Methodology for the Retrofitting of Manufacturing Resources for Migration of SME Towards Industry 4.0

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Abstract. Small and medium enterprises (SMEs) represent one of the main forces in economic development and employment generation. It is expected that these SMEs can turn towards new manufacturing paradigms such as Industry 4.0 to ensure their competitiveness in a future market. Nevertheless, these companies regard Industry 4.0 more as a challenge rather than a chance or as enabler for new value added opportunities. For this reason, in this article a literature review of Industry 4.0 officials reports and standards is carried out, in order to define a step by step the procedure of manufacturing resources migration towards Industry 4.0 by means of digital retrofitting, specifying both hardware and software requirements, the systems structure and required technology mapping for the Industry 4.0 implementation over traditional manufacturing resources. The main objective is to obtain the benefits of applying the Industry 4.0 paradigm without incurring in huge investments and provide technologic tools to SMEs that allow them to participate in globalized markets. Finally, the proposed methodology is applied in the retrofitting of a CNC machine given as result an industry 4.0 component ready to be integrated on a high-level application.

Keywords: Small and medium enterprises · Industry 4.0
Retrofitting of a CNC machine

1 Introduction

One of the key elements during the transformation of emergent economies countries, as Latin Americans, it is the start-up and development of small and medium enterprises (SMEs). They represent one of the economic development main forces, in fact they have been important players under global economy, and experience a generalized increase in production and employment, and, in some countries, even increased their productivity relative to that of larger firms [9]. As in Colombia case, the SMEs constitute more than 90% of the enterprise and these will generate around 80% employment [11]. The previous idea shows how important are the contribution of SMEs to the country economy, nevertheless, the SME tend to be less competitive when they

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confront globalized markets, due to common factors such as: lack of information technologies and non-formal jobs [25]. As a result, statistics show that on average 75% of SMEs close after two years and 25% only remain until the fifth year. [25].

On the other hand, the evolution of information technology has enabled new business paradigms like the Industry 4.0 (I.40). This forth industrial revolution defines an organization and control model of the value supply chain through the product life cycle and throughout manufacturer systems supported by the information technology [21]. This new approach for the organization and implementation of manufacturing systems offer new capabilities, such as, decentralized decision-making, mass customization, horizontal and vertical integration and end-to-end engineering [19]. Allowing companies perform on a higher level and also having a competitive advantage throughout time on a globalized market and increasing opportunities for value creation [22].

However, company migration, mainly in emergent economies, towards the I4.0 paradigm is not trivial and requires the deployment of theories and technological tools, such as: the Internet of Things (IoT), connectivity, digitalization, automation, big data among others, to ensure the proper integration [10].

According to the PricewaterhouseCoopers (PwC), Industry 4.0 report [24], the 33% of the global industrial company have an advanced digitalization level and is being expected this percentage reaches even a 72% at 2020. However, in Latin America the process is complex and slow, especially, when it comes to the transition of SME towards the I4.0 [13]. Several are the factors that have effect in this critical scenario such as the lack of economic and technological resources, cultural barriers, among others. Besides, it is also identified the risk involved in innovation for SME, due to the inclusion of new technologies requires a significant economic effort, which under a poor management could mean meaningful losses for small company and the lack of incentive from government in many regions of Latin America. From a cultural point of view, several SMEs underestimate the importance of acquire and adopt digital technologies in the short term in order to reduce remarkable barriers to compete on globalized markets [8, 13, 15].

Industry 4.0 offers new solution approaches, product innovations, product-related services and improve with a combination of already existing technologies. On the other hand, I4.0 can aid companies in reduce production costs. Furthermore, an increase in sales can be achieved through the enhanced utility and value of their own products [23].

Although the embracement of new technologies allows more efficient process, they also could have a negative impact if those changes are not adjusted on time or not properly implemented. For the above-mentioned is necessary to establish a standard procedure which can enable the migration towards the usage of this new technology. the above considering that, to be truly effective, it is necessary to be focused on improved some concrete technologies proportionally to the company's capabilities, so it fulfils the greatest possible benefit, on a performance level, and at the same time should be translated into a short-term positive impact on the company's income [15].

