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D5.8 Interoperability for M2M and HMI in factory environments II

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1 Executive Summary

COMPOSITION aims to develop an integrated information management system (IIMS) for the manufacturing industry which optimises the internal production processes by exploiting existing data, knowledge and tools to increase productivity and dynamically adapt to changing market requirements. This deliverable is part of work package 5, which is investigating the key enabling technologies for inter and intra-factory interoperability and is intended to act as an early guide and initial frame of reference. This report examines the human machine interface (HMI) and machine to machine interface (M2M) within the factory environment and the underlying opportunities and challenges.

The Industry ('Industrie') 4.0 working group has proposed a vision of the latest industrial revolution through the use of cyber physical systems. Factories will be capable of dynamically changing their business and engineering processes based on real time information at every level of the value chain. An important step in achieving this new factory model is to increase the interoperability between machinery and machinery (M2M) on the factory floor and also between human machine interfaces (HMIs). This report will utilise the methodologies of industry 4.0 as a reference.

This report outlines the challenges and value of information and communication technology (ICT) with respect to inter-operability. It describes the general emerging technologies in ICT today and how they will define the factory of the future. The next section then describes the methodologies and standards which are being used in the report. The new vision of a factory of the future through industry 4.0 is described in detail with respect to interoperability. The general reference architecture of a manufacturing plant is given with a brief description of systems that operate at each level. The machine to machine communication protocols that are used in manufacturing are described in detail. The strengths and weaknesses of each protocol are discussed and a comparison is made between the protocols. Furthermore a section on human machine interfacing HMI incorporating a scientific methodology of evaluation is provided. The common user interfaces used in industry today are discussed along with some emerging technologies which are expected to redefine what is expected from HMI. The last section discusses the use cases of the COMPOSITION project from the perspective of interoperability. Each use case is discussed briefly and accordingly a suggestion is made on the interoperability requirements.

2 Abbreviations and Acronyms

Acronym	Meaning
AGV	Automatic Guided Vehicles
ANSI	American National Standard Institute
B2MML	Business to Manufacturing Mark-up Language
BIM	Building Information Modelling
BMS	Building Management System
BPD	Business Process Diagram
BPMN	Business Process Model and Notation
CCTV	Closed Circuit Television
CCOM	Common Conceptual Object Model
CIP	Common Industrial Protocol
CMMS	Computerised Maintenance Management System
CPS	Cyber Physical Systems
CRC	Cyclic Redundancy Check
CRIS	Common Relational Information Schema
DCS	Distributed Control System
DSS	Decision Support System
DFM	Digital Factory Model
DLT	Deep Learning Toolkit
EMI	Electromagnetic Interference
ERP	Enterprise Resource Planning
GbXML	Green Building XML
HMI	Human Machine Interface
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information Communication Technology
IEC	International Electromechanical Commission
IEEE	Institute of Electrical and Electronic Engineers
IIMS	Integrated Information Management System
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Reference Architecture
ISO	International Organisation of Standardization
ISA	International Society of Automation
LAN	Local Area Network
M2M	Machine to machine
MAC	Media Access Control
MASON	Manufacturing’s Semantics Ontology
MES	Manufacturing Execution System
MESA	Manufacturing Enterprise Solutions Association
MRB	Material Review Board
MSDL	Manufacturing Service Description Language
NC	Non-Conformance
OEE	Overall Equipment Effectiveness
OGC	Open Geospatial Consortium
OGI	Oil and Gas Interoperability
OSI	Open Systems Interconnection Model
PCB	Printed Circuit Board
PERA	Purdue Enterprise Reference Architecture

PLC	Programmable logic Controller
PoE	Power Over Internet
PU	Production Unit
RAMI4.0	Reference Architectural Model for Industry 4.0
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
SCADA	Supervisory Control and Data Acquisition
SensorML	Sensor Model Language
SMEMA	Surface Mount Equipment Manufacturers Association
SPC	Statistical Process Control
SPD	Solder Space Deposit
SPI	Solder Paste Inspection
TCP	Transport Communication Protocol
UDP	User Datagram Protocol
WLAN	Wireless Local Area Network
XML	eXtensible Markup Language

Table 1. Table of Acronyms and Meanings

3 Introduction

The factory environment has an abundance of machinery and instruments to assist the manufacturing process. Each piece of equipment is often optimised for its individual task and can efficiently complete this task at a pace which meets the requirements for the plants manufacturing rate. A delay in the manufacturing process is often attributed to latencies and interruptions in the communication of information between machinery and also between machinery and factory staff. This makes the interoperability of machinery and staff on the factory floor a significant limiting factor in a plant's manufacturing performance.

The interoperability protocols in a factory must adhere to a number of requirements which are often far more stringent to standard interoperability requirements. The high cost of machinery in the factory demands long life cycles which leads to legacy equipment being a commonplace in the factory. These older legacy systems need to be integrated with newer systems and also with emerging systems. An interoperability protocol must be selected that caters for legacy, existing and emerging technologies. The rate of data transfer required in the factory environment is often significantly higher than at home or in the office. Complex control systems can at times demand a high data through-put and with low latency; a communication protocol that is capable of dealing with these transfer rates must be selected in these times. There are also instances when data throughput and latency is not of significant importance, a simple and easy to implement communication protocol suitable for the given task should be selected in this instance. At other times the safety of the information being transferred may be of critical importance and an appropriate communication protocol should also be selected for this instance. To ensure interoperability in a factory, a limited number of communication protocols should be selected, this allows enough flexibility to so that an appropriate protocol is used for each specific task while minimising complexity and reducing cost and effort of implementation. The interoperability protocol in a factory needs to consider the harsh environmental conditions that are present in a factory. The physical hardware needs to be able to withstand the mechanical shocks and variable temperature and humidity conditions which are common place in the factory environment. In wireless communication, Electromechanical Interference (EMI) and Radio Frequency Interference (RFI) can significantly affect data transfer rates.

Standards are a useful reference when developing an interoperability protocol in a factory. These are methodologies which are developed by non-profit organisations such as the International Electromechanical Commission (IEC) and International Organization for Standardization (ISO) which aid in the integration of different technologies by defining clear boundary conditions. They have been developed with compatibility in mind for both present and future technology. The equipment on the factory floor will often comply with a technology standard and similarly the communication technology interfacing with it will use a technical standard. In theory, these standards will be compatible, however this is not the case in practice and alterations need to be made.

3.1 Purpose, context and scope of this deliverable

The purpose of this report is to learn about the existing and emerging communication technologies being used in the factory environment. This information will be based on feedback from the industrial partners gathered through questionnaires, site visits and questions during partner meetups. A brief review of the use cases in the factory environment with regards to interoperability will form a base for the initial specifications.

COMPOSITION is a consortium of industry and academic partners who have aligned in order to implement the vision of Industry 4.0's factory of the future. The aim is to improve the agility and flexibility in modern manufacturing plants to achieve faster production, increased productivity, less waste and more sustainable production. The project aims to combine information in the value chain with information in the supply chain so to aid in business decisions. This is achieved by completing a number of parallel projects among the partners which include creating a digital automation framework, implementation of cross domain analytics, the development of a decision support system and by developing a system to connect factories and their stakeholders. This body of work is part of work package 5, which investigates the key enabling technologies and representations needed to enable efficient interoperability at all factory layers.

The scope of this document is the interoperability within the manufacturing environment. This is the communication between data gathering systems which are present at the lower levels of manufacturing plant system architecture such as control systems, manufacturing equipment, sensors and actuators. It makes brief reference to higher level systems such as the Manufacturing Execution Systems (MES) and Building Management Systems (BMS) for the purpose of giving context to the manufacturing environment.

3.2 Content and structure of this deliverable

This report begins with the benefits and challenges of ICT in the factory environment. A section is included which analyses the general system architecture of a manufacturing plant. A brief overview of the requirements and functionality of each system in the factory architecture is then given with a focus on the systems that communicate with the data acquisition systems being used in the factory floor. Section 5.2 discusses industry 4.0 with regards interoperability. The Open systems Interconnection model will then be described, this model characterises and standardises communication functions and will allow for the comparison of technologies. A review of the most common communication protocols for their suitability for use in a manufacturing plant is undertaken. This review includes the emerging communication protocols which may not yet be a viable commercial option however should be considered from an interoperability respect to allow for a long term solution. Furthermore section 5.7 gives an example of a commercially available industrial communication solution which includes wired and wireless protocols. Finally, an assessment of the interoperability based on the industry partners use cases and additional information from site visits, questionnaires and meet ups is undertaken in section 6. These use cases will be looked at from an interoperability perspective and a basic proposal given for the communication standard used for each. Section 7 outlines schematic based modelling and resource / device abstraction. The final section covers data security standards which also ties into T4.3.

4 Challenges and Value of ICT

ICT has been well integrated into the manufacturing process for a number of years. However, it has yet to maximise its potential as state of the art technology continues to be integrated into the manufacturing process. The goal of ICT is to seamlessly interconnect every step in the manufacturing process so that opportunities for optimisation are identified and actioned and anomalies detected.

Cyber Physical Systems such as wireless RFID tags can be used to track product and equipment, particularly mobile and portable devices and parts. Such systems can be used to more efficiently manage the supply chain in a company and also by the remote monitoring of work processes and flows in the plant. These devices can have a significant economic benefit to a manufacturing plant yielding reductions in fixed asset and in stock costs. A technologically advanced factory that has a well-integrated supply and value chain can have sustainability benefits. Well managed stock allows for minimisation of waste and encourages recycling in factories.

Cloud computing is facilitating the rapid growth of ICT in the manufacturing industry. It allows for customisable IT infrastructure that can guarantee reliability, security and performance. The powerful analytical capabilities of the cloud allows complex data analytics to be called upon when required in the factory environment by sharing computer processing resources. The large volume of data stored on the cloud can be used in factory process models and simulations that can be incorporated into manufacturing execution systems. These allow management to make more informed business decisions.

A well-structured ICT infrastructure can allow for easily reconfigurable facilities and systems. These are agile and are capable of ramping up production when required. Interoperability between equipment on the factory floor will minimise the risk of process delays through efficient communication of trends, anomalies and events. An easily reconfigurable plant also allows for flexibility in the manufacturing processing such that products can be manufactured based on individual customer specifications.

There has been a significant development in the way we interact with digital information through innovative developments in human machine interfaces (HMIs). Devices such as the smart phones, tablets and wearables allow factory staff and operators to interact with equipment or other staff much more efficiently than previously possible. This has a significant influence on the productivity of a manufacturing environment.

Automation of equipment in factory environment can reduce the need for an operator’s time and effort. This decreases the amount of monotonous tasks associated with equipment maintenance and operation. Significant changes in the socio economic status of employees is expected to occur where employees will be repurposed to a role in the company which will require creative manufacturing solutions.

Interoperability on the factory floor is a significant limiting factor when it comes to manufacturing productivity and reliability. If the information flow between manufacturing partners and the manufacturing process would become quicker and more reliable manufacturing quality would increase significantly. An important part of this information flow is the communication between the machines on the factory floor and the software being used by the manufacturing partners and this will be discussed in this report.

5 Methodologies and Standards

This section includes a paper based review of the methodologies and Industrial standards which govern the interoperability within a factory.

5.1 Manufacturing System Architecture

ANSI/ISA-95 is an international standard from the International Society of Automation (ISA) for developing an automated interface between enterprise and control systems (ISA, 2000), (ISA, 2001), (ISA, 2005). This standard has been developed for global manufacturers. It was developed to be applied in all industries, and in all sorts of processes, such as batch processes, continuous and repetitive processes. The standard uses hierarchy models that describe the levels of functions and domains of control which are based off the Purdue Enterprise Reference Architecture (PERA) and also the equipment hierarchical model from the IEC 61512-1 (ANSI/ISA-S88.01-1995) standard. The objective of the standard is to achieve consistent terminology that is a foundation for supplier and consumer communication and to provide consistent operations and information models which is a foundation for clarifying application functionality.

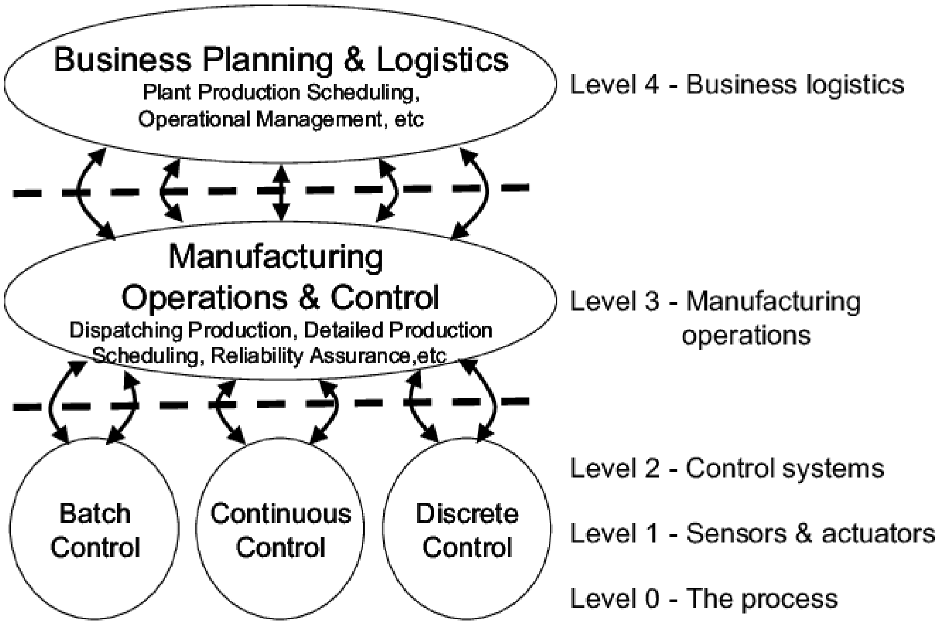

Figure 1. Layers of ISA95 Reference Architecture

Level 4 is managed by the ERP system in the plant; activities involve the collection and maintaining of raw materials and spare parts inventory, quality control information, machinery and equipment historical data and manpower use data for transmittal to personnel and accounting. It also modifies the plants schedule based on resource availability (PCS, 2017). Level 3 is managed by MES systems involving tasks such as variable manufacturing cost management, preforming off-line analysis, personnel functions management as well as detailed production scheduling. Levels 2, 1, and 0 are controlled using industrial control systems such as SCADA, PLC or DCS. They define the cell or line supervision functions, operations functions, and process control functions.

RAMI4.0 is the reference architectural model for industry 4.0. It is a three-dimensional map showing how to approach the issue of Industry 4.0 in a structured manner, ensuring that all participants involved in discussions understand each other. It is a service oriented architecture combining combines all elements and IT components in a layer and life cycle model. It breaks down complex processes into easy-to-grasp packages, including data privacy and IT security.

