Z - B R E 4 K

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Strategies and Predictive Maintenance models wrapped around physical systems for Zero-unexpected-Breakdowns and increased operating life of Factories

Z-BRE4K

Deliverable D1.2

Z-BRE4K State-of-the-Art analysis

Work Package 1

Industrial Demonstrators Analysis & System Specifications

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Executive Summary

Abstract	From description of Work Package 1 (WP1), this deliverable D1.2 is expected to: • analyze new, existing and past projects/initiatives; • report on the introduction into the market of new products/technologies; • have a special focus on new potential opportunities and possible threats. Accordingly, this document is made of three chapters, one for each bullet point to address. • Chapter 2 provides an exhaustive overview on projects and initiatives related to Z-BRE4K, starting from exiting harmonization and supporting programs (i.e., those created by the European Commission to foster the advancement of European industry on digitalization), then focusing on other related projects that address the predictive maintenance issue for manufacturing and finally discussing on diverse IoT initiatives that may nevertheless be of interest for Z-BRE4K (i.e., for the overall approach they propose or the particular technology developed); • Chapter 3 investigates related products, technologies and services already available in the market: in this perspective, it provides a comparative survey on commercial IoT platform solutions and an outline on new products (by start-ups, companies or parallel projects). Furthermore, descriptions of real-case examples of IoT exploitation by industry give feedbacks that may guide Z-BRE4K solution's development; • Chapter 4 addresses a preliminary study (to be deepened in deliverables D7.4 and D7.8) on potential opportunities and threats for Z-BRE4K. It first introduces the tools useable to this end, then explores possible businesses and stakeholders for Z-BRE4K technology outcomes and concludes with a SWOT analysis. Furthermore, D1.2 commences with Chapter 1 that reports a useful rundown on digital manufacturing platform with sections introducing (and referring to useful reference for further insights) all the topics necessary to understand and go through the next chapters, core of the deliverable. Finally, Chapter 5 concludes the deliverable pointing out the main outcomes (collected material, suggestions, best-practices and overall considerations) of this state-of-the-art work that should constitute the lighthouse for future development of the Z-BRE4K project.
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List of Contributors

Partner	Contributors
CRIT	Riccardo Masiero, Diego Bartolomé Espinosa, Gianluca Berghella
ATLANTIS	Jovana Milenkovic, Ifigeneia Metaxa
AIMEN	Adrián Pallas, Roi Méndez
BRUNEL	Veerendra C. Angadi, Ali Mousavi
INNOVALIA	Óscar Lazaro, Alicia González, Cristina Regueiro
Fraunhofer	Nikolas Zimmermann
EPFL	Cho Sang-Je, Gökan May
IMEC	Diego Nieves Avendaño, Olivier Janssens

SUMMARY

TABLE OF ACRONYMS AND ABBREVIATIONS

ACID	Atomicity, Consistency, Isolation, Durability
ADC	Analog to Digital Converter
AI	Artificial Intelligence
AMQP	Advance Message Queuing Protocol
AMMP	Adaptive Machine Messaging Protocol
ANN	Artificial Neural Network
API	Application Programming Interface
APP	Application
AR	Augmented Reality
ARTEMIS	Advance Research & Technology for Embedded Intelligent Systems
A/V	Audio/Video
BBN	Bayesian Belief Network
BI	Business Intelligence
BT	BlueTooth
CEN	Comité Européen de Normalisation
CENELEC	Comité Européen de Normalisation en Électronique et en Électrotechnique
CIP	Common Industrial Protocol
CMMS	Computerized Maintenance Management System
COAP	Constrained Application Protocol
COMM	Communication(s)
CONN	Connection(s)
CLPA	CC-Link Partner Association
CPPS	Cyber-Physical Production System
CPS	Cyber-Physical System
CRM	Customer Relationship Manager

CUDA	Compute Unified Device Architecture
DAC	Digital to Analog Converter
DEI	Digitising European Industry
DG CONNECT	Directorate-General for Communications Networks, Content and Technology
DSM	Digital Single Market
DB	Database
DHT	Distributed Hash Table
DSI	Display Serial Interface
DSS	Decision Support System
EAM	Enterprise Asset Management
EC	European Commission
ECSO	European Cyber Security Organization
EFFRA	European Factories for the Future Research Association
EFNMS	European Federation of National Maintenance Societies
EG	Edge Gateway
ENET	Ethernet
ENSIA	European Network and Information Security Agency (former name of the agency)
ERP	Enterprise Resource Planning
ESO	European Standards Organization
ETSI	European Telecommunications Standards Institute
EU	Europe
FCM	Fuzzy C-Means
FoF	Factory of the Future
FMECA	Failure Mode, Effects and Criticality Analysis
FPGA	Field-Programmable Gate Array

GNU	GNU's Not Unix
GPIO	General Purpose Input/Output
GPU	Graphics Processing Unit
gRCP	Remote Procedure Call by Google
MES	Manufacturing Execution System
HDMI	High-Definition Multimedia Interface
HI	Health Indicator
HMAC	Keyed-Hash Message Autentication Code
HMI	Human-Machine Interface
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol over Secure Socket
HW	Hardware
H.264	alternative name for the MPEG-4 AVC (Advanced Video Codec) standard
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IDS	Industrial Data Space
IEC	International Electrotechnical Commission
IF	Interface
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Reference Architecture
IIS	Industrial Internet System
IM	Industrial Manufacturing
IMS Center	Center for Intelligent Maintenance Systems
IoT	Internet of Things
IP	Internet Protocol

IPR	Intellectual Property Rights
I²C	Inter Integrated Circuit
I²S	Integrated Interchip Sound
I4.0	Industrie 4.0
LwM2M	Lightweight Machine to Machine
JSON	JavaScript Object Notation
KPI	Key Performance Indicators
LCD	Liquid-Crystal Display
LED	Light Emitting Diode
LTI	Linear Time Invariant
LVDS	Low-Voltage Differential Signal
MCU	Microcontroller Unit
MEMS	Micro Electro-Mechanical System
MES	Manufacturing Execution System
MIPI	Mobile Industry Processor Interface
MPEG	Moving Pictures Experts Group
MPU	Microprocessor Unit
MQTT	Message Queue Telemetry Transport
M2M	Machine to Machine
ODVA	formerly Open DeviceNet Vendors Association
OEM	Original Equipment Manufacturer
OMG	Open Management Group
OPC Foundation	Object linking and embedding for Process Control Foundation
OPC-UA	OPC Unified Architecture
OpenIL	Open Industrial Linux
PCM	Pulse-Code Modulation

PdM	Predictive Maintenance
PESTEL	Political, Economic, Social, Technological, Environmental and Legal
PLC	Programmable Logic Controller
PRM	Prognostics and Resources Management
PPP	Public-Private Partnership
PROJ	Project
PWM	Pulse Width Modulation
P2P	Peer to Peer
RA	Reference Architecture
RAMI 4.0	Reference Architecture Model Industrie 4.0
REL chart	Relationship chart
REST	Representational State Transfer
RGB	Red-Green-Blue
RJ45	Registered Jack of type 45
ROM	Reduced Order Modelling
ROS	Robot Operating System
RUL	Remaining Useful Lifetime
R&D	Research and Development
R&D&I	Research, Development and Innovation
SCADA	Supervisory Control and Data Acquisition
SDK	Software Development Kit
SNMP	Simple Network Management Protocol
SOAP	Simple Object Access Protocol
SPI	Serial Peripheral Interface
SQL	Structured Query language
STD	Standard

STOMP	Streaming Text Oriented Messaging Protocol
SVM	Support Vector Machines
SWOT	Strengths, Weaknesses, Opportunities, Threats
SYS	System(s)
TBI	To Be Implemented
TCP	Transmission Control Protocol
TLS	Transport Layer Security
UART	Universal Asynchronous Receiver-Transmitter
US	United States
USB	Universal Serial Bus
VC-1	informal name for the SMPTE (Society of Motion Picture and Television Engineers) 421M standard
VHDL	VHSIC Hardware Description Language
VHSIC	Very High Speed Integrated Circuits
VM	Virtual Machine
Wi-Fi	Wireless Fidelity
XMPP	Extensible Messaging and Presence Protocol
ZDM	Zero Defect Manufacturing

1 General overview on IoT applications with a special focus on Digital Manufacturing Platform

This chapter contains useful references and summaries about technological, social and management topics that characterized Digital Manufacturing Platforms which, in turn, constitute a specialization of Internet of Things (IoT) applications.

First, Section 1.2 presents the main enabling technologies (or technical building blocks) to build such platforms: form physical components, to programming languages, protocol and interfaces, with a particular focus on data processing techniques (i.e., machine learning) that are at the core of the predictive functionalities to implement within Z-BRE4K.

Successively, in Section 1.3 an overview on platform architectures (both as models and examples) is presented whilst Section 1.4 is on cyber-security.

Sections 1.5 and 1.6 discuss delicate matters such as safety and new roles of employees due to company digitalization, which are both key-points for the good success and pervasive adoption of IoT technologies in industrial environments.

Finally, Section 1.7 addresses the standardization and interoperability issues providing useful references for full treatment of these topics.

1.1 Glossary

Digital Manufacturing Platforms are a multidisciplinary field that encompasses several topics: automation, electronics, computer science, telecommunications, economics, social science, mechanics, robotics and several others, including the specialization of each company where this technology is implemented. In detail, platforms for digital manufacturing are solutions that provide services to support, in a broad sense, manufacturing processes [1]. These services are related to the collection, storage, processing and delivering of data that describe products, machineries, assets and/or processes characterizing the manufacturing system.

In this context, a tool that collects and briefly explain all the different aspects involved in digital platforms for manufacturing is very useful, both for experts and newbies. EFFRA [2] answers to this need by providing a Structured Glossary [1] that collects business model concepts, terms of the technology building blocks (data acquisition and storage, data modelling and processing, analytics techniques, protocols, software, interfaces, architectures), a list of available standards, concepts on performance, social aspects, perspective related to the interaction of digital manufacturing with existing processing (i.e., manufacturing or product life-cycle).

The following paragraphs of this chapter do not intend to duplicate the work of EFFRA that can be used for deepening study on the topic; conversely, a self-sustained summarized overview on the technologies involved in digital manufacturing (with a focus on tools enabling predictive maintenance, i.e., machine learning) is provided. This resume will allow to have sufficient information to understand better the following chapters.

1.2 Enabling technologies

There are several technologies needed to develop a Digital Manufacturing Platform solution, and it is necessary to select among them depending on the provided manufacturing service and the required application. The services provided are mainly related to data management: relevant information must be collected, processed and transmitted between components that form a digital manufacturing platform architecture (e.g., see the RAMI 4.0 [3] model in Section 1.3). These components are of different types (PCs, embedded, PLCs…) and they have different Operating Systems, running software and communication interfaces. The technologies that enable the Digital Manufacturing Platform are divided in several groups, addressed in the following.

1.2.1 Data Management

Data is the core part of a Digital Manufacturing Platform solution because it is related to the manufacturing process and to every product manufactured enabling traceability and data analytics. The data storage, structure and management used should be standards compliant. There are two main types of data storage:

1. Databases, which in turn can be classified as:
    - Relational, where data is stored in tables which each row has a unique identification key. The data is structured following an Entity-Relation model, each table is an Entity or a Relation and can be linked with other tables adding a column with the other table id. These databases use SQL (Structured Query languages) language to manage the information. Some examples of this type of databases are MySQL [4] or PostgreSQL [5];
    - Non-Relational, that is a type of storage that does not guarantee completely ACID (Atomicity, Consistency, Isolation, Durability) but is very scalable horizontally. This type of solution is often used in big data applications.
2. Data Representation, which consists of a structured representation of data so that information not only can be transferred through the system but properly managed for processing and archiving. There are several known standards developed for such purposes as XML [6], JSON or HDF5 [7].

1.2.2 Data Processing and Data Analytics

Data acquired from manufacturing processes and manufactured products should be processed and analysed to improve future product quality and manufacturability. Data processing techniques are used over the raw data to clean and format data by removing the outliers, reducing the signal frequency or denoising it. Data Analytics is instead concerned with the elaboration and modelling of information with data mining techniques based on statistic or Machine learning.

Machine learning is a large group of techniques in which a computer is taught to solve a problem without explicit instructions of how to do so [8]. The field has been successful in solving tasks such as classification, image recognition, prediction, optimization, among others, and has been applied in many industrial and research domains such as manufacturing, healthcare, transportation, finance, and maintenance.

Research into **machine learning for predictive maintenance has resulted in new approaches for** (incipient) **fault detection, complex anomaly detection and remaining useful lifetime estimation of machine components** [9]. One of the main drivers of this research domain is the fact that data-driven machine learning techniques require minimal involvement of domain experts.

The most applied machine learning algorithms are ANNs (Artificial Neural Networks) [10] **and SVMs (Support Vector Machines)** [11].

1.2.3 Communication Protocols

The different components of Digital Manufacturing Platform solutions should communicate with each other, depending on the RAMI 4.0 layer the communication requirements are different, therefore the communication protocols should fit those requirements. Most protocols run over physical (Ethernet) or Wireless (Bluetooth, Wi-Fi…) interfaces and use TCP/IP protocols to manage the information exchange routing such as OPC-UA [12], SOAP or REST.

1.2.4 Communication Interfaces

The communication interfaces between components can be physical such as USB or RJ45 but also can be wireless such as Bluetooth or Wi-Fi. The interface selected depends on latency, bandwidth, accessibility and distance between components.

1.2.5 Operating Systems

Microsoft Windows and GNU/Linux, commonly-used operating systems in PCs, are equally used on industrial computers. The mobile devices operating system such as Android or iOS and robot operating system known as ROS [13] are used in other type of components such as tablets or robots. There are also operating systems specially designed to ease the deployment of the digital industrial platform such as OpenIL (Open Industrial Linux) [14].

1.2.6 Programming Languages

The choice of programming languages used for software development on the different components are dependent of the functional and non-functional requirements of the application and the component. There are also legacy reasons to use one language instead of another, such as interoperability with existing software and existing libraries that implement algorithms needed in the application.

Low-level-compiled languages such as C or FORTRAN are used to implement low-level functions and highly intensive computing applications because of their performance and flexibility. Languages such as CUDA or VHDL are also used in those applications where a GPU (Graphics Processing Unit) or a FPGA (Field-Programmable Gate Array) are available.

High-level languages such as Java, C#, C++ or Python are used to implement complex application behaviours and algorithms, those languages provide an extensive amount of development tools. Since C++ is a compiled language the source code should be compiled for each platform. Other languages, such as Java or C#, are compiled into an intermediate language that enables the multiplatform deployment using a virtual machine. Other languages as Python, which nowadays is the most popular programming language for Machine learning [15] and Data science, are directly interpreted by a multiplatform interpreter.

1.2.7 Physical Components

Physical components that enable the digital industrial solution are the sensors that acquire the raw process data such as cameras or thermocouples; the actuators that interact with the process such as robot arms or lasers; the control and monitor components such as PLCs or SCADA systems and also the systems that store and process the data acquired for decision-making and reconfiguring the overall system behaviour to improve performance in the near future.

1.3 Architectures

This section provides an overview of some reference architectures, which are of relevance to the Z-BREAK projects. First, three reference models are presented to discuss the levels of abstraction required according to RAMI 4.0, IIRA and OpenFog reference frameworks. Then, based on the AUTOWARE framework and FIWARE for Industry generic and specific open source modules provided therein, the section describes how a data driven architecture can be derived to support the analytic model envisioned by Z-BREAK in the implementation of the predictive maintenance operations. The model derives from the application of the layered RAMI4.0 model and the P2P model for communication on various data spaces supported by the IIRA and OpenFog reference models.

1.3.1 Reference Models

1.3.1.1 RAMI 4.0

The Reference Architectural Model for Industrie 4.0 (RAMI 4.0) [3], [16] is a generic RA addressing the manufacturing sector. As its name clearly states, it's the outcome of Platform Industrie 4.0 [17], the German public-private initiative addressing the fourth industrial revolution – i.e., merging the digital, the physical and the biological worlds into cyber-physical production systems. The expected benefits of the adoption of CPS in the factory are:

- higher quality;
- more flexibility;
- higher productivity;

- standardization in development;
- products can be launched earlier;
- continuous benchmarking and improvement;
- global competition among strong businesses;
- new labour market opportunities;
- creation of appealing jobs at the intersection of mechanical engineering, automation, and IT;
- new services and business model.

To ensure that all participants involved in discussions understand each other, RAMI 4.0 defines a 3D structure for mapping the elements of production systems in a standard way. This well-known diagram, also referred to as "a solution space with a coordinate system for Industrie 4.0" is depicted in **Figure 1.1**.

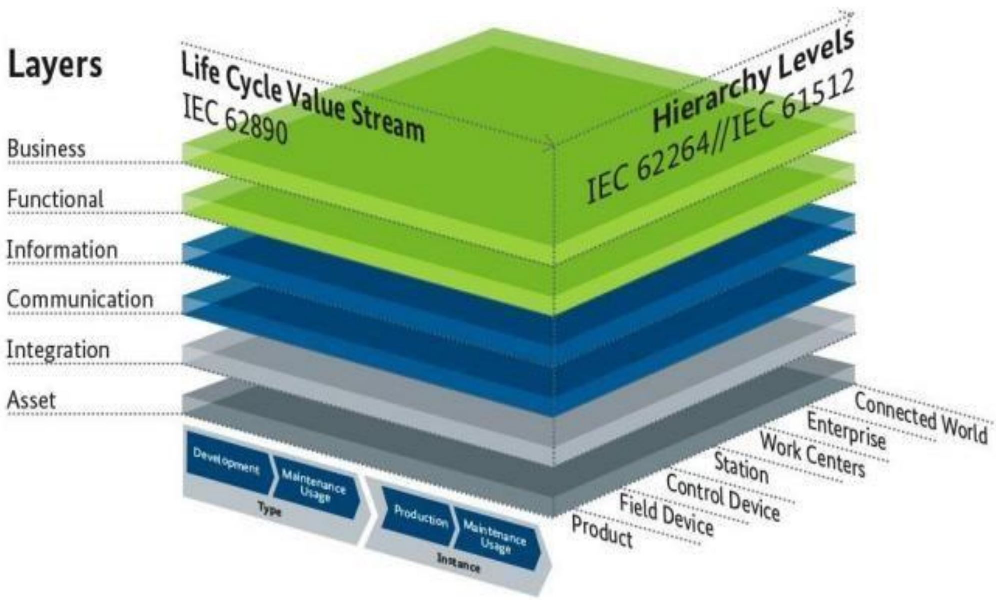
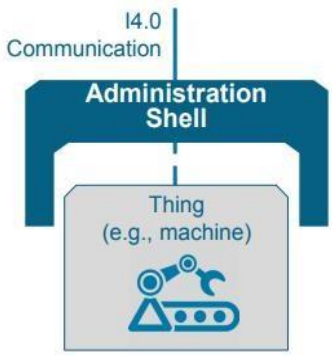


Figure 1.1 - RAMI 4.0 3D coordinate system.



RAMI 4.0 however is also a standard-setting effort. While still a work in (slow) progress, its roadmap includes the definition of a globally standardized communication architecture that should enable the plug-and-play of "Things" (i.e., field devices, connected factory tools and equipment, smart machines, etc.) into composite cyber-physical production systems. Nowadays, only the general concept of **I4.0 Component** (see figure on the right) has been defined: i.e., **any "Thing" that is wrapped inside an Administration Shell, which provides a standard interface for communication, control and management while hiding the internals of the actual physical object**. Future work will identify standard languages for the

exchange of information, define standard data and process models and include recommendations for implementation – communication protocols in the first place. With respect to the latter point, OPC-UA is central to the RAMI 4.0 strategy. It's the successor of the much popular (in Microsoft-based shop-floors) OPC machine-to-machine communication protocol for industrial automation. Unlike OPC, OPC-UA is open, royalty-free, cross-platform and supports very complex information models. I4.0 Components will be required to adopt OPC-UA as their interfacing mechanism, while also relying on several IEC standards (e.g., 62832, 61804, etc.) for information sharing.