Several research about I4.0 applications has been published since 2015, but few of them are focused on provide well define procedures for supporting the SME in the adoption of Industry 4.0. As an example, there are applications that do not use standards and not define a system architecture such as in [6, 20]. There are projects which propose a system architecture but do not integrate formal standards such as on [14, 17, 30]. Finally, there are projects which defines a system architecture and integrate some standard such as quoted on [16].

The previous works lack the adoption of the standards defined by the platform Industrie 4.0, therefore, if in the future they wish to fit into the world network conceived by I4.0 (see connect world Fig. 1), they must rethink their current architectures. In this context, a methodology that integrates formal standards defined by the Platform Industrie 4.0 to define a system architecture for supporting the SMEs in the adoption of I4.0 paradigm is proposed in this article. This methodology ensures that SMEs can be easily coupled to the global network. In addition, it is based on the use of Open Source tools to achieve it, allowing cost reduction in the acquisition of specialized software and providing open architecture solutions. To implement this methodology, it is required manual and routine activities, such as the completion of databases and the linking of the native function of the system with the OPC UA methods.

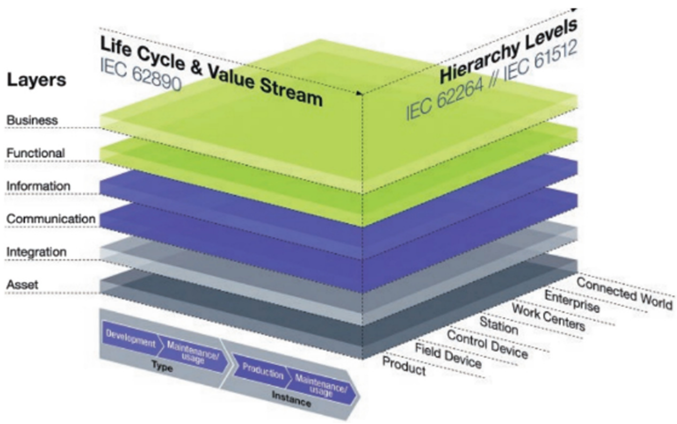

Fig. 1. Reference architecture model for I4.0. **Source:** [2].

The methodology proposed in this article is being evaluated in different areas of manufacturing. Currently, it has been implemented in machining processes, chemical products mix, robotics systems and assembly stations, as well as different field devices. As an example, this article presents a case of study, where this methodology is applied to retrofitting an industrial CNC.

This article is constituted by four sections. First, a formal definition of industry 4.0 is shown. Afterwards, a procedure for the migration from traditional manufacturing to I4.0 is proposed. Next, it is exposed a retrofitting of an industrial CNC machine compliant with I4.0 as application example. Finally, conclusions are stated

2 Formal Definition of I4.0

Since the concept of Industry 4.0 was introduced in 2011, many authors, researchers and companies have contributed to the construction of the concept with new proposals on architecture, dynamics and implementation of manufacturing systems. However, considering standardization as one of the pillars of this revolution [31], not every contribution can be accepted as a correct solution in the I4.0 context. In order to present a right definition of the concept, the sources of fundamental information for the architecture definition, dynamics and implementation of an I4.0 manufacturing systems should be limited to the official agents, which conforms the Plattform Industrie 4.0. This section shows some important concepts of I4.0 concerning to the implementation of new applications.

2.1 Reference Architecture Model for I4.0

In a report presented in 2015 [2] is submitted the reference Architecture Model Industrie 4.0 (RAMI 4.0) (see Fig. 1), developed among many Institutions such as the Society for Measurement and Automatic Control (GMA) y German Commission for Electrical Engineering (DKE) And also coordinated by the Plattform Industrie 4.0. RAMI4.0 displays a guide for whom seek to develop I4.0 system. The RAMI4.0 is depicted by three axes. The vertical axis represents the elements of information technology constituting the I4.0; the right horizontal axis, the hierarchical roles that the assets perform within the factory; the left horizontal axis, the life cycle of assets along their development and implementation phases. The architecture uses a functional hierarchy described on the standard IEC 62264, adding as new elements the "Connected world", "field device" and "product" in order to extend the standard to the I4.0 features.

