The Impact of Cloud Manufacturing on RAMI 4.0

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***Abstract*—The paper deals with an empirical way of approaching the cloud manufacturing system on Reference Architectural Model Industry 4.0 (RAMI 4.0). The complex system wants to provide an overview of the advantage offered by cloud manufacturing through direct interaction with RAMI 4.0. For modeling the empirical system, we used the Visual Object Net++ package, which is simple to implement, offers the possibility of optimizing the system right from the design and analysis stage. It provides real-time information on the various activities in the nodes under analysis. The diagrams thus obtained are clear and relatively easy to analyze and interpret by qualified persons. This system is easy to implement and comes to the aid of company managers with the necessary information provided in real time with the actions carried out through RAMI 4.0.**

***Keywords*—cloud, manufacturing, petri net, Reference Architectural Model Industry 4.0 (RAMI 4.0)**

I. Introduction

The recent literature dealing with cloud manufacturing has grown. It thus considers the concept of cloud manufacturing as "a networked manufacturing model in which locally and globally distributed manufacturing resources for the entire product life cycle are made available to meet requirements and are organized and centralized controlled as production of cloud services. The model supports the interaction of participants for trading and use of resources, as well as dynamic and flexible cooperation and collaboration with partners.

The paper is organized into three sections as follows: the first section discusses the fundamentals and working principle of the cloud manufacturing concept and RAMI 4.0. The second section provides an architecture and structure of cloud manufacturing platforms that differ in terms of the number of layers as well as the type of resources inserted in the layers relative to RAMI 4.0. The third section introduces the proposed cloud manufacturing framework, combining all input resources and thus incorporating resources with well-established relationship on axis of RAMI4.0 [1].

The basic objectives of this work are to approach the idea of direct connection for manufacturing Cloud systems and the key elements represented by RAMI 4.0 [2, 3]:

-Fundamental study of Petri nets that can be analyzed and validated through a discrete system,
-Petri nets are useful for modeling and analyzing systems with discrete events,
-Validation methods and results obtained from the analysis of the subject model, deterministic and stochastic model that are used to reorganize and re-evaluate the system and increase its flexibility.

The fundamental idea of the cloud manufacturing concept is to encapsulate production resources and manufacturing capabilities and meet the demands of consumers through the platforms used. Thus production resources and capabilities are transformed into production services that can be managed and operated in an intelligent and unified way. Cloud manufacturing reflects both the concept of "integrated distributed resources" and the concept of "integrated resource distribution" [4].

The analysis of specialized literature allowed the identification of participants in a cloud production system.

According to the literature "cloud manufacturing is a distributed manufacturing execution model where the underlying resources envisioned in the Internet of Things are elastically exposed and used as cloud services, then composed and orchestrated for use as cloud services, then composed and orchestrated for a production task in an on-demand fashion" [5, 6].

Another approach, "Cloud manufacturing is an intelligent networked manufacturing model that embraces cloud computing, aiming to meet the growing demands for greater product individualization, broader global cooperation, knowledge-intensive innovation, and increased agility in market response ".

The main advantages of cloud manufacturing for manufacturers are:

-Leasing/release on request of production assets,
-Flexible reconfiguration of production assets according to needs,

The advantages are really attractive, so there are three main areas where cloud manufacturing can be applied in manufacturing companies.

-Production software is supported as a service in the production cloud. This can be treated as the production version of cloud computing.
-Collaboration between factories that has an extended scope; services such as supply chain visibility, transportation management, supplier/contract negotiation. Partners can create cloud computing modules to address other manufacturing issues, supply chain execution, shop floor planning, demand planning and production scheduling.
-High-performance computing that uses digital models to (1) virtually test products or manufacturing systems, (2) better understand the business environment through business intelligence, (3) make decisions. Models are typically highly parallelizable and well suited to a cloud environment.