RAMI 4.0 has gained a significant traction in Germany and it is also driving the discussion around Industry 4.0 solutions and platforms in Europe. In particular, its glossary and 3D structure for element mapping are increasingly used in sector-specific projects (in particular platform-building ones) and working groups as a common language.

1.3.1.2 Industrial Internet Reference Architecture (IIRA)

The Industrial Internet Reference Architecture (IIRA) [18] has been developed and is actively maintained by the Industrial Internet Consortium (IIC), a global community of organizations (>250 members, including IBM, Intel, Cisco, Samsung, Huawei, Microsoft, Oracle, SAP, Boeing, Siemens, Bosch and General Electric) committed to the wider and better adoption of the Internet of Things by the industry at large. The IIRA, first published in 2015 and since then evolved into version 1.8 (Jan 2017), is a standards-based architectural template and methodology for the design of Industrial Internet Systems (IIS). Being a RA, it provides an ontology of IIS and some architectural patterns, encouraging the reuse of common building blocks and promoting interoperability. It is worth noting that a collaboration between the IIC and Platform Industrie 4.0, with the purpose of harmonizing RAMI 4.0 and IIRA, has been announced [19].

IIRA has four separate but interrelated viewpoints, defined by identifying the relevant stakeholders of use cases and determining the proper framing of concerns. These viewpoints are: business, usage, functional and implementation.

- The **business viewpoint** attends to the concerns of the identification of stakeholders and their business vision, values and objectives. These concerns are of particular interest to decisionmakers, product managers and system engineers.
- The **usage viewpoint** addresses the concerns of expected system usage. It is typically represented as sequences of activities involving human or logical users that deliver its intended functionality in ultimately achieving its fundamental system capabilities.
- The **functional viewpoint** focuses on the functional components in a system, their interrelation and structure, the interfaces and interactions between them, and the relation and interactions of the system with external elements in the environment.
- The **implementation viewpoint** deals with the technologies needed to implement functional components, their communication schemes and their lifecycle procedures.

The **functional viewpoint decomposes a IIS into** functional **domains**, which are, following a bottom-up order, control, operations, information, application and business. The diagram in **Figure 1.2** shows how these are related.

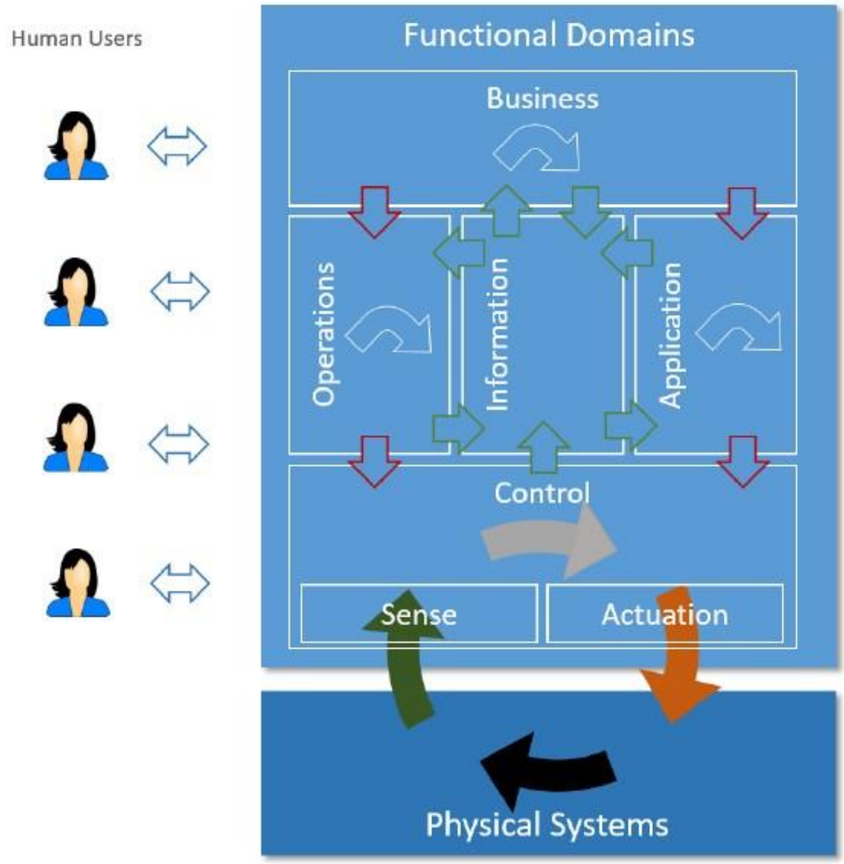


Figure 1.2 - IIRA functional domains.

The **control domain** represents functions that are performed by industrial control systems: reading data from sensors, applying rules and logic, and exercising control over the physical system through actuators. Both accuracy and resolution in timing are critical. Components implementing these functions are usually deployed in proximity to the physical systems they control and may therefore be distributed.

The **operations domain** represents the functions for the provisioning, management, monitoring and optimization of the systems in the control domain.

The **information domain** represents the functions for gathering and analyzing data to acquire high-level intelligence about the overall system. As opposed to their control domain counterparts, components implementing these functions have no timing constraints and are typically deployed in factory or corporate data centers, or even in the cloud as a service.

Overall, the functional viewpoint tells us that control, management and data flow in IIS are three separate concerns having very different non-functional requirements, so that implementation choices may also differ substantially.

The **implementation viewpoint describes** some well-**established architectural patterns for IIS**: the three-tier, the Gateway-Mediated Edge Connectivity and Management and the Layered Databus. They are of interest, as they all deal with Edge Computing – although in different ways.

The **three-tier architectural pattern** is made of three separate but connected tiers: Edge, Platform and Enterprise. Each of them plays a specific role with respect to control and data flows, as depicted in **Figure 1.3**.

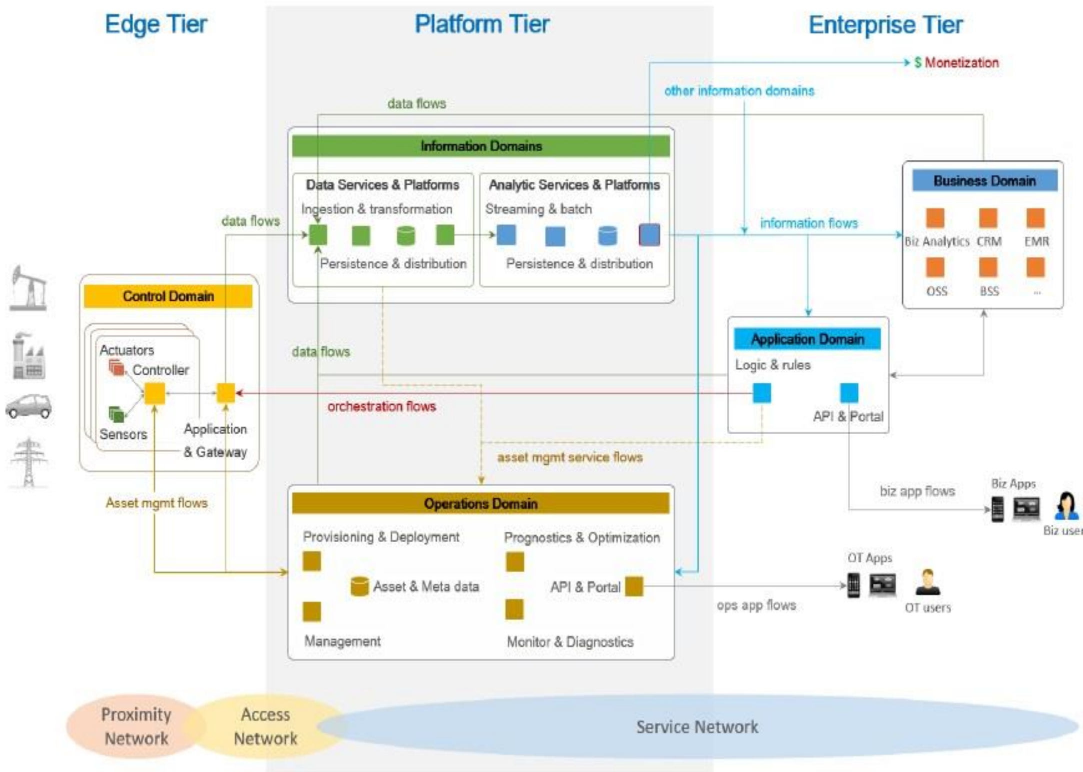


Figure 1.3 - IIRA Three-tier architectural pattern.

Consistently with the requirements stemming from the functional viewpoint, control functionality is positioned in the Edge tier – i.e., near the controlled systems – while data-related (information) and management (operations) services are part of the Platform. However, the IIRA document v1.8 also states that in real systems, some functions of the information domain may be implemented in or close to the edge tier, along with some application logic and rules to enable intelligent edge computing. Interestingly enough, though, the opposite – **Edge computing as part of Platform functionality – is not contemplated by IIRA, probably because intelligent edge nodes** (i.e., connected factory equipment with onboard computing capabilities) **are deemed to be an OEM's** (Original Equipment Manufacturer) **concern**. However, there is a component in the IIRA diagram suggesting that such boundaries may be blurred: the Gateway, which is part of the Edge tier and connects it to both the Platform and Enterprise ones.

The Edge Gateway (EG) is in fact the focus point of another IIRA architectural pattern: the **Gateway-Mediated Edge Connectivity and Management**. It **allows for localizing operations and controls (edge analytics and computing)**. Its main benefit is in breaking down the complexity of the IIS, so that it may scale up both in numbers of managed assets as well as in networking. The EG acts as an endpoint for the wide area network while isolating the individual local networks of edge nodes. It may be used as a management point for devices and as an aggregation hub where some data processing and control logic is deployed.

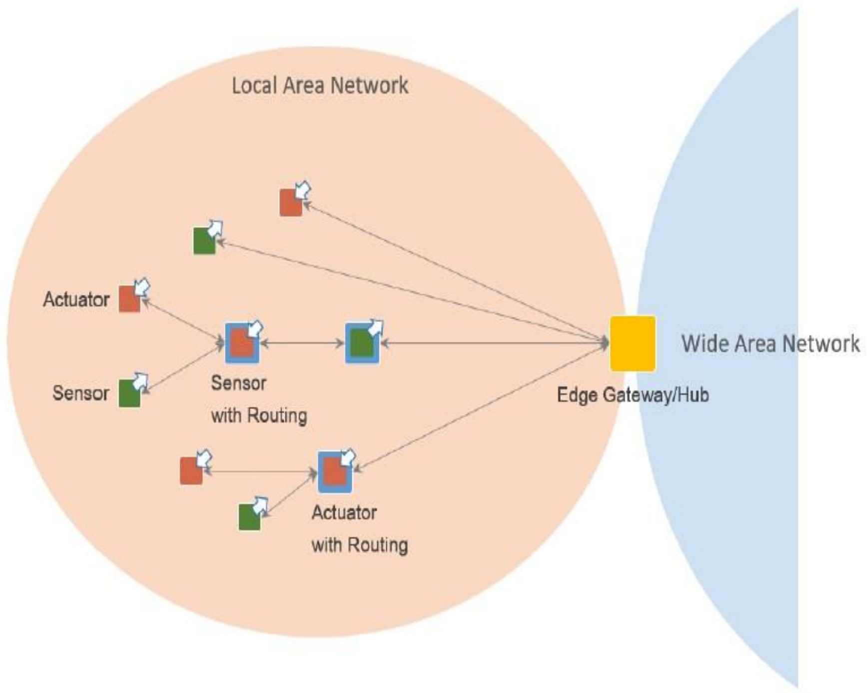


Figure 1.4 - IIRA Gateway-Mediated Edge Connectivity and Management architectural pattern.

A gap in the IIRA approach, up to this point, is the lack of such a block for addressing distributed computing – which is implied in the very notion of edge computing when used as a load-distribution technique for systems that are still centralized in their upper tiers. A partial answer to this question is given by the third and last IIRA architectural pattern: the **Layered Databus**. According to this design, a IIS can be partitioned into multiple horizontal layers that together define a hierarchy of scopes: machine, system, system of systems and internet. Within each layer, components communicate with each other in a peer-to-peer (P2P) fashion, supported by a layer-specific databus. A databus is a logical connected space that implements a common data model, allowing interoperable communications between endpoints at that layer. For instance, a databus can be deployed within a smart machine to connect its internal sensors, actuators, controls and analytics. At the system level, another databus can be used for communications between different machines. At the system of systems level, still another databus can connect together a series of systems for coordinated control, monitoring and analysis.

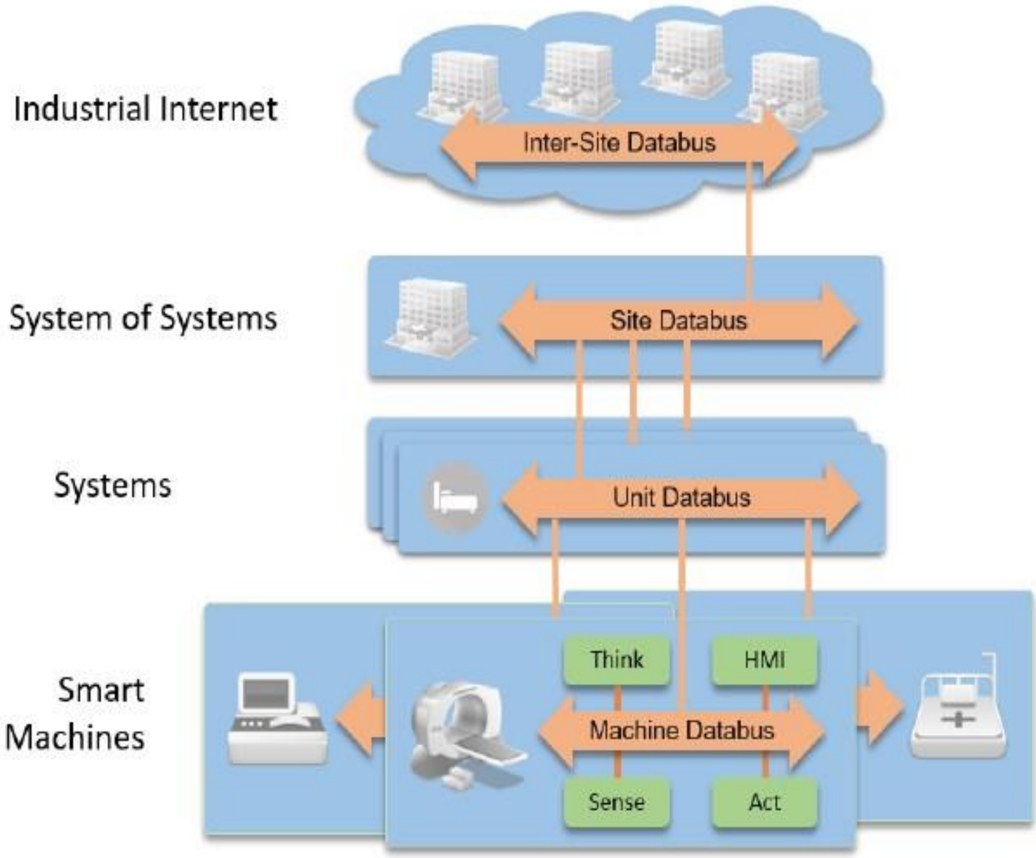


Figure 1.5 - IIRA Layered Databus architectural pattern.

1.3.1.3 Open Fog Reference Architecture

The OpenFog Consortium [20] is a public-private initiative, which was born in 2015 and shares similarities to the IIC: both consortia share big players like IBM, Microsoft, Intel and Cisco as their founding members, both of them use the ISO/IEC/IEEE 42010:2011 international standard [21] for communicating architecture descriptions to stakeholders. However, the OpenFog initiative is not constrained to any specific sector: it's a technology-oriented ecosystem that fosters the adoption of fog computing to solve the bandwidth, latency and communications challenges of IoT, AI, robotics and other advanced concepts in the digitized world. Fog computing is a term first introduced by Cisco and is basically a synonym for edge computing[1]: both refer to the practice of moving computing and/or storage services towards the edge nodes of a networked system.

[1] The terms convey the concept of cloud computing moved at the ground level.

The OpenFog RA was first released at the beginning of 2017, and as such it is the most recent contribution to the mainstream world of IoT-related architectures. The technical paper which describes it [22] is quite rich in content. **As in IIRA, viewpoints are used to frame similar concerns, which in OpenFog RA are restricted to functional and deployment** (the latter being roughly equivalent of IIRA's implementation viewpoint). However, these topics are not discussed in much detail. In particular, the functional viewpoint is nothing more than a placeholder (for example, "use cases"), while the deployment viewpoint just skims the surface, introducing the concept of multi-tier systems. With respect to this, however, a very interesting example is made which shows how the OpenFog approach to deployment is close to IIRA's Layered Databus pattern: as **Figure 1.6** demonstrates, OpenFog is realized into a hierarchy of layers where nodes on the same level can interact with each other – in what is called "east-west communication" – without the mediation of higher-level entities. The layers themselves, although more relevant to a smart-city context, are quite consistent with the IIRA ones. The means by which P2P communication should be implemented are not specified (no databus, in this case).

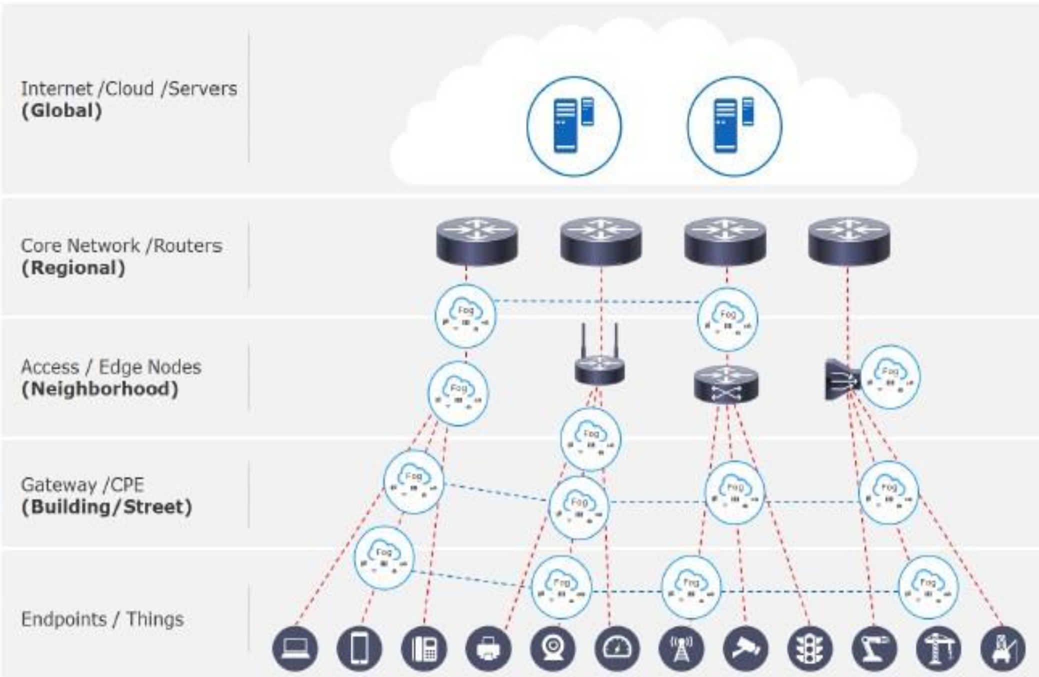


Figure 1.6 - OpenFog RA east-west communication.

Besides viewpoints, two additional kinds of frames are used to organize concepts: **views and perspectives**. The former includes aspects (i.e., node, system and software) that have a clear positioning in the structure of a system, and are further articulated into sub-aspects (e.g., the node view includes security, management, network, accelerators, compute, storage, protocol abstraction and sensors/actuators); the latter deal with cross-cutting concepts (e.g., performance, security, etc.). The big picture of the OpenFog RA, with its views and perspectives, is given in **Figure 1.7**. It must be said that sometimes the boundaries of concerns addressed by each view/perspective seem to overlap, and there appear to be also some inconsistencies in the document.