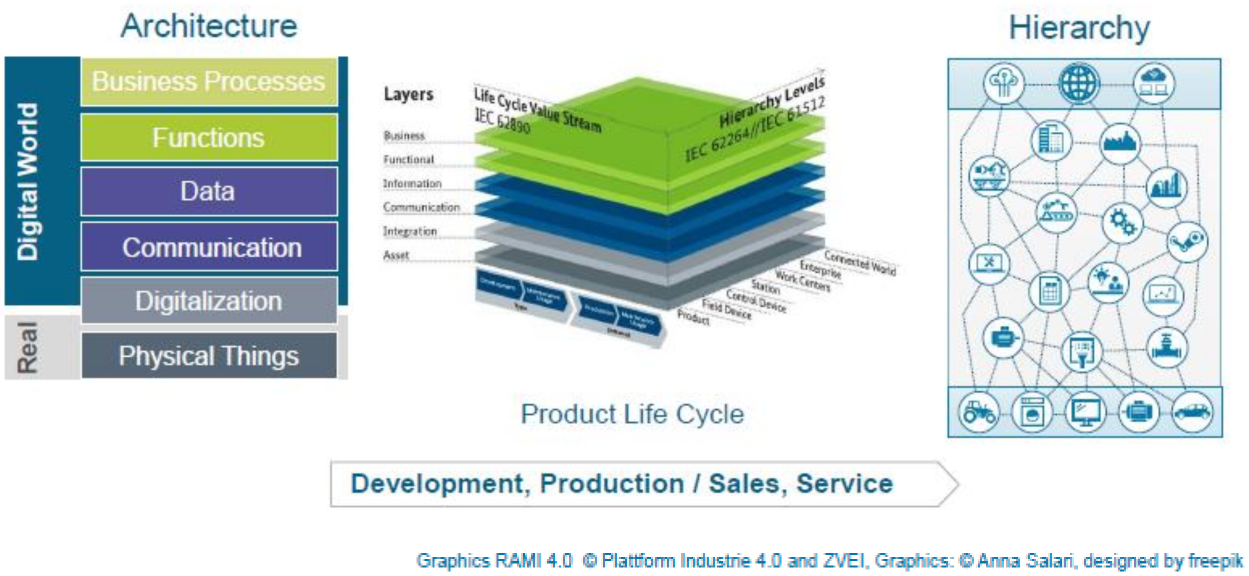

Figure 2 Reference Architectural Model for Industry 4.0

Key attributes include

- •Flexible systems and machines
- •Functions are distributed throughout the network
- •Participants interact across hierarchy levels
- •Communication among all participants
- •Product is part of the network

Details outlining the implementation of RAMI4.0 in COMPOSITION can be found in D2.3 – the COMPOSITION architecture specification.

Another common source of reference is **IIRA** the Industrial Internet Reference Architecture (latest version is v 1.8). First published in 2015 by the Industrial Internet Consortium Architecture Task Group this standards-based architectural template and methodology enables Industrial Internet of Things (IIoT) system architects to design their own systems based on a common framework and concepts and achieve the true promise of IIoT. It is a living document that will continually represent the latest thinking of the Industrial Internet Consortium and the IIoT community. IIRA addresses the need for a common architecture framework to develop interoperable IIoT systems for diverse applications across a broad spectrum of industrial verticals in the public and private sectors.

5.1.1 Control Systems

Industrial control systems are used frequently in industrial automation (B. Gal, G. Hal, 2014). These systems are generally seen at level 2 of the ISA95 reference architecture. A typical control system monitors the progress of parts through the manufacturing and finishing process. These control systems are receipt driven allowing the controls system to configure its operating parameters for each item being produced. These control systems have multiple HMI's and used for system monitoring and troubleshooting along with M2M interfaces for autonomous processes.

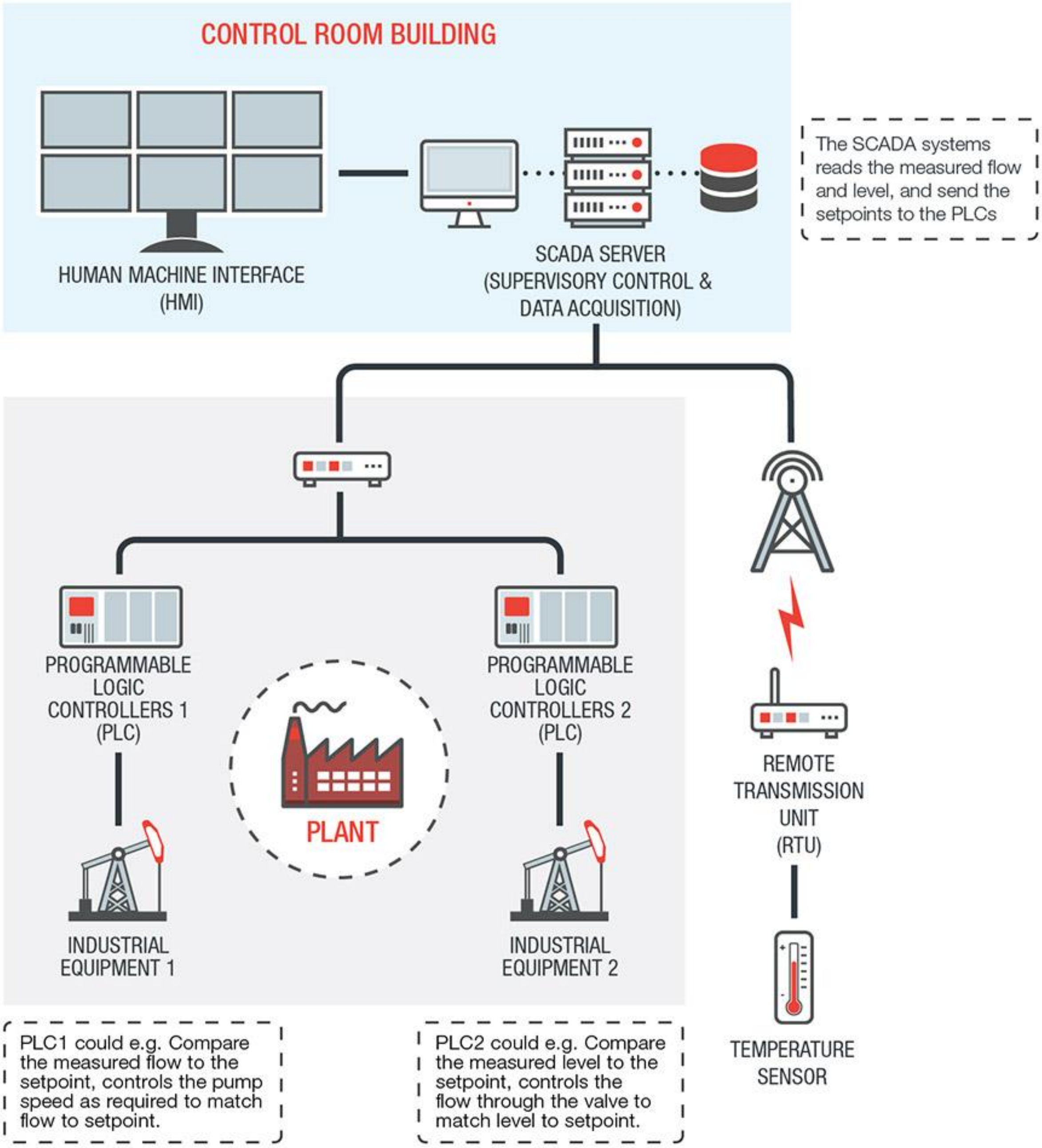

Figure 3 Example of a SCADA implementation

PLC's are specialised, computer-based, solid-state electronic devices that form the core of industrial control networks. They offer benefits through being easily programmed and reprogrammed; easily maintained and repaired; small in size, capable of operating within a plant and capable of communicating with central data collection systems. PLCs are available with a wide range of cost and capabilities. Modern PLCs have the ability to perform both binary and analogue input and output, as well as implement proportional, integral and derivative control loops. PLCs generally consist of a power supply, processor, input/output module and communication module. These modules are usually separate and interchangeable, especially in larger, more powerful PLCs. This modularity allows for easier maintenance, as well as greater flexibility of installation - more than one module of each type and modules with different functionality can be combined according to the requirements of the system to be controlled.

SCADA systems are a purely software layer, normally applied a level above control hardware such as PLC’s within the hierarchy of an industrial network. As such, SCADA systems do not perform any control, but rather function in a supervisory fashion. The focus of a SCADA is data acquisition and the presentation of a centralised HMI, although they do also allow high level commands to be sent through to control hardware - for example the instruction to start a motor or change a set point. SCADA systems are tailored towards the monitoring of geographically diverse control hardware, making them especially suited for industries such as utilities distribution where plant areas may be located over many thousand square kilometres. Another example of a software level control system is a Distributed Control System (DCS). The main difference between the two is that SCADA is generally event driven and DCS is process driven with a focus on presenting a steady stream of information.

5.1.2 Manufacturing Execution System

MES is a key component in manufacturing plant system architecture and manages most features of level 3 in the ISA 95 reference model. It is software that acts as a bridge between the manufacturing floor control systems and the ERP systems. An MES takes data from the control systems on the manufacturing floor and uses it to generate reports that show clearly production rate, quality of production and resource efficiency. There are a number of different types of MES’s available on the market (e.g. Siemens CAMSTAR, ORACLE NETsuite, IQMS and Fishbowl Manufacturing) and are generally tailored specifically for a manufacturing process. It should be noted that certain ERP systems come with an Integrated MES system.

An MES electronically manages all documentation for manufacturing activity to achieve a built in audit trail which can include electronic signatures and data collection validations. Scheduling is also managed by the MES in conjunction with the ERP. It can provide information about jobs in production, in queue or waiting to be scheduled. This allows a manufacturing manager to view in real time any potential bottlenecks in production and make appropriate changes. An MES will also provide cost analysis on the machinery production analysis and down time and generate OEE (Overall Equipment Effectiveness) reports. The MES flags operators for inspection of operations based on statistical process control (SPC). Non conformities in the process are tracked and recorded by the MES and analysed for trends. The MES generates a Device History Record (DHR) as the device is being processed which can remain associated with the product post production to ensure end to end traceability for the customer.

An example of a commercially available MES system is Camstar Manufacturing by Siemens. The MES system can be tailored specifically for manufacturing processes for medical devices, semiconductors and electronics. The medical devices tailored MES can assist with the production quality and compliance associated with this type of manufacturing. It can generate a self-auditing electronic Device History Record (eDHR) which is a valuable tool when manufacturing products. This is an important feature in a medical device manufacturing where compliance is such a significant issue and the cost of post-production failure is so high.

5.1.3 Building Management System

A Building Management System (BMS) is a common system in all manufacturing environments. It fits on level 3 of the ISA 95 reference architecture for manufacturing plants. A Building Management System (BMS) is an automation system which controls and monitors mechanical and electrical equipment of the facility itself. A BMS is both software and hardware: a very basic setup consists of a server with a database and a set of smart sensors connected to an Internet-capable network. Smart sensors around the building gather data and send it to the BMS, then data is stored in a database. Depending on the system, BMS software can be installed as a standalone application or it can be integrated with other monitoring programs. More advanced BMS can monitor and manage a wide range of building services across multiple platforms and protocols, providing facility administrators with a single, shared view of the facility's operation.

BMSs are a critical component to managing energy demand: an improperly configured BMS can even strongly increase building energy usage. In addition to controlling the building's internal environment, a BMS can be linked to access control (gates or doors controlling who is allowed access and egress to the building) and to other security systems such as closed-circuit television (CCTV) and motion detectors. Fire alarm systems and elevators are also usually controlled by a BMS for monitoring. The main functions provided by a BMS include lighting control, electric power control, heating, ventilation and air-conditioning (HVAC), security and observation, access control, fire alarm system, lifts and elevators.

The implementation of a Building Management System allows building owners to address all those concerns at one time, by combining various building management systems and services, considerably improving functionality and overall performance of those systems and integrating them into an enhanced IT infrastructure. So, it results in much lower operational costs and increased energy savings through automated energy conservation features. For instance, motion sensors can register when an area is unoccupied and turn off the lights and lower the temperature; late night cleaning crews can be monitored as they check in, and lights automatically turned on and off as they work through various areas of the building. With the use of IP networks, control is expanded, allowing users to adjust the settings of the building over their smartphone or tablet. Since they provide a unified operating environment, BMSis easy and cost effective to operate and maintain.

The BMS is of significance with regard to interoperability as it needs to communicate with a number of different systems to operate. These are generally using field bus protocols such as Modus or Profibus and also Ethernet protocols such as EtherNet IP and Profinet IO. This makes the building management system a significant gateway option for a sensor network to interface. For the COMPOSITION project, a proprietary BMS software developed by one project partner (NXW) has been adopted (Symphony BMS).

The first phase of COMPOSITION pilot deployments involved both BSL and KLE shop-floors. Sensors have been installed ad connected to the BMS for demonstrating use cases. The BMS provides a set of tools to collect and filter the real-time data incoming from the production facilities, moreover, through a component called Storage Handler, it provides a repository for information valuable to be kept during the whole machine lifetime as well. These raw measurements can also be enhanced by providing additional metadata to be attached to them, in case it should become necessary.

In order to be as much as possible compliant with existing standards (actual or de facto), the design choice has been to exchange field information between devices and BMS through the MQTT protocol and using OGC SensorThings format, and to implement a RESTful API that follows the specifications of "FIWARE-NGSI v2 Specification API " for accessing the storage.

For all these reasons, the BMS needs to pre-process the data that is flowing from the shop-floor, before it is ready to be exposed to the rest of COMPOSITION components. The specific set of devices supported for the first tier of use cases is:

- Vibration sensors, indicating the vibrations (acceleration) measured on each of the three axes (x, y, z)
- Fill-level sensors, indicating the level of the waste in bin containers
- Temperature sensors, indicating the temperature of the ovens
- Acoustic sensors, indicating the intensity of the loud measured on the ovens

Beside this last two set of devices, installed on BSL pilot, events regarding errors and breaks of the ovens are collected and exposed by the BMS as well, by receiving periodic logs from the ovens. Afterwards, such events are translated into information that are understandable by the rest of COMPOSITION modules (in particular by the DLT) and so then forwarded.

5.1.4 Enterprise Resource Planning System

Enterprise Resource Planning (ERP) software is used in manufacturing to manage administrative tasks. It predominantly manages the level 4 functionality in the ISA95 reference architecture model. An ERP is generally split into a number of different modules where each module focuses on one specific task within the business. The most common ERP modules include stock control, sales and purchasing, distribution, production management, marketing, accounting and Human Relations.

The major ERP suppliers include Infor, ORACLE and SAP. A manufacturing plant’s ERP system must be tailored for a business’ size, process and production volume. The Infor ERP software suite is developed for industries such as manufacturing, healthcare, wholesale distribution, fashion, hospitality, retail and the public sector. Infor differentiates itself from other providers through focusing on user experience and embracing future technologies such as machine learning. ORACLE is originated as a database supplier and has used its expertise in this area to make the move to enterprise source software. Through a series of acquisitions ORACLE has developed a large amount of knowledge in the engineering field. ORACLE has significant cloud based functionality which sets itself apart from other vendors. SAP is known as an extremely flexible ERP system that offers solutions for all sizes of businesses. It achieves this functionality through a number of third party add-ons which allows it to support a number of different industries.

5.2 Industry 4.0

Industry 4.0 (also called 'Industrie 4.0') is the latest standard in manufacturing as presented in figure 4, which uses smart products, procedures and processes to its advantage. It is a dual strategy approach which horizontally integrates through the value chain along with vertical integration and networked manufacturing systems. This is to allow for individual customer requirements, dynamic business and engineering process, optimised decision making and new ways of creating value and novel business models. If Industry 4.0 is to be successfully implemented, research and development activities need be accompanied with industry involvement. The Industry 4.0 working group believes that action is needed in the following areas so as to achieve this new type of smart manufacturing.

Standardisation and reference architecture is vital for this strategy to work. Industry 4.0 involves the networking and integration of several different companies through the value chain. This collaborative partnership will agree to a single set of common standards and follow the same reference architecture. A significant amount of planning is required to manage the more complex systems (FMER, 2013).

Methods and tools should be developed so as to manage large production and manufacturing systems. Safety and security are critical for the success of smart manufacturing systems. The production facilities and product must not pose a danger to the people or the environment. The data and information generated must be protected against misuse and unauthorised access. This is achieved by the deployment of integrated safety and security architectures and unique identifiers, together with relevant training and continuous professional development.