2.2 Asset Administration Shell

Additionally, the RAMI4.0, defines the I4.0 components (I4.0C), in this definition sets that non-industry 4.0 compliant devices, i.e. sensors, actuators and controllers, can be turn into I4.0C by adding an Asset Administration Shell (AAS). This AAS is a virtual element, which encapsulates the information technology layers of the RAMI 4.0. The AAS allows the communication among other AAS through the I4.0 compliant communication, using the RAMI4.0 communication layer, and encapsulates the functionality of the system. (see Fig. 2). As an example, Adolphs poses on [4] an axis positioning electric system where it is shown how a I4.0C can be composed by the integration of the physical assets and the AAS. This data belong to the RAMI4.0 information layer.

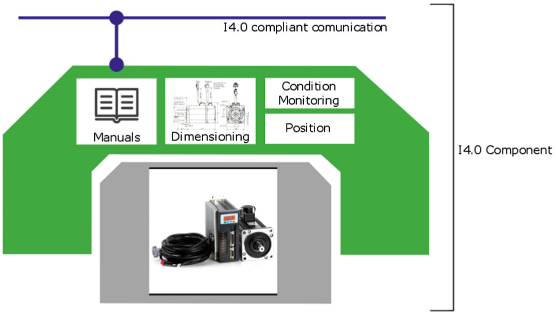

Fig. 2. Example of an I4.0C and the administration. **Source:** Own

3 Procedure for the Migration from Traditional Manufacturing to Industrie 4.0

According to the DIN SPEC 91345 [1], an Industrie 4.0 component consists of an asset and its virtual representation, this asset virtualization is implemented in the "administration shell", which turns a conventional object into an I4.0C. In this way, the procedure proposed for the SMEs migration to I4.0 has to be established in order to integrate the AAS into their manufacturing resources.

3.1 Prerequisites

To begin the migration procedure, it is necessary that the SME has an adequate infrastructure, defines the target system architecture, and have the technologies that will allow the correct implementation of said architecture. This could be achieved guaranteeing the following three steps:

Enable Information and Communication Technology (ICT) Capabilities
Afirst step for the implementation of the AdmonShell is to integrate the physical resource with a physical computational system (e.g. single board computer) or a virtual computational system (e.g. cloud computing) able to withstand the AAS requirements. Regarding of the implementation requirements of the communication, information and functional layers of RAMI4.0, the computational systems where the AAS is planned to be implemented should fulfill the following:

- IP communication for implementation of the communication layer
- Data storage in relational and non-relational databases for implementation of the information layer. Note: Some micro and nano embed devices just need some bits of storage for the state of sensors and actuators.
- Data acquisition and control through physical ports for the implementation of the integration layer. An example of this can be GPIO ports or serial communication, as well as other type of digital or analog inputs and outputs.
- Information processing through software functions for the implementation of the functional Layer.

Depending on the application, each of these characteristics will be necessary to a greater or lesser extent.

ASS Structure

The AAS structure has been under develop since the RAMI4.0 was revealing on 2015. Subsequently a more detailed structure was presented on [4]. On this depiction, the AAS is divided as follows: a Header, where the identification of the asset and the AAS are stored; and a Body, where the sub-models (the asset virtual representation) are stored.

In a later report, a more formal structure was proposed [7] (see Fig. 3). Here the ASS has a Header and a Body, but at the same time specifying the body composition as an integration of multiple data elements, collections of data elements, views, services, collection of services and references. It is also specified the relation between these elements, as well as the standards that must be followed.