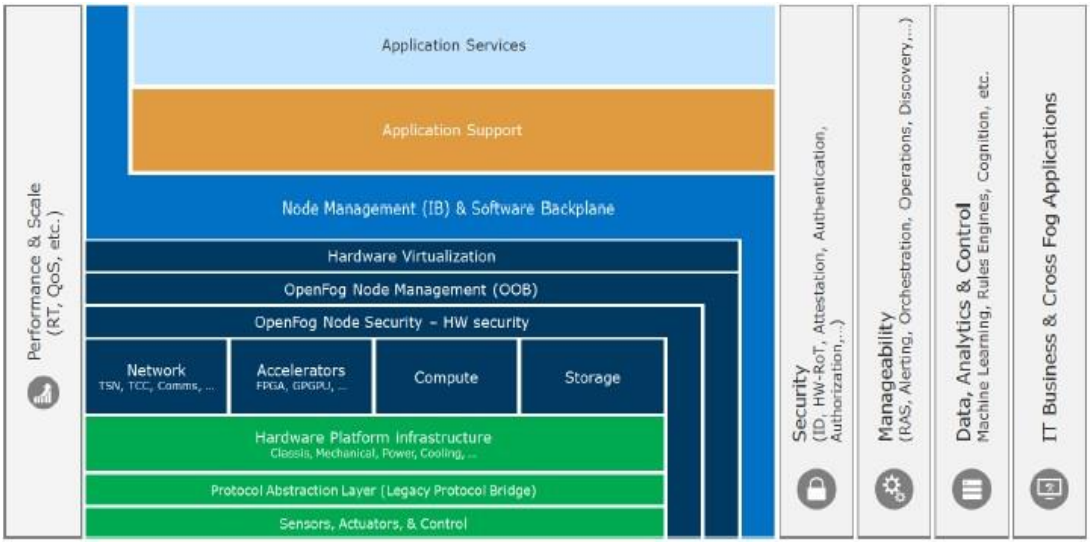


Figure 1.7 - OpenFog RA overall view.

Overall, the OpenFog RA gives the impression of being a highly theoretical and ambitious exercise, with the main goal of creating a universal conceptual framework that is at the same time generic, comprehensive and detailed. The mapping of a large scale, complex and critical use case, as provided in the reference OpenFog document, is impressive, but this comes as no surprise because that was obviously the case study on which the RA itself was fine tuned. The reverse path – designing a new system using OpenFog RA as the blueprint – appears to be a daunting task, in particular in industrial scenarios where a very pragmatic approach is the norm.

1.3.2 Examples of Architectures

The ICT reference architecture underlying the platform is a data-oriented interpretation of the Industrial Internet Consortium Reference Architecture [18], which is now aligned with the RAMI 4.0 of Platform Industrie 4.0 through the recent Architecture Alignment and Interoperability white paper [23].

Data is the oil for Industry 4.0, enabling Smart Products, Smart Manufacturing and Smart Business Models. A data-driven reference architecture poses data at the center and applications running around them (on the contrary of an Object-Oriented architecture), allowing for instance highly distributed low-latency edge/fog solutions where smart thin applications go towards huge amount of data, which remain in the domain of the provider, and not vice-versa like in traditional cloud architectures.

In **the FIWARE Foundation community**, there is an effort leading a working group **to define FIWARE for INDUSTRY Data in Motion (Industrial IoT) and Data at Rest (Industrial Analytics) reference architecture**, which is at the basis of any advanced modelling and simulation facility as well as of any one-stop-shop marketplace. This is **of**

fundamental importance for the implementation of predictive maintenance applications and services.

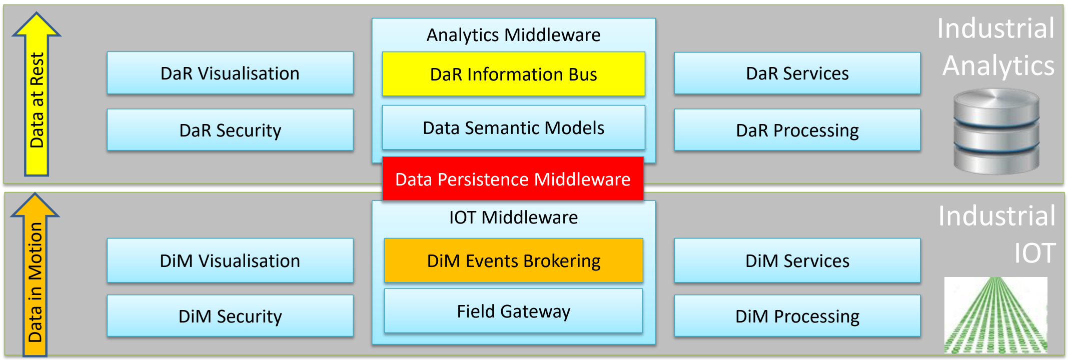


Figure 1.8 - FIWARE for INDUSTRY Reference Architecture.

In the case of Z-BREAK, Smart Factory **Data in Motion** CPS equipment (Industrial Shop-floor of advanced manufacturing equipment) **is simulated by advanced and configurable Data Emulators following OPC-UA and implementing** the most diffuse Industrial IoT protocols such as **MQTT, LwM2M and AMQP** in a layered databuses architecture (Machine Databus, Unit Databus, Site Databus). This is **in full alignment with** the AUTOWARE and IDS reference architecture and in more general terms with **the Digital Shop-floor Alliance initiative, which AUTOWARE belongs to**.

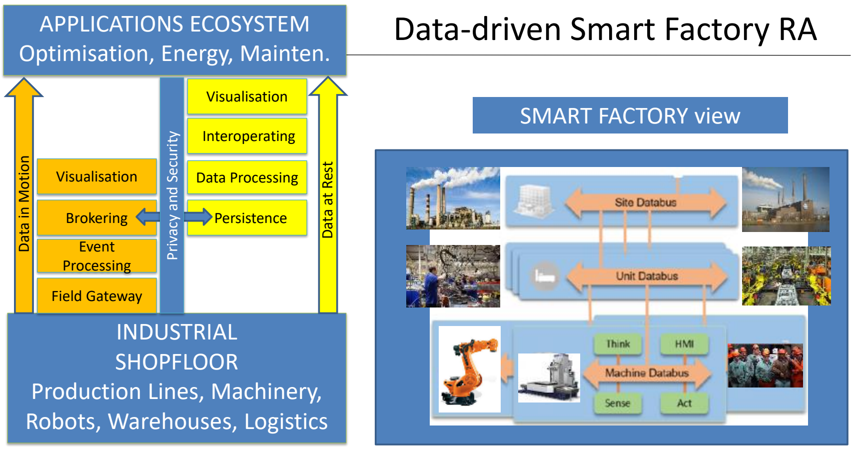


Figure 1.9 - Data-Driven Smart Factory Reference Architecture.

Secure Inter-site Databuses have to be implemented in order to allow the exchange of input data and simulation results between equipment manufacturers and users (being them system integrators or manufacturing companies).

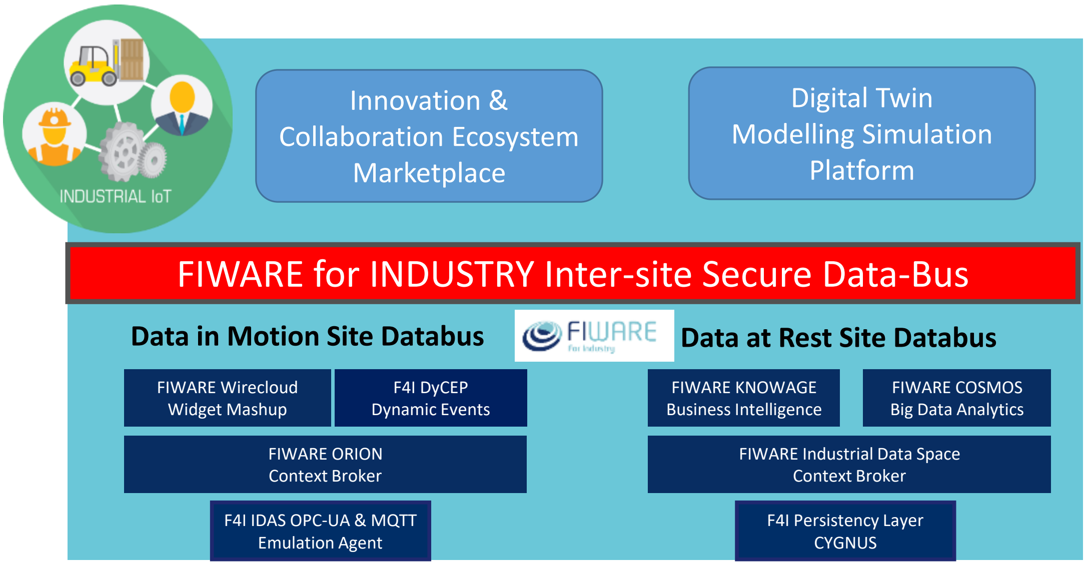


Figure 1.10 - Inter-site Data-bus.

The F4I Industrial Analytics Platform is implemented by 4+4 main enablers implementing Data in Motion and Data at Rest site Databuses. A full open source implementation of this reference architecture could be implemented with application of FIWARE Components:

- **FIWARE Wirecloud Widget Mashup**: Wirecloud offers an end-user centered web application mashup platform aimed at leveraging the long tail of the Internet of Services, allowing end users without programming skills to easily create web applications and dashboards/cockpits, using widget and easy wiring capabilities.
- **F4I DyCEP Dynamic Events**: This Complex Event Processing (CEP) engine analyses event data in real-time, generates immediate insight and enables instant response to changing conditions. While standard reactive applications are based on reactions to single events, this component reacts to situations (e.g. a specified event pattern) rather than to single events.
- **FIWARE ORION Context Broker**: The Publish & Subscribe Context Broker plays the role of a central hub for information exchange, enabling each mediated component to gather, publish, exchange, process and analyze massive context data in a fast and efficient way. In every data intensive scenario, it is possible to register context producer devices/applications which will provide updates to context information, as well as context consumer devices/applications which will be notified of updates and query producers.
- **F4I IDAS OPC-UA & MQTT Emulation Agent**: Devices and/or gateways may use different standard or proprietary communication protocols and APIs. The IDAS component connects IoT devices/gateways to FIWARE-based ecosystems, by translating IoT-specific protocols into the NGSI context information protocol, that is the FIWARE standard data exchange model. Specific developments have been carried out in the context FIWARE for INDUSTRY to support industry-related protocols such as OPC-UA.

- **FIWARE KNOWAGE Business Intelligence**: Business Intelligence platform enabling users to build information support applications that help organizations in their decisional processes for the strategic and tactical management of the enterprises. This component, built on an Open Source Suite developed by ENGINEERING, is a complete tool for modern business analytics over traditional sources and big data systems, integrated in the FIWARE ecosystem.
- **FIWARE COSMOS Big Data Analytics**: This component is intended to deploy means for analyzing both batch and/or stream data to get, in the end, insights on such a data revealing new information that was hidden.
- **FIWARE Industrial Data Space Broker**: FIWARE implementation of the IDS broker.
- **F4I Persistency Layer CYGNUS**: To make persistent context status changes in ORION Context Broker, it can be connected to other FIWARE components such as Cygnus. Cygnus implements a connector for context data coming from Orion Context Broker and aimed to be stored in a specific persistent storage, such as HDFS, CKAN or MySQL.

Any of these components could be substituted by proprietary implementation of the described and advanced function based on the open APIs that FIWARE is supporting.

1.4 Security

The breach of cyber security in manufacturing systems has major information and operational implications. In specific systems wide (integrated) IoT enabled monitoring and control systems by definitions could become more vulnerable to intentional or unintentional cyber intrusions as well the harsh manufacturing environments (i.e. climate, heat, humidity, vibration, etc.) The materials used for the operations and communications of the information must withstand the required stress parameters such as temperature, ambient conditions and pressure to maintain the integrity of sensors data. Any discontinuity in the sensor data should be detected by standard mathematical models such as differential methods and Fourier analysis to cross check the integrity of the data. This will make sure that the sensor data is continuously fed to the decision-making systems further up in the chain of manufacturing information systems. The traditional Fourier analysis is known to miss the sudden transitions (discontinuities) in the signals, see [24], [25] and [26]. More sophisticated methods such as wavelets can be used in the transient signals as the sensors are dynamic systems.

A robust data processing technique can be implemented to remove outliers from the sensor data to avoid false flags being raised in the successive decision-making systems. The linear time invariant (LTI) outlier removal methods may be insufficient as the shot noises are random and unpredictable. As shot noises are statistically Poissonian in nature, a median filtering could be ideal as it is extensively used in image processing techniques in 2D signals [27]. A Hampel filter [28][29] which replaces the central value of a given window with its median given the value deviates thrice (can be varied according to end user) the standard deviation.

The accessibility of the sensors in the remote or extreme conditions for regular maintenance is crucial as the sensors depreciate over time and the quality of sensor data are reduced. The environment of the information storage is essential as the heat generated by large data storage facility needs to be vented properly. The vibrations and temperatures affect the durability of the stored data. The power spectral analysis (see [30], [31] and [32]) and Fourier frequency would reveal the presence of higher frequencies. Comparison of these two analyses with the historical and live (dynamic) data can be used to make decision on the level of depreciation and the appropriate action plan needs to be setup to increase the signal-to-noise ratio by undergoing maintenance. The cases where the depreciation of health of the machines are used as an indicator for breakdown using deep learning methods are reported in [33] and [34]. However, the problem of installing sensors at inaccessible places in the system could lead to unforeseen breakdowns. Hence, the product quality evaluations (online/offline) could be used to reverse engineer the depreciation of the machines or parts of the machines using for example multivariate and/or event-based analyses. These methods are linear, robust and can be implemented for 'on the fly' decisions and raise the flags for maintenance.

On the other hand, a system intruded by a cyber-attack may not necessarily notify the monitoring system or the operator of malfunction (i.e. sensors showing normal operations fooling the control-operating system). In these cases, historical data of the various operating settings need to be used and compared with the current behaviour to ensure that the system is truly working to the expected settings and specifications. Hence the event-based analysis will help to link the states of the machines with condition monitoring sensor outputs. Any genuine modifications and upgrade of the monitoring, control and predictive failure detection analysis software/hardware needs to be mapped to the operations (production and machine state scenarios) in the system to increase the robustness of the functionality. To implement this a correlation analysis and Markov chain Monte Carlo simulations could be used to determine all possible outcomes. This redundancy will help in the diagnosis of sudden or a possible breakdown. The data that drives the core of the manufacturing needs to be protected from the unauthorized exfiltration. The exfiltration can be avoided by having an authorization system in the intranet rather than in a remote server. The availability of the sensor data must be in sync with the baud rates of the operating system that is driving the system to avoid delays and wrong sampling of the data that would affect the decision-making system. The frequency analysis of the baud rates could be used to check the health of the electronic synchronization.

1.5 Safety

Safety of the system is of utmost importance for seamless operations without interruptions due to risks of physical injuries or health of the personnel [35]. The sudden breakdowns of the machines could cause the risk of higher levels of hazardous gases and materials such as carbon monoxide, micro chippings, dust and dispersion of contaminants are monitored through sensors. Potentially these breakdowns may mainly cause fire and emission of hazardous substances that may cause respiratory and skin damages or cause slippery surfaces. Such issues need to also be considered in the risk evaluation of machine/equipment sudden breakdown.

The risks of operational safety of the workshop floor requires regular assessment and the personnel should be trained to avoid and deal with such incidence. A set of guidelines must be put in to action in case of unforeseeable emergency situations to account for safety in entirety of the workshop floor. The safety of the workshop floor can be enhanced by architecture of the floor planning by isolating the modules (i.e., activities or departments) that may risk the safety. These could be done as part of the system layout planning approach [36] such as REL chart as shown in Figure 1.11. The plan weights (A, E, I, O, U and X rating values) the importance of different modules (D1, D2, etc.) according to different criteria or reasons (i.e. material flow.) Health and safety can also be incorporated in the system planning as “reasons for rating” modules to isolate the potentially hazardous ones.

A	Absolutely important
E	Especially important
I	Important
O	Ordinary importance
U	Unimportant
X	Undesirable

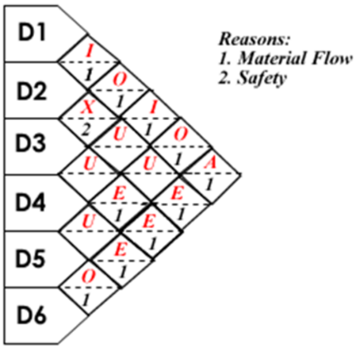


Figure 1.11 – Example of a relationship chart that rates industrial modules according to flow of material and safety reasons.

The risks of safety can be incorporated in the sensor data monitoring as part of the Z-BRE4K project and this could be a vital by-product of the predictive breakdown monitoring as the safety will be at highest risk during breakdowns or abnormal operations.

The risks of safety are not only confined to physical injuries but may occur also as cyber-attacks to the operational information which could be fatal as detailed in [37]. Therefore, the software system must be robust to cyber-attacks and should indicate any instance of malware attacks. During testing phases, the software system to deploy should be tested for all possible inputs (i.e.: Monte Carlo simulations) to avoid unexpected breakdowns and this could be a vital step in developing a robust control system. Even though, the patterns of outputs from successive modules may hide possible cyber-attacks on the integrity of the data. Hence traditional tests that consist of only checking correctness of the software [38] may be not enough for information cyber-safety and more sophisticated tools (Markov Chain MC simulation) should be adopted.

Many of the tools used for security of the industrial information (especially from sensors) can be also used to identify cyber-safety risks, raise the flags or even directly mitigate them. **The safety regulations and guidance** [39] **must be put in to action for safety-critical systems to rigorously test and validate the robustness of the software systems**.

1.6 Human and work

In [40] the author reports about a study conducted by PwC (Digital Factories 2020 Shaping the future of manufacturing) [41]. According to this study, 91% of Europe-based company are setting up digital factories and 98% of them expect a substantial efficiency leveraging on Manufacturing Execution System (MES), predictive maintenance and augmented reality solutions. A complementary analysis performed by McKinsey Global Institute (What the future of work will mean for jobs, skills and wages) [42] pointed out that about 50% of currently work activity can be already automated by adapting available technologies and that 6 out of 10 current occupations show a 30% of potentially automatable activities. In addition, by 2030 a potential work displacement ranging 10 to 800 million workers globally due to digitalization is foreseen, this along with a change of occupational category for 10 up to 375 million workers and the creation of totally new occupations that will represent the 8-9% of overall professions. As further confirmation, this trend belongs also to common perception: [43] conducts a survey reporting that a large majority (94%) of the participants believes that the increasing of smart devices, intelligent solutions and robots will revolutionize the way in which job is conceived and the corresponding skills required.

In this scenario, according to the ConnectedFactories [44] project, **there are three main human aspects that influence and are in turn affected by digitalization:**

- **Skills**, where currently one can observe a lack of digitalization expertise in the workforce as well as a mismatch between competences currently available in the market and those required by companies;
- **Motivation**, that relates to persuasion of the workforce about the importance, convenience and advantages of a digital transformation;
- **Training**, namely investments for training employees on new technologies and processes as well as on integration of new systems with legacy solutions.

As a matter of fact, **real and effective industrial digitalization cannot work if the human element is ignored** [45] and important digital enablers are:

- efficient education/training required even at the university/school level;
- easy and smart access to new system solutions, i.e., by means of **intuitive, functional, effective and user-friendly Human-Machine Interfaces** (HMIs);
- **definition and adoption of persona-specific digitalization approaches**;
- workplace re-organization (from the production-line definition to security processes, passing by cross-department communication);
- and, most importantly, the adoption and spread of a digital culture within the company itself.

To move in this direction, several initiatives are stemming. Examples of them can be: 1) the MANUWORK (Balancing Human and Automation Levels for the Manufacturing Workplaces of the Future) project [46], that supports the design and operation of a human-centred manufacturing system able to adapt according to workers limitations (such as, e.g.., lack of skills and knowledge, or disabilities) or 2) the VTT Digimaturity tool [47], which aims at assessing the maturity level of digitalization in the industry, with a special attention to customer interface, organization and processes, people and culture (in addition to information technology, strategy and business model). However, the transformation path towards a pervasive factory digitalization is still long and a lot of work need to be done: considering the above, what is important to **remember** is **to always keep "human in the centre" so that to make fruitful all the technology advancements and corresponding potential of this breaking new ground field**.