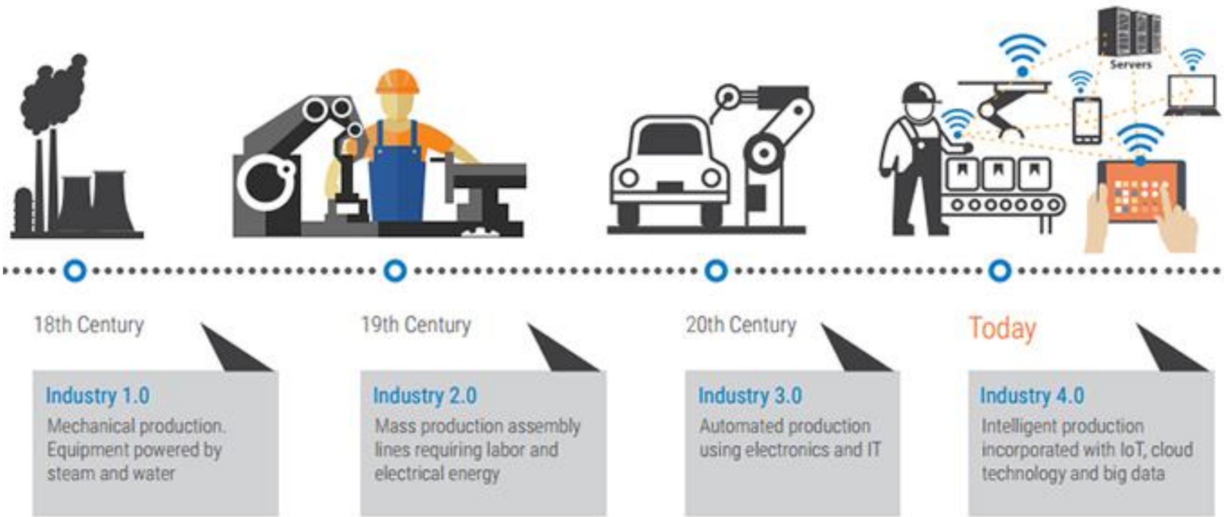

Figure 4. Industry 4.0

Conventional work organisation and design will change during the implementation of Industry 4.0. Increasing real-time oriented control will transform work content, work processes and the working environment. It will therefore be necessary to implement appropriate training strategies and to organise work in a way that fosters learning and work-place based continued professional development.

Regulatory framework will require significant alterations to meet the needs of Industry 4.0. Whilst the new manufacturing processes and horizontal business networks found in Industry 4.0 will need to comply with the law, existing legislation will also need to be adapted to comply with the law. Industry 4.0 will deliver gains in resource productivity and efficiency. To make Industry 4.0 a viable option for industry it will be necessary to calculate the trade-offs between the additional resources that need to be invested in smart factories and the potential savings generated.

A significant amount of academic research has been conducted on the implementation of Industry 4.0 (A. Sal, Y. Li, 2015). The Industry 4.0 working group describes the vision, the basic technologies and selected scenarios of Industry 4.0 but does not provide a clear definition. Academic groups have aimed to address this by publishing papers on the principles for Industry 4.0. Based on a qualitative text analysis and qualitative literature review 4 design principles have been identified. These include interconnection, information transparency, decentralised decisions and technical assistance. For connecting machines, devices, sensors and people with each other, common communication standards are of great importance. Due to the increasing number of interconnected objects and people, the requirement for new forms of information transparency is increased. To analyse the physical world raw sensor data must be aggregated to higher-value context information and interpreted. Decentralized decisions is an important part of the Industry 4.0 roadmap watch. Their embedded computers, sensors and actors allow for monitoring and controlling the physical world autonomously. In the Smart Factories of Industry 4.0, the main role of humans shifts from an operator of machines towards a strategic decision-maker and a flexible problem solver.

5.3 Monitoring and Control Methodologies and Considerations

There are many ways in which sensing, monitoring and control systems can gather data and convert where appropriate to information, prompts/alerts, actions, etc. through HMI or M2M. The following is a high level description of such functions and related considerations is described in this work. Of course any given system needs to be supported by models and decision support systems (DSS) to take context into account, convert data to information and determine next steps. This becomes clearer when each use case is examined.

Sensory Data: In many cases equipment and infrastructure will have built in sensors (e.g. temperature & airflow in HVAC) so where possible this should be captured and fed into the DSS & control systems along with any data from retrofitted sensors. Wireless sensors are particularly useful for retrofitting on, in or near equipment and infrastructure in order to capture missing data or improve granularity (e.g. temperature distribution across a given area rather than a 'spot value').

Context & Data Fusion: Frequently contextual data from other sensors gives a very good indication of whether actions are required based on data accumulated. For example, a machine will consume different amounts of energy at different operating conditions (load, belt speed, temperature) so looking collectively at the data from multiple sensors at a given point in time can give good insight. Similarly, historical data can help with the DSS, for example changes in temperature values over a given period when a heat/cooling cycle is activated versus past production cycles, or how many parts were processed versus a previous production cycle. The DSS also needs to understand how data should be analysed in terms of thresholds & variations/drift so historical data can prove extremely useful in determining such parameters using data mining techniques. Reference baseline data may also be available from suppliers of equipment and/or from maintenance service providers.

Status: In many cases an absolute value is not required, just a status. Some examples (i) It is sufficient to know whether a machine is on/off or which operational mode it has been set to? (ii) Is there a person near a machine? (iii) Is a door or window open or closed? (iv) Is a fan on or off? There are many types of sensors that can capture such data and in many cases the data is contextual and used as part of the DSS.

Alarms: In cases where data indicated anomalies are detected, the system needs to know how to create prompts and determine if alerts and/or actions are required. This can be done automatically through M2M or through HMI whereby an operator receives an alert and is prompted to take corrective action. The DSS needs to determine the urgency and immediacy required, e.g. a temperature or energy consumption value that is slowly drifting outside norms but not immediately impacting yield or quality that perhaps indicates some predictive maintenance at some near future date versus a machine malfunction whereby there is a safety issue or the production line is stalled. The overall HMI system also needs to be assessed to determine how such data is transmitted and visualised (mobile phone, computer screen, machine display (colour coded?), flashing light, klaxon, etc. so that the respondent understands what actions are required.

Security & Privacy: The infrastructure for capturing data needs to be assessed holistically to ensure the risk of cyber-attacks is eliminated whereby data is corrupted/falsified and/or control systems hacked. Again, the DSS should be able to identify any attacks based on anomalies seen in data and/or alarms/alerts/control actions taken. Data captured may also be sensitive to the manufacturer (yield, finance, vendors, throughput, etc.) or employee (location & movement, activity level, visual data) so it needs to be clear to all how it is captured, stored, anonymised, aggregated, etc.

Latency & Redundancy: Some (particularly health and safety) use cases require 100% guarantee that the data is received and acted upon immediately (e.g. fire alert in a building - there needs to an immediate transmission of data, acknowledgement of receipt of data, alarm triggering, corrective action taken, etc.). In other cases it is less critical, e.g. if temperature is being measured in an office area every 10 mins and fed to a HVAC system and a couple of data points are lost during the day it is not critical. For wireless sensors, it is particularly important that the simplest possible system is used in order to minimise power consumption and battery life and maximise the likelihood that energy harvesting can be used. For example, it may be sufficient to capture temperature data every 10 mins but only transceive every hour except in the case where a temperature difference of say >2 ºC is detected in a given interval. The sensory infrastructure, scalability, level of redundancy and latency needs to be carefully considered in advance based on the application need.

RFID systems: In addition to sensors RFID system (Radio Frequency Identification) can also provide useful information (OPA, 2004), particularly on portable and mobile high value assets. RFID is an automatic identification technology that can be used to provide electronic identity to an item or object. Tags, reader(s), antennas and a computer for data processing are the basic components of a typical RFID system. RFID uses electromagnetic fields to automatically identify and track tags attached to items. Nowadays, RFID middleware frameworks (Prabhu, 2006) are used in tracking applications. RFID middleware is software which facilitates data communication between automatic identification physical layer and applications. These frameworks provide distributed environments to process tags' data and route them to backend applications. RFID data can be part of the contextual data supplied to the DSS. For example, for use case UC-BSL-3 if a reel of components being moved is co-incident with a prompt on the system for a reel of such parts to be replenished on a production line (ref D4.6 for further information).

5.4 Open Systems Interconnection Model (OSI)

The OSI Model or ISO/IEC 7498-1 is a model used for defining digital communication; it was developed by the OSI project. It splits up digital communication in a generalised way which can be applied to all types of digital communication. The model divides a communication system into seven layers to split up the function of data communication. The seven layers of the OSI model each have their own specific functionality; each layer passes data to the layer below it and receives data from the layer above itself on the stack. The bottom layers of the model relate to the physical transfer of data (e.g. routers, wires, repeaters) while the upper layers relate to the user application. Another method for defining digital communication is known as the Internet protocol suite or TCP/IP which is based on RFC 1122 and provides a similar conceptual model. However it does not include the physical layer and merges the application, presentation and session layer.

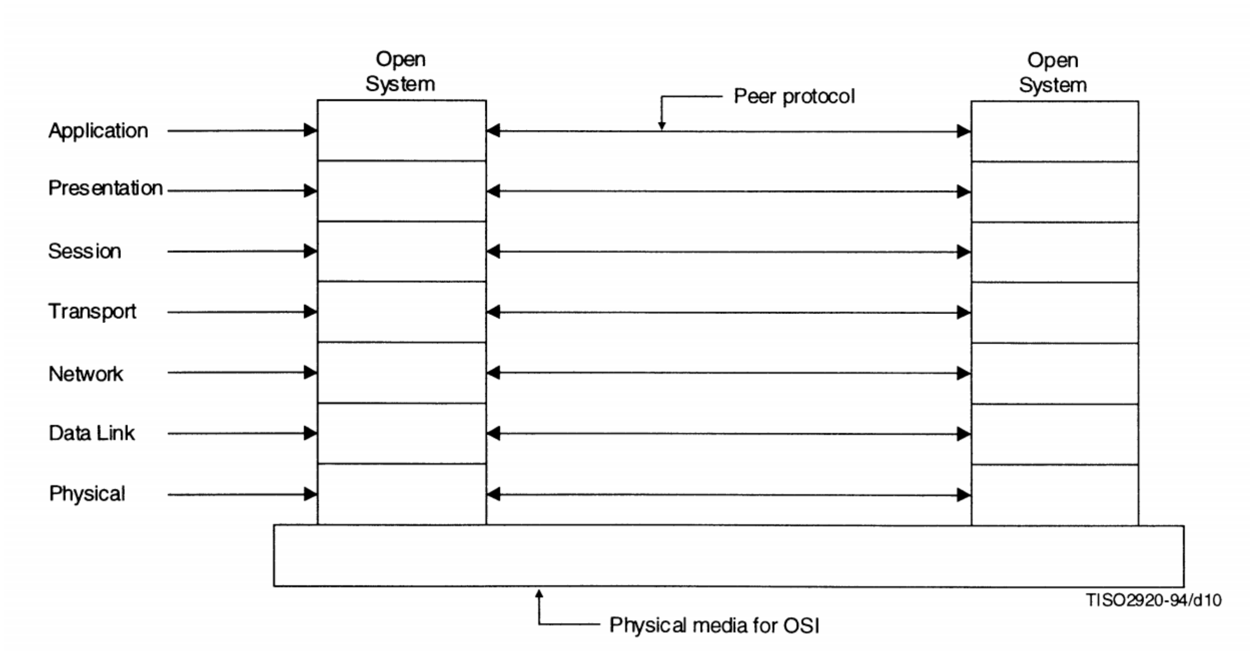

Figure 5. Layers of the OSI communication Model

The application layer is the scope within which applications create user data and communicate this data to other applications on another or the same host. Application layer protocols generally treat the lower layers as black boxes which provide a stable network connection across which to communicate and are usually only aware of key information such as IP addresses and port numbers. Higher level application architecture models such as client-server models and peer to peer networking are implemented in this layer.

The presentation layer converts data into the form that is accepted by application layer. It provides independence from data representation by translating between application and network format. It is in this layer where encryption occurs. The session layer controls connections between computers. It establishes, manages and terminates connections between the local and remote application.

The transport layer performs host-to-host communications. It is responsible for end to end message transfer independent of the underlying network. Other tasks such as error control, segmentation, flow control and segmentation are also handled at this layer. Communication can be categorised as connection oriented where a semi-permanent connection is established (such as TCP) or connectionless such as with UDP communication which individually addresses all datagrams.

The internet layer has the responsibility of sending packets of data across potentially multiple networks. It is responsible for unreliable communication between hosts and is therefore dependent on the transport layer for end to end message transfer. Its functions include host addressing and identification which is accomplished with a hierarchical IP addressing and packet routing which involves sending of datagrams from source to destination by forwarding them to the next network router closer to the final destination. The internet protocol version 6 (IPv6) is the principal component of the internet layer, and it defines two addressing systems to identify network host computers and to locate them on the network.

The link layer is used to move packets between the Internet layer interfaces of two different hosts on the same link. The processes of transmitting and receiving packets on a given link can be controlled both in the software device driver for the network card. These perform data link functions such as adding a packet header to prepare it for transmission, and then actually transmit the frame over a physical medium. The OSI model includes specifications of translating the network addressing methods used in the Internet Protocol to link layer addresses, such as Media Access Control (MAC) addresses.

The physical layer defines the electrical and physical specifications of the data connection. It manages the transmitting of raw bits rather than logical data packets over a link connecting network nodes. It specifies the shape and properties of the electrical connectors, the frequencies to broadcast and the modulation scheme to use. It also contains specifications for networking hardware which includes network interface controllers, repeaters, Network hubs, modems and Fibre Media converters.

5.5 Communication Protocols

This section describes the common Machine to Machine (M2M) communication protocols used in manufacturing plants. This communication occurs between devices on the lower levels of ISA reference architecture 95 (Level 0, Level 1 and Level 3, presented in figure 1). They include both wired protocols (EtherNet/IP, ModBus, CIP, Profinet/IO, EtherCAT, DeviceNet, ControlNet) which are generally based on the Internet protocol suite and wireless protocols (Wireless Local Area Network (WLAN), ZigBee, Bluetooth, EnOcean, Wireless HART and ISA 100). M2M applications involve transmission of event data from end nodes (such as a sensor or a meter), through a network, to a software application which use these data. This communication is accomplished by using a remote network of machines relaying information back to a central hub and then processed information is rerouted into a personal computer.