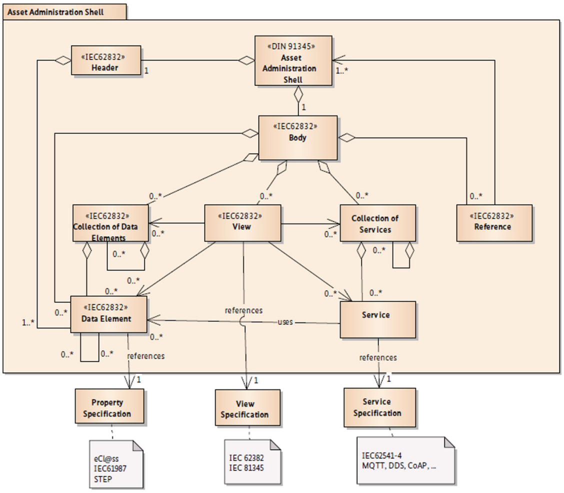

Fig. 3. AAS formal structure. **Source:** [7].

This structure (see Fig. 3) is generic and depends on the device and its application. Different sub-models should be selected, which integrate relevant data elements and services. For instance, in the Fig. 4 an AAS includes a sub-model for the P&ID plan, circuit diagram, mechanical CAD, among others.

Technology Mappings

The models of the AAS structure above shown are technology-agnostic and need to be mapped into different technological tools in order to be deployed as a real application.

Bedenbender exposed on [7] some alternatives for technology mapping such as the OPC UA for devices, MQTT, OpenASS and NAMUR MTP. On [28] a methodology for the migration towards I4.0 using OPC UA is presented. Also, several projects as [12, 18, 26, 27] agreed with the usage of OPC UA to implement I4.0 applications.

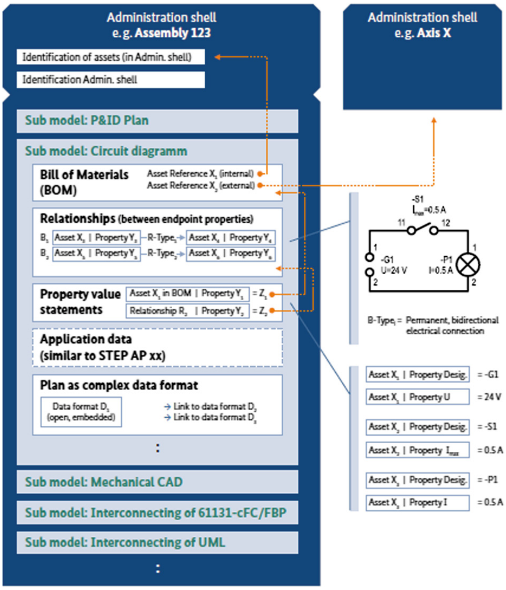

Fig. 4. AAS sub-model example. **Source:** [32]

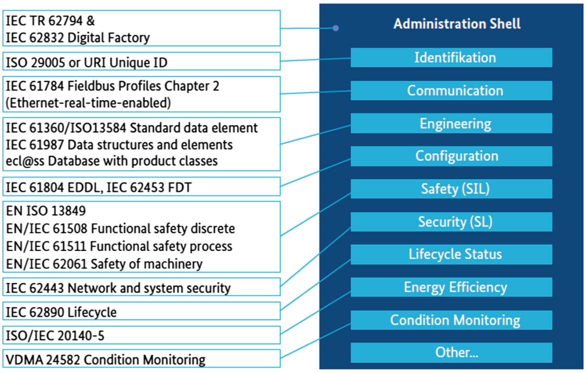

Fig. 5. Generic sub-models standardized by the ASS. **Source:** [4].

According to this, on this article will be used OPC UA as the technology on which the AAS will be mapped following by methodology proposed on [7].

3.2 Migration to Industry 4.0 Procedure

A systematic migration procedure is proposed based on the following conditions:

- The requirements of RAMI 4.0 must be fulfilled [3].
- Implement the AAS using the architecture exposed on Fig. 3 [7].
- Implement the I4.0 communication using the OPC UA guideline [28].

