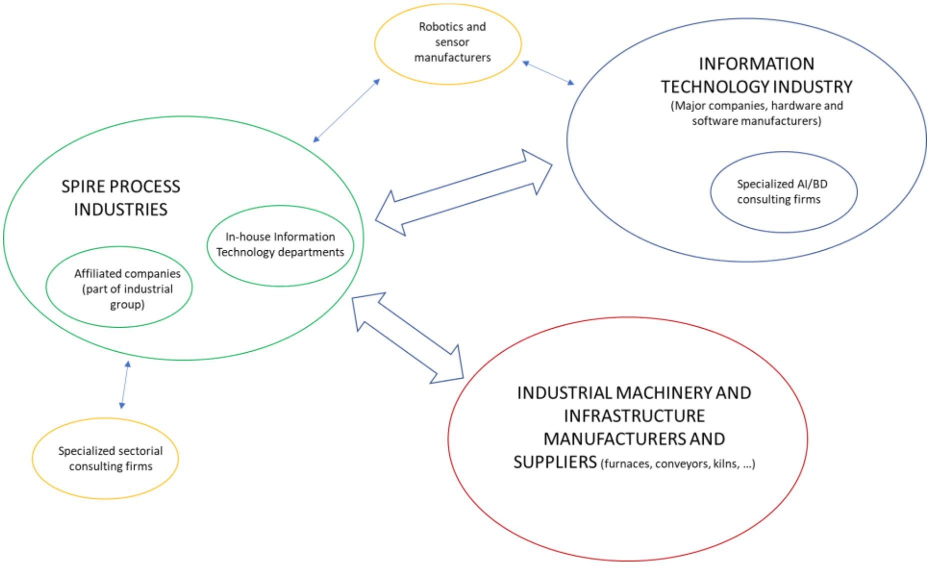

Figure 9. Proposal for process industries/technology Ecosystem - inter-relations and dependencies between different players

Hence, we can expect an evolution of the AI deployment and support eco-system where big players in the process industries form alliances with big technology companies and consortiums. This will create a framework for smaller companies (both from process industries and technology companies) to find niche areas as the market expands. The CUBE (Figure 8) will be linked and useful to define the ecosystem of Figure 9 by the future classification of stakeholders into the different types of players who are identified, such as SPIRE process core industry company, affiliated company, specialized sectorial companies, specialized information technology companies, and so on. Hence, companies can be specialized and classified by the CUBE dimensions: sector, process and technology.

8. IMPLICATIONS FOR THE PROJECT: WP 2 AND 3

Relations and implications for WP2

The framework described and finalised in this deliverable is an important basis for the planned tasks in Work Package 2 of the AI-CUBE project. In Task 2.2, the definition of the levels for the maturity models are based on the three dimensions identified in WP1. The glossary defined in D1.3 will be the basis for introduction to the three dimensions when introducing the questionnaire to companies. Also the activities in T2.3 related to the impact evaluation will take into consideration the three dimensions for the MAMCA approach.

Relations and implications for WP3

The framework described and finalised in this deliverable is an important basis for the planned tasks in Work Package 3 of the AI-CUBE project. In Task 3.1, all identified and currently deployed technologies from the fields of artificial intelligence and big data will be mapped into the AI-CUBE based on the three developed dimensions and sub-classifications from this deliverable. The fourth indicator, describing the maturity level, is additionally determined for each entry in each sector and for each process. This Maturity Levels are formed following the Maturity Level Model designed in Work Package 2.

Based on this detailed representation of the current maturity levels, a more in-depth cross-sector and cross-process comparison can be carried out in order to identify gaps and transfer possibilities. This cross-comparison task will be executed in Task 3.2. Through an increased stakeholder involvement, the results from the literature reviews in work package one can be supplemented with practical reports in order to archive the most complete scope possible. The cross-comparison will be carried out by comparing the AI and BD technology use in all sectors and processes from this deliverable, considering the number, the implemented technology and the maturity level of the different entries.

These two Subtasks of Work Package 3 are strongly linked to the findings of Work Package 1 and this deliverable D1.3. Especially the Mapping and Clustering of technologies and the identification of existing gaps and transfer possibilities require distinct and well delineated categories. The additional tasks from work package three further develop the key findings from these tasks.

Further comments and implications

In this document we have obtained and confirmed the definition of the CUBE framework dimensions (technologies and processes), supported by detailed literature searches and analysis reported in deliverables D1.1 and D1.2. As mentioned in the introduction, recently new sectors have been added by SPIRE as industrial process sectors (“paper & pulp” and “refineries”). However, as this has occurred posterior to the work on deliverables D1.1 and D1.2 and was not in the original scope of the project, they have not been studied in detail as for the existing 8 sectors. However, we may investigate later (in WP2 and WP3) how to take these sectors into consideration.

As described in the methodological sections of D1.1 and D1.2, as well as in the task definitions of the DoA, the key approach for WP1 in order to obtain information about the “state of play” of the use of AI and BD in the process industries has been through literature searches. However, information was also obtained from real stakeholders and project results in the first stakeholder workshop held in February 2021. It is expected that WP2 and WP3 will incorporate more "real world" experience and information such as this.

The literature search may not have revealed the details of the ecosystem of AI and BD solution providers in our technology, and process area mapping. For this reason, in WP2 and WP3, through the involvement of Consortium's industry contacts, we will add further and more specific knowledge and information on where and how AI and BD technologies are currently developed/deployed together with process industries and in which process macro areas. Hence, we would say that in the next iteration of the CUBE (WP2 and WP3), there will be a need to define maturity levels and spot where AI and BD have the highest potential.

9. REFERENCES

- Chen, D.Q, Preston, D.S. & Swink, M (2015) How the Use of Big Data Analytics Affects Value Creation in Supply Chain Management, Journal of Management Information Systems, 32:4, 4-39, DOI: 10.1080/07421222.2015.1138364. (https://www.tandfonline.com/doi/abs/10.1080/07421222.2015.1138364?journalCode=mmis20)

- Hau L. Lee, Haim Mendelson, Sonali Rammohan, Lauren Blake. Value Chain Innovation: The Promise of AI. Standford Value Chain Innovation Initiative. White Paper - October 2018. (https://www.gsb.stanford.edu/faculty-research/publications/value-chain-innovation-promise-ai)

- Toorajipour, R., Sohrabpour, V., Nazarpour, A., Oghazi, P., & Fischl, M. (2021). Review of Artificial intelligence in supply chain management : A systematic literature review. Journal of Business Research, 122, 502–517. (https://doi.org/10.1016/j.jbusres.2020.09.009. (https://www.sciencedirect.com/science/article/pii/S014829632030583X)