# Reference Architecture for Efficient Computer Integrated Manufacturing

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Keywords: Manufacturing Systems, Smart Manufacturing, Computer Integrated Manufacturing, Systems Architecture.

Abstract: The technological progress combined with the rapidly changing customer demands are pushing for continuous changes in manufacturing environments. This led industrial companies into seeking the optimization of their processes through Computer Integrated Manufacturing (CIM). The main purpose of the latter is to link the shop floor systems to the high business layer ones. Based on a literature review that we have conducted earlier on CIM architectures, we have identified the different aspects related to CIM and detected the limitations of the existing approaches. With the aim of overcoming these limitations, we present in this paper a reference architecture for CIM based on the ISA-95 standard. We also explain how the proposed architecture was applied on a case study from the automotive industry.

## 1 INTRODUCTION

The exponential and never ending progress of customer demands alongside fierce competition can only be seen as instigators of continuous change within manufacturing environments. That is why, industrial companies found themselves compelled to manipulate the concurrent advancement of products efficiently, along with processes and production systems (Meziane et al., 2000). Accordingly, companies began to merge information technologies related to other fields with the manufacturing process. This adjustment is known under several names among which we find: Smart Manufacturing (Li et al., 2019) and Computer integrated manufacturing (Hedberg et al., 2016).

There are two key elements to this tendency: Cybernation of the industrial processes, and the facilitation of the exchange of data. This is feasible through integrating every system in the manufacturing process in the same architecture. The purpose is the creation of an exhaustively connected plant, where every retrieved data is reusable in order to optimize the various business processes. This is what is called a smart factory (Li et al., 2017). In an attempt to fulfill that, the connection between the different levels of the plant must be ensured. It should stretch from the shop floor level, containing the production machines, all the way to the highest level of the plant where the company's strategies are elaborated. This connection is defied by the innate difficulty of agglomerating and contextualizing data from heterogeneous systems across the production life cycle (Tolio et al., 2013). Consequently, researches have managed to put forward numerous solutions. The aforementioned solutions are able to encompass the totality of the company's major IT systems into one architecture all the while securing the interchangeability among them. In this article, we are proposing a reference architecture capable of connecting the production and information systems of the company. This architecture is based on six aspects that we identified as main ones: Data integration, Systems integration, Security, Monitoring & Data analysis, Mobility and finally Cloud computing.

Thus, this paper is structured in the following way: Section 2 explains the background that prompted us to propose this architecture. In Section 3, we present the proposed architecture and we try to project the six predefined aspects on it. An application of our approach on a case study is presented in Section 4. Lastly, Section 5 winds up the paper.

## 2 BACKGROUND

In this day and age, it has become a must for industrial companies to digitize and optimize their processes. The goal behind it is to keep up with the concurrence. This digitization is fulfilled trough connecting the real



Remli, A., Khtira, A. and El Asri, B.
Reference Architecture for Efficient Computer Integrated Manufacturing.
DOI: 10.5220/0010497903280334
In *Proceedings of the 23rd International Conference on Enterprise Information Systems (ICEIS 2021) - Volume 1*, pages 328-334
ISBN: 978-989-758-509-8

world to the virtual one, using cyber physical systems, data sensors and IT Systems. However, the usage of several systems and technologies in the same environment is very challenging. This is due to the dissimilarities between them and particularities of each one of them. Subsequently, researchers have been able to propose architectures that are capable of encompassing every system in the CIM context.

## 2.1 CIM Architectures

A systematic literature review (SLR) has been conducted on this topic. Its main objectives were: to investigate the different approaches proposed to handle computer integrated manufacturing architecture between 2015 and 2019, to identify the nature of contributions in this area and to determine the different aspects covered by them (Remli et al., 2020). At the beginning, we identified 4073 papers retrieved from four digital libraries. Based on a set of quality assessment and exclusion criteria, 29 relevant papers were selected.