Starting from RAMI 4.0 (see Fig. 1), the migration procedure consists of performing a sequential implementation from the integration layer to the functional layer, since it is not possible to implement a layer without having previously implemented the adjacent layer immediately below. Firstly, the physical and virtual world are integrated (i.g integration layer). Secondly, a basic communication is configured using OPC UA (i.g communication layer). Next, the OPC UA server is populated using, information model (i.g information layer). After this, the asset functionality is implement as services (i.g functional layer). As a later step, the views and references are deployed considering that they need the previous data and services.

First Step: Integrate Physical and Virtual World
First, the connection between the physical world and the virtual world must be guaranteed, this will depend on the nature of the asset and the computational system where virtualization is implemented. Some examples of integration are:

- Sensors and actuators can be monitoring and controlled directly using, the GPIO ports of a Raspberry Pi board with the correct interface.
- PLC memory registers can be monitored and modified from a computer using, an industrial protocol through a serial port.
- Functions and state of an industrial robot can be accessed from a cloud computing application deployed in a thin client PC connected to the robot control unit.

Second Step: Configure Communication with OPC UA
In this step, it is deployed the OPC UA servers and clients to communicate the manufacturing resources allowing that resources such as machines, robots or people can browse, read, write, call methods and subscribe in a generic information model such as OPC UA Device Integration (OPC DI).

Third Step: Populate OPC UA Server
Depending on the virtualized asset, the corresponding companion specification and the extended information model provided by the manufacturer should select. Some examples of companion specifications are:

- MDIS OPC UA Companion Specification for interfacing the Subsea Production Control System (SPCS) with a Master Control Station (MCS) or a Subsea Gateway to the Distributed Control System (DCS)-
- OPC Unified Architecture for CNC Systems for the information model Computerized Numerical Control (CNC) systems.
- OPC Unified Architecture for FDT for network representation using the FDT® standard.
- OPC UA PackML Companion Specification for packing machines.

It is important to mention that both the companion specifications and the extended information model are in current development, this decreases the possibility of finding a companion specification for unconventional manufacturing systems.

In addition to the particular representation of the asset, some generic and standardized sub-models can be added depending on the application of the asset within the

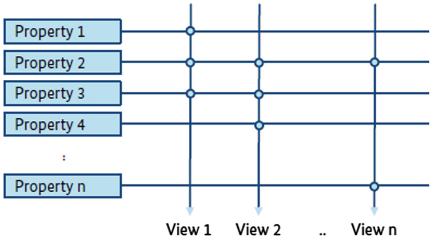

Fig. 6. Pre-defined properties as views. **Sources:** [4].

manufacturing system. In the Fig. 6, some examples of sub-models with its corresponding standard are presented.

Some models such as AutomationML (AML) and FDI are used to integrate different system points of view. However, they use data formats that not compliant with OPC UA, for this reason, there are standards that define the mapping rules that allow migrating the AML and FDI models to the OPC UA information model, an example of this can be found on [10] (Fig. 5).

Forth Step: Define and Implement the Services

Services are the gate to execute AAS functionality. They would refer both higher logic level and asset-specific functionality (e.g. "open grip", "lubricate", "drill hole"). This may include administrative services to retrieve historical data or alarm conditions.

These services should be implemented using the preferred programing language and defining the inputs, outputs and the information required from the information model. In order to relate with the service, interaction paradigm needs to be defined regarding the requirement of the RAMI 4.0 that sets *"A high level of cohesion is to prevail within the layers, with loose connections between them. Events may only be exchanged between two adjacent layers and within each layer"*. This means that the services can interact between them using a web service platform or triggering events from the information layer through OPC UA.

The services should be grouped according to their application as follows: communication, transformation, administrative, and data visualization among others.

Fifth Step: Define and add the Views

Depending on the context, some view can be added to the information model facilitating the access to relevant information. Views allow automating the access to some pre-defined properties avoiding the navigation along the information model. According to Fig. 6 the view 1 is related with the properties 1, 2 and 3.

As an example, for maintenance proposes, a view can be assigned to the supervisory system to access directly to relevant properties like temperature or pressure.