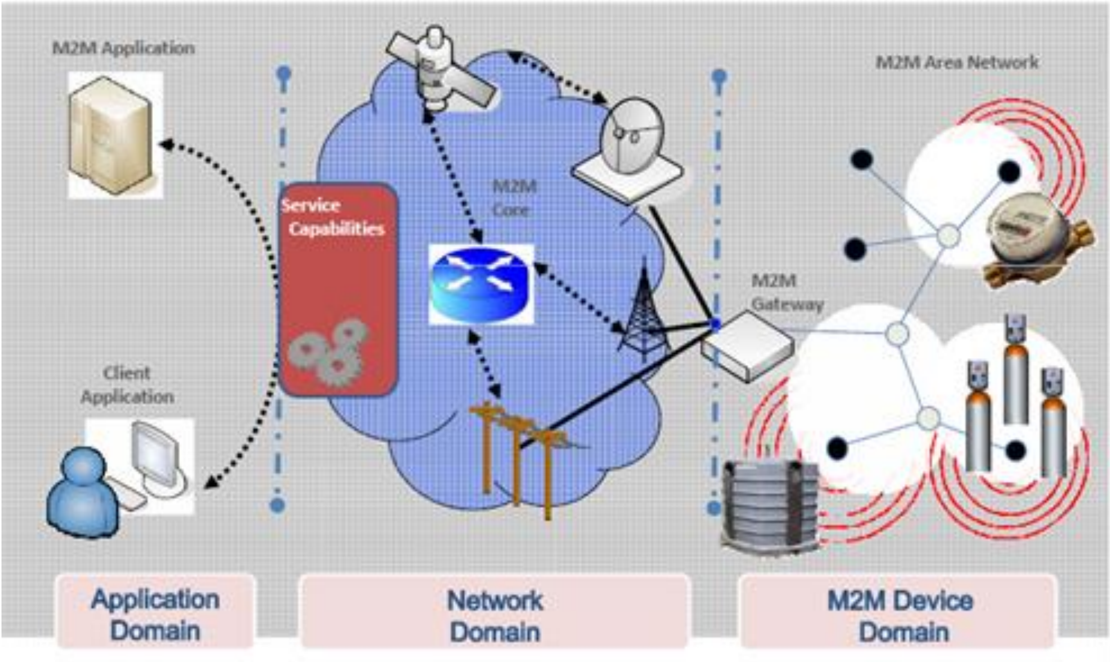

Figure 6. Example of use of Communication Protocols

Modern M2M communication has changed into a system of networks that transmits data to personal appliances. M2M communication has become quicker and easier due to the expansion of wireless networks around the world. Today, M2M solutions are deployed in many sectors due to the evolution on wireless networks, sensors and computer capabilities:

Manufacturing and Inventory Control: Factories use smart labels and RFID tags to track goods through the production process. Data from scanners is transferred to servers and applications, helping to monitor inventory turnovers and production yields.

Environmental Monitoring: Sensors measure physical attributes such as temperature, light, noise, wind speed, air quality and transfer these data to servers for use in a wide range of applications such as weather and physical phenomenon predictions, smart energy buildings and alarm systems.

Vehicle Systems: Due to high levels of embedded ICT, applications for vehicles maintenance, safety and repair have increased significantly. The information from a vehicle is continuously collected and transmitted to vendors' servers using M2M communication systems.

Based on feedback for industry partners there are often too many standards implemented in the factory environment. Standards were often introduced on an ad hoc basis with no systemic approach for installation, operation and maintenance. Unstructured communications architectures can decrease factories flexibility, increase latency between systems and increase the security risk in a factory. It is for this reason that a communication standard should be developed for a factory which is carefully thought out based on the current state of the art technology and emerging technology. This is one of the key drivers of industry 4.0.

5.5.1 Fieldbus

This is most widely used type of serial communication protocol in all of industrial automation. It is commonly used at the lower levels of the ISA95 reference architecture. Fieldbus is a very simple-to-understand and easy to implement communication protocol. Field bus is implemented using a single wire making it very is simple and robust. Its advantages are its easy deployment and maintenance. Limitations of fieldbus include the limited number of data types which can be sent and the requirement for contiguous transmissions.

Modbus ASCII is a common fieldbus communication protocol which makes use of the compact, binary representation of data for protocol communication. It is the simplest version of the Modbus protocol which typically runs on the RS-232 or RS-485 physical layer. Other versions of Modbus include Modbus RTU and

Modbus TCP/IP. It is an open protocol so it is freely available to use. All slaves are polled on demand by the master meaning there is a maximum of 247 addresses. It uses a longitudinal redundancy check checksum. The data transfer rate of Modbus ASCII depends on the baud rate which is typically 19.2kbit/s.

Profibus is another commonly used field bus communication standard. It was designed in 1990 making it a much newer protocol. It also has a number of different variations such as Profibus DP and Profibus DB. Profibus DP can achieve maximum speeds of 12Mbit/s and Profibus PA can achieve speeds of 32.2 Kbit/s. Similarly to Modbus it is a master/slave type communication but Profibus uses an additional token ring to allow for multiple masters. Profibus also has additional features like a start-up sequence when new devices join the network. The ability for slaves to give diagnostics is also a feature which has been built into Profibus where each slave can alert its master of diagnostics. Another notable feature of Profibus is the immunity of the physical layer to electromagnetic noise through modified RS-485.

5.5.2 Industrial Ethernet

Ethernet is now common place in the home or office. However, Industry demands a higher level of determinism and reaction times than that which is available from the common TCP/IP standard of Ethernet. The transmission rates of industrial ethernet protocols is affected by a number of different factors however 100Mbit/s is the most popular speed used in industrial Ethernet. Industrial Ethernet protocols often make adoptions to certain layers of the TCP/IP model in order to achieve very low latency and deterministic responses. The most useful feature of Ethernet over fieldbus communication is the flexible network topologies and increased number of nodes in the system.

Ethernet/IP is an application layer industrial network protocol which sits on the TCP/IP stack in a similar way to other protocols such as ControlNet and DeviceNet. It utilises the object oriented common industrial protocol (CIP) where each object has attributes (data), services (commands), connections, and behaviours (relationship between attribute values and services). This protocol was specifically designed for industrial automation and offers a complete set of messages and services for manufacturing automation applications such as control, safety, synchronisation, motion, configuration and information. The advantage of EtherNet IP is improved response times and greater data throughput than DeviceNet and ControlNet. The fact that Ethernet/IP utilises CIP increases its compatibility with other equipment. Another benefit of using Ethernet IP is the large support network that comes with using ODVA (a global association whose members comprise the world's leading automation companies) technology. A dis-advantage of Ethernet/IP is the difficulty and cost of implementation.

Profinet IO offers a number of different variations of its technology including Profinet Real Time (Profinet RT) and Isochronous Real Time (Profinet IRT). Profinet RT offers similar performance to Profibus and can achieve cycles times is the range of 10ms. Profinet IRT introduces the use of special hardware in order to achieve sufficient performance and synchronicity for motion control applications and can achieve cycle times in the sub ms range. Profisafe is another Profitnet protocol which fulfils the requirements of black channel safety protocol which can be used to protect sensitive data. An advantage Profinet has over other technologies includes its compatibility with Siemens and General Electric. Profinet has also been described as a more deterministic communication protocol when compared against other vendors. The disadvantage of Profinet protocols is the expensive cost associated with the specialised switches.

5.5.3 Wi-Fi

IEEE 802.11 is a standard which defines a set of physical layer specifications for implementing a wireless local area network computer communications in the 900MHz and 2.5, 3.6, 5 and 60GHz frequency bands. They are created and maintained by the Institute of Electrical and Electronics Engineers (IEEE). WLAN has a range of 200 metres in the 2.4 GHz band and some 50 metres in the 5 GHz band (802.11a). Data throughput of 11 to 300 Mbit/s gross can be achieved by the standard. A benefit to using WLAN is the high availability in consumer products which include personalised HMI via smartphone or tables. Operating systems such as Apple iOS, Android or Windows allow for simple development using WLAN

WLAN is well suited for monitoring, configuring and data acquiring, but can also sometimes be used for time critical control. Furthermore, the built-in roaming functionality is useful in factory automation applications with moving devices. Implementing Wireless LAN in these types of applications often requires customized solutions such as tailored or proprietary roaming software as well as frequency planning and specific installation means. With these tailoring of the wireless solution, one achieves stabile latency and low roaming hand-over delays

5.5.4 IEEE 802.15.4 Standard

The IEEE 802.15.4 is a standard for low complexity, low cost, low power consumption, and low data rate wireless connectivity among devices. The communication protocols in this standard can achieve data transfer rates of 800kbit/s over a 10 metre range. The first release of the IEEE 802.15.4 standard was delivered in 2003 and was revised in 2006. Its protocol stack is simple and flexible, and does not require any infrastructure. This standard forms the basis for protocols such as Zigbee, ISA100, Wireless HART, MiWi, and SNAP specifications.

The low power consumption of this standard makes it reasonably suited for battery operated devices when compared with several other protocols. However, battery life remains a major impediment for wireless devices with parts typically requiring battery replacement every few months. The technologies are mostly used in applications such as energy monitoring, process data collection and building automation where data rate capture demand is low and transceiving is of use, particularly where some latency can be tolerated. For example, the transceiver & microcontroller can be put into sleep mode (10s of uW) for much of the time for a temperature sensor measuring once every 5 mins and requiring < 1 second of wake up and transceive time. It is less suited to high data applications such as video surveillance. The mesh network functionality makes it capable of covering wide areas when there are no requirements on low latency but this has impact on battery life particularly if attempts are made to create a large-scale deployment.

ZigBee is a higher-level protocol used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection. The IEEE 802.15.4 standard only defines the physical and MAC layers without specifying the higher protocol layers, including the network and application layers. The ZigBee standard is developed on top of the IEEE 802.15.4 standard and defines the network and application layers. The network layer provides networking functionalities for different network topologies, and the application layer provides a framework for distributed application development and communication. The two protocol stacks can be combined together to support short-range low data rate wireless communication with battery - powered wireless devices.

Wireless HART was designed based on a set of fundamental requirements: it must be easy to use and deploy, self-organizing and self-healing, different applications, scalable (i.e., fit both small and large plants), reliable, secure, and support existing HART technology. It is based on the PHY layer specified in the IEEE 802.15.4 in a similar fashion to ZigBee but specifies new Data-link, Network, Transport, and Application layers. It should be noted that both Wireless HART and HART are compatible at transport and application layers. Wireless HART is a Time Division Multiple Access (TDMA) based network in that all devices are time synchronized and communicate in pre-scheduled fixed length time-slots. It also implements frequency hopping spread spectrum which allows it to hop across the 16 channels in the 2.4GHz frequency band. Wireless HART has advantages over other protocols in its low susceptibility to self-interference through the use of frequency hopping and retransmission limits.

5.5.5 EnOcean

The EnOcean communication standard is a proprietary technology where EnOcean has developed a communication protocol to be used in conjunction with their energy harvesting devices. There is interoperability between EnOcean Alliance Equipment and ZigBee but a gateway is required for both protocols to be used. The International Electro technical Commission (IEC) has ratified a new standard ISO/IEC 14543-3-10 for wireless applications with ultra-low power consumption. It is the first and only wireless standard that is also optimized for ambient energy harvesting solutions. It is optimised for use in building and industrial automation applications.

The standard operates at 868MHz for Europe, 902MHz for North America and 928MHz for Japan. This frequency band avoids the busy networks such as the 2.4GHz ISM band. This lower frequency band allows for better penetration of objects and a longer range (30m indoors). It has an effective transfer speed of 125kbit/s. The standard utilises an 8 bit Cyclic Redundancy Check (CRC) as a data integrity method to ensure a sub telegram has arrived intact. It also uses a listen before talk feature where a repeater senses its wireless environment before transmitting. This helps avoiding collisions with other senders.

5.5.6 Bluetooth

Classic Bluetooth technology (IEEE 802.15.1) is well suited for wireless integration of automation devices in serial, fieldbus and industrial Ethernet networks. Bluetooth technology is specified for devices with high demands on small footprint, low power consumption and cost-efficiency. Compared to Bluetooth low energy, Classic Bluetooth is preferred in an application where streaming data is used as the latter achieves substantially greater throughput. Classic Bluetooth offers a range of 10 metres up to 1km. Cyclic and fast transmission of smaller data packages achieve a data throughput of maximum 780 kbit/s gross. Security features with 128-bit encryption that offers protection against data eaves dropping. Bluetooth offers robust features such as Adaptive Frequency Hopping (AFH), Forward Error Correction (FEC), narrow frequency channels, and low sensitivity to reflections multi-pathing. Similarly to WLAN there is a high availability in consumer products which are compatible with Classic Bluetooth technology.

Bluetooth also offers a low energy technology known as BLE which is ideal for applications requiring episodic or periodic transfer of small amounts of data. Bluetooth low energy is especially well suited for sensors, actuators and other small devices that have a limited power source, high numbers of communication nodes with limited latency requirements. Similarly to ZigBee it has a very low power consumption through shortened wake-up and connection times. It has a robustness equal to Classic Bluetooth technology while also providing good real-time features (if a small number of nodes are connected).

5.5.7 AMQP

The Advanced Message Queuing Protocol (AMQP), ISO/IEC 19464:2014, is an open standard application layer protocol for message-oriented middleware. While not a light-weight protocol like MQTT, AMQP allows for a variety of message queuing and routing patterns (including publish-and-subscribe) while stressing reliability and security. AMQP declares a model, protocol methods, format (application payload is opaque to the broker, however) and type system that broker and client implementations must conform to for different implementations to be interoperable. Both versions 0-9-1 and 1.0 are supported by a number of software vendors. In COMPOSITION the Message Broker[1], which builds on the widely used AMQP 0-9-1 implementation RabbitMQ with extensions developed by the project, will manage the AMQP and MQTT protocols.

5.5.8 MQTT

MQ Telemetry Transport or Message Queue Telemetry Transport (MQTT), ISO/IEC 20922, is a simple, lightweight protocol running on TCP/IP using a publish-subscribe model. It is designed to minimise network bandwidth and device resource requirements, making it very suitable for collecting data from edge network devices like sensors. Implementations of MQTT brokers and clients are available on multiple platforms.

5.5.9 OPC-UA

OPC Unified Architecture (OPC UA), IEC 62541, is an open, SOA-based, platform-independent machine to machine communication protocol for industrial automation. RAMI4.0 has OPC-UA confirmed as an appropriate design mechanism for the Communication Layer. It is a multi-part specification defining e.g. an Information Model, Services and Security Model. MQTT and AMQP are a part of the OPC UA PubSub specification[2]. There is both a binary and HTTP protocol specified for communication. A connector to OPC-UA has been developed by COMPOSITION. The responsible development stakeholder is a member of the OPC-UA Foundation, which allows use of OPC Foundation source code in commercial products and Distribution of OPC Foundation source code.

5.5.10 Comparison of Communication Protocols

On deciding on a communication standard for a factory environment it is first necessary to discuss the communication requirements in a factory environment. These requirements are expected to be quite different to that of the office or home environment. The application is also an important factor which must be considered when deciding on a communication protocol as certain scenarios demand different requirements. It is best to minimise the number of communication protocols used in the manufacturing environment so as to achieve a non-complex flexible commutation system. However, the standard of communication should not be jeopardised by doing this.

[1] The Message Broker is described in deliverables D6.1 and D6.2

[2] https://opcfoundation.org/developer-tools/specifications-unified-architecture/part-14-pubsub

Interoperability is the ability of a communication protocol to communicate with other communication protocols. This is the most important requirement for a communication protocol in a factory and communication protocols with poor interoperability should not be considered in the factory environment. However, there are certain instances where communication protocols are required which have very low interoperability. This generally occurs during extreme scenarios when communication needs to done at extremely long length, at extremely high speed, for extreme data safety or for extremely low power consumption. In table 2 below, a low score indicates a proprietary communication protocol with little to no ability to interface with other protocols without the use of a gateway device. A high score indicates a communication protocol which adheres to an international standard closely to ensure interoperability with other protocols.

Reliability of data is one of the most important factors when deciding on a communication protocol in a factory. Industrial Ethernet protocols have better determinism than fieldbus technologies due to more stringent data checking. The durability of the physical layer is a significant factor of a wired communication protocol. Wireless communication on the other hand needs to deal with RFI and EMI which can cause data packets to be lost. Lost data packets can cause significant effects due for example to the shut-down safety functionality of time critical industrial machinery in the event of a communication delay or interruption. In the table below, a low reliability score means a communication standard where the probability of a datagram being lost in transmission is low. A high score indicates a communication protocol where a number of checks are conducted to ensure that all data is transferred reliably.