Out of the analyzed papers, twelve have proposed architectures in relation to our research. For example, Sprock and McGinnis proposed an architecture for smart manufacturing to bridge the gap between system data and analysis models (Sprock and McGinnis, 2015). Similarly, Tang et al. proposed the Cloud-Assisted Self-Organized Architecture (CASOA) to build a vertically enabled system for data consolidation (Tang et al., 2018). Caggiano and his colleagues' Cloud Based Framework enables smart monitoring of machining in order to offer real time diagnosis (Caggiano et al., 2016). In the same vein, Tao et al. presented the Data-Driven Smart manufacturing Framework, which enables the usage of the data collected through the manufacturing process, in order to increase its efficiency (Tao et al., 2018).

## 2.2 CIM-related Aspects

After the analysis of the selected papers, we identified six aspects that we deemed essential to handle in a contribution: Data integration, Systems integration, Security, Monitoring & Data analysis, Mobility and Cloud computing.

- **Systems Integration.** It is the capability of a solution to ensure the integration and the cooperation between different IT systems in the same architecture (Thames and Schaefer, 2016).
- **Data Integration.** It consists of applying context to data from heterogeneous systems across the production life cycle (Leitão et al., 2017).
- **Security.** It is the ability of the proposed solution to provide secured connection for systems' integration and data exchange (Lia et al., 2018).
- **Monitoring and Data Analysis.** It consists of utilizing collected manufacturing data to improve productivity. In this aspect, we can distinguish two types of data. The first one is Real-time Data used generally for monitoring and the second type is Historic Data used for Data analysis (Bousdekis et al., 2015).
- **Mobility.** It is the ability to integrate IT systems on phones and tablets, generally for data monitoring. (Menezes et al., 2018).
- **Cloud Computing.** This aspect concerns the capability of the solution to ensure the usage of cloud computing for some or all the functionalities (Weihraucha et al., 2018).

The common point between the chosen papers of the literature review is that each and every one of them encompasses the aspect of data integration. Right after it, comes Data analysis and monitoring as well as Systems integration. We find it very logical that these two aspects be the most covered ones. This is owing to the fact that computer integrated manufacturing largely revolves around connected systems, data interchangeability in addition to re-usability. The aspect that ranks third is the cloud computing. Regarding Security, this facet in research draws little to no attention. However, it stands as a pivotal requirement in ensuring the sustainability of the business. Mobility was the least tackled one of the aspects. This came as a surprise, considering that, in the era of industry 4.0, it has been an important feature. This qualifies it, alongside with security, to be major features worthy of being covered in a reference architecture.

# 3 ISA-95 BASED REFERENCE ARCHITECTURE

In order to overcome the limitations of the existing approaches, we propose a new architecture based on the hierarchy of the ISA-95 standard. In this section, we first give an overview of the ISA-95 standard. Then, we explain the concept of Open Platform Communication. Finally, we present the proposed architecture.

## 3.1 ANSI/ISA-95

Generally, modern industrial companies have at least two information systems; an ERP (Enterprise resource planning) for managing the inner resources

(Human resources, stock, suppliers..) and a MES to manage real time production. The two systems have separate scopes. The communication between the pair of systems is an important task. It is usually carried using different communication protocols. To standardize the communication between the control systems, the MES and the ERP, there are several standards. The most commonly used one is the ANSI/ISA-95.

The ANSI/ISA-95 standard was jointly developed by the International Society of Automation (ISA), and the American National Standards Institute (ANSI) with the objective of providing abstract models and standard terminologies for the exchange of information between the enterprise business systems and manufacturing operations systems in an enterprise (Brandl and Consulting, 2008).

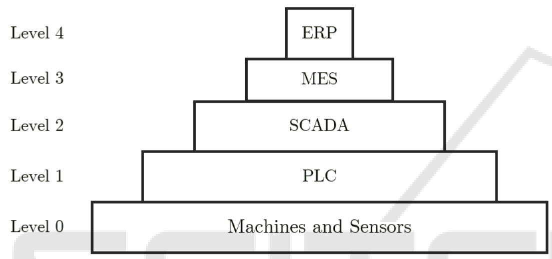


Figure 1: The CIM pyramid.

The ISA-95 presents a reference model that defines five levels, in which we can cover the whole layers of a manufacturing company. These five levels are schematized in Figure 1. This representation is called the CIM Pyramid, the higher one climbs in this pyramid, the stronger the level of decision gets.