The Reference Architecture Model for Industry 4.0 (RAMI 4.0), provides a neutral reference architecture model for solutions for applications using the Internet of Things (IoT), big data analytics and other technological advances in manufacturing processes, which is known under the name of intelligent manufacturing, or simply Industry 4.0. One of the main objectives adopted is to be able to communicate the scope and design of the system, to stimulate collaboration and integration with other relevant initiatives by framing the concepts and technologies developed in a common model [7–9].

II. Presentation of Architecture

Cloud manufacturing is a modern manufacturing concept that transforms traditional manufacturing resources into services using cloud computing, the Internet of Things (IoT), as well as virtualization and makes them available on the Internet. In terms of how it works, the available production services are controlled by an intelligent, cloud-based platform and can be used in a cost-optimized way where needed. The concept of cloud manufacturing covers the entire life cycle of a product, from development and design, to production and testing, to maintenance during operation.

For the analysis, we chose the technological flow analyzed in, which we adapted for the ideal case to highlight the most representative cloud and RAMI 4.0 systems that can be schematically represented using Petri nets. For this model we used the RAMI architecture to make the connection and to highlight the impact of cloud manufacturing associated with RAMI 4.0. you can see on the diagrams the flow of information that can be obtained relatively easily, and that can be visualized, read, stored, analyzed so that the decisions are as direct as possible, because the simulation results are in real time.

According to the transfer of production resources, the cloud manufacturing system can be divided into three parts: service-oriented input, production resource operation platform, and service-oriented output. The working principle of the production cloud is shown in Fig. 1.

As illustrated in Fig. 1, the production resource provider enters the production resources, including mainly processing equipment, auxiliary software, technical documentation, machining centers. Then, they are grouped and virtualized in the response of virtual resources through the cloud production platform with the use of IoT. After requesting the services, the response of virtual resources is automatically searched and a quick response is given to the request, finally the production services are transmitted through the interface.

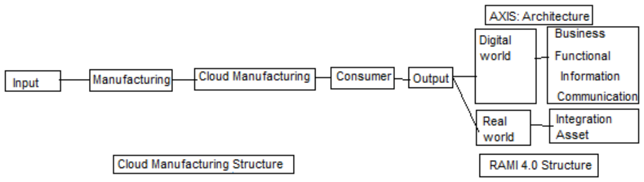

Fig. 1. Architecture, general model, relationship between cloud manufacturing and RAMI 4.0.

The Industry 4.0 Reference Architecture Model (RAMI 4.0), analyzed in the general complex mode, combines aspects related to the manufacturing process, product and IT through a three-dimensional service-oriented hierarchical structure. RAMI 4.0 is a network of components, interconnected all together contains the data of the virtual representation of a real-world object with its own characteristics and functionalities.

In this architecture proposed for analysis in this work, the Axis (from the three-dimensional structure) is Hierarchy—it represents the new Factory and is based on the standard in force. This axis includes: smart products, Smart Factory and the connected world. The smart factory is divided into: field device, control device, station, work centers and enterprise. The Axis is Architecture—refers to IT and includes six levels: Active, Integration, Communication, Information, Functional and Business.

The asset layer represents the physical things in the real world, the integration layer is the link between the real world and the digital world, digitally represents the assets [3].

The next four layers correspond to the digital world: the Communication layer allows communication of services and events/data to the upper layer, and services and control to the lower layer.

The Information Tier comprises services and data related to real-time batch and technical functionality.

The functional level contains information about the functions that describe the logical, technical functions and the integration platform. The Business level contains all the information related to the organization, business processes, legal and regulatory aspects.

One of the great advantages of cloud manufacturing is flexibility, so depending on the production platform, cloud manufacturing offers a wide variety of capabilities in one place. Fabrication is assigned to the nearest manufacturer who has the expertise to perform the job. Supply chains are highly configurable and non-fixed, minimizing reliance on specific connections and partnerships. The ability of the automated system to choose a manufacturing partner based on those qualities explains the achievement of lower costs and reduced environmental impacts through shorter delivery distances [8].