Sixth Step: Add References According to the Context References depicts information about AAS external connections. These connections can refer to other assets connected to the AAS, in which plant segment it is located, and from which other asset it is derived. Some common references are:

- Containment reference
- Inheritance reference
- Type-Instance reference

These references can be mapped almost directly to OPC UA using ReferenceType instances.

Seventh Step: Implement the identification of the AAS
In the last step, the ASS Header should be implemented by adding to the AAS and the asset a unique identifier based in standards like ISO 29002-5.

This identifier items can be added as properties in the top of the OPC UA information model. Other option consists on use the identification variables of OPC DI.

4 Retrofitting of an CNC Machine Compliant with Industry 4.0

Considering the SMEs as an essential part of the economy, the VDMA German Engineering Federation, proposed a Guideline that aims to *"support small and medium sized companies of the German mechanical engineering industry in identifying potentials for products and production with a systematic process in relation to I4.0 and in developing their own specific ideas in this respect"*. To achieve this goal, a Toolbox Industry 4.0 is proposed in [29]. Different levels of application are presented on it and each broken down into five technological and sequential development stages.

As a case of study, a CNC Lathe that is part of a flexible manufacturing cell was used (see Fig. 8). Using the Toolbox Industry 4.0, the Machine-to-Machine Communication layer (M2 M) is selected as roadmap, where, as shown in Fig. 9, the CNC lathe is in the second stage of development and the objective of this application example is to take the system to the fifth stage using the methodology proposed in the previous section (Fig. 7).

4.1 Results

Addition of ICT Capacities
In order to retrofit the CNC Lathe to accomplish the I4.0 requirements, a computational module was added to the machine (see Fig. 10). This module is conforming by a Raspberry Pi Zero W, this device allows the IP communication through a Wi-Fi network; a MAX3232 board that allows the Raspberry to use industrial RS232 interface to communicate with the machine's serial port; finally, a optocopler interface which allows the GPIO of the Raspberry board to write and read the digital inputs and outputs of the machine.

Fig. 7. Case of study: flexible manufacturing cell

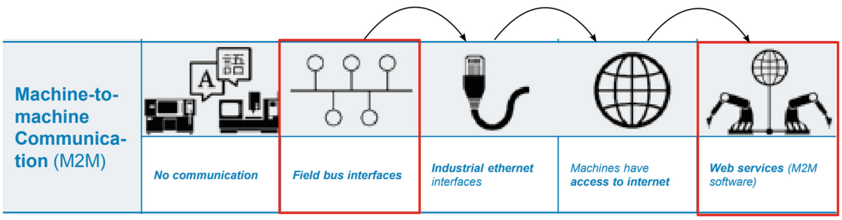

Fig. 8. M2M layer of the Toolbox Industry 4.0

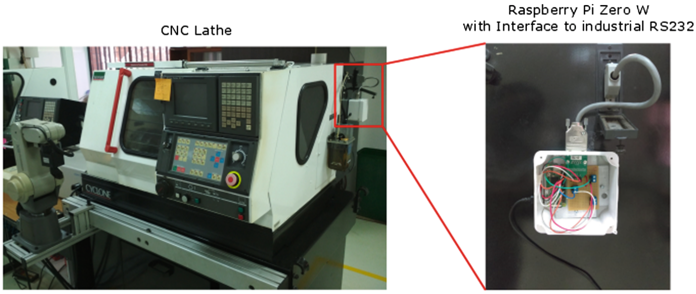

Fig. 9. Computational module linked to the CNC. **Source:** Own.

ASS Implementation

The ASS was implemented using the Python programing language for each migration process step. The result of each step is presented in Table 1.

The final result will be an OPC UA server that the other ASSs can access using I4.0 compliant communication. The resulting server is in accordance with the ASS structure. Due to lack of space, not all the OPC UA server elements were presented on this model (see Fig. 8).