1.7 Standardization and interoperability

The use and promotion of standards within the manufacturing industry aims to create an environment where ICT technologies fulfil user requirements. There is also a special interest in promoting the integration of these standards as they serve as guidance and set a path towards quality, security, interoperability and scalability. Following subsections summarize in tables some relevant initiatives.

1.7.1 Official International and European standardization groups

CEN European Committee for Standardization	Association that brings together the National Standardization organizations of 34 European countries. Focused in the development of standards of different products, materials, services and processes including security, machinery, ICT services among others.	[48]
CENELEC European Committee for Electrotechnical Standardization	Focused in the standardization of electro-technical engineering technologies, this organization develops standards to encourage technological development, ensure interoperability, guarantee user's safety and provide environmental protection.	[49]
ETSI European Telecommunications Standards Institute	The European Standards Organization (ESO) which creates the standardization guidelines for telecommunications, broadcasting and other electronic communication services.	[50]
IEC International Electrotechnical Commission	Leading global organization that creates international standards for electrotechnology systems services and products.	[51]

1.7.2 Industrial standardization organizations

OMG Open Management Group	International consortium of industries that create integration standards for a large range of industries.	[52]

oneM2M	Global initiative that develops technical specifications to address requirements, security, interoperability and management of new M2M and IoT technologies (note that one of the oneM2M partners is ETSI).	[53]
OPC Foundation The Industrial Interoperability Standard	Organization focused on standards concerning security and reliability in data exchange for industrial automation and other industries.	[54]
CLPA CC-Link Partner Association	Promotion of CC-Link industrial network, and Ethernet-based integrated network to help communication among products of the partners.	[55]
ODVA	Common Industrial Protocol (CIP) standardization. It aims towards interoperability of production systems.	[56]

1.7.3 Roadmaps and initiatives

Factories 4.0 and Beyond.	Strategic discussion by the European Commission on key points for the "Factories of the Future" work programme (2018). It acts as an update of the roadmap Factories of the Future 2020.	[57]
German Standardization Roadmap - Industry 4.0.	Description of an innovative structure (Cyber-Physical Production Systems, CPPS) in which information and communication networks are extensive exchange of information in which production and business processes are matched.	[58]
Strategic Agenda for CPS Standardization.	Fostering interoperability of tools to develop Cyber-Physical Systems (CPS).	[59]
Industrial Internet Consortium - Platform Industrie 4.0.	Joint white paper on architecture alignment and interoperability between IIRA and RAMI 4.0 architectures.	[60]

1.7.4 Data security initiatives

ECSO European Cyber Security Organization	Institution that supports all types of initiatives or projects that aim to develop, promote and encourage European cybersecurity including ICT infrastructure and Industrial Control Systems.	[61]
ENISA European Union Agency for Network and Information Security	Centre of expertise for cyber security in Europe that provides recommendations for developments, support policy implementation and fosters collaboration with and among working teams cross-Europe.	[62]

1.7.5 Overview of Standards

For **a list of relevant standards**, we refer to the documents below that already provide exhaustive overviews:

- **Connected Factories, Structured Glossary (EFFRA)** [1];
- **Smart Manufacturing Standards Landscape** [63].

2 State of the art on new, existing and past related projects / initiatives

This chapter analyzes new, existing and past projects/initiatives related to Z-BRE4K project and is organized in three sections.

Section 2.1 pans over main exiting harmonization and supporting programs, considering both initiatives created to financially support research, development and adoption of IoT technology for industries, and projects that aim to collect and unify different development activities.

Section 2.2 illustrates past and ongoing projects focused similarly to Z-BRE4K on predictive maintenance.

Section 2.3 reports IoT initiatives not directly connected with predictive maintenance and explains why they are however of importance for Z-BRE4K.

2.1 Ongoing harmonization programs

Digital Manufacturing Platforms are technological solutions that require quite a few expertise from several areas of knowledge, attract different stakeholders and can be specialized in a broad variety of industrial fields (potentially with different approaches and ultimate needs). Such scenario calls for guides and supporting actions, as well as for harmonization and information-sharing initiatives both on a national and international level.

This section presents and briefly explains existing organizations, programs and initiatives that aim to direct all different projects and developments on Digital Manufacturing Platforms towards a common goal of interoperability, standardization, best-practice definitions and efficiency.

Since April 2016, the European Commission (EC) launched a strategy called Digital Single Market (DSM) [64] package, which aims to strengthen the European economy by removing digital walls. DSM acts by means of policy instruments, financial support, spurring public and private investments via coordination initiatives and suitable laws.

Within the DSM package the Digitising European Industry (DEI) [65] initiative focuses on the digitization of European industries and at the core of this coordination effort there is the European Platform of national initiatives [66]. The platform is a place where to share experiences, trigger collaboration and joint investments, explore common approaches to regulatory problems and exchange tools and methods for re-skilling the workforce. Under the responsibility of the Technologies and Systems for Digitising Industry (DG CONNECT – Unit A.2) team, DEI and the Platform build on and complement 15 national initiatives:

- Industrie 4.0 in Austria;
- Made different – Factories of the future in Belgium;
- Průmysl 4.0 in Czech Republic;
- Industrie 4.0 in Germany;

- Manufacturing Academy of Denmark (MADE) in Denmark;
- Industria Conectada 4.0 in Spain;
- Alliance pour l'Industrie du Futur in France;
- IPAR4.0 National Technology Initiative in Hungary;
- Industria 4.0 in Italy;
- Pramonė 4.0 in Lithuania;
- Digital for Industry Luxembourg in Luxembourg;
- Smart Industry in Netherlands;
- Initiative and Platform Industry 4.0 in Poland;
- Indústria 4.0 in Portugal;
- Smart Industry in Sweden.

A preliminary analysis of these 15 national initiatives has been conducted by the EC to map the corresponding measures along the action lines of the DEI strategy [67].

EFFRA (the European Factories of the Future Research Association) [2] is a non-profit and industry-driven European organization that promotes the adoption and development of innovative technologies: within this frame **is the official private-side representative of the Factories of the Future (FoF)** [68] **public-private partnership (PPP) with the European Union**. Overall aim of FoF is to enable competitiveness and sustainability of European industry by fostering cooperation among small, medium and large enterprises with universities, research centres and organizations. The activity of FoF is realized on the base of a priority roadmap which define the research topics of interest for research calls. Supported by the FoF PPP, there is also the ConnectedFactories project [44], a Coordination and Support Action (CSA) which aims to enhance awareness on manufacturing digitisation. ConnectedFactories wants to collect and disseminate all the needed information about the use of digital technologies and corresponding business models so that companies can make informed choices about digital manufacturing deployment and development. The project is made of four work packages: 1) challenges and requirements from the field; 2) research & innovation projects; 3) digital manufacturing platforms on the market and 4) pathways to the industrial deployment of digital manufacturing platforms.

Another private (world-wide) company organization is the Industrial Internet Consortium (**IIC**) [69] which addresses different industrial use cases (energy, healthcare, manufacturing, mining, retail, smart cities and transportation), **coordinates actions and establishes priorities to enable the quick adoption of Industrial Internet's technologies**. IIC is currently made of 19 Working Groups organized in 7 areas: business strategy and solution lifecycle; liaison (for external partnerships); marketing; security; technology; testbeds.

ARTEMIS (Advance Research & Technology for Embedded Intelligent Systems) Industry Association [70] is also a private organization for Embedded Intelligent System players that operates in Europe. The main objective of the association is **to define a coordinated pan-European strategy that focuses on embedded and cyber-physical systems, IoT and Digital Platforms**.

Furthermore, various projects intended for networking, dissemination, harmonization and interoperability there exits.

One of them is the H2020 sCorPiuS project [7] [8], which aims at fostering the diffusion of Cyber-Physical System (CPS) for the Factory of the Future. In particular, sCorPiuS covers:

- Analysis of the literature and research about CPS;
- Identification of technological challenges and drivers for the future;
- Development of a roadmap on the advance of CPS to support research streams in this area;
- Increase of knowledge and awareness about the use and impact of CPS.

CPSoS project [71] (Towards a European Roadmap on Research and Innovation Engineering and Management of Cyber-Physical Systems of Systems) was instead a Support Action under the FP7 Programme [72] which aimed to bridge the different approaches to the design, analysis and control of systems of systems (category to which also the Digital Manufacturing Platforms belong), raise public awareness and identify industrial & societal needs as well as synergies and future research directions.

IoT-EPI (IoT European Platforms Initiative) [73] is an initiative addressing the new EU-funded H2020 programs about IoT platform development that wants to create a more unified and approachable ecosystem of platforms for future development of IoT applications, both into and outside Europe. It is supported by a network of 120 partners (both private companies and public entities) and is made of seven research and innovation projects:

- Inter-IoT [74], to realize seamless integration of heterogeneous IoT platforms;
- BIG IoT [75], for data inter-operability leveraging on a set of dedicate Web APIs;
- AGILE [76], to build a modular and adaptive gateway for IoT devices;
- symbIoTe [77], to realize an abstraction layer for a unified view (based on virtualization of real real-devices) on various IoT platforms that allows for a rapid cross-platform application development;
- TagItSmart [78], to develop smart tags to easily connect, monitor and track mass-market products;
- VICINITY [79], to provide interoperability as a service for the M2M communication at the semantic layer (classification of services);
- bIoTope [80], to ease the deployment of new IoT systems by providing necessary standardised Open APIs and enabling new forms of co-creation of services.

Finally, DIMMEC (Digital, Internet, Materials & Engineering Co-Creation) [81] is an example of national (Finnish) wide ecosystem that wants to reduce time to market by means of the co-creation of a platform for digital transformations. It is supported by EFFRA and collects a network of over 2000 R&D&I professionals, over 400 organizations, 69 shareholders and more than 10 facilitators.

2.2 Projects on Predictive Maintenance

This section would report about the various projects that relates, similarly to Z-BRE4K, on Predictive Maintenance (and that, therefore, can be regarded as possible threats in Chapter 0). For readability descriptions of projects are reported, for each case, in a tabular framework.

mainDSS	http://www.maindss.eu/
From 2015-05-01 **to** 2015-10-31, closed project **Project ID:** 674549 **Funded under:** H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT), H2020-EU.2.3.1. - Mainstreaming SME support, especially through a dedicated instrument **Topic(s):** ICT-37-2014-1 - Open Disruptive Innovation Scheme (implemented through the SME instrument) **Funding scheme:** SME-1 - SME instrument phase 1	
General claim and objectives	mainDSS (Maintenance Decision Support System) represents a disruptive innovative IT solution supporting industries to improve the performance of their maintenance departments, irrespectively of the industrial sector and the plant size.
Use cases and application scenarios	• A comprehensive report on performance assessment indicators and criteria in the industrial maintenance domain, as a result of consultation and consensus amongst key European decision makers in maintenance. • An ontology which unambiguously models all main entities and their relationships in a typical maintenance domain, taking into account also the identified Key Performance Indicators (KPI) and simple performance criteria. • An Auditing tool, which incorporates the ontology, the KPIs and the assessment criteria, in order to perform automated audit based on retrieved maintenance data from the corporate CMMS. • A Progress Control tool, which monitors the progress of the maintenance department and issues electronic progress reports. • A Decision Support tool (DSS), which analyses CMMS data and data from the ambient environment of the specific industry, in order to derive recommendations for leveraging maintenance performance and offer proposals for ameliorating identified shortcomings.

mainDSS	http://www.maindss.eu/
Developed Technology	1. A comprehensive report on performance assessment indicators and criteria in the industrial maintenance domain, as a result of consultation and consensus amongst key European decision makers in maintenance. 2. An ontology which unambiguously models all main entities and their relationships in a typical maintenance domain, considering also the identified Key Performance Indicators (KPI) and simple performance criteria. 3. An Auditing tool, which incorporates the ontology, the KPIs and the assessment criteria, to perform automated audit based on retrieved maintenance data from the corporate CMMS. 4. A Progress Control tool, which monitors the progress of the maintenance department and issues electronic progress reports. 5. A Decision Support tool (DSS), which analyses CMMS data and data from the ambient environment of the specific industry, to derive recommendations for leveraging maintenance performance and offer proposals for ameliorating identified shortcomings.

AUTOWARE	http://www.autoware-eu.org/
From 2016-10-01 **to** 2019-09-30, ongoing project **Project ID:** 723909 **Funded under:** H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT) **Funding scheme:** RIA - Research and Innovation action	
General claim and objectives	AUTOWARE objective is to build three distinct pillars to form a multi-sided ecosystem: (i) from the BeinCPPS project's outcomes [82], leverage a reference architecture (fully aligned with CRYSTAL and EMC2 CPS design practices and ARROWHEAD cloudification approach) across I4MS competence domains (cloud, CPPS, robotics), acting as a glue that will attract potential users and developers to a friendly ecosystem for business development, more efficient service development over harmonized architectures (smart machine, cloudified control, cognitive planning- app-ized operation); (ii) To leverage a number of SME enablers; i.e. augmented virtuality, reliable wireless communications, CPPS trusted auto-configuration, smart data distribution and cognitive planning to ease cognitive autonomous systems; and (iii) to leverage digital automation investments. AUTOWARE brings together the best of breed ARTEMISIA/ECSEL platforms, I4MS innovation, SAFIR business platforms and neutral experimental sites (robotics & process).

AUTOWARE	http://www.autoware-eu.org/
Used Technology	AUTOWARE (www.autoware-eu.org) has recently proposed a reference architecture rooted on solid foundations and intensive large-scale piloting of technologies for development of cognitive digital manufacturing in autonomous and collaborative robotics as extension of ROS7 and Reconcell8 frameworks and for modular manufacturing solutions based on RAMI 4.0 industry 4.0 architecture.
Developed Technology	AUTOWARE provides the necessary components and interfaces for: 1. Extension of automation and control equipment for appized smart open control hardware (open trusted platforms) operation. This is leveraged by TAPPS framework. 2. Support to resilient & reliable time sensitive industrial (wireless) control communication and data distribution. Leveraged by OPC and rt-TSN edge computing and control framework. 3. Access to cloud-based engineering and simulation capabilities. Leveraged through CloudFlow and FortissimoHPC and Engineering Cloud marketplaces. 4. Smart service development for added value cognitive industrial services. This is leveraged by the FIWARE for Industry assets10 and the BEinCPPS IIoT/CPPS blueprint

DISRUPT	http://www.disrupt-project.eu/
From 2013-03-25 **to** 2015-03-24, closed project **Project ID:** 299255 **Funded under:** FP7-PEOPLE **Funding scheme:** MC-IIF - International Incoming Fellowships (IIF)	
General claim and objectives	The purpose of this project is to advance knowledge and management practice on supply chain approaches to managing sustainability and responding to natural disruption. Three dimensions are used in literature to categorize sustainability: social, environmental and economic.
Developed Technology	1. Identification of the candidate supply chains where our study could have more impact. 2. a mathematical model, and solving it analytically using theoretical data/from previous work experience of the fellow.

COMPOSITION	http://www.composition-project.eu/
From 2016-09-01 **to** 2019-08-31, ongoing project **Project ID:** 723145 **Funded under:** H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT) **Funding scheme:** RIA - Research and Innovation action	
General claim and objectives	The main objectives of COMPOSITION are; (i) to optimise the manufacturing processes by exploiting existing data, knowledge and tools to increase productivity and the ability to adapt to the market; and (ii) to design and implement a technical operating system which connects the factory and its suppliers to optimise processes through new services and practises.
Use cases and application scenarios	Within the COMPOSITION project, there are two pilots focusing on Intra-Factory (Value-Chain) and four Inter-Factory pilots (Supply-Chain) scenarios. For each of these scenarios, different use cases are reported, i.e., seven Intra and eleven inter in total. Five different end users - pilot partners are participating in this project.
Used Technology	The technology will be based on extending existing FIWARE and FITMAN catalogues and LINKSmart® Middleware and adapt the concept of Industrial Data Space.
Developed Technology	COMPOSITION will implement, demonstrate and validate the system in two multi-sided pilots that show the modularity, scalability and re-configurability of the platform across multiple application domains. The first pilot in the biomedical device domain focuses on the integrated information management system in a multi-sided manufacturing process. The second pilot concentrates on the interaction between different companies using the COMPOSITION ecosystem with the agent-based marketplace for collaboration.

PREVIEW	http://www.preview-project.eu/
From 2015-01-01 **to** 2017-12-31, closed project	

<table>
<tr><td colspan="2">PREVIEW http://www.preview-project.eu/</td></tr>
<tr><td colspan="2">Project ID: 636892
Funded under: H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT), H2020-EU.2.1.5.1. - Technologies for Factories of the Future
Funding scheme: RIA - Research and Innovation action</td></tr>
<tr><td>General claim and objectives</td><td>The objective of PREVIEW (PREdictiVe system to recommend Injection mold sEtup in Wireless sensor networks) is to develop a Cyber Physical System (CPS) for plastic injection manufacturing processes monitoring, control and optimization, by incorporating several innovative and cutting edge technological solutions: advanced artificial intelligence and machine learning techniques, robust industrial wireless communication, IoT and indoor location. PREVIEW is a middleware solution that facilitates easy, ubiquitous, holistic and fast sharing of product and process information across the entire injection production process.</td></tr>
<tr><td>Developed Technology</td><td>PREVIEW development incorporates several innovative technological solutions: PREVIEW Advanced Predictive system offers a powerful knowledge-based system for data analysis. Based on the data analysis results compared to historical data, the system will provide feedback, closing the loop by recommending actions to improve productivity. In details,
PREVIEW will develop and implement the Data acquisition modules to collect the data from the in-mould cavity pressure and temperature sensors as well to collect data from the injection machine PLC;
Thanks to the data acquisition modules and the industrial wireless communication capabilities developed in the project, mould and machine become IoT-capable, allowing for interoperability at intra-plant level with other devices, including the PREVIEW server, database and mobile devices such as tablets and smartphones;
PREVIEW system offers the possibility to share among the Cloud the mould-DNA functionalities as well as the Setup Predictive System. These functionalities enable to reuse historical data when setting up a mould in another location.
PREVIEW deploys a set of technologies and enablers (Information and communication technologies, manufacturing strategies, modelling, simulation and forecasting methods and tools), for process optimization of manufacturing assets in the injection sector.</td></tr>
</table>

PROGRAMS https://www.programs-project.eu/
From 2017-10-01 **to** 2020-09-30, ongoing project **Project ID:** 767287 **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future

PROGRAMS	https://www.programs-project.eu/
Funding scheme: IA - Innovation action	
General claim and objectives	The PROGRAMS (Prognostics based Reliability Analysis for Maintenance Scheduling) project aims to: • Develop a model-based prognostics method that integrates the FMECA analysis with the PRM (Prognostics and Resources Management) approach for predicting status of equipment; • Design and implement a new MDSS (Maintenance Decision Support System) tool to establish the best maintenance strategy for smart industries and manage resources via integration with ERP; • Create a MSP (Maintenance Service Platform) solution to stare maintenance information among interested users.
Use cases and application scenarios	PROGRAMS use cases comprise two main scenarios: • Monitor of milling machine (AURENNAK) to reduce downtime, breakdowns, overall maintenance cost, increase sales and competitiveness (as result of cost saving); • Control status of robots for the manufacturing of solar-thermal energy system parts (CALPAK). The predictive maintenance solution to implement will help in reducing typical failures as backlash on the gears, damaged motors and data loss due to battery consumption, in addition, will allow operators to monitor auxiliary equipment (grippers, sensors, etc.).
Used Technology	PROGRAMS will leverage on: • FMECA and PRM methods; • ERP (integration); • Sensors and prognostics algorithms to investigate.
Developed Technology	PROGRAMS main technological outcome will be: • the MDSS solution integrated with ERP for maintenance scheduling and resource planning; • the MSP for maintenance information sharing.