Regarding the description of the function for each layer, it is presented according to the specialized literature as follows [9]:

- The asset layer describes the physical components of a system. For each asset represented in this layer there must be a virtual representation. This layer includes the digital interface with people and the relationship with elements in the integration layer.
- The integration layer deals with easy-to-process informational content and is considered a bridge between the real world and the IT world.
- The communication layer is responsible for standardized communication between the integration and information layers. It performs data and file transmission and standardizes communication from the Integration Layer, providing uniform data formats, protocols and interfaces towards the Information Layer.
- The information layer holds the required data in a structured and integrated form. It is responsible for the processing, integration and persistence of data and events, as well as for data description. Events are received from the communication layer, transformed and transmitted accordingly.
- The functional layer describes the logical and technical functions, providing a digital description of its functions and a platform for the horizontal integration of different functions.
- The business layer is responsible for connecting the services provided by the functional layer. It models the

business rules, legal and regulatory constraints of the system. The processes of securing the economy are located at this level.

III. Model Analysis

In the production system mainly used as handling systems:

-Automatic linear lines,

-Pallet transfer to processing centers,

-Industrial robots for handling materials.

Since the manufacturing process is monitored at cloud levels, two very important factors influencing the handling are known, these are: the quantities of materials transported and the transport times [8].

A very important role is to ensure the maintenance of the system influenced by the faults that may occur and implicitly the time to repair the fault. This topic will be debated in another paper in which the complexity of the maintenance insurance system will be analyzed.

The advantages of Petri net modeling and analysis systems used in production are:

-Explicit relationships between events.

-The same modeling language can serve to describe the system abstract at different levels.

-Analysis of system properties to validate the solution.

For the chosen manufacturing System I will model and evaluate based on data from a manufacturing line, empirically analyzed, collected but reduced so that a complete simulation can be made. Because it is a theoretical research, the modeling of Petri nets is attempted, which with the help of dedicated technologies can be realized with IoT devices [8].

Starting from the general model, tried to implement the system, with structural compliance both for the relationship in the manufacturing system and for the axis in the RAMI 4.0 system under analysis.

This system is mainly dedicated to the decision-making bodies for the entire process in case of an implementation. This system has the advantage of providing real-time information both on the manufacturing system, which can be a classical one, but also on the direct link it establishes with the axis under analysis.

The information requested in real-time from different nodes of interest can be relatively easy to read and interpret, which leads to decreased times in terms of any type of intervention on the system.

The transport system model can be assimilated to a discrete event system. These systems form a class of nonlinear dynamical systems using their own mathematical tools other than the differential equations used in the theory and practice of automatic tuning.

Many models have been proposed to represent embedded systems, including extensions to finite state machines, data flow graphs, communication processes, and Petri nets. Some of them give a rigorous mathematical treatment to the formalism. Various computational models for embedded systems reported in the literature are presented here [10].

Data flow graphs are quite popular in modeling data-driven systems. Computationally intensive systems could be conveniently represented by a directed graph where the nodes describe the computations and the arcs represent the order in which the computations are performed. Calculations are performed only when the required operands are available and the operations behave as functions without side effects. The conventional graph model of data flow is inadequate for representing the control unit of systems [10].

System modeling using Petri Nets (PN) has been widely applied in many fields of science. The mathematical formalism developed over the years, which defines its structure and firing rules, has made Petri nets a well-understood and powerful model. A great deal of theoretical results and practical tools have been developed around Petri nets. However, several disadvantages have been highlighted, especially when it comes to modeling embedded systems: a) Petri nets tend to get large even for relatively small systems; b) The classic PN model lacks the notion of time. However, in many embedded applications, time is a critical factor; c) Uninterpreted Petri nets have no expressivity for formulating calculations, as long as tokens are considered “black dots” [10].

Petri nets are a fairly simple and versatile way to model factory and field activities with complex logic. With appropriate extensions, it can prove most useful in high-fidelity modeling of robo-activities and automated construction operations. As the package used for modeling, used Visual Object Net++.