#### 3.1.1 Enterprise Resource Planning (ERP)

Enterprise resource planning (ERP) is defined as an integrated computer based system that manages internal and external organization resources. These resources include tangible assets, financial resources, materials and human resources (Radovilsky and Bidgoli, 2004). ERP provides an integrated and continuously updated view of core business processes using common databases maintained by a database management system.

#### 3.1.2 Manufacturing Execution System (MES)

A MES is an information system whose main objectives are tracking and gathering real time data about the production life-cycle from all the factory or a part of it (Zhao et al., 2018). A MES provides inputs for decision makers to decide how current conditions on the plant can be improved and optimized. The collected data set is used to carry out a certain number of analysis activities:

- Traceability.
- Quality control.
- Production monitoring.
- Scheduling.
- Preventive and curative maintenance.

The final goal of a MES is to ensure effective execution of the manufacturing operations and improve production output.

### 3.2 Open Platform Communication (OPC)

Formerly known as Object Linking and Embedding for process control, or simply OLE for process control (OPC). It is an interoperability standard used to secure the exchange of data in the industrial automation space and in other industries. It is a cross platform technology to ensure the seamless flow of information among devices from multiple vendors (OPC Foundation, 2021). The OPC Foundation is responsible for the development and maintenance of this standard. The OPC is implemented in server/client pairs:

- **OPC Server.** It is a software that can read one specific machine language or many and can collect data from it and expose it in OPC United Architecture (OPC UA). It converts the hardware communication protocols used by Programmable Logic Controllers (PLC) into one standardized protocol.
- **OPC Client.** An OPC client is any information system that needs to connect to the machines to get the data, such as HMI or MES. The OPC client uses the OPC server as a bridge to get data from the machines or to send commands.

### 3.3 Proposed Architecture

The architecture we are proposing is based on the ISA-95 standard. Consequently, the hierarchy of the proposed systems is respected (the ERP on the top of the Pyramid and the machines in the bottom). Also, the architecture is based on the idea that the MES is the core element of the CIM, for it binds the whole production system to the enterprise resources.

We propose that the company's production system should be divided into two levels as shown in Figure 2:

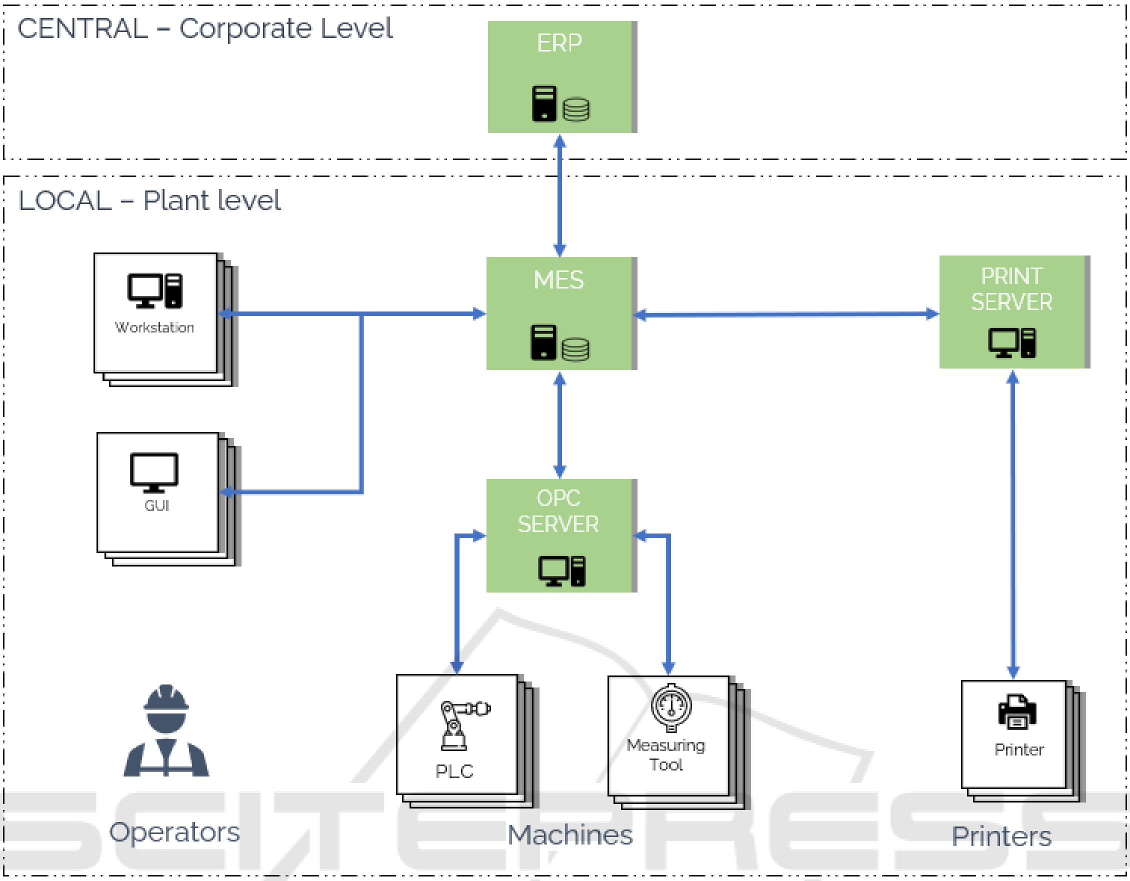


Figure 2: The proposed architecture.

- **Plant Level.** It consists of the local part of the production system that will be specific to each plant. It contains all the physical manufacturing systems and equipment, such as: the machines and their PLCs, the printers and their server, the workstations, and finally the MES. This level thus represents the four first levels of the CIM Pyramid (Level 0, 1, 2 and 3).
- **Corporate Level.** It is the Central part of the production systems that will be shared between the company's plants. It contains only the ERP system of the company (Level 4).

To prove the consistency of the architecture, we are going to project it on the six aspects we retrieved from the literature.

### 3.3.1 Systems Integration

The proposed architecture allows the company's systems to communicate with each other, using common communication protocols:

- **OPC Server / PLCs-Measuring Tools.** The OPC Server has the ability to communicate using several protocols depending on the machine. It can use either OPC UA Protocol for machines that are using it, or use the specific PLC Driver of the machine.
- **MES / OPC Server.** The MES is considered an OPC Client. As a result, this communication is carried out using OPC UA Protocol or in some cases HTTPS. MES Editors nowadays are adapting their solutions to the needs by providing OPC-UA interpreters in their systems.
- **Workstations-GUIs / MES.** The MES system Data can be accessed using HTTP Protocol by workstations or by any other type of GUI (ANDONs for example).
- **Print Server / MES.** The printing server is connected to the MES using TCP/IP Protocol, and it is connected to the Printers using The IPP protocol.
- **ERP / MES**: This communication is fulfilled generally by using HTTPS Protocol. But for some ERP solutions, RFC protocol or even some specific communication canals are mandatory.