Data Transfer Rate is an important figure of merit when determining the speed of a communication protocol. The response is the time that it take for a device to send a request and receive a response. Industrial Ethernet protocols such as Profinet or EtherNet I/P have made adaptions to the MAC layer so as to achieve response times in the sub ms region. These speeds are sometimes required for applications such as complex motion control in robotics. Wired communication has faster response times than wireless communication making wireless more suitable for monitoring and non-critical control.

Maintenance The maintenance requirements of wireless communication are a lot more stringent than wired communication. Wireless communication networks have less hardware that needs to be monitored. The health and safety risk associated with frayed wires can be more significant in the factory environment where there may be flammable materials present. International Standards such as IEC 60079-0 can be used as a guide for the maintenance of wired systems against corrosion, wear and tear. A low score indicates a communication protocol where frequent maintenance checks are required to prevent the failure of the communication standard or a health hazard. A high score suggests a wireless protocol which can be implemented and left alone with no fear of failure in the future.

Implementation of wired commutation is significantly more challenging to implement than wireless communications. The cost of cabling and power supplies prevent wired communication being a viable option when a few devices are located far away from each other. Battery powered transmitters require no wired infrastructure or local power supply so they can be installed in locations where cabling would be too expensive. Wireless has the advantage in that it is easy to expand and accommodate changes, re-configurations and additions. Wireless communications also allow for a more flexible communication network. This is true for both green field capital (factory) projects and existing brown field facilities. Industrial Ethernet protocols are the most challenging of the protocols for implementation due to their complex network structure. A high score in the implementation section indicates a communication protocol which can be implemented on an existing infrastructure or takes little to no effort to implement. A low score indicates a communication protocol that is costly and time consuming.

Ruggedness Any communication protocol should be resistant to the harsh physical environmental conditions present in the factory. The factory environment can pose a number of threats to the physical hardware used in communication. This is more relevant for wired communication which requires a good deal of cabling. The hardware is required to withstand mechanical shock, vibration, crush and impact which are common place in an industrial environment. The physical hardware needs to be resistant to liquid spills and dust particles. This is of particular importance for electronic communication equipment that has fans. All equipment must also be rated for the varied temperature, humidity, contaminants and solar radiation conditions that are present in the factory environment. A high score in this section is or a communication protocol which is immune to all of these environmental factors. A low score indicates a communication protocol which is likely to fail in the presence of any of these factors.

Security of data is becoming a significant risk for manufacturing plants. The increase in digital information being gathered and sent in the industrial environment increases the risk of proprietary information being received by a third party. Authentication, encryption and intrusion detection technologies have drastically improved over the past years. However, most manufacturing plants are still reluctant to implement wireless systems. Industrial Ethernet protocols often have stringent security protocols however. A high score in this section would indicate a protocol which allows for significant encryption and would require physical interference to intercept a transmission. A low score indicates a protocol with little to no data protection and could be hacked remotely.

Support is an important factor for manufacturers when deciding on a communication protocol to be used in an industrial environment. Wired communication also has the advantage of having widespread support from international vendors. It is also supported by the majority of instrument suppliers and automation system suppliers. Maintenance personnel are familiar with a wired communication based on decades of operating experience. A high score in vendor support reflects a protocol which is supported by a multinational vendor where support local support is readily available. A low score indicates an open source protocol with little reference material online.

Power Consumption For wireless sensors average power consumption is dictated by several parameters such as micro controller and transceiver power, data transfer requirements, sensor type and activation modes. Some protocols are designed with ultra-low power IoT applications in mind where battery life should be maximised. In addition to this the big opportunity for power consumption reduction is in sensory duty cycling e.g. a sensor being activated and collecting data at the required intervals and then the microcontroller and transceiver executing data processing and transfer and going to sleep between sensing intervals. Every effort should be made to minimise average power consumption to maximise likelihood that energy harvesting can be used to eliminate the need for battery replacement or at least extend battery life. Whilst power consumption in sensing and transceiving modes is typically 10's to 100's of mW average power can be reduced to sub mW levels with intelligent duty cycling. Applications using 10-100uW typically have a decent chance of self-powering using indoor solar energy or periodic vibrations or perhaps small temperature gradients.

Wired communications have significantly bigger transmission rates (in the order of 10Gbits/s) than that of wireless communication, these transmission speeds are sometimes required in complex control scenarios and mean that wired communication is the only option. Wired Ethernet protocols can also support Power over Ethernet (PoE) whereby devices can draw power and communicate over the same Ethernet line. Wired communication is the preferred method of communication for most application for these reasons.

In a survey conducted by Cisco Technologies in 2010 of over 600 enterprise customers, 56% quoted RF interference from Wi-Fi and other sources as a contributor to wireless network performance problems. Many studies have been undertaken in the area of interference to Wireless Sensor Networks in the crowded 2.4GHz band that highlights this issue (Azmi et al, 2014). While newer wireless technologies have better penetration through walls and manufacturing equipment RF interference is still an issue. Manufacturing equipment with large electrical motors and dense material as seen in an industrial environment can cause interference in wireless communication and sometime results in lost packets of data. Multiple wireless devices in the same location can also interfere with each other if the frequency spectrums overlap. The 2.4GHz ISM band in particularly busy and is susceptible to this type of RF interference. This can be an issue if there is a number of different sensors present on the same network. A potential solution to this can be frequency hopping when the transmitter hops between available narrowband frequencies within a specified broad channel in a pseudo-random sequence known to both sender and receiver. Because no channel is used for long, and the odds of any other transmitter being on the same channel at the same time are low. This can help in reducing interference in busy spectrum bands.The chief advantage of wireless technologies is that they can be installed virtually anywhere in an efficient, timely and cost effective manner. It can be excellent in monitoring applications however is lacking the data throughput required for more control applications. It should be noted that wireless communications is still a relatively new technology that is still evolving. It is likely that future developments such as 5G will solve the current issues and make wireless communications the predominant communication method in industry.

	Fieldbus Technologies	Industrial Ethernet	Wi-Fi	IEEE 802.15.4	Bluetooth	EnOcean
Inter-operability	4	4	3	3	3	2
Reliability / Determinism	4	5	3	2	2	2
Transmission Rate	2	5	4	2	1	1
Maintenance	2	2	3	4	4	4
Implementation	2	1	5	3	4	4
Ruggedness	3	2	4	4	4	4
Security	4	5	3	2	2	2
Vendor Support	4	5	2	1	2	3
Power Consumption	n/a	n/a	2	4	3	5

Table 2. Comparison of Industrial Communication Protocols

Rating	Transmission Rate	Power Consumption
5	>500Mbit/s	<80mW
4	500Mbit/s – 10Mbit/s	80mW – 100mW
3	10Mbit/s – 1Mbit/s	100mW – 200mW
2	1Mbit/s – 200kbit/s	200mW – 1W
1	<200kbit/s	>1W

Table 3. Quantified values for Transmission Rate and Power Consumption

5.6 Human Machine Interface

Human Machine Interfaces (HMI) consist of software and hardware components which handle the communication between humans and machines. The user's inputs are translated to machine signals in order to be a valid input for the machines. Conversely the machines reply to or prompt the user by providing data (request/result) in a human readable form.

A HMI also referred as User Interface or Terminal. A HMI consists of two basic components: input devices and output devices. An input device offers to a human user the capability to request an output from the machine or generally to send a command. The output will be displayed in an output device. Examples of inputs devices are keyboards, mice, touch screens, microphones, switches and toggles. Different types of display monitors are the most representative examples of output devices. HMI's design is of great importance. A user interface should be easy to use. Moreover, it should be fit the goals and the needs of the users. In general, a HMI should follow the principles and practices of User-Centered Design (P. Paul, 2011).

A HMI standard has been approved as an American National Standard (ANSI). ANSI/ISA-101.01-2015, Human Machine Interfaces for Process Automation Systems (ANSI/ISA, 2015) defines the models and the terminology to develop an HMI. The standard is the first work ISA-101 committee (ISA-101, 2017) and it covers the philosophy, design, implementation, operation, and maintenance of HMIs for process automation systems, including multiple work processes throughout the HMI life cycle. The target audiences include developers, designers and end users of HMIs.

The development of particular HMIs for the COMPOSITION components is part of Task T5.3 - *Advanced Human-Machine-Interfaces for Direct Interaction with Real-World Objects* will be described in Deliverable D5.5 and D5.6 - *Human-machine-interfaces for direct interaction with the factory*. Within the scope of task T5.4 - *Interoperability Between Data Collection Systems* and this deliverable, we only focus on hardware and interoperability issues.

5.6.1 User Centered Design

The evaluation of a user interfaces can be based on user experience and usability. User experience focuses on the users feelings, emotions and values and their immediate and delayed responses. The usability focuses on the task related aspects and getting the job done. A system can be described as usable if it meets the following requirements of the user on anthropometrics (physical size and shape), behavioural (perception and motivation), cognitive (previous knowledge and learning ability) and social (context and relationship with other users). **Anthropometrics** is how the physical attributes of the user will affect how they use the human machine interface. An example of this in the factory environment is the weight of a handheld device it affects the physical capabilities of the user. **Behavioural** characteristics are related to the sensation and perception through sight, hearing, touch, smell and taste. Sensation is the stimulation of the sense organ and perception is the information which is inferred based on previous knowledge and context. **Cognitive** ability relates to the mental capability of the user relating to memory, attention and learning. An example of a user interface which meets this requirement is a user interface which can adapt based on the experience of an operator. **Social** processes or how people interact with each other are important as they affect how systems and interfaces are used.

5.6.2 Input Devices

In human machine interaction, the means by which the human gives commands and input information to the computer is known as the input device. In recent years input devices have changed hugely as innovative new methods are being developed.

The touch screen is one of the most common input devices used in industry. It is seen as a direct input device as there is a unified input and display surface. The two most common touch screen devices are the capacitive touch screen and resistive touch screen. The resistive touch screen reacts to pressure change on the surface from a finger or stylus. This method can be fatiguing if used continuously by an operator but can be used by an operator using gloves. The capacitive touch screen uses the human body’s electrostatic field to measure a capacitive change on the surface of the screen. Only a soft touch is required for this method however it cannot be used with gloves. Other methods of touch screens are surface acoustic waves, optical, dispersive signal and strain gauge touch screens. Touch screens can also be single touch where only one point can be detected on the screen or multiple touches where more than one point can be detected.

Some of the most common input methods for human machine interfaces are mice, keyboards, touchpads, trackballs and joysticks. These are intuitive to use and are familiar to most people. Touchpads are useful as they allow for all the functionally of a mouse and can be fitted on the device. Joysticks are a common input device in robotics in manufacturing as they are a good method of sensing an angle of deflection. The main factors to consider when choosing these types of input devices are size, shape, activation, travel distance, and the sensory feedback in use.

Another method to give a command or input is body gesture or movement. This is developing technology and is not widely used but has significant potential as a method of input device in the future. It is difficult to differentiate between general hand movements and when the user is trying to interact with the machine. Gesture based devices can also cause fatigue to a user if used as the only method of interaction. Kinect is an example of a company that has a line of motion sensing input devices that is currently has TRL 9. This product uses a combination of IR depth sensors, colour sensors and machine learning to detect gestures.

Speech control is an emerging technology which is becoming common. The issue with using speech recognition technology in industrial applications is the lack of accuracy compared to existing input devices. There is also the difficulty of deciphering the many sources of distortion in the audio signal which is being used. Speech recognition technology is often used in application when other input devices are not possible like when the user’s hands are being used for another task.

5.6.3 Output Devices

The output device of a human machine interface is that which is used to communicate information from the computer to the human. In recent years, there has also been a huge shift in the types of output devices being used.

The output device for industry human machine interfaces is conventionally a dumb terminal which consists of a monitor and a connection to the main server through a wired connection. Recently output devices in industry have seen a move towards mobile interfaces. These devices initially began being used as personal devices; this significantly reduces their learning curve when introduced to industry. The advantages of mobile devices is that information can travel up the value chain quicker and provide instantaneous information on the process so that more informed business decisions can be made. The introduction of wireless interfaces has also made human machine interfaces simpler to install, more flexible and also more cost effective. The most commonly used wireless human machine interfaces being used in industry today are tablets and smart phone devices. A large amount of the software packages being used in industry such as the ERP can now be used with tablets and smart phones. This makes activities such as stock taking simpler. The Motorola ET1 is a tablet device which was developed specifically for industry applications. In addition Samsung have also entered this market with the Galaxy Tab Active 2.

An emerging technology in the world of output devices is virtual reality (and associated augmented reality). Virtual reality devices allow users to enter and interact with a computer generated reality. Augmented reality is the fusion of 3D virtual objects into a 3D real environment. These technologies are achieved by the use of head mounted displays which offer a 3D experience and tracking devices to monitor the movement of the user. The use of these technologies in industrial applications is rare, however it is expected to grow in the future. Recent advances in wearable technology allow devices to become smaller allowing for a better ergonomic design of these devices. The common applications of this technology in the industrial environment is conceptual product design, education, training and remote support. Commercial examples of this technology includes Microsoft HoloLens and GlassUp F4 smartglasses. .

5.7 Example of a commercially available Interoperability solution

This section provides an example of a commercial state of the art communication system which offers a solution to interoperability on the factory floor using a number of different communication protocols. This example uses Profinet industrial ethernet, Siemens physical layer and a WLAN wireless communication protocol. This example is included for the purpose of showing how communication protocols can be used in conjunction with each other and could also be shown with different communication protocols.

This wireless communication system has been implemented in Saarschmiede GmbH Freiform schmiede, a company which produces turbine and generator shafts for power plant construction. The factory forges turbine shafts at a temperature of 700 °C in the open-die forges using a 12,000-t press. The press is fed with two cranes, to ensure that the load is not too great during machining, the crane and press controllers continually exchange information, which is transmitted wirelessly via IWLAN, so that the press can be stopped if necessary. To do this uninterrupted radio contact with a fast response time is required. There had also been the additional issue of the solid steel material having an extremely negative effect on the propagation of radio waves in its vicinity. This challenging interoperability problem was achieved using the Scalance X204-2 switching module, Scalence W786-1RR access points on the press and Scalence W747-1RR access points on the crane.

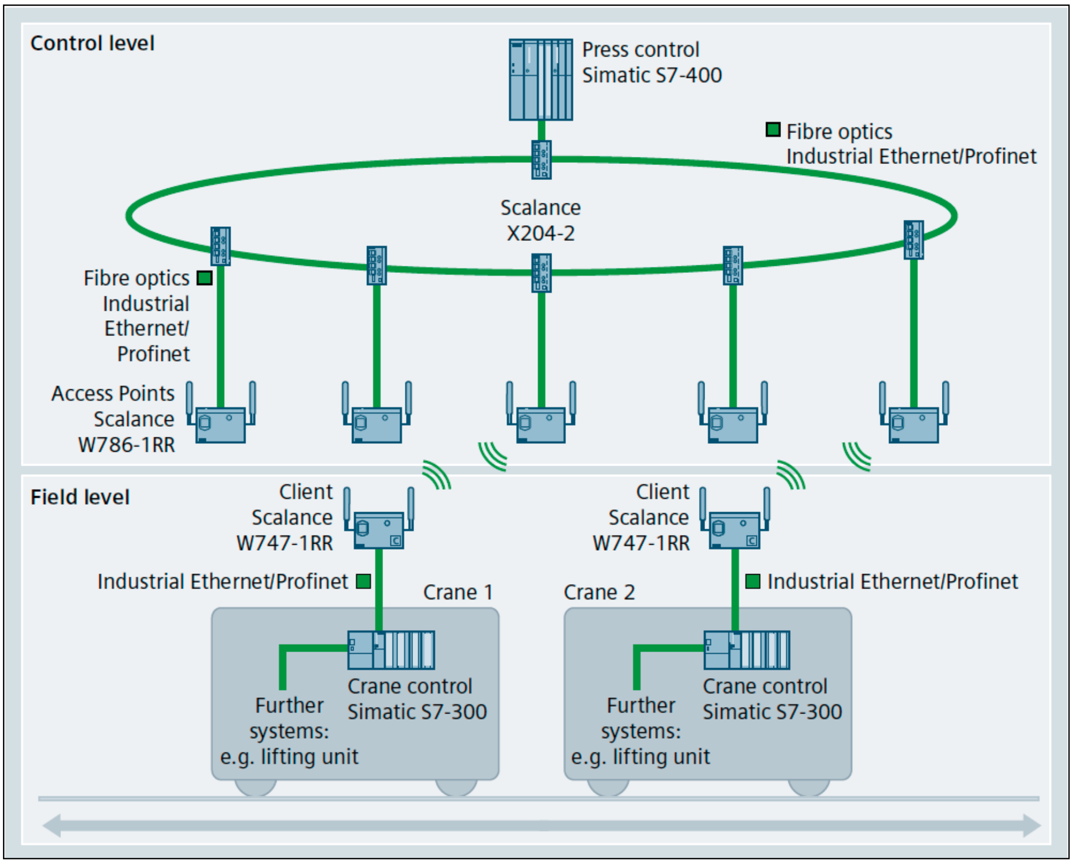

Figure 7. Commercial Example of a Communication Network

6 Intra-Factory Use Cases

In this section the intra factory scenarios will be discussed with regards the interoperability of the data collection systems. This section describes the implementations of the deployment and how the information is interfaced through a common architecture and protocol to the HMI.