Visual Object Net++ is an innovative Petri-Net-CAD/CAE tool for PC and supports hybrid Petri nets. Special attention has been directed to the intuitive use for: easy design, fast simulation and uncomplicated and powerful documentation of hybrid Petri nets.

The modeled system chosen is schematic and contains the cloud core components, RAMI 4.0 and the connection between them. It is a generic system and has the role of highlighting the component elements. (Fig. 2)

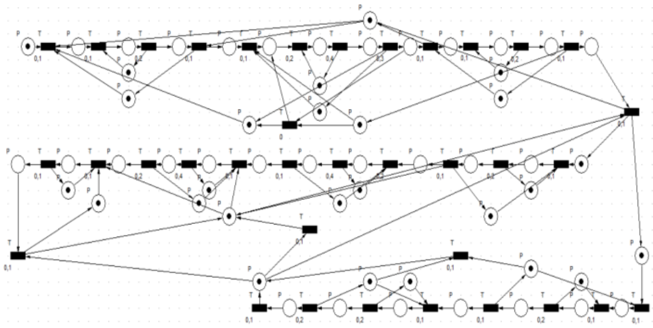

Fig. 2. Analysis of the simulated model.

Among the results of the simulation are several important aspects that vary according to the flow of information transmission.

Below are presented some of the results that most eloquently describe the evolution of the flow of information in the locations under analysis. All simulations correspond to an information modeling batch. For different batches and the flow of information is varied, for this reason we chose that all simulations correspond to a single batch of information.

The intense activity and the request of the equipment from the entire architectural model proposed for the analysis that can be observed is in the gathering of information. Here the flow repetition has predefined intervals to avoid overlapping. It is a dynamic system that must be followed carefully to detect errors before starting the manufacturing of the necessary products.

The simulated model, figure 2, suggestively respects the components presented in the proposed general architecture. In addition to structuring the components, a feedback system is also implemented in the simulation so that no errors are introduced into the network. Because the chosen system is empirical and the transport times are chosen for an entire flow so as to obtain graphical results as close as possible to a real system. Possible errors and the maintenance system will be analyzed in another paper. Here I wanted to highlight the impact of cloud manufacturing associated with an architecture axis from RAMI 4.0 research on a complex system.

The flow of information from the two big sections, namely from cloud manufacturing Structure and from RAMI 4.0 structure, was analyzed.

At each central node of the components of these sections, it is possible to intervene because a large variation in the flow of information can be encountered. Representative are shown in Figs. 3 and 4.

The indicated nodes correspond to the block represented in the proposed architectural model. In this way, you can follow each variation according to work levels. The proposed architectural model makes a direct connection between RAMI 4.0 and the manufacturing system, included in the dedicated cloud.

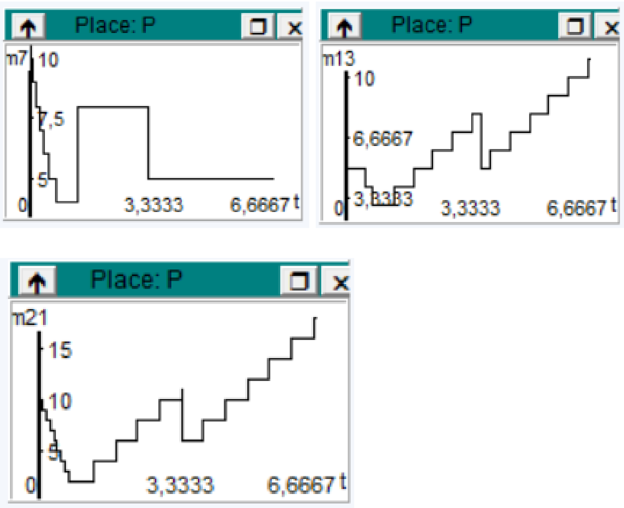

Fig. 3. The variation of the flow of information to the cloud manufacturing structure.