PROPHESY	http://prophesy.eu/
From 2017-10-01 **to** 2020-09-30, ongoing project **Project ID:** 766994	

PROPHESY	http://prophesy.eu/
Funded under: H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Funding scheme:** IA - Innovation action	
General claim and objectives	The technical solutions provided by the PROPHESY (Platform for rapid deployment of self-configuring and optimized predictive maintenance services) project will be the pillar to establish an ecosystem of PdM services to enable all the stakeholders to engage the development and deployment of innovative PdM services. This ecosystem will focus on the development, deployment and operationalization of dynamic, self-adaptive and cost-effective (turn-key) PdM solutions. The purpose is to lower the deployment time and cost associated with the operation of PdM solutions, while at the same time providing a host of business opportunities for all stakeholders.
Use cases and application scenarios	Project's demonstrations entail two real-world scenarios: • The first one, to be held in PHILIPS consists in implementing predictive maintenance techniques in two key-points of the production line of mechanical objects: the cold forming and the flange cut-out one. Main objectives of the predictive solutions are to continuously guarantee a product quality in the order of micron, extend life-time of machinery and increase production uptime; in addition, data-driven approaches are intended to realize predictable and well-dimensioned spare part stock levels, manage production and resource planning; • The second one, to be held in JLR wants to apply predictive maintenance techniques to monitor and give insights about a machining made of cubic metallic cylinder heads with a multi-axis fabricating center.
Used Technology	PROPHESY will use: • CPS platform; • Predictive Data Analytics Toolbox for Self-Configuring and Self-Adaptive PdM; • Framework for Secure and Trustworthy information exchange; • Remote Visualization; • Augmented Reality services for remotely supported maintenance.

<table>
<tr><th colspan="2">PROPHESY http://prophesy.eu/</th></tr>
<tr><td>Developed Technology</td><td>All PROPHESY technology assets will be offered through a single-entry point, the PROPHESY-SOE service engine. PROPHESY-SOE will enable the composition of CPS and non-CPS services to turn-key PdM solutions. These assets include:
1. PROPHESY-CPS, that provides the means for collected data from multiple sensors and production systems, analyzing them and ultimately closing the loop to production processes;
2. PROPHESY-ML, which includes Machine Learning, Data Mining and Statistical techniques for Adaptive Self-Configuring PdM programmes;
3. PROPHESY-AR that provides visualization and Augmented Reality Services for Remotely Supported maintenance.
Along with these solutions the project will offer as part of PROPHESY-SOE:
4. Tools for calculating KPIs, such as OEE, time to complete a production order, end-of-life (EOL) and operating life for components and equipment, MTBF indicators and more.
5. Tools for cost-benefit analysis of PdM solutions, including utilities for calculating financial parameters and indicators such as ROI and IRR.
These tools will facilitate stakeholders in assessing the business relevance and viability of solution, including resolution of trade-offs associated with the timeliness and cost of the maintenance task. Likewise, they will enable the specification of turn-key services that adhere to novel pay-per-use models for production systems and equipment.</td></tr>
</table>

<table>
<tr><th colspan="2">UPTIME https://www.uptime-h2020.eu</th></tr>
<tr><td colspan="2">From 2017-09-01 to 2020-08-31, ongoing project

Project ID: 768634

Funded under: H2020-EU.2.1.5.1. - Technologies for Factories of the Future

Funding scheme: IA - Innovation action</td></tr>
<tr><td>General claim and objectives</td><td>UPTIME (Unified Predictive Maintenance System) aims to design a unified predictive maintenance framework and an associated unified information system to enable the predictive maintenance strategy implementation in manufacturing industries.</td></tr>
</table>

UPTIME	https://www.uptime-h2020.eu
Use cases and application	1. Construction of Production and Logistics Systems: the use case deals with the maintenance of manufacturing equipment within the aviation sector (FFT); 2. White Goods and Home Appliance: the use case deals with a complex automatic production line to produce drums for dryer (WHIRLPOOL); 3. Steel Industry - Cold rolling mill lines: the use case deals with cold rolling mill to produce steel strapping (M.J. MAILLIS GROUP).
Used Technology	UPTIME will use: • Sensors and PLC; • Edge computing techniques; • Cloud communication and storage; • Data-Driven FMECA; • Prognostic algorithms.
Developed Technology	1. Extend and unify the new digital, e-maintenance services and tools for UPTIME solution: UPTIME will reframe predictive maintenance strategy and will extend and unify the new research-based digital, e-maintenance services and tools to exploit the full potential of a predictive maintenance strategy in manufacturing companies through UPTIME Solution 2. Deploy and validate the UPTIME solution in manufacturing companies: UPTIME will deploy the unified extended digital e-maintenance services in different representative manufacturing environments and evaluate the predictive maintenance framework as well as the e-maintenance services. 3. Diffuse the UPTIME solution in the manufacturing community: UPTIME will exploit the project's results to generate business flows and to maximize the impact on the industry through creation and management of manufacturing communities.

PreCom	https://www.precom-project.eu/
From 2017-11-01 **to** 2020-10-31, ongoing project **Project ID: 768575** **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Funding scheme: IA - Innovation action**	

<table>
<tr><th colspan="2">PreCom https://www.precom-project.eu/</th></tr>
<tr><td>General claim and objectives</td><td>PreCom (Predictive Cognitive Maintenance Decision Support System) aims to deploy and test a predictive cognitive maintenance decision-support system to improve preventive maintenance and ultimately increase in-service efficiency of machines. It will be demonstrated in three different use cases with low volume, high volume and continuous manufacturing.</td></tr>
<tr><td>Use cases and application scenarios</td><td>1. Low Volume Manufacturing: SORALUCE Milling machine at SAKANA producing wind hubs. Critical components monitored: Spindle head, spindle gearbox, feed drives, and machine geometry
2. High Volume Manufacturing: DANOBAT OVERBECK Grinding Machine at SPINEA producing reduction gears. Critical components monitored: Spindle workhead, grinding spindle, feed drives, process vibration and load.
3. Continuous Manufacturing: Paper mill at GOMA-CAMPS with components from LANTIER. Critical components monitored: Yankee dryer roll, suction press roll, forming roll, creping doctor.</td></tr>
<tr><td>Used Technology</td><td>PreCom will use:
• Intelligence, combining physical, statistical and self-learning models;
• CM sensors;
• Cloud communications;
• AR technologies;
• Dynamic FMECA.</td></tr>
<tr><td>Developed Technology</td><td>The platform includes four modules:
1. a data acquisition module leveraging external sensors as well as sensors directly embedded in the machine tool components;
2. an artificial intelligence module combining physical models, statistical models and machine-learning algorithms able to track individual health condition and supporting a large range of assets and dynamic operating conditions;
3. a secure integration module connecting the platform to production planning and maintenance systems via a private cloud and providing additional safety, self-healing and self-learning capabilities and
4. a human interface module including production dashboards and augmented reality interfaces for facilitating maintenance tasks.</td></tr>
</table>

SERENA http://serena-project.eu/
From 2017-10-01 **to** 2020-09-30, ongoing project **Project ID:** 767561 **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future

<table>
<tr><th>SERENA</th><th>http://serena-project.eu/</th></tr>
<tr><td colspan="2">Funding scheme: IA - Innovation action</td></tr>
<tr><td>General claim and objectives</td><td>SERENA (VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce) is aiming at:
1. Enabling technology transfer and validation in different industrial sectors (white goods, metrological engineering, elevators production industries and steel parts production), by designing, applying, testing and quantifying SERENA technologies in terms of feasibility, adaptability, scalability and flexibility;
2. Enabling remote factory condition monitoring and control and derive and separate the ‘smart data’ from the ‘big data’ based on edge computing capabilities;
3. Developing AI condition-based techniques and planning of production and maintenance activities, by using AI methods for condition-based monitoring and planning, as well as hybrid methods (physics-models and data-driven approaches) for increased prediction accuracy;
4. Enabling AR-based tools for remote assistance and operator support, by introducing AR device for providing critical information or guidance to the maintenance personnel within the factory;
5. Plug-and-play concept for cloud-based platform enabling predictive diagnostics, by managing the data remotely, applying data analytics and predictive maintenance algorithms in a remote cloud and proposing corrective actions and guidance for maintenance in near real time and in the correct place within the factory.</td></tr>
<tr><td>Use cases and application scenarios</td><td>SERENA will tackle five different pilots:
• Calibration and maintenance of metrology solutions (TRIMEK);
• Rolling mill process and maintenance of rolling segments (VDL);
• Robotics equipment predictive maintenance and scheduling (COMAU);
• Refrigerator Cabinet Polyurethane foaming (WHIRPOOL);
• Punching and bending processes (KONE)
with the objectives of to ease maintenance of machineries and reduce the corresponding costs, increase measurement, product quality and safety, guarantee data security and privacy.</td></tr>
<tr><td>Used Technology</td><td>SERENA will use:
• AI methods for monitoring and planning;
• Physics-models and data-driven approaches for prediction;
• Data analytics and predictive maintenance algorithms;
• AR devices.</td></tr>
</table>

SERENA	http://serena-project.eu/
Developed Technology	The SERENA platform consists of the following main components: 1. Remote factory condition monitoring and control; 2. AI condition-based maintenance and planning techniques; 3. AR-based technologies for remote assistance and human operator support; 4. Cloud-based platform for versatile remote diagnostics.

2.3 Other related projects and initiatives

Complementary to the previous section, the current one briefly reports ongoing projects and initiatives not directly related to Predictive Maintenance, which nevertheless is of Z-BRE4K interest, either because they constitute opportunities or possible threats. These projects and initiatives are detailed in terms of:

- General claim and objectives;
- Main technical outcomes;
- Why they are of interest for Z-BRE4K.

As done in Section 2.2, corresponding descriptions are provided in tables for each investigated case.

FALCON	http://www.falcon-h2020.eu/
From 2015-01-01 **to** 2017-12-31, closed project **Project ID:** 636868 **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Topic(s):** FoF-05-2014 - Innovative Product-Service design using manufacturing intelligence **Funding scheme:** RIA - Research and Innovation action	

FALCON	http://www.falcon-h2020.eu/
General claim and objectives	The FALCON (Feedback mechanisms Across the Lifecycle for Customer-driven Optimization of iNnovative product-service design) project aims to deploy user experiences and user data collected via the Internet of Things (IoT) and social media for improvement of product-service systems (PSS). Customers play no longer a passive role in the product and service development process as they express their product and service experiences and opinions through social media. In addition, sensor systems in combination with products incorporated in the IoT, are becoming increasingly common. The potential endless amounts of available information offer a rich ground for value creation in the product-service innovation chain. Accordingly, FALCON will develop a Virtual Open Platform to seamlessly connect product-service usage information to design and development processes.
Main technical outcomes	FALCON's mission was to investigate how and which sources of PUI (Product Usage Information) can be used to (re-)design or improve PSSs (Product Service Systems). Hence, the main purpose of FALCON is to exploit sources of PUI are CPS/IoT, social media and equivalents. As the result of the project, the FALCON Virtual Open Platform (VOP) for collaborative PSS (re-)design, improvement, manufacturing and lifecycle management was developed. The FALCON VOP facilitates the use of PUI in design, simulation, forecasting, LCA and other applications. It leverages semantic representation, natural language processing, knowledge-based engineering and other approaches to support these activities.
Why of interest	FACON H2020 project is of interest to Z-BRE4K since it derives a global ontology of innovative product-service design using manufacturing intelligence via semantic analysis. In terms of exploitation of product usage/behavior data, the FALCON project is associated with Z-BRE4K in the way of semantic enrichment. Semantic technologies facilitate alignments of all the data sources which are multiple and heterogeneous are into Triplestore with semantic interoperability, and exploitation of semantics for design/collaboration tools. To summarize semantic technologies applied in the FALCON project, wrappers connect with the PUI sources which are steaming or static with semantic interoperability. PUI is mapped to the FALCON ontology linking it to the PSS and sector knowledge domains, and it stored/aligned with ontology in a semantic data base. And then, PUI can be queried based on the ontology via an open API and functions and operations over PUI can be executed to generate actionable PSS design knowledge.

Boost 4.0	http://boost40.eu/
From 2018-01-01 **to** 2020-12-31, ongoing project **Project ID:** 780732	

Boost 4.0	http://boost40.eu/
Funded under: H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT) **Topic(s):** ICT-15-2016-2017 - Big Data PPP: Large Scale Pilot actions in sectors best benefitting from data-driven innovation **Funding scheme:** IA - Innovation action	
General claim and objectives	BOOST 4.0 (Big Data Value Spaces for COmpetitiveness of European COnnected Smart FacTories 4.0) will demonstrate in a measurable and replicable way, an open standardised and transformative shared data-driven Factory 4.0 model through 10 lighthouse factories. BOOST 4.0 will also demonstrate how European industry can build unique strategies and competitive advantages through big data across all phases of product and process lifecycle (engineering, planning, operation, production and after-market services) building upon the connected smart Factory 4.0 model to meet the Industry 4.0 challenges (lot size one distributed manufacturing, operation of zero defect processes & products, zero break down sustainable operations, agile customer-driven manufacturing value network management and human-centred manufacturing).
Main technical outcomes	Expected technical outcomes of the project include: (i) Establishment of 10 big data lighthouse smart connected factories; (ii) RAMI 4.0 and IDS based BOOST 4.0 open EU framework and governance model, for both services and data assets; and (iii) Development of methodologies, assets, models and communities in order to maximise visibility, mobilization, replication potential, and impact (business, financial, standardization) of BOOST 4.0.
Why of interest	BOOST 4.0 is an ongoing H2020 project which aims at creating a global EU Industrial Data Space, that the Z-BRE4K data outcomes may join. The use cases of BOOST 4.0 include predictive maintenance scenarios among others.

Z-FACT0R	http://www.z-fact0r.eu/
From 2016-10-01 **to** 2020-03-31, ongoing project **Project ID:** 723906 **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Topic(s):** FOF-03-2016 - Zero-defect strategies at system level for multi-stage manufacturing in production lines	

Z-FACTOR	http://www.z-fact0r.eu/
Funding scheme: IA - Innovation action	
General claim and objectives	The Z-Fact0r (Zero-defect manufacturing strategies towards on-line production management for European factories) solution comprises the introduction of five (5) multi-stage production-based strategies targeting (i) the early detection of the defect (Z-DETECT), (ii) the prediction of the defect generation (Z-PREDICT), (iii) the prevention of defect generation by recalibrating the production line (multi-stage), as well as defect propagation in later stages of the production (Z-PREVENT), (iv) the reworking/remanufacturing of the product, if this is possible, using additive and subtractive manufacturing techniques (Z-REPAIR) and (v) the management of the aforementioned strategies through event modelling, KPI (key performance indicators) monitoring and real-time decision support (Z-MANAGE).
Main technical outcomes	The implementation of Z-Fact0r solutions will lead to the achievement of zero defects in a multi-stage production line. In this context, Z-Fact0r novel correlation of machine behaviour with the process performance and the produced quality will provide a vital feedback to the control loop in manufacturing systems. The innovative synergies between online data gathering systems, real-time simulation models, data-based models and the knowledge management system will form 5 strategies which will eliminate the generation and the propagation of defects.
Why of interest	Z-Fact0r focuses on multi-stage production with strategies such as Z-PREDICT, Z-PREVENT, Z-DETECT, Z-REPAIR, Z-MANAGE. The concept of Strategies (PRE-DICT, DETECT, REPAIR, MANAGE) could be used in the Z-BRE4K DSS, as well as the models for detecting machinery deterioration rate. Besides, other concepts and tools developed for zero-defect manufacturing in Z-Fact0r could be adapted to predictive maintenance context in Z-BRE4K. EPFL, ATLANTIS, HOLONIX and BRUNEL are also project partners in Z-Fact0r and involved in some topics that may be of interest for inspiration, as product-process monitoring, defect life-cycle management, decision support system and context-aware algorithms.

BEinCPPS	http://www.beincpps.eu/
From 2015-11-01 **to** 2018-10-31, ongoing project **Project ID:** 680633 **Funded under:** H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT) ; H2020-EU.2.1.5.1. - Technologies for Factories of the Future	

BEinCPPS	http://www.beincpps.eu/
Topic(s): FoF-09-2015 - ICT Innovation for Manufacturing SMEs (I4MS) **Funding scheme:** IA - Innovation action	
General claim and objectives	BEinCPPS (Business Experiments in Cyber Physical Production Systems) Innovation Action aims to integrate and experiment a CPS-oriented Future Internet-based machine-factory-cloud service platform firstly intensively in five selected Smart Specialization Strategy Vanguard regions, and afterwards extensively in all European regions, by involving local competence centres and manufacturing SMEs. The final aim of this Innovation Action is to dramatically improve the adoption of CPPSs all over Europe by means of the creation, nurturing and flourishing of CPS-driven regional innovation ecosystems, made of competence centres, manufacturing enterprises and IT SMEs.
Main technical outcomes	The BE in CPPS project stems upon three distinct pillars: • A FI-based three-layered (machine-factory-cloud) open source platforms federation, integrated from state-of-the-art R&I advance in the fields of Internet of Things, Future Internet and CPS / Smart Systems and able to bi-directionally interoperate data pertaining to the machine, the factory and the cloud levels; • A Pan-European SME-oriented experimentation ecosystem. In a first phase of the project, the five Champions will provide requirements to the platforms integrators. In a second phase, an Open Call for IT SMEs developers (applications experiments) will award 10 third parties. In a final third phase, the extended platform will be instantiated and deployed in additional 10 third parties' equipment experiment SMEs; • A well-founded method and toolbox for Innovation management, where an existing TRL-based methodology for KETs technology transfer will be enriched by a CPPS certification, education and training programme for young talents and experienced blue-collar workers and by a well-founded three-fold (objectives-variables-indicators) method for results assessment and evaluation.
Why of interest	BEinCPPS is an H2020 project in which INNOVALIA is a Core Partner in charge of the Digital Innovation Hub (DIH) network and is involved in the development of the Cyber-Gauge experiment with Mondragon corporation in the Maier Plant. Z-BRE4K will exploit these assets and knowledge to build zero defect and Z-BRE4K strategies. Moreover, TRIMEK serves as CPPS system provider in BEinCPPS and it is involved in the provisioning of 3D scanning and machine digitalization equipment as well as point cloud and metrology information analysis platform. Z-BRE4K will exploit these assets and knowledge to build additional applications and uses of quality control information with applications to Zero break down of inline quality control equipment and predictive maintenance services for smart and fast machine verification and condition monitoring.

Productive4.0	https://productive40.eu/
From 2017-05-01 **to** 2020-04-30, ongoing project **Project ID:** 737459 **Funded under:** H2020-EU.2.1.1.7. - ECSEL **Topic(s):** ECSEL-2016-2 - ECSEL Key Applications and Essential Technologies (IA) **Funding scheme:** ECSEL-IA - ECSEL Innovation Action	
General claim and objectives	The main objective of Productive4.0 (Electronics and ICT as enabler for digital industry and optimized supply chain management covering the entire product lifecycle) is to achieve improvement of digitising the European industry by electronics and ICT. Ultimately, the project aims at suitability for everyday application across all industrial sectors – up to TRL8. It addresses various industrial domains with one single approach of digitalisation. What makes the project unique is the holistic system approach of consistently focusing on the three main pillars: digital automation, supply chain networks and product lifecycle management, all of which interact and influence each other. This is part of the new concept of introducing seamless automation and network solutions as well as enhancing the transparency of data, their consistence and overall efficiency. Currently, such a complex project can only be realized in ECSEL.