The diagram below shows the primary interfaces of the deployments in KLE and BSL.

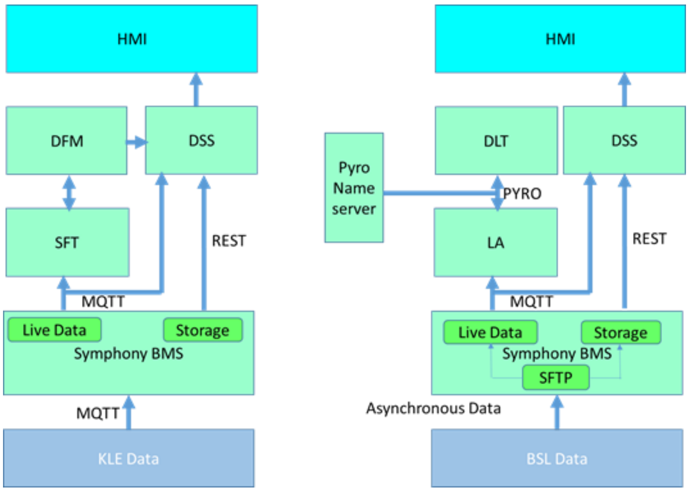

Figure 8. Use Case system diagram

The propagation of data from the shop floor level is fed to all the different components that constitute the intra-factory scenario. In fact, a combination of data coming from both newly deployed and legacy sensors, form a heterogeneous data stream that flows from the shop floor to the Composition ecosystem.

The first entry point of the Composition realm is the Building Management System, which receives data through different protocols depending on the specific pilot setup. KLE's shop-floor is equipped with Composition dedicated sensors that publish field data through a publish/subscribe protocol, such as MQTT, whereas BSL's relies on legacy hardware for monitoring the devices. Therefore it requires the data to be transferred in an asynchronous manner through SFTP protocol. The BMS is in charge of normalizing these inputs with the aim of dispatching them to registered listeners through the MQTT protocol, whilst maintaining throughput performance. It also acts as a storage for the entire ecosystem.

Many components are subscribed to these MQTT topics and are therefore authorized listeners of the pre-processed data. The Decision Support System, for instance, reads and process data while visualizing them either live or from stored sources, alongside contextual information coming from the DSS Rule engine. The Learning Agent also reads dispatched data and acts as an entry point for the forecasting tools. It aggregates and formats the data while providing buffering and batches aggregation, before passing them to the Deep Learning Toolkit. The latter is a component that receives the information pre-processed, filtered and organized in order to feed them to artificial neural networks models. These models provide forecasting and previsions for predictive maintenance applying continuous learning techniques. The Learning Agent is also in charge of actions like initiate, evaluate and destroy models provided by the Deep Learning Toolkit, while choosing the best model and topology to adopt, based on its KPIs. These two components are directly connected and share the same logical links, while communicating through a remote procedure call based protocol named Pyro, maximizing security, trustworthiness and performances.

In use cases in which the Deep Learning Toolkit is not available, the Simulation and Forecasting Tool is deployed, overcoming the limitations of the continuous learning the former component imposes. Its strength is to use a Dynamic Reasoning Engine for creating simulation models for evaluating and forecasting shop floor patterns in the long term through data analysis, mainly on historical basis.

On the top of all this, security is granted by design through authorization, authentication and non-repudiation mechanisms that are placed under the hood, granting seamless interactions among components without adding unnecessary overheads.

Finally, the components described above with their exposed APIs and REST interfaces are orchestrated to grant a layer of interoperability in the intra-factory scenario.

6.1 UC-BSL 2 Predictive Maintenance

This use case focuses on the predictive maintenance of manufacturing machines on the factory floor. An effective predictive maintenance system can minimise the machine downtime through better prediction of failure, allowing the factory to calculate the optimal time for replacing parts in terms of cost and downtime. This will also prevent failures to occur while there is product inside the machine, thus preventing the loss of that product. The machines that require predictive maintenance most frequently, in Boston Scientific Clonmel, are the laser/spot welders and the blower fans in the reflow ovens. There is currently no predictive maintenance mechanism for the reflow ovens in the factory, only preventive maintenance.

The predictive maintenance system proposed for the fan blowers consists of key parameter measurements being displayed on the factory visualisation screen. These parameters are compared against pre-set limits. If the limits are exceeded, an alarm is displayed on the visualisation screen. The process technician and technician supervisors are notified and decide whether to change the fan before resetting the alarm.

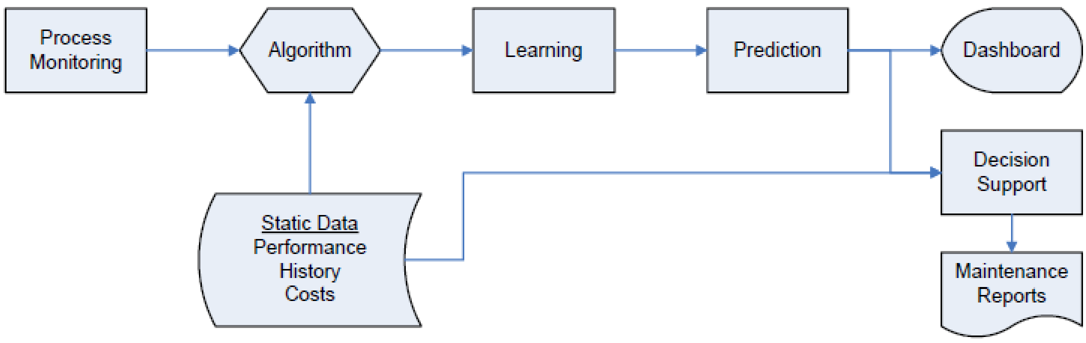

Figure 9. Diagram of proposed predictive maintenance process for BSL

In order to achieve a successful predictive maintenance, the Composition IIMS will collect a combination of the data outputted from the reflow ovens, real-time and historical, along with additional data outputted from the acoustic sensors installed near the fans. The Composition IIMS will then use a combination of statistical models, algorithms and different machine learning technologies to attempt to predict a likely point in time when the machine would fail.

There are currently three sets of data being analysed:

1. The real-time data file from the Reflow oven (Set Temperature, Actual Temperature and Output Power)
2. The real-time event file from the Reflow oven (which logs any event that takes place on the oven during that day e.g. Heat 17: Hi Warning 227°C.)
3. The acoustic data generated from the sensors that Tyndall has placed in the reflow oven, near the blower fans.

Current Status

When the Reflow ovens begin to fail, the motors often make high pitched noises. This acoustic data was therefore defined as useful data to collect to use in combination with the data the machine already outputs. In order to collect this data, five of Tyndall's Raspberry Pi Micro Controllers fitted with acoustic sensors were installed near the motors in BSL's Rythmia oven. The picture bellow shows one of these sensors (left) and the motors which the sensors are monitoring (right). The sensors are constructed with Knowles SPH0645LM4H I2S acoustic sensors integrated into a Raspberry Pi model B. The data is stored temporarily on the Raspberry Pi as a wave file. This is then sent to the local PC on the shopfloor over ether-net and converted into a single amplitude value expressed as dB in a csv text format and sent to the COMPOSITION server.

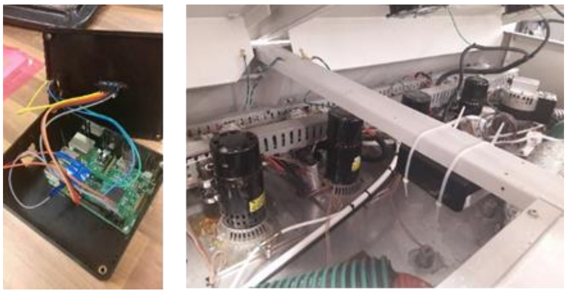

Figure 10: Images of Acoustic Sensor and deployment

Every 5 minutes, the 3 sets of data are generated and sent to the external Composition server. The method by which this data is being transferred can be seen below.

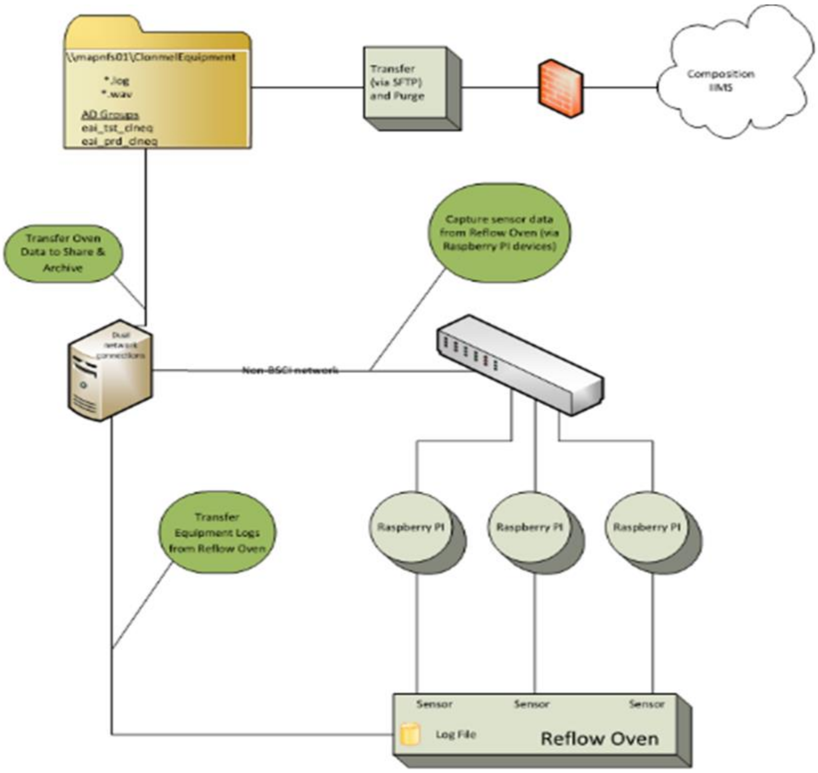

Figure 11: Acoustic Sensor System diagram

The interoperability examples in this use case are between the sensor which gathers information from the motor and the data being generated by the legacy equipment. A combination of both will be processed and presented in the visualisation tool.

6.2 UC-BSL-3: Component Tracking

This use case is part of the material management scenario. The challenges BSL have encountered is the unknown location, quantity, quality of stock and products on the factory floor. There is a large cost associated with the scrap due to missing or damaged equipment. Apart from the direct financial impact (value of a material/asset), there are other significant indirect financial impacts due to machines unexpectedly being short of components, test fixtures going missing and disrupting production.

The proposed solution to this problem is to compare the stock information from SAP with the information from the MES. This information will then be described on the material management dashboard in real time. A batch tracking system will also be created where operators can tag each tray or reel with products in process. The batch tracking system receives information when a component has entered the factory or moved within the factory. The system is then updated with the component location, data and time the data was obtained.

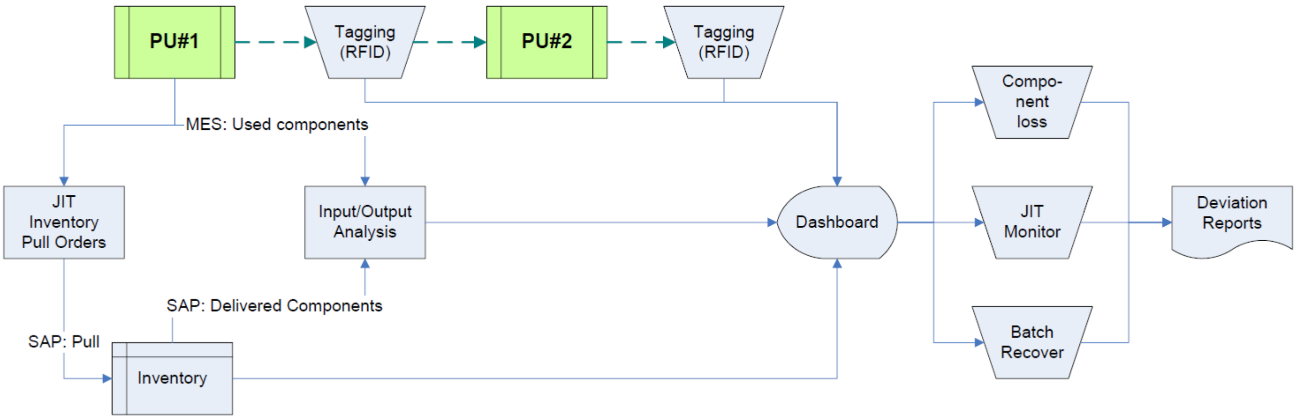

Figure 12: Diagram of proposed component tracking method in BSL

The interoperability requirements of this use case are between the sensors of the asset tagging method and the IIMS software. The asset tracking of components in BSL is conducted using a number of methods such as sensor fusion, ultra wide band &/or inertial measurement. All of these methods require an RF signal and an anchoring unit. (Ref. D4.6 for further details). This anchoring unit is usually fitted with a power wire due to its energy demands from trancieving. A good communication option which maintains interoperability would be to use a wired connection to link up the asset tracking anchor with the IIMS software. This could be conducted using an ethernet or a fieldbus connection.

The figure below shows the asset tracking system that is being implemented in the test site. The tag is attatched to the items that are being tracked. This listens for a BLE beaconing signal from a Beacon that is in a fixed kown location. This signal has a unique identifier that identifies it. There are many Beacons in kown positions and the tag simply decides which has the strongest signal to determine which zone it is located in. (Proximity based location). The tag then transmits this information via BLE to the gateway with its own unique identifier. This information is then sent to cloud based software that enables visualisation of the location on a customised map of the building via secure web services. An API is available that may enable integration of this information into the COMPOSITION HMI, this is currently under investigation.