In order to be able to track and analyze the entire system, it has been divided into two sections. The cloud manufacturing section and its related nodes can be followed and decisions can be made individually, that is, decisions related only to the cloud manufacturing system. And the second system with its six components can be tracked, analyzed and controlled individually by following the diagrams in figure 4. Between the graphic representations in the two figures 3 and 4 have the common feature that they are used for the same type of information values and the results are in real time.

In Fig. 3, the distribution of nodes is as follows: node m7 is dedicated to manufacturing, node m13 is dedicated to cloud manufacturing, and m21 is dedicated to consumer.

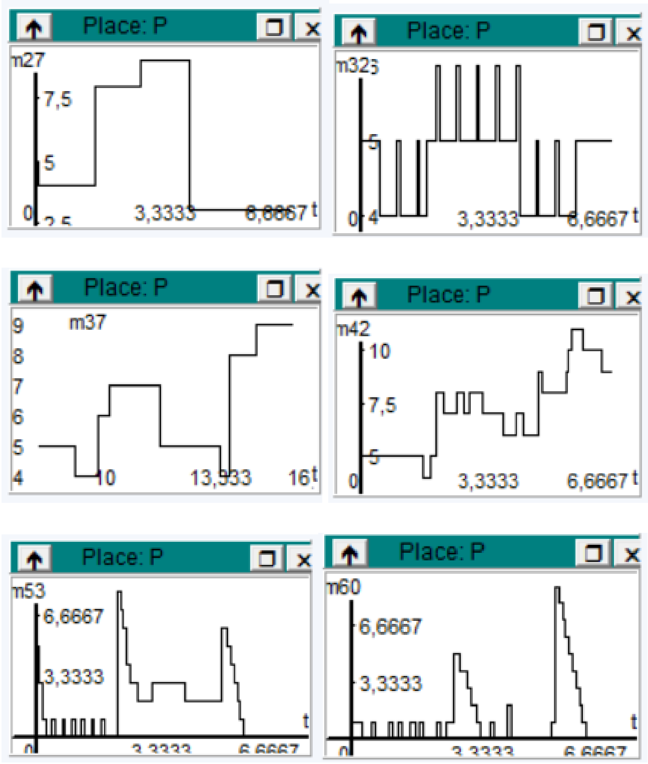

Fig. 4. The variation of the information flow to the RAMI 4.0 structure, for the architecture axis.

In Fig. 4, the distribution of the nodes is as follows: node m27 is dedicated to the business section, node m32 is dedicated to the functional mode, node m27 is dedicated to the transmission of information, node m42 is dedicated to communications, these being included in a digital action from this section. Then follows a real action that takes the following representations: node m53 is dedicated to the integration system and node m60 is dedicated to the active sector from the real activity found in the RAMI4.0 structure.

IV. Conclusion

The work wants to highlight a possibility of interconnection between cloud manufacturing and one of the axes of RAMI 4.0 and the method of analysis, tracking and control of the whole assembly.

Cloud manufacturing and RAMI 4.0 have become well-known paradigms and many different applications have been developed on top of them. Despite this, the main challenges in the technologies addressed for the cloud still remain, in particular systems evolution and application of systems comprising a large volume of heterogeneous connected devices, tools and machines. There is a great demand for new system architectures, for new approaches to complex systems. Cloud production platforms and direct connection to RAMI 4.0 are rarely applied today due to considerable security and return on investment concerns, but their tiered action plays a decisive role especially for various optimizations and maintenance.

Through the proposed architecture and the way to achieve the simulation of the structured system, I tried to highlight the favorable impact that cloud manufacturing has in association with the continuous research for RAMI 4.0 on the current manufacturing. The decision-making system can be more efficient, faster in accordance with the requested changes.

The presented study confirms the viability of the proposed system to create more specific models for RAMI 4.0, extending the studies on modeling the level of interest requested and presenting an example of a mobile production system with product traceability that can be implemented according to the reference architecture.

Conflict of Interest

The author declares no conflict of interest.

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