Productive4.0	https://productive40.eu/
main technical outcomes	Productive4.0 will furnish companies with fundamental tools necessary for the digital transformation. It focuses on a digitalized production applicable to all kinds of products. The results such as IoT components modelling and simulation methods as well as tool chains for cross-lifecycle and cross-domain digitalization are suitable means for linking all stages of a product lifecycle in a sustainable way. The project consists of 10 work packages (WPs), each with individual technical objectives. Therefore, Productive4.0 provides hands-on solutions for the European digital industry. In doing so, Productive4.0: • Tackles technological and conceptual approaches in the field of Industry 4.0. The term comprises IIoT (Industrial Internet of Things), CPS (Cyber Physical Systems) and Automation; • Takes a step further towards hands-on solutions. In the process, practical reference implementations such as 3D printer farms, customised production or self-learning robot systems will benefit in fields like service-oriented architecture (SOA), IOT components & infrastructures, process virtualization or standardization. These fields are addressed in the work packages WP1 through WP6. In addition to furnishing the industry with tailor-made digital solutions, the Productive4.0 Framework will be provided; • Serves as a brain pool initiated to strengthen the international leadership of the European industry.
Why of interest	Productive 4.0 is an ECSEL project that started in May 2017. This will be the EU Industry 4.0 lighthouse project with over 120 partners piloting in over 20 sites first industry 4.0 processes. INNO is coordinating the Spanish automotive pilot in the EPC (Engine Power Component plant) dealing with application of artificial intelligence and big data analytics for the implementation of cognitive quality control solutions that will be extended towards prescriptive maintenance approach with the Z-BRE4K solution.

Connected Factories http://www.effra.eu/connectedfactories
From 2016-09-01 **to** 2019-08-31, ongoing project **Project ID:** 723777 **Funded under:** H2020-EU.2.1.1. - INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies - Information and Communication Technologies (ICT) **Topic(s):** FOF-11-2016 - Digital automation **Funding scheme:** CSA - Coordination and support action

Connected Factories	http://www.effra.eu/connectedfactories
General claim and objectives	There is a consensus among industry and policymakers that Europe is currently in the middle of an industrial revolution initiated by the digitization of industrial processes. Cyber Physical Systems (CPS), the Industrial Internet and the Internet of Things (IoT) connect people, devices, machines and enterprises like never before. For many years, companies and research organizations have been addressing these challenges and opportunities both at European level (through the Factories of the Future PPP and related activities) and at national level. The Connected Factories project builds upon these activities and consolidate their expert networks, aiming at industrial consensus building across Europe. The Connected Factories (Industrial scenarios for connected factories) project will establish and maintain a structured overview of available and upcoming technological approaches and best practices that are needed for mastering this paradigm shift. Present and future needs and challenges of the manufacturing industries will be identified in order to then identify possible scenarios of how digital platforms will enable the digital integration and interoperability of manufacturing systems and processes.
Main technical outcomes	The work carried out within the Connected Factories project will enhance the awareness among companies of the use of digital technologies in the manufacturing sector and equip them with knowledge to make informed decisions regarding technology and business model choices. It will reinforce the European manufacturing industries' position in the international scene.
Why of interest	This CSA is establishing a landscape of digital manufacturing platform strategies and technologies in Europe. Z-BRE4K will exploit this landscape and contribute to the assessment of the platforms, including AUTOWARE for maintenance support.

ForZDM	http://www.forzdmproject.eu/
From 2016-10-01 **to** 2020-09-30, ongoing project **Project ID:** 723698 **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Topic(s):** FOF-03-2016 - Zero-defect strategies at system level for multi-stage manufacturing in production lines **Funding scheme:** IA - Innovation action	

ForZDM	http://www.forzdmproject.eu/
General claim and objectives	The aim of the ForZDM (integrated Zero-Defect Manufacturing solution for high value multi-stage manufacturing systems) project is to develop and demonstrate tools to support the rapid deployment of ZDM solutions in industry and design more competitive and robust multi-stage manufacturing systems. From one side, the ForZDM solution will rely on both knowledge-based data-gathering and root-cause analysis techniques to reduce the generation of defects; from the other side, it will exploit innovative on-line defect management and improved production traceability solutions to mitigate the propagation of defects along the various stages of production lines.
Main technical outcomes	ForZDM project will deliver an innovative ZDM methodology for production and quality control of multi-stage manufacturing systems. This will be achieved through the proper integration of advanced cyber-physical, multi-level system modelling and innovative solutions as selective inspection, big data analysis and advanced analytics, real-time data management integrated process and part-flow control. The methodology will be implemented and validated in three industrial cases, namely, the manufacturing of jet engine shafts, medical microcatheters and railway axles.
Why of interest	It is expected that this new methodology will significantly contribute to achieve near zero defect level in all European manufacturing sectors, with an emphasis on the production of high-value, high-performance parts. Therefore, this ForZDM can be seen as complementary to the Z-BREAK main focus with outcomes that can be useful also for this latter project.

GO0DMAN	http://go0dman-project.eu/
From 2016-10-01 **to** 2019-09-30, ongoing project **Project ID:** **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Topic(s):** FOF-03-2016 - Zero-defect strategies at system level for multi-stage manufacturing in production lines **Funding scheme:** IA - Innovation action	

GO0DMAN	http://go0dman-project.eu/
General claim and objectives	The overall objective of the GO0DMAN (aGent-Oriented Zero-Defect Manufacturing) project is to realize process and quality control for a multi-stage manufacturing production by defining and implementing a distributed system architecture built on agent-based CPS and smart inspection tools designed to support ZDM strategies. Big Data management and analysis are within the project the key enablers to provide a mean for knowledge build-up, system control and ZDM management: at local level, these techniques will be used for real-time monitoring of trends and early identification of deviations (so that to prevent the generation of defects at single stage and their propagation to down-stream processes); at global level, the system aims to be not only predictive (early detection of process faults) but also proactive (self-adaptation to different conditions).
Main technical outcomes	Successful completion of this project will provide a replicable system architecture for ZDM. The results will be broadly applicable in a variety of industries to improve the overall quality and efficiency of production systems impacting on the following performance indexes: production quality, waste and scraps reduction, energy efficiency, production rate and production costs.
Why of interest	GO0DMAN's use cases are representative of key European industrial sectors and have different types of multi-stage production systems: the first use case concerns highly automated serial mass production of automotive components, the second use case is about batch production of high precision mechanical components for automotive electro valves, the third use case produces professional customized products such as ovens for restaurants. Moreover, the exploitation of Big Data techniques (management and analysis) as well as the approach for a modular and flexible architecture are outcomes of interest also for the Z-BREAK project.

STREAM-0D	http://www.stream-0d.com/

From 2016-10-01 **to** 2020-03-31, ongoing project

Project ID: 723082

Funded under: H2020-EU.2.1.5.1. - Technologies for Factories of the Future

Topic(s): FOF-03-2016 - Zero-defect strategies at system level for multi-stage manufacturing in production lines

Funding scheme: IA - Innovation action

STREAM-0D	http://www.stream-0d.com/
General claim and objectives	First challenging objective of STREAM-0D (Zero Defect manufacturing solution) is to apply the Reduced-Order Modelling (ROM) approach for manufacturing processes. ROM techniques reduce the complexity of a mathematical model (that describes, e.g., real-life manifold physical phenomena or processes) to make the computational effort of corresponding numerical simulations affordable. As result, ROM models, fed with measurement data collected in-line during a given manufacturing process, can generate control data for the production line machines and allow to tune process parameters to get the final product with the desired design characteristics and quality levels. The STREAM-0D system wants to help manufacturing industries in reaching the following high-level objectives: • Higher product's quality with low variability (i.e., aiming at zero defects); • Shorter product's production cycles and higher production-line re-configurability; • Lower manufacturing costs.
Main technical outcomes	Technical outcomes of STREAM-0D will come in two steps: • First, a collection of requirements and feasibility assessment (i.e., definition of the needed hardware, specification of ROM solutions and data management systems) for three real-world applications; • Then, the actual implementation in factories of the STREAM-0D solution.
Why of interest	The exploitation of the ROM technique to design suitable simplified models of complex processes and consequentially data interpretation can be of interest also for Z-BREAK: selecting the appropriate measurements to transmit and process is a key-point to avoid side-effects ad bandwidth saturation or useless redundancy of communication.

ZAero	http://www.zaero-project.eu/
From 2016-10-01 **to** 2019-09-30, ongoing project **Project ID:** 721362 **Funded under:** H2020-EU.2.1.5.1. - Technologies for Factories of the Future **Topic(s):** FOF-03-2016 - Zero-defect strategies at system level for multi-stage manufacturing in production lines	

ZAero	http://www.zaero-project.eu/
Funding scheme: IA - Innovation action	
General claim and objectives	The ZAero (Zero-defect manufacturing of composite parts in AREOspace industry) projects focuses on aerospace industry and in particular on the production of carbon fiber parts. Currently, these composite objects require extensive end-of-line inspections, combined with re-work processes to remedy defective parts. In addition, quality control is realized visually leading to important productivity losses during the lay-up phase, constituting a bottleneck in carbon fiber parts manufacturing. ZAero aims at improving efficiency in the aerospace industry by implementing in-line quality control systems for two key-steps of the manufacturing process: lay-up and curing.
Main technical outcomes	The ZAero project will provide, at the system level, a solution (based on simulation and logistical planning tools) to support human operators in decision-making when evaluating defects of produced parts and planning the part flow through the production line.
Why of interest	The ZAero solution is featured by in-line quality control methods, similarly to Trimek component (see Deliverable D2.2) solution for the zero unexpected breakdown strategies of Z-BRE4K.

3 INTRODUCTION INTO THE MARKET OF NEW PRODUCTS AND TECHNOLOGIES

Chapter 3 reports on the introduction into the market of new products/technologies related to Z-BRE4K objectives, which has been broken down into three sub-sections. Section 3.13.1.1 compares commercial IoT platform solutions according to the main components that characterize such platforms; Section 3.2 outlines new products realized by innovative start-ups, consolidated companies or parallel projects to Z-BRE4K. Section 3.3 completes the picture with real-case examples of IoT exploitation in industry.

3.1 Consolidated software and platforms available in the market

Nowadays there is a huge offer and variety of Internet of Things (IoT) platforms (according to [83] they are more than 300, and the number is still growing) intended for both industrial maintenance and other applications, i.e., monitoring and analytics services for customers, data backups, business intelligence.

In the world-wide scenario, global players, start-ups, national and international initiatives are present, each one proposing its specific solution thus boggling the mind of the customer when trying to select the best one.

References [83], [84] and [85] agree on a similar approach to describe (and therefore identify) IoT platforms; merging their corresponding output it results that an IoT platform is characterized by the following main components:

1. **External Interfaces**, namely SDK and APIs for third party integration (i.e., ERP or CRM);
2. **Application**, which enables data visualization of real-time sensor data and provides additional development tools such as prototyping facilities or IDE;
3. **Services & Advanced Analytics**, to orchestrate multiple data-streams and implement advance calculations techniques and machine learning;
4. **Abstraction & Action Management**, i.e., rule engine to map incoming sensor & device data into actions;
5. **Database**, for storage of high volume data;
6. **Device Management**, that is the backend necessary to control device status and perform remote software update;
7. **Network Connectivity**, hardware and software (i.e., libraries) components that allow the platform objects to communicate, implementing various communication protocols and harmonizing data formats. Optionally, these building blocks may also provide basic edge analytics;
8. **Physical Layer**, hardware and low-level software elements that make physical objects able to work including operating systems, modules and drivers, microcontroller or microprocessor units (MCUs/MPUs).

This section aims to provide an exhaustive (even though not completed) overview on the currently available platforms in the market. In detail, an IoT platform can be generally viewed as the hardware (HW) on which it is built, the middleware implementation that enables its functionalities or a complete solution provided for a set of smart services.

Industrial IoT (IIoT) represents a branch of the general IoT concept, regarding the industrial world and hence involving the whole ecosystem of sensors, machines and people connected to industrial products and processes.

IIoT applications embrace all levels of a factory, from the interconnected devices on the factory floor to the logistic organization/distribution and customers care. IIoT describes systems that connect and integrate industrial control systems with enterprise systems, business processes, and analytics.

An IIoT system must have some important features to enable efficiency and security, that distinguish itself from a tradition IoT system. The key characteristics are:

- Safety;
- Security;
- Reliability;
- Resiliency;
- Privacy;
- Scalability.

For the sake of readability and considering the focus of the document, what follows is a survey on complete IoT solutions available in the market that are illustrated according to the building blocks explained above. For a comparison overview on IoT HW Platforms one may refer to [85] whilst different IoT Middleware platforms are analyzed in both [85] and [86]. A parallel among IoT Middleware platforms according to their supported and non-supported functional requirements is provided in [87] and an assessment of industrial middleware is instead reported in [88] (with the aim to select the best one for the project of interest).

3.1.1 Survey on Complete IoT Platform solutions available in the market

This section focuses on complete IoT platforms by industrial providers that occupy a leading position in IIoT development. These players are nowadays considered the most relevant ones by IoT-One [89] (one of the most trusted source of information about IIoT) according the brand influence, innovation and ecosystem openness criteria [90].

Providers and corresponding solutions can be divided into three main categories up to the offered services: 1) cloud-centric (i.e., platforms which mainly aim at offering solution as IaaS back-end to provide hosting space and processing power for application and services); 2) industry-centric (i.e., platforms primarily designed to address the challenges of industrial IoT and therefore integrating extensive features compared with the IoT consumer and business solutions) and 3) connectivity-centric (i.e., platforms whose main objective is to connect IoT devices via communication networks). The following platforms will be briefly described and compared using the same table than above:

- **Microsoft Azure IoT** [91] is a cloud-centric service fully managed within the Microsoft Azure's cloud. This platform enables a robust and secure communication between millions of IoT devices and between devices and cloud;
- **Amazon Web Service** [92] is a cloud-centric hosted functionality that allows different devices to be securely connected to the cloud and to communicate with each other and with cloud itself;
- **IBM Watson IoT platform** [93] is a cloud-centric solution based on top of Bluemix, IBM's cloud and service offering, which provides connectivity and management of devices;
- **Google cloud platform** [94] is a cloud-centric offering that provides different services and applications. It enables the possibility of connecting and manage devices allowing to collect data from and on the devices;

- **SAP HANA cloud platform** [95] is a cloud-centric solution that allows the processing of huge amount of data in real-time. The platform comes with more than one-thousands of prebuild applications and can be integrated with any kind of device and sensors;
- **Siemens MindSphere** [96] is a cloud-centric solution based on SAP HANA that offers open interfaces, application framework and possibility to choose where to store data (i.e., in public or private cloud);
- **PTC ThingWorkx** [97] is an industry-centric cloud application development platform created to facilitate the implementation of end-to-end smart applications for many vertical fields in the industrial world, especially those interested in data collection and analysis for data-driven decision making;
- **Bosch IoT Suite** [98] is an industry-centric set of elements for IoT applications organized in a modular way for advanced flexibility and provide building tools for the development of IoT personal applications;
- **GE Predix** [99] aims at providing rapid access to data and timely analytics while minimizing storage and compute costs in a secure and trustworthy environment. This industry-centric platform allows the connection of GE and non-GE machines from which collecting data can be processed in real time and organized for a fast and precise analysis;
- **AT&T IoT platform** [100] is an industry-centric solution made of three components: M2X, that handles cloud-based data storage, device management, data analysis and visualization; Flow, that provides development and prototyping tools and Data Plans, which implements device connectivity and monitoring;
- **PTC Axeda** [101] is a connectivity-centric cloud-based platform for managing connected products and machines and implementing IoT and M2M applications. It focuses on raw-data transformation into valuable information;
- **Cisco Jasper** [102] is a connectivity-centric platform that provides features to launch and manage connected devices and IoT applications. It serves IoT needs offering network visibility across devices and real-time monitoring for precise control and deeper insights to drive decision-making.

IoT Platform	External Interfaces	Application	Services & Advanced Analytics	Abstraction & Action Management	Database	Device Management	Network Connectivity	Physical Layer
Microsoft Azure IoT	YES	**Libraries and tools** for JavaScript, Java, C and Python **Dashboard** for data view	Mashup of differed data stream **Complex data processing** **Edge data processing**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage**	Remote support	Via (optionally cloud) gateway or direct Support to **AMQP**, **MQTT**, **HTTP**	Low-level system SW Modules, drivers and source libraries

IoT Platform	External Interfaces	Application	Services & Advanced Analytics	Abstraction & Action Management	Database	Device Management	Network Connectivity	Physical Layer
Amazon Web Service	**REST APIs**	**SDK** for Embedded C, JavaScript, Python, iOS, Android and Arduino Yún **Dashboard** for data view	**Complex data processing** (Kinesis and Amazon **Machine Learning**)	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage** (S3)	Remote support	Via cloud gateway or direct Support to **MQTT**, **AMQP**, **Websockets**, **HTTP**	Modules, drivers and source libraries
IBM Watson IoT platform	**REST APIs**	**SDK** (Node-RED and developer portal developerWorks) **Dashboard** for data view	Mashup of differed data stream **Complex data processing** **Edge data processing**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage** Blockchain integration	Remote support	Via gateway or direct Support to **MQTT**, **HTTP**	Modules, drivers and source libraries
Google cloud platform	**REST APIs**	**SDK** (for Go, Java for Android, .NET, JavaScript, Objective-C for iOS, PHP, Python and Ruby) **Dashboard** for data view	**Complex data processing (deep learning)** **Edge data processing**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage**	Remote support	Via gateway or direct Support to **HTTP**, **gRCP** and **XMPP**	Modules, drivers and source libraries
SAP HANA cloud platform	**APIs**	**SDK** (mainly in Java) **Dashboard** for data view	**Complex data processing (deep learning)**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage** (SAP HANA DB)	Remote support	Via SAP Cloud Connectors Support to **MQTT**, **TCP**, **HTTP**, **WebSocket**	
Siemens MindSphere	**APIs**	**SDK & Development tools** (plugins for IntelliJ and Eclipse and local sandbox)	**Complex data processing** (Gradient Check, Linear Regression, Outlier Detection) **Edge Data processing**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage** (SAP HANA DB)	Automated tools for continuous deployment and integration of the platform	Support to HTTP, TLS, JSON, HMAC	-

IoT Platform	External Interfaces	Application	Services & Advanced Analytics	Abstraction & Action Management	Database	Device Management	Network Connectivity	Physical Layer
PTC ThingWorkx	**Open APIs**	**App modelling** via Thingworx Composer and Mashup Builder (no coding required) **Dashboard** for data view based on SQueAl	Mashup of differed data stream **Complex data processing** **Edge data processing**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage** (DataStax, Neo4j, PostgreSQL)	Remote support	Via third-party clouds or direct leveraging on edge SDKs (C, .NET, Java, Android, iOS) Support to **MQTT**, **HTTPS**, **SNMP**, **CoAP**	Modules, drivers and source libraries
Bosch IoT Suite	YES (Bosch IoT Integration module and **REST APIs**)	**SDK** (Cloud Foundry) **Dashboard** for data view	Mashup of differed data stream **Complex data processing**	**Mapping** of low-level sensors to high-level events Data normalization (Bosch IoT Things module)	**Cloud storage**	Remote support (Bosh IoT Remote Manager and Rollouts modules)	Via gateway devices Support to **MQTT**, **CoAP**, **AMQP**, **STOMP**	Modules, drivers and source libraries
GE Predix	YES (Predix Time Series API and Predix Asset Data **REST API**)	**Dashboard** for data view	Mashup of differed data stream **Complex data processing** **Edge data processing**	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage**	Remote support	Via Machine, Cloud and Mobile gateways Networking modules Support to **MQTT**	Modules, drivers and source libraries
AT&T IoT platform	YES (API Keys and **RESTful APIs**)	**SDK** (for Ruby, Python, JavaScript, C and others) **Dashboard** for data view	-	**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage**	Remote support	Via LTE cellular network Networkingmodules Support to **HTTPS, MQTT**	Modules, drivers and source libraries
PTC Axeda	YES (web services, **REST APIs** and **SOAP services** in the Axeda	**SDK** (Axeda Build module) **Dashboard** for data view	Mashup of differed data stream	**Mapping** of low-level sensors to high-level events	**Cloud storage**	Remote support (Axeda Manage module)	Axeda Connect module (device CONNs)	Modules, drivers and source libraries

IoT Platform	External Interfaces	Application	Services & Advanced Analytics	Abstraction & Action Management	Database	Device Management	Network Connectivity	Physical Layer
	Build module)			Data normalization			Axeda Connect module (wireless CONNs) Support to **AMMP**, **HTTPS**, **JSON**, **MQTT**	
Cisco Jasper		**Dashboard** for data view		**Mapping** of low-level sensors to high-level events Data normalization	**Cloud storage**	Remote support	Via proprietary M2M and cellular network CONNs Network modules	Modules, drivers and source libraries

Table 3.1 - Description of some of the most important complete IoT platform solutions reported in [84].