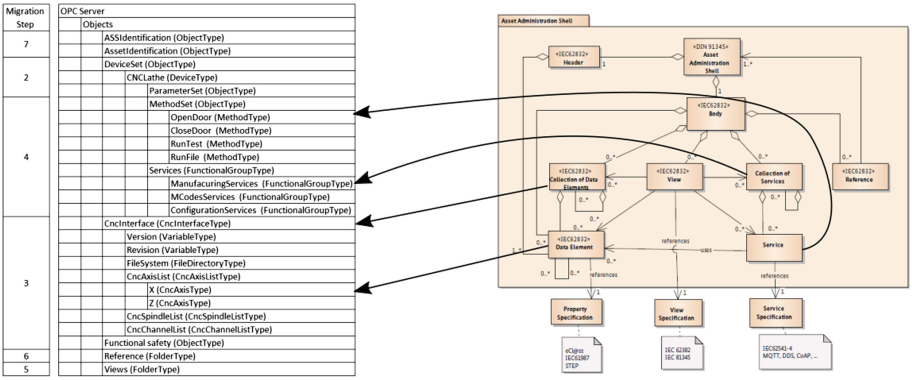

Fig. 10. Resulting OPC UA server from the migration procedure. **Source:** Own.

Table 1. Migration process results. **Source:** Own.

Migration step	Results
1	Pyserial library was used to send codes to the machine. A generic DNC control library was develop to interact with the machine, using object oriented programing
2	A OPC UA server was deployed, using FreeOpcUa Li-brery and the OPC DI information model. The communication was proved using the UAExpert Client
3	The OPC Unified Architecture for CNC Systems was selected as the corresponding specification companion and the Functional safety as a additional sub model, both are added to the OPC UA server using XML importation function of FreeOpcUa
4	All services were implemented as Python functions and linked to the method set of OPC DI using Python threads. The method sets were implemented as OPC DI functional groups, they have an organize relation with the methods in the MethodSet
5	Views were added as a folder that contains the view names and adding an organized relationship to the model properties
6	References were implemented using the same procedure as views, but adding hierarchical and non-hierarchical references, such as association, composition, aggregation and dependency
7	The ASS identification was carried out as two separate objects, whose contained identification variables and it was accomplished according to ISO 29002-5

5 Conclusions

Considering the impacts of SMEs in emerging economies, such as Colombia, it's necessary to support this sector of the industry with a correct implementation of international models that leads to the fourth industrial revolution, Industry 4.0. This economic force can be integrated into the value chain with a global impact, minimizing the risks of market variability. At this point, this article presented an approach of migration from the productive infrastructure, in the context of the SMEs, towards a globalized model defined by the I4.0 standard. The strategy defined for the evaluation of the proposed procedure was through experimentation. Appling this, the components of a flexible manufacturing cell where turn into I4.0 Components. As a result of this migration, new development opportunities for this industrial sector were evidenced. For example, at present, the working group is using the resulting I4.0 system in testing adaptive manufacturing strategies, order controlled production and other application scenarios of the industry 4.0 defined in [5].

An important result of this project is the demonstration that the adoption of industry 4.0 in SMEs does not imply a high investment in new equipment and technologies, but can be achieved through a retrofitting of existing equipment using mostly open hardware and software. For instance, a certified commercial solution for the implementation of OPC Communication in CNC machines, such as Fanuc Focas Ethernet driver, has a cost of USD 1356 for each machine, while the developed application had a unique development cost of USD 800 and an implementation cost for each machine of USD 100.

In this article, it has been clearly demonstrated that Industry 4.0 is an issue that has been correctly developed by organizations such as the *Plattform Industrie 4.0*, which providing the open reports and documentation facilitate implementation in SMEs, as it is the case of the Toolbox Industry 4.0 using as a guide in this project.

In the development of this project, it was evidenced that many of the activities necessary for the implementation of an application of industry 4.0 require manual and routine activities, such as the completion of databases and the linking of the native function of the system with the OPC UA methods. For this reason, it is recommended as future work the development of a framework that facilitates the implementation of this applications by automating generic and monotonous tasks.

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