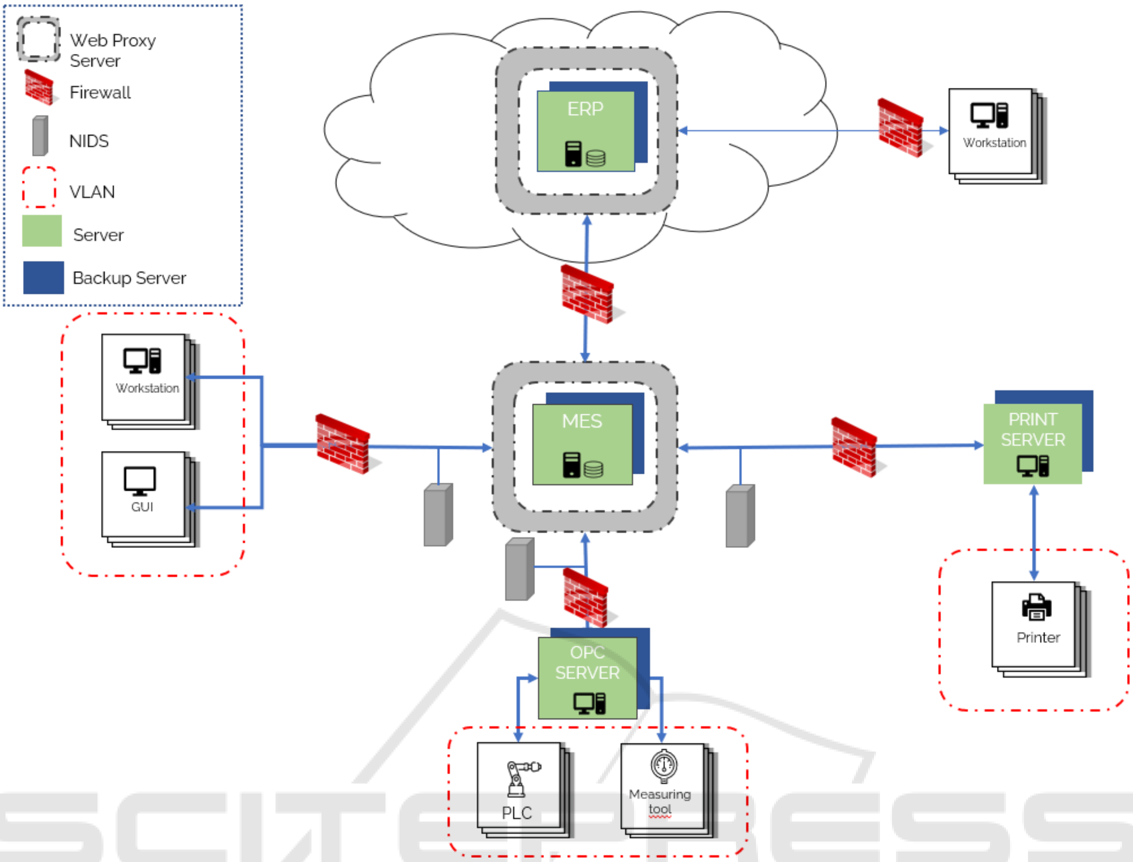


Figure 3: Security implementation.



### 3.3.2 Data Integration

Data integration in the architecture can be summarized in two points :

- The OPC Server allows data coming from machines to be formatted and normalized so that it can be integrated in the MES.
- The communication between MES and ERP allows Data exchange between the two systems.

### 3.3.3 Monitoring & Data Analysis / Mobility

The MES gives us the possibility to expose production data to be used by Client-side applications, using web-services and Web-sockets. Moreover, MES Solutions nowadays provide development modules that Allow us to develop and deploy cross-platform Web Applications for Production monitoring, and for tracing ability and Dash boarding such us ANDONS and Cockpits. These applications can consume the exposed data, which gives real-time visibility on the production life-cycle, provides inputs for decision makers, and represents Mobile-Friendly applications for easy knowledge access.

### 3.3.4 Cloud Computing

As we already explained, there are two levels in the proposed architecture: Corporate level that contains the ERP and that is shared with all the company's plants, so it should be deployed on a Cloud server, and the Plant level that contains all the remaining systems. The IS systems for plant level are to be deployed on-premise.

### 3.3.5 Security

Based on the best practices set up by the Escal Institute of Advanced Technologies also known as SANS institute, we propose the architecture in Figure 3 to illustrate the practices to secure the whole architecture (Oxenhandler, 2003):

- For workstations, a separated network has to be created with a specified address to each machine. An ACL (Access-Control List) is to be implemented to control authorizations. Also, the workstations operating systems must always be up-to date.