For more details on the comparison of the above IoT platform solution see [84].

3.2 New products and technologies

Internet of things has drawn lot of attention lately as it is seen as one of the most important enablers within Industry 4.0, but it will also have major implications in work, transport and lifestile in the future. This section overviews the most important IoT projects, initiatives and products concerning manufacturing as well as general use cases.

One important aspect one has to consider when talking about the use of IoT in the industrial sector is the possibility to trace the way of products throughout their life-cycle process or the way of cargo on its way between sender and acceptor. The Swiss corporation “Nexiot” already uses smart sensors to track i.e., cargo on train wagons or shipping containers, and boxes. The data gathered includes updates on location, impact events, border crossing, and mileage. Its next step will be to combine the Internet of Things with the blockchain technology. This will add a time and date stamp to the information already gathered, making the information legally binding, which will add a layer of accountability. Another use case of the combination of blockchain technology and the Internet of Things could be digitally signed contracts that are entered, supervised and fulfilled with virtually no human interaction [103].

The EU-funded project “TagItSmart!”, with industrial partners such as Unilever, Fujitsu Laboratories or Siemens, pursues a slightly different approach by tagging consumer goods with smart QR tags called “FunCode”. The Tag allows end users as well as manufacturers to maintain up-to-date information about the product throughout the product life-cycle. By using a specific, functional ink it will also be possible to gather information like temperature or oxygen exposure [78].

Another big issue one deals with in the context of IoT is the standardization and compatibility of IoT platforms and applications. Currently there are many different IoT-platforms which are not-necessarily compatible with each other, as many companies design their own platforms and applications for their specific uses. Rapid-cross platform development will help to make the most out of the huge potential of the Internet of Things brings with it. To tackle the barriers holding back a holistic use of IoT-applications several EU-funded projects approach the problem with slightly different solutions.

For instance, SymbIoTe's and Inter-IoT's main goal is to develop a software framework that establishes a connection between the different heterogeneous IoT platforms [77] [74]. In this case data and applications are made compatible by conversion via the framework mentioned above. "Vicinity", instead, goes in a slightly different direction by giving a closer look on Machine to Machine (M2M) communication, which will lead to a better compatibility between IoT-applications across platforms through a more semantic approach [79]. "BIG IoT" aims at establishing a special API. Every application designed with this API is compatible with all the IoT platforms involved in the project. Furthermore the aim is to establish the so-called "BIG IoT Marketplace", where it is possible to upload and download the applications that best fit your needs [75].

BIG IoT however is not the only one that came up with the idea of a market place for IoT-applications. The multimedia company Ericsson just recently opened its so-called "IoT Accelerator Marketplace". Comparable to a normal app store as already known for smartphones and tablets, the IoT Accelerator Marketplace shall give companies an overview on all the existing IoT-applications and a way to find the applications suiting best for them. Furthermore, it can be used as a platform for companies or single working programmers to distribute the applications they developed, see [104] and [105].

In a booming industry like the IoT sector radical innovations are not only generated by major players but also by small businesses with brilliant ideas. In the following section an overview on interesting upcoming and already existing start-ups can be found. The German company "Aucobo" focuses on the emerging relationship between worker and machine and looks to optimize the communication between those two partners. Smartwatches are included in the production process showing important information immediately on the watch. Possible use cases for the smartwatch are the operation of machines which includes efficient self-organization of production or maintenance procedures where warnings and maintenance messages are sent directly to the smartwatch. Furthermore, the smart watch allows the user to give and take picking commands to the machine and supply messages to the logistic centre [106].

Another example for the use of wearables in manufacturing context is given by the start-up "ProGlove". They develop gloves helping workers during crafting and construction, which will shorten production time, make manufacturing more efficient and less error prone. The newest prototype “Mark” helping during the assembly of a product is the best example for this. If the worker takes a wrong part or assembles the parts in a wrong way, the glove will indicate this [107]. The last example for recent developed wearables is “ZEI°” by “timeular”, a small octahedron-formed device helping employees to keep track of what they do during their work hours. It is a fast and accurate way to analyze how much time is spent on different activities and how one can improve one’s efficiency. To capture the time one simply turns the octahedron and the activity that is now on top will automatically be tracked [108].

Axoom is a start-up founded by German machine manufacturer Trumpf. It developed an IoT enabled platform with integrated applications for the manufacturing process. The system captures, analyzes and processes all production data in a holistic approach. Using Trumpf’s expertise in the field of engine construction Axoom created a whole new business model [109].

Another example for the development of end-to-end solutions for sensor technology in the manufacturing sector is the Munich based start-up Konux. Its key competence is the processing of sensor data, although their product also follows a holistic approach to enable intelligent maintenance, which means that their system automatically tells the workers when to service or to repair certain parts of machinery to have a minimum of downtime [110].

A good way to get to know the Internet of Things in a playful way is offered by SAM Labs. They make app enabled construction kits which allow users to learn how to program and to experiment with the Internet of Things. And it is also a wonderful way to get students and children to get into IT and IoT issues and teaching them the basics of their future work life with little effort [111].

Further information on EU-projects, their runtime and the partners from the manufacturing sector involved can be found in the two charts below.

Name	Short description	Run time	Outcome/products	Partners from the manufacturing sector
Daedalus initiative	Development of cyber-physical, service-based automation systems for real-time management and orchestration of manufacturing taks	01.10.2016 to 30.09.2019	Cyberphysical system based on IEC-61499 standard, allowing to connect single machines, sub-systems and systems and to let them communicate with each other [112]	Bluebotics, Schunk, qbrobotics, Jetter AG [113]
bIoTope	Platform enabling companies to easily create new IoT systems [80]	01.01.2016 to 31.12.2018		BMW Group, Bremer Institut für Produktion und Logistik GmbH [114]
U4IoT	Analysis of social, ethical and ecological issues and barriers related to pilot IoT projects with end-users to improve the adoption of the projects	01.01.2017 to 31.12.2019	toolkits for Large Scale Projects end-user engagement and adoption, including online resources, privacy-compliant crowdsourcing tools, guidelines and an innovative privacy game for personal data protection risk assessment and awareness, online training modules [115]	-

Name	Short description	Run time	Outcome/products	Partners from the manufacturing sector
Create IoT	stimulate collaboration between IoT initiatives, foster the take up of IoT in Europe and support the development and growth of IoT ecosystems based on open technologies and platforms	01.01.2017 to 31.12.2019	Connection network between major IoT initiatives [116]	Philips Lighting B.V. [117]
SynchroniCity	establish a reference architecture for the envisioned IoT-enabled city market place where cities and businesses develop shared digital services to improve the life of citizens and grow local economies	01.01.2017 to 30.09.2019	IoT-enabled city market place [118]	Philips Lighting B.V. [119]
MONICA	Management of Networked IoT Wearables.	01.01.2017 to 31.12.2019	MONICA aims at developing an ecosystem that uses innovative wearable and portable IoT-sensors connected to an interoperable, cloud-based platform offering multiple apps [120]	Fraunhofer FIT, Brüel & Kjær, Optinvent S.A., DigiSky S.r.l. UAV & Robotic systems [121]

Name	Short description	Run time	Outcome/products	Partners from the manufacturing sector
IoF2020	Internet of Food and Farm 2020, adoption of IoT-trends in farming and the food chains in Europe	01.01.2017 to 31.12.2020	19 use cases grouped in 5 trials forming a symbiotic ecosystem of farmers, food industry, technology providers and research institutes [122]	Bayer, Agrom, Exafan and more [123]
Autopilot	AUTOmated driving Progressed by IoT aims at increasing safety, provide more comfort and create many new business opportunities for mobility services by evaluating the impact of IoT-services on pushing the level of autonomous driving	01.01.2017 to 31.12.2019	A few examples for use cases are autonomous car sharing, automated parking, or enhanced digital dynamic maps to allow fully autonomous driving [124]	NEC Corporation, PSA Groupe, T-Systems, TOMTOM, Continental, DLR, Huawei, IBM [125]
ACTIVAGE	ACTIVAGE aims at developing Active & Healthy Ageing IoT based solutions and services, supporting and extending the independent living of older adults in their living environments, and responding to real needs of caregivers, service providers and public authorities	01.01.2017 to 30.06.2020	User-demand driven interoperable IoT-enabled Active & Healthy Ageing solutions for the promotion of independent living, the mitigation of frailty, and preservation of quality of life and autonomy [126]	Medtronic, Samsung, Technosense, Fraunhofer IGD [127]

Name	Short description	Run time	Outcome/products	Partners from the manufacturing sector
AGILE	Agile builds a modular and adaptive gateway for Internet of Things devices	01.01.2016 to 31.12.2018	Fast prototyping of IoT solutions for various domains through modularity on hardware level and innovative software features such as: data collection and management on the gateway, intuitive interface for device management, visual workflow editor for creating IoT apps with less coding, and an IoT marketplace for installing IoT apps locally [76]	-
TagItSmart!	TagItSmart is changing the way consumer goods and other products can be tracked and monitored with the goal to connect mass products.	01.01.2016 to 31.12.2018	The printable smart QR tag called “FunCodes” is able to convey all kind of product information throughout the product life-cycle (i.e. temperature and oxygen exposure). Furthermore, service platform and APIs to develop the range of new services are included [78]	Unilever, Fujitsu laboratories of Europe, Siemens Srl [128]

Table 3.2 - EU projects dealing with IoT-issues.

Name	Short description	Runtime	Outcome/products	Partners from the manufacturing sector
symbIoTe	enable interoperability and interaction between several existing and future IoT-platforms.	01.01.2016 to 31.12.2018	Framework software enabling to work with different existing IoT-platforms [77]	Sensing & Control Systems S.L., Fraunhofer IOSB [129]
BIG IoT	Interoperability between existing and future IoT-platforms	01.01.2016 to 31.12.2018	BIG IoT API and BIG IoT market place, creating an interplatform ecosystem [75]	Siemens AG, Bosch Software Innovations GmbH, Seat SA [130]
Inter-IoT	Framework enabling interoperability between heterogenous IoT-platforms [74]	01.01.2016 to 31.12.2018		Telekom Italia SPA [131]
Vicinity	Development of standards for machine-to-machine communication	01.01.2016 to 31.12.2019	platform and ecosystem that provides “interoperability as a service” for infrastructures in the Internet of Things [79]	-

Table 3.3 - Projects dealing with interoperability and connection between existing and future IoT-Platforms.

3.3 Outcomes from industry

The World Economic Forum (in collaboration with Accenture) [43] reports the following set of recommendations for IIoT stakeholders:

- Technology Adopters should orchestrate organization’s ecosystems (i.e., identify the strategic partners and define if to join a third-party platform or develop their

own) and start with pathfinder projects (i.e., test case scenarios that can be piloted with a six-month time scope);
- Technology Providers should drive technology testbeds, establish security commons, develop and deploy new software solutions taking in consideration also the presence of existing or legacy applications (i.e., brownfield innovation) and help adopters to address opportunities and risks;
- Public Policymakers should clarify data regulation, update industry regulations, invest in digital infrastructure and raise awareness among policymakers;
- All stakeholders should invest in strategic R&D, collaborate on lighthouse projects and, very important for inclusions of workers in the new scenarios (see Section **¡Error! No se encuentra el origen de la referencia.**) accelerate digital reskilling.

This section wants to provide a representative overview on the Digital Industrial Platform applications currently ongoing in real-world industry context. Each exemplification is reported in terms of:
- General description of the case;
- Main achievements;
- Feedbacks from the industry (i.e., possible indications for future research and development).

The objective is to provide a state-of-the-art overview of the penetration-level in the industries of the technologies related to the Z-BRE4K project and to highlight, by comparison with the guidelines in or directed feedbacks from industries, where Z-BRE4K can enhance the current knowledge.

SCANIA	https://www.scania.com/
Scania is a world-leading provider of transport solutions for heavy transport applications (i.e., trucks and buses, but also marine and industrial engines) and offers also a wide set of related services (i.e., financing, insurance, rental). Within the frame of “Smart Factory Industry 4.0”, it is seeking for coordination among the different production units. The idea is to implement, evaluate and coordinate pilot projects among these units for subsequent integration into a larger system [132].	
Achievements	• On-going pilots for advanced automation and digitalization [133] (i.e., the Oskarshamn factory) • Current focus on data analysis to understand what can be predicted.
Feedbacks	• Formalized processes that allows to interpret data are the basis, otherwise there is the risk to digitalize useless information; • Necessity to mix data elaboration and capacity of interpreting such data; • Main challenges: safety, cybersecurity, standard, competence development and additionally, ownership of data in the business model.

<table>
<tr><th>GE Aviation</th><th>https://www.geaviation.com/</th></tr>
<tr><td colspan="2">General Electric Aviation, is a world-leading provider of commercial and military aviation jet and turboprop engines, as well as electric and mechanic components for aircraft. GE Aviation, in a joint venture with Accenture, developed Taleris™ [134], solution that deploy analytics to help airlines minimize disruptions from mechanical failures and weather delays [135].</td></tr>
<tr><td>Achievement</td><td>• data and analytics exploited to identify ways to reduce operating costs, increase aircraft utilization and improve the comfort of the fly.</td></tr>
<tr><td>Feedbacks</td><td>• Leveraging on predictive maintenance not only for service maximization, but also for aircraft fleet optimization (i.e., cost reduction and decision making on investments for machine renewal)</td></tr>
</table>

<table>
<tr><th>Komatsu Ltd.</th><th>https://home.komatsu/en/</th></tr>
<tr><td colspan="2">Komatsu Ltd. manufacture construction and mining equipment, as well as forest and industrial machinery. In collaboration with the Centre for Intelligent Maintenance Systems [136] (IMS Center), this company developed a systematic approach to convert the diesel engine data into health information [137] leveraging on the Watchdog Agent® Prognostic Toolkit [138].
The designed solution is based on: 1) the Huber’s method for removal of measurements distant from other observations; 2) an autoregressive model to recover possible missing values due to a data transmission error or the previous measurement-removal step; 3) a Bayesian Belief Network (BBN) to classify data patterns into engine-related problems; 4) a fuzzy logic-based algorithm to finally predict the RUL.</td></tr>
<tr><td>Achievements</td><td>• Remote prognostics, monitoring system assessment and health prediction of the diesel engine components (daily analysis of a set of parameters including pressures, fuel flow rate, temperature, and the rotational speed of the engine)</td></tr>
<tr><td>Feedbacks</td><td>• Evaluation of the prognostic tool to be conducted at the key-operating points for the engines (i.e., at idle engine speed or at maximum exhaust gas temperature);
• Machine health prediction reduces the machine downtime;
• Prognostics information can support ERP systems to optimize manufacturing management, maintenance scheduling and machine safety;</td></tr>
</table>

	• Predictive maintenance solutions may help industrial management to be better organized by favouring the communication among production line, supply chain and business.

Tetra Pak	https://www.tetrapak.com/
Tetra Pak is the world-leader in food processing and packaging solutions. This company in 2017 has launched a new service to customers (called "Condition Monitoring") to help them predicting machine failures before they occur [139]. The solution is based on Microsoft Azure Cloud and connected more than 5000 machines world-wide. In addition, Tetra Pak is active in the research field of connected and smart industries. As an example of the research activity conducted by Tetra Pak, [140] is a paper that stems from the collaboration with researchers from Politecnico di Milano [141] and University of Modena and Reggio Emilia [142]: this work comes up with a new solution for on-line assessment of the degradation state of knives installed on the Tetra Pak® A3/Flex filling machines used to cut package material. The proposed method is based on four steps: 1) statistical and frequency analysis of the raw data coming from measurements; 2) selection of a set of Health Indicators (HIs) for the identification of the component degradation; 3) leveraging on the Fuzzy C-Means (FCM) clustering algorithm, identification of the optimal number of degradation states in which the degradation process should be discretized; 4) labelling on-line monitored data with their corresponding degradation state.	
Achievements	• Successful six-month pilot in January 2016 on "Condition Monitoring" (support to 17 lines, across 10 customers locate in EU and US) • Successful application of the proposed method to real-world data
Feedbacks	• During the 2016 six-month pilot downtime was eliminated by up to 48 hours for each line, saving up to 30K € for Tetra Pak's customers.

A set of representative examples of connected factories applications from industries have been presented above. Technology is already mature to obtain some benefits, but still work is necessary to improve the solutions. From feedbacks reported it is possible to gain insights useful also for the development of the Z-BRE4K project:

- prognostics solutions must rely on well-defined models that are specific for each use case and that, in turn, need a good definition of the processes involved (to avoid the "digitalization of the unnecessary");
- predictive maintenance solutions can help in favouring the communication among different departments of a company (supply chain management, business management, production line).

To conclude, Z-BRE4K must therefore put special attention in providing these outcomes: 1) focus on pilots that can be exploitable within a time scope of six-months; 2) provide clear and innovative methods to model use cases and processes and, successively, define a set of rules for digitalization (i.e., identification of key operations to monitor and definition of measurement data sets to collect) and data transmission (i.e., sampling, aggregation, coding); 3) possibly design a cross-function solutions that allow to provide useful information to different company departments.

4 POTENTIAL OPPORTUNITIES AND THREATS

Special focus of deliverable D1.2 is expected to be on potential opportunities and possible threats. Therefore, this chapter completes the previous analysis with a preliminary study on this subject.

In detail, Sections 4.1 and 4.3 briefly present the first overview of tools (i.e., business models) and analyses (i.e., SWOT analysis) on opportunities and threats. Further, detail work and refinement of this sections will be examined within the **Task T7.8 Reassessment of Business models** and reported in **deliverable D7.8** at the end of the project.

Section 4.2, instead, consists of first discussions and recommendations of successful stakeholder analysis. Detailed work will be completed within the **Task T7.4 Market analysis and segmentation, business modeling** and it will be reported in **deliverable D7.4**.

4.1 Business models

Today many innovative business models are emerging while new industries are being established challenging the old ones that are disappearing due to the anxious struggle to reinvent themselves. A business model describes the rationale and it is the foundation of how an organization creates, delivers and will capture the value in economic, social, cultural or other contexts. It must be noted that it **is essential to understand what business model concept will be used and how the model will enable the description and manipulation of business as well as which new strategies are to be followed**.

Up to present, there are many different business models that are described and implemented through organizational structures, processes and systems. They are used for a broad range of informal and formal descriptions of business in general. **Choosing the correct business model is the essential representation of a business as well as it**

influences the core products/services the company offers/will offer. Up to day several different business models and analysis are registered i.e., Model by Shikhar Ghosh [143], Osterwalder and Pigneur's Model [144], SWOT [145], Pestel Analysis [146], Value Chain Analysis [147], Porter's five forces analysis [148], etc., and some of them are mentioned and presented below.

4.1.1 The Shikhar Ghosh's Model

A very known model that represents core aspect of a business is the one by **Shikhar Ghosh**. It recognizes eight main elements:

- **Value proposition**, consists of benefits that customer will experience from a company during the time of acquisition;
- **Revenue model**, presents the way on how the money will be made;
- **Market opportunity**, endures the nature and size of the company's marketplace;
- **Competitive advantage**, introduces the advantages a company will gain over its competitors;
- **Market strategies**, reviews how a company will target the customers and how will promote its products;
- **Organizational development**, typify the management status of a company;
- **Management team**, consists of company leaders with experience and skills.