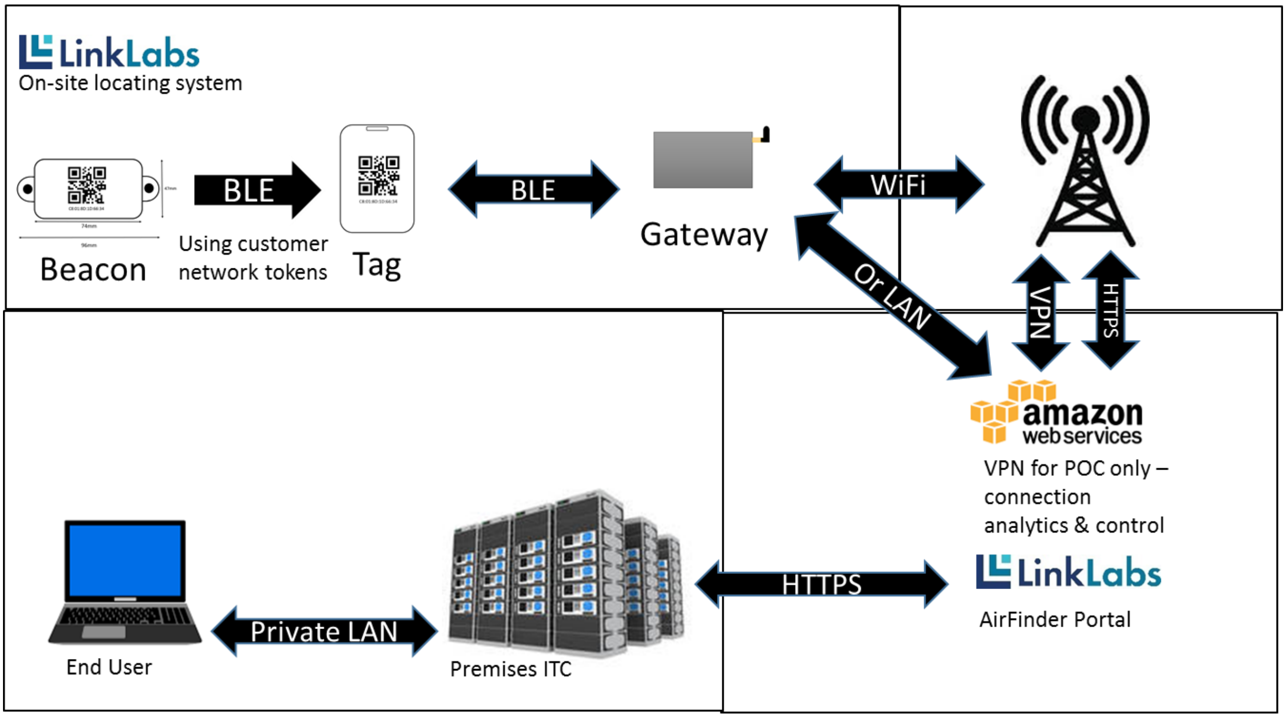

Figure 13. Asset tracking dataflow map

6.3 UC-BSL-5: Equipment monitoring and line visualization

Currently there is no automatic record of how long (a piece of) equipment is in alarm state or even what's the overall status of each production line. This data is not readily available and needs to be obtained manually which takes a lot of time with a lot of effort. Updates on the status of equipment are completed by e-mail or in person where it is hard to keep track of, which results in relevant personnel (PB, Technicians, Supervisors, Engineers, Managers) not being correctly informed.

There is no reliable way to track equipment up-/downtime or the production hours lost due to equipment issues. An automated record would display how long which equipment is down or in alarm state and how that translates into the rest of the production line.

The ideal scenario shall have the ability to display an analytic view of all assets of the production line (relevant information on the equipment, products currently on the line, flow of the product through the lines, etc.) on a visualisation screen on the factory floor.

Logged in users can retrieve the history and performance of the equipment (uptime/downtime; green/amber and red state), previous failure modes, and production compared to build plans (units processed per time period, target, quantity) from a GUI. For history of failure modes, the individual information should be available (duration, comments). Additionally, comments can be entered and retrieved from the system which are intended to give updates on equipment status to interested personnel and keep track of what measures are/have been taken to fix the equipment downtime.

The equipment/line information will be pulled directly from BSL's MES (manufacturing execution system) in a .csv format, processed by COMPOSITION and the final result displayed on a visualization screen, with the following flow of information (see Figure 14).

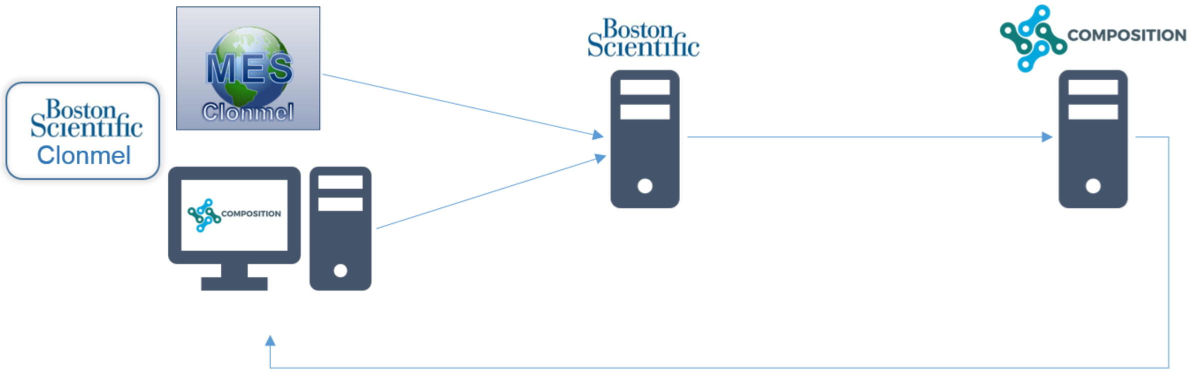

Figure 14. Information flow for UC BSL-5

The application will allow the personnel to assess the line status as well as to check equipment/line capacity amongst other relevant metrics that are currently being defined and for which BSL will provide formulas for their calculation (as seen on the visualization screen concept in Figure 15). The exact indicators will be discussed as the use case progresses, but the target is to use live data. This use case will serve as a planning tool for new investments based on historical data about up-/downtime. BSL is planning to implement this onto the PCBA Front End; if successful it will have the potential to be run across all production lines.

Currently, an information path is already established between BSL and the COMPOSITION cloud and the MES data will go through that same path. A first version of the metrics that will be displayed directly (i.e. don't need necessary calculations) is already being processed to assess the feasibility of its display on a COMPOSITION monitor on the factory floor.

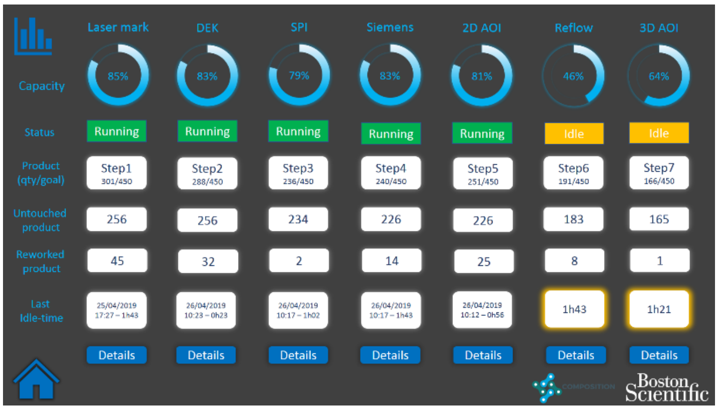

Figure 15. Concept of the line visualization screen

6.4 UC-KLE-1: Predictive Maintenance

The software Kleemann uses is (CMMS-AIMMS) and is partly efficient. However, paperwork is required to collect all the necessary information and data for supporting the maintenance services. The CMMS (Computerised Maintenance Management System) holds information about machines i.e. how often does it break? When was the last maintenance? When should the next maintenance be done? Manual measurements are performed by the technicians who then write it down onto the maintenance special forms. Then all this paperwork is gathered by the maintenance planner who registers all these data in CMMS. The suggestion for preventive maintenance comes from the system based on a measurement point that might be hours worked, number of batches worked etc. The maintenance planner can make use of this feature of the CMMS to plan maintenance tasks. However, at this moment, the suggestion of predictive maintenance is actioned manually, based on the experience of the operators and the maintenance team.

Figure 16: Images of Manufacturing Equipment seen in KLE – Vibration Sensor is installed in 3rd one

The interoperability in this use case is related to the integration of deployed sensors and IIMS components (BMS, analytic tools and DSS). The vibration sensors which gather information from the motors need to be integrated with the IIMS. The polishing machines in Kleemann are no so susceptable to temperature fluctuations as in BSL cases but have significant vibrations from the motors. Two vibration sensors have been installed on two external Bossi machine motors. The sensors were enclosed in a plastic case. The sensors are powered by micro-USB wires which are connected to Bossi power supply. The communication is carried out via WiFi. An SSID and password was given by KLEEMANN's IT to connect the sensors, who also arranged for a static IP to ease firmware updates over the air. In order to enable interoperability not only in the connectivity level (use of WiFi technology) but also in the data exchange format level the DFM schema was used. The DFM schema uses OGC Observation and Measurements (see Section 7) data format in order to describe the sensors measurements. So all the measurements form KLEEMANN are described using this common format and become available to analytics tools of the IIMS. The same data format is used also for the predictions of analytics tools related to the Bossi Machine. So, the DSS is able to receive both sensors data and analytics tools prediction in OGC Observations and Measurements format. Furthermore, the Bossi machine is described as a DFM asset (B2MML XML format) which has deployed sensors that are modeled in a similar XML format.

6.5 UC-KLE-3: Scrap Metal and Recyclable Waste Transportation

This scenario relates to the management of scrap metal. In Kleemann, a worker from the maintenance department is responsible for the detection of fill levels of scrap metal and recyclable waste bins. The worker then estimates a specific time for pick-up of the bins and transportation to the container. The worker does not know the exact time the container is full. For example, the operator picks up scrap metal from piston cylinder plant every 3 days and transports it to the factory's open top container. The container may be full and then the worker will dispose the scrap metal in another place causing space problems. This procedure is not optimized, because orders do not have the same volume every day and different quantities of scrap are produced. This increases fuel consumption and sometimes traffic with other forklifts or trucks within the factory.

Figure 17. Images of recycling material containers (left) and scrap waste containers (right) and the installed fill level sensors in KLE

The solution to this is to have sensors fitted on or near the scrap containers which will detect the level of scrap in the container and send this information to the IIMS. The IIMS will inform an operator of the scrap container which needs to be emptied and also the open top bin where it should be disposed. There will also be sensors fitted on or near the open top containers, which will determine the fill level. The interoperability requirements are between the sensors located in the scrap waste and recycling bins and the IIMS. The bins are moveable objects so wired communications may add complexity to the design as a detaching method would need to be incorporated.

For this use case fill sensors were installed in the two types of bins. One sensor on a bin where the scrap metal is being tossed in production and one on a set of 4 bins for recyclable materials (plastic, paper, aluminium and cardboard). The sensors were enclosed in a plastic case. Special constructions were manufactured by KLEEMANN in order to install the sensors on the bins. Presently two indoor fill sensors are deployed, one for each type. All fill sensors installed on KLEEMANN's bins are communicating using LoRa wireless network. A LoRa base station (LORANK 8) was installed on a suitable location within the factory, to ensure coverage for all the sensors and access to an active Ethernet socket. All the measurements are described in the common format coming from DFM schema. The OGC Observation and Measurements format is used. The data coming from bins are available to all IIMS components in this common format. The data become available to BMS using MQTT protocol. Moreover, every bin is described as factory asset in the KLEEMANN's plant, in B2MML/DFM XML format. The fill level sensors are modelled in a similar format and are connected to assets/bins that they are installed. This enables, the other components of IIMS to explore in a common way digital factory instances and find assets for a use case and their connected sensors in order to request data.

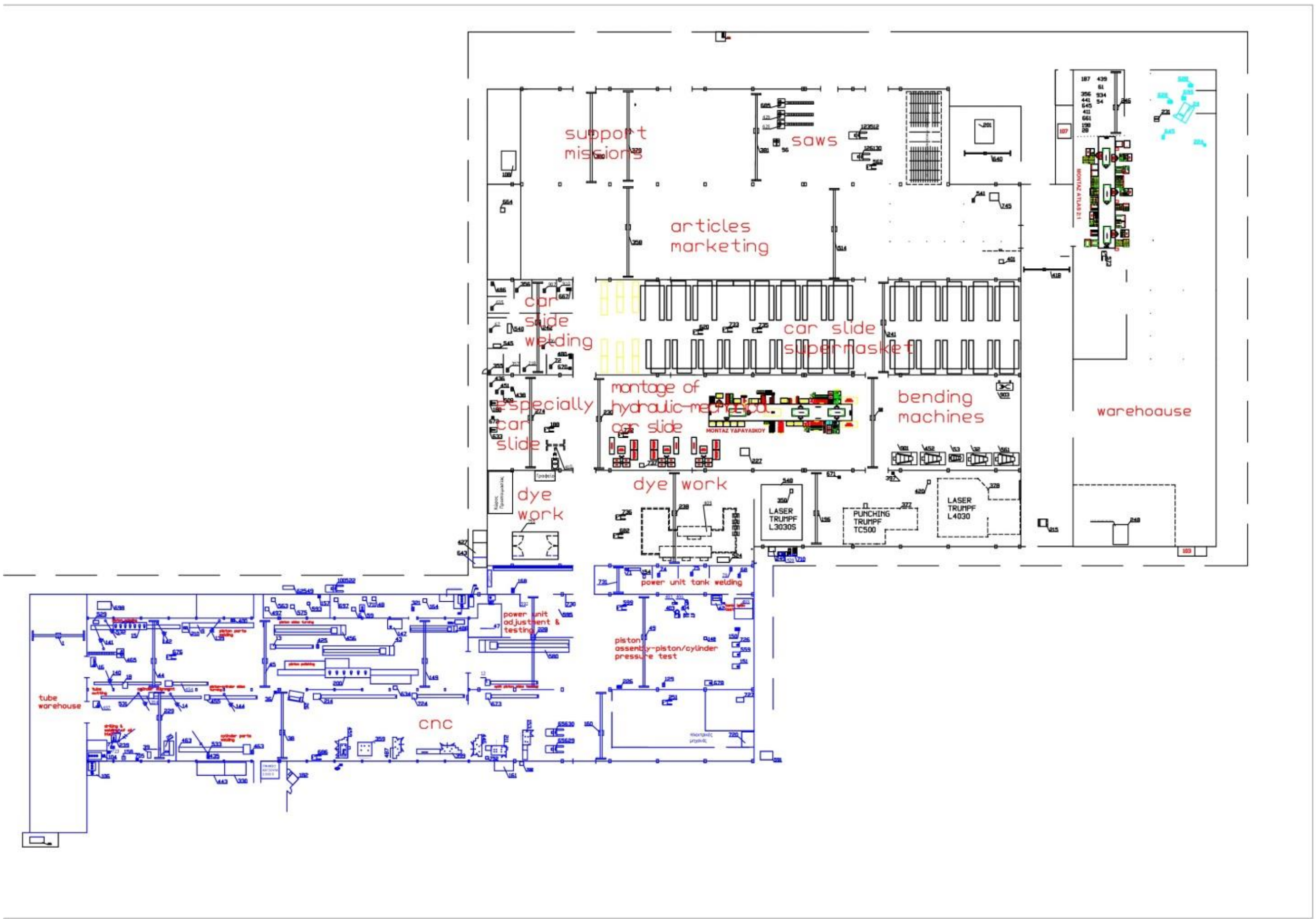

Figure 18. Floor plan of KLE manufacturing plant

7 Inter-Factory Use Cases

This section provides some discussion on the Inter-Factory use cases in relation to interfaces used.