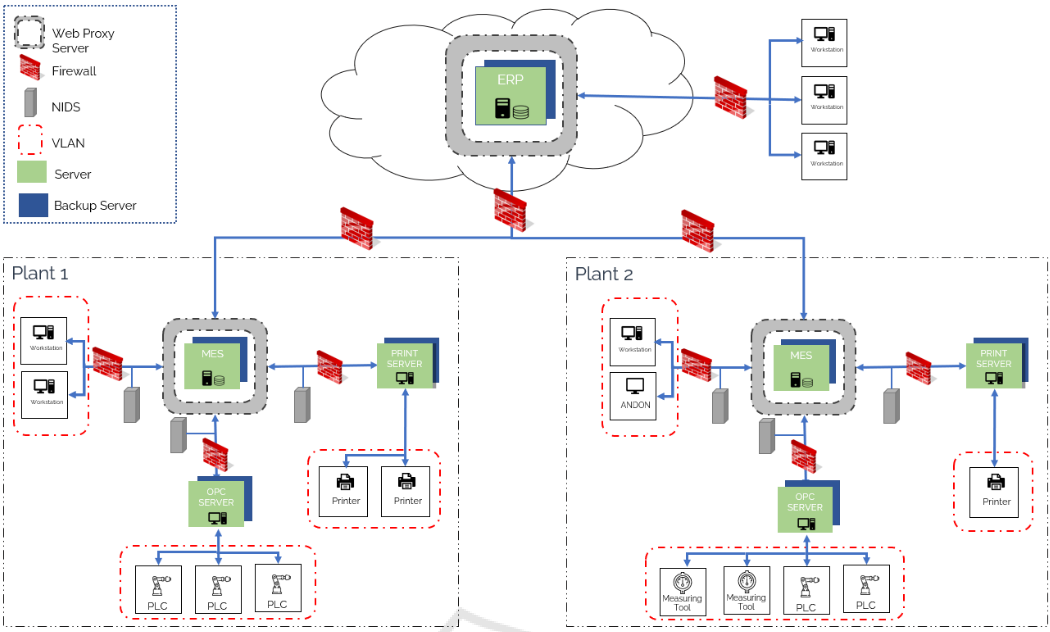


Figure 4: The Architecture of an Automotive Company.

- PLC and Measuring tools: The PLCs are connected to OPC server only trough Ethernet in a VLAN, so an ACL is mandatory to secure them. We can install SSL certificates to secure data access in PLC for more security.
- MES server: As the core element of the architecture, it should be secured on a highly level. For that, we propose a Firewall for all the Local connections (Plant level), an ACL to control access to the Data (Operators can have HTTPS Access and Printers can access only through TCP/IP). For more security, a Web Proxy Server should be setup to secure the MES as a web application from DDOS attacks, and finally, a NIDS (Network-based Intrusion Detection Systems) is used to analyze all traffic.
- For the printers, a separated network has to be created with a specified address to each printer, an ACL (Access-Control List) is to be implemented to set the appropriate permissions on files and folders (Xiaodong et al., 2012).
- The servers besides the VLANS have to be physically separated.
- To ensure the continuity of the production life Cycle and the availability of all the functionalities trough it, the MES, the ERP, the OPC server and the printing server should have at least one backup server each.

## 4 CASE STUDY

In this section, we apply our architecture on a concrete example from the automotive industry. This example consists of a company that has two main plants, one plant in Tangiers, the second plant in Angers. The company's main business is assembling cars spare parts. Figure 4 presents the projection of our architecture on the case study.

The Local level of Plant 1 contains three production machines with a PLC for each, two printers and two workstations. In the local level of Plant 2, we have three machines; two of them have their own PLC and one with two sensors. We have also two printers, one workstation and finally an ANDON.

The security in the local level is insured by using separated systems for the two plants, in other means, nothing relates the two plants except for the Corporate level. The elements of each plant are secured using the best practices we listed in the section above.

To guarantee the data integration, the MES security should be taken to a highly level, because of its role as the corporate messenger in the plant, and without which data will no longer be integrated in the ERP.

The MES we used allows us to customize several dashboards that will provide information to the operators, which covers the Dash-boarding aspect. The input that will be used is going to be the collected manufacturing data. It also allows us to develop web applications using cross-platform frameworks. These ones can be accessed from the operator's workstation or from mobile terminals. The central level of the company's architecture contains the ERP. It orchestrates the production on corporate level and communicates the company's strategies to plants to be translated by the MES as orders to the Shopfloor.

## 5 CONCLUSION AND FUTURE WORK

At the present time, digitization of processes has become a must for companies that feel the need to optimize their costs, to keep up with the customers' demands and to lead over their competitors. This digitization is done by connecting the virtual world to the real one using several technologies such us, data sensors, IT Systems and cyber-physical systems. However, the usage of many systems and technologies in the same environment can be really challenging, due to the differences between them and particularities of each one of them.

For that, we proposed in this paper a reference architecture for computer integrated manufacturing, which is able to encompass every system in the CIM context. This architecture is based on the ISA-95 standard and takes into consideration six major aspects: Data integration, Systems integration, Security, Monitoring & Data analysis, Mobility and finally Cloud computing. However, much work remains to be done in order to identify other aspects that can be interesting in the CIM context and can also be handled by our architecture.

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