4.1.2 The Osterwalder and Pigneur's Model

There are many different business conceptualizations that exist and **Osterwalder and Pigneur's Model** distinguished nine basic building blocks w that are commonly used in today's Business Model Canvas:

1. **Customer Segments** defines one or several targeted customer segments (i.e. industries) [149] ;
2. **Value Propositions** is a declaration which identifies and presents a clear customer benefit that will be experienced, achieved and delivered when a given product or service is bough [150] and it should prove to consumers that the specific product or service considered is much better than any others and worth their money [151];
3. **Channels** are fast, efficient and cost-effective ways (i.e. through communication, distribution or sales) on how to reach the customer/client and how to deliver its Value Proposition [152] ;
4. **Customer Relationships** define the types of associations a company establishes with a Customer Segments and are influenced by one or more motivations (i.e. customer acquisition, customer retention and increased sales) [149];
5. **Revenue Streams** reveal the revenue a company makes from all the methods used be (i.e., direct sales, licensing, pay per use, post service, licensing, etc.) for each Customer Segment [153];
6. **Key Resources** are the important assets (physical, financial, intellectual or human) necessary to generate, offer and deliver Value Proposition and

Revenues, reach markets, maintain relationships with Customer Segments and earn revenues [154];

7. **Key Activities** are the most important activities in executing a company's Value Proposition (especially prominent in production, problem solving and platform/network);
8. **Key Partnerships**, i.e., the network of suppliers and partners needed to optimize business models, reduce risk and retrieve resources;
    a.
9. **Cost Structure** describes all costs calculated once defined Key Resources, Key Activities and Key Partnership (i.e., fixed costs, variable costs, economies of scale and economies of scope) [154].

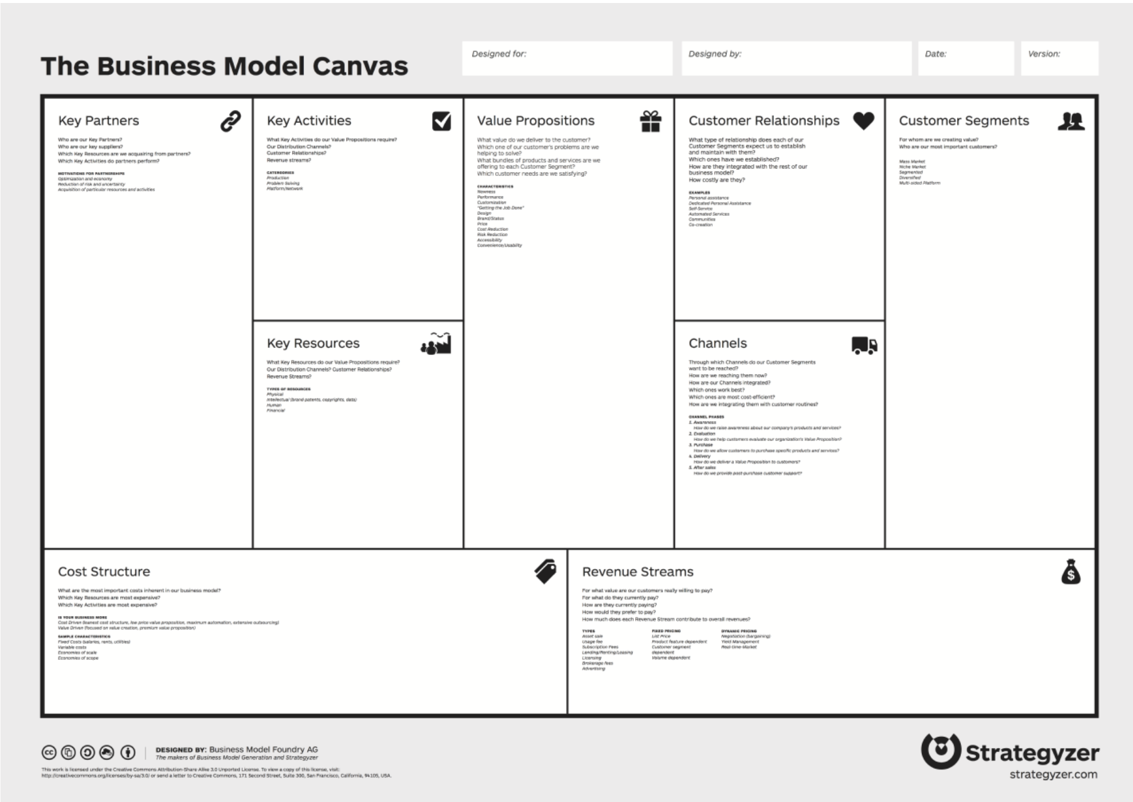


Figure 4.1 - Business Model Canvas [155].

4.1.3 SWOT Analysis

This analysis is a strategic planning technique and while helping a company to identify four strategic outlook factors: Strengths (S), Weaknesses (W) Opportunities (O) and Threats (T) [156]. These strategies are identified using the known 2x2 matrix presented in **Table 4.1**.

	HELPFUL	***HARMFUL***
INTERNAL	**Strengths**	**Weaknesses**
EXTERNAL	**Opportunities**	**Threats**

Table 4.1 - SWOT 2x2 matrix, Factors x Impacts.

Strengths and Weakness are frequently classified as internal, while Opportunities and Threats are usually focused on external/environmental placement. In Section 4.3, details of SWOT analysis for Z-BREAK compare opportunities against the possible threats, weaknesses of the project, possible competitors that emerged in Sections 2.2 and 3.2, as well as additional threats correlated with projects described in Section 2.3.

4.1.4 PESTEL Analysis

This analysis is like the SWOT analysis encompassing the following factors: Political (P), Economic (E), Social (S), Technological (T), Environmental (E) and Legal (L). The PESTEL factors are explained in **Table 4.2**.

Political factors (i.e. tax policies, fiscal policy, trade tariffs, etc.) determine the extent to which a government may influence the economy or a certain industry: • • • •	*Economic factors* (i.e. inflation rate, interest rates, foreign exchange rates, economic growth patterns, etc.) are determinants of an economy's performance that directly impacts a company and have resonating long term effects: • • • •
Social factors scrutinize the social environment of the market, and gauge determinants like cultural trends, demographics, population analytics, etc.: • • • •	*Technical / technological factors* relate innovations in technology that may affect the operations of the industry and the market favourably or unfavourably. This refers to automation, research and development and the amount of technological awareness that a market possesses: •

	• • •
Legal factors (i.e. consumer laws, safety standards, labour laws, etc.) have both external and internal sides since there are certain laws that affect the business environment in a certain country while there are certain policies that companies maintain for themselves: • • • •	*Environmental factors* (i.e. climate, weather, geographical location, global changes in climate, environmental offsets, etc.) are those that are determined or those that influence the surrounding environment: • • • •

Table 4.2 - PESTEL Template.

4.1.5 Value Chain Analysis

This strategic tool is used to analyze internal activities of a company, to record the most valuable activities as well as those that could be improved to provide competitive advantage. Michael E. Porter introduced a business strategy framework, the generic value chain model (see **Figure 4.2**) identifying five forces that prevents this understandable result: supplier power, threat of new entrants, threat of substitutes, buyer power and rivalry.

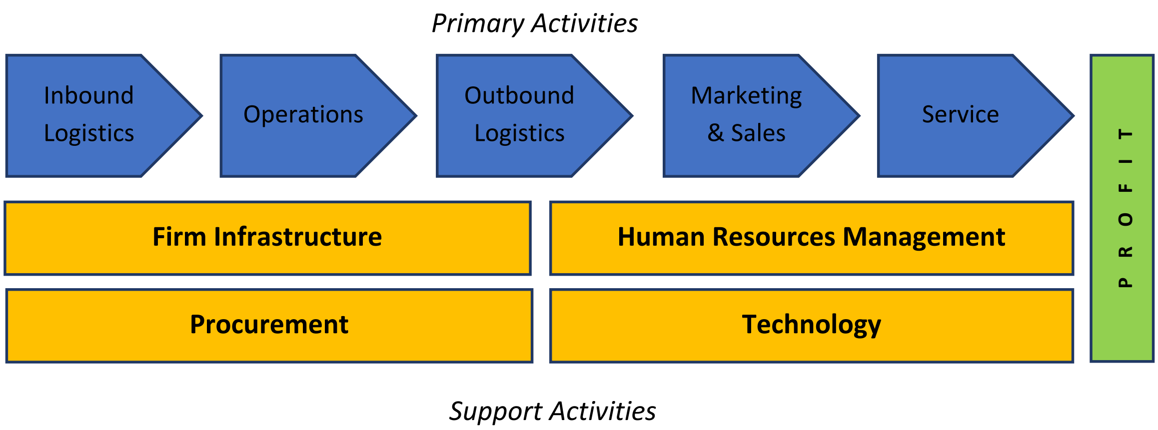


Figure 4.2 - Porter's Value Chain Model.

4.2 Analysis of possible businesses and stakeholders

For project team it is very important to identify key partners who share a common business, manage their needs and develop good cooperation with them, ensuring the successful outcomes for the project. It is necessary to understand motivations for pursuing project results of relevant stakeholders and target groups and to have a clear picture the way people engage with each other in order to be able to follow, obtain and preserve that possible cooperation and business opportunity. Note that detailed analysis and elaboration of stakeholders and markets will be part of WP7 work.

In general, stakeholders can be divided into primary and secondary stakeholders. Primary stakeholders are engaged in economic transactions with the business and usually they are internal (i.e., stockholders, customers, suppliers, employees, etc.). The secondary stakeholders are not directly involved in economic exchange with the business, however they are affected or can affect its actions (i.e., public, communities, business support groups, media, etc.). Specifically, Z-BREAK project will relate knowledge management with dissemination and exploitation of the project results as well as Intellectual Property Rights (IPR) for both internal consortium and external use and will be carefully focused at existing key stakeholders [157]. Also there are the interface stakeholders whose function is both internally and externally in relation to the organization (i.e. board of directors within the company) [158].

The strategy that Z-BRE4K consortium can follow is to aim at creating technical and business interest in the opportunities that project results create for industrial stakeholders such are: end users, IoT, EAM technology providers, integrators, maintenance consultants, etc. Key stakeholders have been identified using a business model Canvas, that could play an important role in the exploitation as well as in international market replication. Full range of potential users exists in manufacturing value chains as well as industrial and ICT/FoF R&D communities. Furthermore, the scientific and standardization communities are other groups to be targeted as well and the strategy is to aim and to highlight the Z-BRE4K validated results beyond the state of the art, including the results with potential for contribution to standards. Note, that this section consists of first discussions and recommendations of successful stakeholder analysis. Detailed work will be completed within the Task T7.4 Market analysis and segmentation, business modeling and it will be reported in the respective deliverable D7.4.

It is familiar that important stakeholders are involved in participation of EFNMS, Canada, USA, Brazil, Australia, Japan, South Africa and Middle-East. Many of them are experts and specialists in the Industrial Manufacturing and Enterprise Asset Management (IM/EAM) and IIoT domain such are:

- EFNMS European Federation of National Maintenance Societies,
- NMS - National Maintenance Societies,
- Maintenance consultants and CMMS/EAM integrators,

- GSMP - Gulf Society of Maintenance Professionals, SMRP - Society for Maintenance and Reliability Professionals,
- GFMAM - Global Forum of Maintenance and Asset Management, etc.

To reach various stakeholders and to highlight the Z-BRE4K impact, the project will perform extensive demonstration activities and several validations. This will provide data and feedback for the evaluation through iterative cycles: technical, stakeholders' acceptance, impact assessment while applying the reengineering to address the significant findings.

Z-BRE4K project introduced three end users and their complementary use cases in the deliverable D1.4 Z-BRE4K Use case demonstrating the potential and the full value of the project. As a holistic framework, this project addresses the predictive maintenance strategies for operation in high diversity of machinery (i.e., robotic systems, injection molding, stamping press, inline quality control equipment, etc.). It includes very challenging and critical manufacturing processes (i.e., multi-stage zero-defect adaptive manufacturing of structural light-weight component for automotive industry, highly automated packaging industry, short-batch mass customized production process for consumer electronics and health sector, etc.) and key economic European sectors with the strongest Small and medium-sized enterprises (SME) presence (i.e., automotive, food and beverage, etc.). Hence, the gained and obtained knowledge during the work in this project will be elaborated, examined in detailed and reported as the part of WP6 within the deliverables and D6.5 Consolidated Evaluation Report. Lessons learned and proposed demonstrators (deliverables D6.1 Demonstration Report on SACMI demo activities, D6.2 Demonstration Report on GESTAMP CHASSIS demo activities, D6.3 Demonstration Report on PHILIPS demo activities) within the project will be transferred to industry as the extreme value with the multiplication effect on a very wide range of stakeholders. Specifically, the analysis of the collected data will allow to take advantage of trends and assess of the Z-BRE4K effective operation and will present conclusions on the fulfilment of expected impact and stakeholders' expectations, such are objectives, effectiveness, reliability, efficiency, expectations fulfilment analysis and of social and economic impact on the manufacturing environment.

In general, there are many possibilities and various markets that can be considered where Z-BRE4K can offer the developed technologies. Such markets are: Manufacturing and Process Industries, Utilities (Energy, Water), Telecom, Food & Beverage, Transport, Process Monitoring, Manufacturing industries, Accommodation, Manufacturing, Manufacturing and Process Industries, Construction /Buildings, Maritime Transport, Maintenance and Inspection, OEM Designers, Process Monitoring, Manufacturing industries, Cloud Solutions, Inspection, Metrology, and Quality control, Food and Beverages and Packaging. For instance, when we are talking regarding the automotive sector and multi stage zero defect manufacturing of next generation within the sector, Automotive Intelligence Centre (AIC) as one of Z-Break project partners, has established strategic partnership with major stakeholders, including OEMs, Tiers, Tech Centers, etc. Furthermore, leading automotive companies have R&D units in AIC, including among others: GESTAMP (one of Z-BRE4K end users), ZF Lemförder TVA, Pierburg, CIE

Automotive, Maier or Tenneco among others. Also, within the IM/EAM markets, ATLANTIS, through their engagement in the Hellenic Maintenance Society (HMS) and the European Federation of National Maintenance Societies (EFNMS), has access to major industrial manufacturing players and stakeholders in Greece, in Balkans and in whole Europe. With strong background on ICT solutions: (a) INNOVALIA will focused towards manufacturing SMEs to support predictive maintenance smart services in automotive sector, (b) CORE on the application of classification, regression, and labeling techniques in order to identify trends and patterns among different types of data for industries like Manufacturing, Energy, and Transport and (c) HOLONIX will augmented the i-LiKe suite by introducing more functionalities provided through Z-BRE4K and support their customers and network which will benefit Z-BRE4K to realize the expected sales. Also, metrology market is a big market for next generation quality control where TRIMEK has already identified predictive and prescriptive maintenance possibilities.

4.3 SWOT Analysis for the Z-BRE4K project

SWOT analysis [156] is used to put into light the potential business opportunities and examine the potential opportunities and threats that Z-BRE4K project can face in the commercialization faze. Being aware of the current market trends, Z-BRE4K consortium can take advantage of this opportunity satisfying the customers' needs while supporting their values and motivations for increased reliability, availability, performance, quality, reduced accidents and reduced costs. The project will develop a holistic framework that can be used in new but also in existing manufacturing lines to achieve zero-unexpecting breakdowns and failures.

In general, maintenance is facing some very significant challenges to deal with the evolution of the equipment, instrumentation and manufacturing processes that should be supported. Preventive maintenance today should be designed for traditional highly repetitive and stable mass production processes based on predefined components since the machine behavior models are no longer valid. This leads us to the Z-BRE4K selling point and attractiveness to potential customers since main and more predictive, prescriptive maintenance strategies are needed.

Z-BRE4K solution consists of eight synergies which are going to be developed at component level that will interact between each other. These scalable strategies are going to be introduced in machine and system level to minimize errors and defects while improving the life system performance. Predicting and detecting fazes will activate the developed approaches, evaluating the impact of system level events that cause low performance, generating failures while increasing the cost.

Preventive maintenance strategies of Z-BRE4K project will impact the European manufacturing industry and society by increasing the in-service efficiency while reducing the accidents and provide new job opportunities as well. More specifically, the integration of the 8 strategies: (1) Z-PREDICT – prediction of the occurrence of failure, (2) Z-DIAGNOSE – detection of the current or emerging failure in early stage, (3) Z-PREVENT - prevention of failure occurrence, building up, or even propagation in the production system, (4) Z-ESTIMATE assessment of the remaining useful life of assets, (5) Z-MANAGE – coordination of the aforementioned strategies through event modelling, KPI monitoring and real-time decision support, (6) Z-REMEDIATE - substitute, reconfigure, re-use, retire, and recycle the assets, (7) Z-SYNCHRONISE - matching the remedy actions, production planning and logistics, (8) Z-SAFETY - preserving the safety, health and comfort of the workers, is very good selling point in the market similar systems.

	HELPFUL	***HARMFUL***
INTERNAL	**Strengths** • Innovative 8 scalable strategies • Data from machines and sensors automatically collected • Support multiple and disparate data streams from single/multiple manufacturing sites • Better and faster decision making in predicting • Better and faster early detection inefficiencies • Advanced data analysis (cross-comparison, correlation and root cause) • Open infrastructure with suitable interface to commercial platforms • Usage of Integrated Dynamic Machine Simulation	**Weaknesses** • Need to monitor multiple factors and events • More time spent onto studies for each application for Z-BRE4K's new prediction and simulation models • Individual studies respect to the target solution in order for Z-BRE4K models to be fine-tuned ad-hoc • Disjointed due to nature of the number of components to be monitored • Simulation burden & increased data storage needs

	HELPFUL	***HARMFUL***
EXTERNAL	**Opportunities** • Internet of Things (IoT) at shop-floor, enterprise and supply chain level • Autonomous decision making at nearly real time • Advance interface on the basis of diverse data streams and product / workstation models • Empowering operations personnel and manager to take a decision • Integrated approach for improving maintainability • Smart Manufacturing • Pioneers in the area of KPIs, Risk Assessment and FMEA maintenance • Implementation of collective and collaborative prediction models • Digitized production	**Threats** • Competition in solutions developed in other research projects (sections 2.2 and 2.3) • Manufacturers and designers not willing to share their data • Vulnerable to external influence and poor Predictive Capabilities • Slow adoption and acceptance of new maintenance procedures

Table 4.3 - SWOT & Potential business opportunities.

5 CONCLUSIONS

The current document (D1.2: Z-BRE4K State-of-the-Art analysis) reports:

- a survey with references about Digital Manufacturing Platforms has been provided (see Chapter 1);
- an analysis of new and past EU projects and initiatives related to Z-BRE4K (see Chapter 2);
- a review of products and technologies of interest recently introduced into the Digital Manufacturing market (see Chapter 3) and
- an analysis of the opportunities and threats oz Z-BRE4K's solution compared to the current State-of-the-Art alternatives (see Chapter 4).

Each chapter allows Z-BRE4K consortium to grasp insights and increase awareness on important facts that will turn useful in the following development of the project's activities. In particular:

- Chapter 1 stresses how machine learning is the key-enabler for predictive maintenance and identifies ANNs and SVMs as the most popular algorithms on which Z-BREAK may leverage; it also points out which are the most suitable architectural approaches to follow within the project and the extreme importance of realizing a flexible, modular and adaptive solution emerged (i.e., the Z-BREAK architecture must be able to easily adapt to all the considered use-cases and, especially, to those exploitable in the market by: allowing for both direct connection between the central data processing unity and sensors, or letting sensor able to communicate just locally, performing complex computation, machine learning and data analytics, both centrally and at the edge, etc.); in addition, it dwells on the possibility and opportunity for Z-BREAK of incorporating safety-risk indicators into sensor data (which are day-by-day increasingly more advances and accurate, as well as less costly) and on the importance to keep in mind a "human-centered" approach for the solution development;
- Chapter 2 lists the important organizations to consider as reference-guide in order to realize a solution that can be broadly adopted Europe-wide and provides description and analysis of projects related to Z-BREAK (both addressing predictive maintenance and leveraging on IoT technologies for other uses nevertheless exploitable within the project);
- Chapter 3 surveys the current technologies available in the market, near-future possible products and ongoing activities in different industrial realities: all the materials useful to target the right novelty contribution within Z-BREAK that should focus on innovative algorithms for complex computations (machine learning for advance prediction and inference) that still seems to lack or be in an early stage (current solution mainly consists in retrieving and normalizing data, displaying them via suitable report analytics and performing data processing for gradient check, linear regression, outlier detection or other analogous computation);
- Finally, Chapter 4 analyzes the possible exploitable markets for Z-BREAK and provides a detailed SWOT analysis for opportunities and threats paving the way for the work of towards exploitation and commercialization.

All the above important outcomes of this state-of-the-art work constitute the lighthouse for future development of the Z-BRE4K project.

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