7.1 UC-KLE-4 Scrap metal collection and bidding process and UC-ELDIA-1 Fill-level notification – Contractual wood and recyclable material management

Besides the intra-factory use cases, some of the inter-factory use cases of the project are triggered by deployed sensors in the pilots shop floor. Both UC-KLE-4 and UC-ELDIA-1 scenarios are triggered from fill level sensors were installed in large industrial open top containers. All fill sensors installed on KLEEMANN's and ELDIA's bins communicate using LoRa wireless network. A LoRa base station (LORANK 8) was installed on a suitable location within the factory, to ensure coverage for all the sensors and access to an active Ethernet socket. Outdoor installation of the base station demanded the construction of a plastic enclosure capable of protecting the base station from rain and dust.

Figure 19. Open Top Scrap Metal Bin Equipped With Fill Level Sensor

Data from bins become available to BMS using MQTT. The data format is common with the rest data formats for sensor measurements in this project as it is based on DFM schema (OGC Observation and Measurements). Same as KLE-3, for these use cases the bins are described/modelled as assets (DFM-B2MML format) with installed sensors on them.

8 Manufacturing Models

This section is an analysis on existing standards for factory resources' modelling. The following standards examined and some of them are used in modelling tasks of COMPOSITION's WP3 "Manufacturing Modelling and Simulation". A Digital Factory Model has been implemented in Task 3.2 in order to enable modelling of industrial aspects and offer a common format for the description of different data and assets of a factory. Deliverables D3.2 and D3.3 document this Digital Factory Model with a lot of details. So, in this document we will be referred only in the most important Manufacturing Models/standards that used or it was possible to be used for the design of the COMPOSITION Digital Factory Model. Furthermore, an ontology for the Manufacturing Agent Marketplace of COMPOSITION has been implemented based on well-known manufacturing ontologies in order to offer a common vocabulary and interoperability for the connected factories/agents in this Marketplace. More details about this ontology are available at D6.7.

8.1 Business to Manufacturing Mark-up Language (B2MML)

Business to Manufacturing Mark-up Language or B2MML (B2MML, 2017) is an XML implementation of the ANSI/ISA-95, Enterprise-Control System Integration, family of standards (ISA-95), known internationally as IEC/ISO 62264. B2MML consists of a set of XML schemas written using the World Wide Web Consortium's XML Schema language (XSD) that implement the data models in the ISA-95 standard.

B2MML is a complete implementation of ISA-95 and is published by the Manufacturing Enterprise Solutions Association (MESA). The MESA XML Committee maintains B2MML. B2MML is designed to be a common data definition to link ERP and supply chain management systems with manufacturing systems such as Manufacturing Execution Systems.

B2MML covers the basic package of COMPOSITION's Digital Factory Model (DFM) that are developed at Task 3.2 "Integrated Digital Factory Models". B2MML offers basic data types for the domain of manufacturing as Assets, Equipment, Actors and Procedures. Beyond these; B2MML also offers some types for Events sector such as Measurements and Alerts.

8.2 Green Building XML (gbXML)

Green Building XML or gbXML (gbXML, 2017) is an industry supporting schema for sharing building information between disparate building design software tools. It was developed to facilitate the transfer of building information stored in CAD-based building information models, enabling interoperability between disparate building designs and a wide variety of today's engineering analysis software tools. gbXML is widely adopted by Building Information Modelling (BIM) leading vendors including Autodesk, Trimble, Graphisoft, and Bentley. With the development of export and import capabilities in over 40 engineering and analysis modelling tools, gbXML has become a de facto industry standard schema.

In June of 2000, the gbXML schema was submitted for inclusion in aecXML(TM), the industry-led initiative launched by Bentley Systems, by a company called Green Building Studio. After that gbXML became the draft schema for the Building Performance & Analysis Working Group.

gbXML is a type of XML (stands for eXtensible Mark-up Language that was designed to store and transport data) file. gbXML has over than 500 types of elements and attributes that allow the description of all aspects of a building.

gbXML covers the package of DFM (Task 3.2 "Integrated Digital Factory Models") which is related to the building information model within the COMPOSITION project.

8.3 MIMOSA

MIMOSA (MIMOSA, 2017) is a not-for-profit trade association dedicated to developing and encouraging the adoption of open information standards for Operations and Maintenance in manufacturing, fleet, and facility environments. MIMOSA focuses on enabling industry solutions leveraging supplier neutral, open standards, to establish an interoperable industrial ecosystem for Commercial Off-The-Shelf (COTS) solutions components provided by major industry suppliers. In order to accomplish this goal, MIMOSA (working in cooperation with other likeminded groups) has facilitated the development of the Oil and Gas Interoperability (OGI) Solutions Process™, which includes the OGI Pilot™, the OGI Solutions Architecture™ and the ISO OGI Technical Specification. Collectively, these elements establish the basis for the OGI Ecosystem™, which is a true supplier neutral solutions environment enabling a major paradigm shift towards a solutions process providing lower cost, faster implementations and improved quality.

The OGI Solutions Process is driven by high value added industry use cases, developed, validated and managed by MIMOSA and industry partners. The OGI Solutions Process leverages a portfolio of published international and industry standards and specifications, which are incorporated by reference into the various applicable use cases. Key standards in the portfolio include those associated with the OpenO&M™ Initiative (ISA 88/95, MIMOSA CCOM, OPC UA, OAGi BOD architecture and OpenO&M ws-ISBM/CIR), as well as ISO 15926. The OGI Pilot provides an industrial scale environment for use case development and improvement as well as establishing the proving grounds for interoperability within the OGI Ecosystem, which it defines based on the OGI Solutions Architecture. In its technical information part MIMOSA provides a series of interrelated information standards. The Common Conceptual Object Model (CCOM) provides a foundation for all MIMOSA standards, while the Common Relational Information Schema (CRIS) provides a means to store enterprise O&M information.

MIMOSA standard has many similarities with B2MML. However, B2MML is selected over MIMOSA because B2MML has a more flexible structure, making it more suitable for COMPOSITION's needs.

8.4 OGC Standards

Open Geospatial Consortium or OGC (OGC, 2017) is an international not for profit organization committed to making quality open standards for the global geospatial community. The standards are freely available for anyone and are used in a wide variety of domains including Environment, Health, Agriculture, Meteorology, Defence, Sustainable Development and many more.

Sensor Model Language or SensorML (SensorML, 2017) is an OGC Standard. SensorML is focused to provide a robust and semantically-tied means of defining processes and processing components associated with the measurement and post-measurement transformation of observations. The main objective is to enable interoperability, first at the syntactic level and later at the semantic level (by using ontologies and semantic mediation), so that sensors and processes can be better understood by machines, utilized automatically in complex workflows, and easily shared between intelligent sensor web nodes. This standard is one of several implementation standards produced under OGC's Sensor Web Enablement (SWE) activity. This standard is a revision of content that was previously integrated in the SensorML version 1.0 standard (OGC 07-000).

Observations and Measurements (O&M, 2017) is an international OGC Standard. This standard specifies an XML implementation for the OGC and ISO Observations and Measurements (O&M) conceptual model, including a schema for Sampling Features. The origins of the O&M are in the Sensor Web Enablement (SWE) initiative of the OGC. Together with other SWE framework open standards like SensorML and Sensor Observation Service (SOS), O&M provides a system-independent, Internet-enabled ways of data exchange between different parts of sensor networks and other systems using the captured sensor information. O&M standard defines both JSON XML schemas for observations and features involved in sampling when making observations. These provide document models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities.

SensorThings (SensorThings, 2017) is an OGC standard provides an open, geospatial enabled, unified way to interconnect Internet of Things (IoT) devices, data and applications over the Web. SensorThings is a non-proprietary, platform-independent, and perpetual royalty-free standard. It builds on a rich set of proven-working and widely-adopted open standards, such as the Web protocols and the OGC Sensor Web Enablement (SWE) standards, including the ISO/OGC Observation and Measurement data model. A SensorThings API is designed specifically for the resource-constrained IoT devices and the Web developers.

8.5 Business Process Model and Notation (BPMN)

Business Process Model and Notation or BPMN (BPMN, 2017) is a standard that provides a graphical notation for specifying manufacturing processes in Business Process Diagrams (BPD). BPMN is based on flowcharting techniques. BPMN was developed Business Process Management Initiative (BPMI). Today, BPMN is maintained by Object Management Group (OMG). Its current version is BPMN 2.0.

BPMN provides businesses with the capability of understanding their internal business procedures in a graphical notation and gives organizations the ability to communicate these procedures in a standard manner. Moreover, the graphical notation will facilitate the understanding of the performance collaborations and business transactions between the organizations.

In Task 3.1 “Process Modelling and Monitoring Framework” of COMPOSITION project, the process models of the industrial processes will follow the Business Process Model and Notation (BPMN) standard. Moreover, BPMN covers the package of DFM (Task 3.2 “Integrated Digital Factory Models”) which is related to business process list.

8.6 Manufacturing Service Description Language (MSDL)

Manufacturing Service Description Language or MSDL, (Ameri, 2006), is an OWL-based ontology developed for formal representation of manufacturing services. PLM Alliance research group at the University of Michigan started MSDL development and the first version released at 2005. Currently maintained and extended under supervision of Farhad Ameri in the INFONEER Research Group at Texas State University.

MSDL provides sufficient expressivity and extensibility for manufacturing knowledge modelling. MSDL is particularly suitable for description of manufacturing capabilities of SMEs. MSDL decomposes manufacturing capability into different level of abstraction and it is designed to enable automated supplier discovery in distributed environments with focus on mechanical machining services.

MSDL has two basic parts, MSDL core and MSDL extension. MSDL core is a static part which contains the basic classes for manufacturing domain description. MSDL extension is dynamic part which includes sub-classes and instances built by users.

MSDL is used in the COMPOSITION in the Task 6.4 “Collaborative Manufacturing Services Ontology and Language”.

8.7 Manufacturing Semantics Ontology (MASON)

Manufacturing’s Semantics Ontology or MASON is a manufacturing ontology, aimed to provide a common semantic net in manufacturing domain. MASON was introduced at IEEE Workshop on Distributed Intelligent Systems: Collective Intelligence and Its Applications in 2006 by Lemaignan, Siadat, Dantan and Semenenko. (Lemaignan, 2006)

MASON is an upper ontology for manufacturing domain which is built upon three basic concepts:

- Entity aim at providing concepts for specifying an abstract view of the product
- Operation relate to processes and cover manufacturing, logistic, human and launching operations
- Resource stands for the whole set of manufacturing linked resource, such as machine-tools, tools, human resources, and geographic resources like plants and workshops

MASON is also imported to COMPOSITION’s ontology to provide semantic representations of manufacturing services and resources.

9 List of Figures and Tables

9.1 Figures

9.2 Tables

10 References

(FMER, 2013) Federal Ministry of Education and Research. Rommendation for implementing the strategic initiative INDUSTRIE 4.0 (2013) final report.

(ISA, 2000) ANSI/ISA95.00.01–2000. Institute Society of America. Enterprise-Control System Integration Part 1: Models and Terminology

(ISA, 2001) ANSI/ISA95.00.02–2001. Institute Society of America. Enterprise-Control System Integration Part 1: Object Model Attruibutes

(ISA, 2005) ANSI/ISA95.00.03–2005. Institute Society of America. Enterprise-Control System Integration Part 1: Models of manufacturing Operation

(ISO/IEC, 1994) International Organisation of Standardisation / International Electrotechnical Commission, Open Systems Interconnection – The Basic Reference Model, ISO/IEC 7498-1

(NWG, 1989) Network Working Group, RFC 1122 standard, Internet Engineering Task force, Requirements for Internet hosts – Communcaiton Layer

(NWG, 1998) Network Working Group, RFC 2460 standard, Nokia, Cisco, Internet Portocol, Version 6 IPv6

(A. Sal, Y. Li, 2015) Industry 4.0 with Cyber-Physical Integration: A Design and Manufacture Perspective, University of Strathclyde, 21st Interneational Conference on automation and Computing, Glasgow, UK.

(B. Gal, G.Hal, 2014) IEEE Communications Surveys & Tutorials Vol. 15, Issue 2, 860-880, 1553-877X ,10.1109/surv.2012.071812.00124 Introduction to Industrial Control Networks,

(Trend Micro, 2017) figure of an Industrial Control System, https://www.trendmicro.com/vinfo/us/security /definition/industrial-control-system

(R. Oeschsner, 2003) Material Science in Semiconductor Processing, Vol. 5, pg 333-339, From Overall Equipment Efficiecny to Overall Fab Effectiveness

(M. Rostan , 2014) ETG Industrial Ethernet Seninar Sessions, EtherCAT Technology group, Industrail Ethernet Technologies: Overview

(PCS, 2017) Panorama Consulting Solutions, Clash of the Titans, http://panorama-consulting .com/

(Siemens, 2014) Advance, Magazine for Totally Integrated Automation. Merging the virtual and real worlds, Number 1, April 2014, siemans.com/advance

(OPA, 2004) Oppertunity Precurser advisor , Washington DC, From RFID to Smart Dust: The expanding market for Wireless Sensor Technologies, RFID: Investing in the Next Multi Billion IT

(BCM, 2017) BCM Advanced Research, figure for Industry 4.0 – the factory of the future, The factory of the furute, www.bcmcom.com

(Cisco, 2010) Cisco white paper, Wireless RD interface Customer Survay Results

(IEC, 2011) International Electronics Comission, Series Explosive Atmosphere Standards, Equipment General Requirements, IEC 60079-0

(Ritter, F. E, 2014) Foundatinos of desinging user centered systems – What system designers need to know, Springer, ISBN 978-1-4471-5133-3

(Cyber Optics, 2017) SE600 3D SPI datasheet, Cyber Optics Corperation, http://www.cyberoptics.com /pdf/AOI/QX150/QX150-8022888-REV_B.pdf

(Cyber Optics, 2017) SQ2000 datasheet, Cyber Optics Corperation, http://www.cyberoptics.com /pdf/aoi/ sq3000/SQ3000-8022394-REV_C.pdf

(Prabhu, B. S. 2006) WinRFID: a middleware for the enablement of radiofrequency identification (RFID)-based applications. *Mobile, wireless, and sensor networks: Technology, applications, and future directions* 313.

(B2MML, 2017)	MESA International http://www.mesa.org/en/B2MML.asp
(gbXML, 2017)	gbXML is an industry supported schema for sharing building information between disparate building design software tools. http://www.gbxml.org/
(MIMOSA, 2017)	MIMOSA association focuses on enabling industry solutions leveraging supplier neutral, open standards, to establish an interoperable industrial ecosystem for Commercial Off-The-Shelf (COTS) solutions components provided by major industry suppliers. http://www.mimosa.org/
(OGC, 2017)	Open standards for the global geospatial community http://www.opengeospatial.org/
(SensorML, 2017)	Enable interoperability, first at the syntactic level and later at the semantic level. http://www.opengeospatial.org/standards/sensorml
(BPNM, 2017)	Business Process Model and Notation or BPMN is a standard that provides a graphical notation for specifying manufacturing processes in Business Process Diagrams (BPD). http://www.bpmn.org/
(Ameri, 2006)	Manufacturing Service Description Language; https://www.researchgate.net/publication/267486591_An_Upper_Ontology_for_Manufacturing_Service_Description
(Lemaignan, 2006)	Manufacturing's Semantics Ontology or MASON is a manufacturing ontology, aimed to provide a common semantic net in manufacturing domain. http://ieeexplore.ieee.org/document/1633441/
(Azmi et al, 2014)	Interference Issues and Mitigation Method in WSN 2.4GHz ISM band: A Survey https://www.researchgate.net/publication/271440970_Interference_issues_and_mitigation_method_in_WSN_24GHz_ISM_band_A_survey
(D4.6)	D4.6 Viability of WSN as ICT overlay for physical security detection 2017-05-15 Version 0.5 COMPOSITION Consortium. https://www.composition-project.eu/