IEC-62264 BASED QUALITY OPERATIONS MANAGEMENT ACCORDING THE PRINCIPLES OF INDUSTRIAL INTERNET OF THINGS

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Abstract: *Manufacturing Operations Management (MOM) systems as central information and data hub play a very important role for an easy and seamless transition to Industrial Internet of Things (IIoT) applications. IIoT is mainly used in the context of Industry 4.0, that pursues the organization and management of value-added processes in the manufacturing industry with means of digitalization. The main aim of the proposed paper is to suggest some modifications to the IEC 62264 based models and architectures using RAMI 4.0 reference architecture in order to follow the basic principles of IoT and achieving the main advantages of IIoT.*

***Keywords**:* INTERNET OF THINGS, OPERATIONS MANAGEMENT, QUALITY, REFERENCE ARCHITECTURE, ISO/IEC 62264

1. Introduction

Achievements in industry are closely related to the use of the latest developments in information and communication technology. Regardless of the progress made in using ICT, modern enterprises are characterized by a relatively static IT architecture that cannot cope with the changes and uncertainties, lack of flexibility of hardware and software systems as well as rigid boundaries between cooperating companies. It has been found that the advanced Internet of Things (IoT) paradigm can address these issues by ensuring reliable data collection and sharing, ubiquitous computing, and computing clouds using powerful resources to solve a variety of decision-making tasks that abound in production systems.

IoT is an Internet extension that provides immediate access to information about physical objects and leads to innovative services with high efficiency and productivity [1]. IoT is also known as ubiquitous computing, ambient intelligence, and distributed electronics. The core concept is that everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective.[2]

The Industrial Internet of Things (IIoT) is the industrial application of IoT paradigm and is mainly used in the context of Industry 4.0. Industry 4.0 describes a new industrial revolution with a focus on automation, innovation, data, cyber-physical systems, processes and people. Considering a faster adoption of the new concept by industry, it is desirable to ensure a smooth transition to new technologies through the use of transition technologies and standards to achieve the IIoT objectives without major investment. For this reason, there are plenty of prerequisites in the industry: embedded devices and controllers, wireless sensor networks, RFID technologies and more. While hardware industry is relatively prepared for a transition to IIoT, there are serious challenges to software and architectures. An important step in the right direction is to use reference architecture that aims to achieve interoperability, simplify development, and facilitate implementation. Some of the most popular reference architectures are: RAMI4.0 [3], IIRA [4], IoT-A [5]. While IoT-A focuses on the functional and informational aspects of the architecture, RAMI4.0 of the Working Group for Industry 4.0 and IIRA of the Industrial Internet Consortium are industry-focused. Between the last two reference architectures exist some similarities and intersections, and there is an agreement between organizations to precisely identify the interoperability features between the two architectural paradigms and try to align them, as well for defining standardization requirements and using common test beds. The approach, proposed in this paper is based on RAMI 4.0 model, because it is built upon existing standards and functional descriptions and only some modifications are needed to achieve an IIoT application.

Manufacturing Operations Management (MOM) systems are key element in achieving IIoT applications, or also known smart factories. They are increasingly used for real-time control and visualization of production sequences, linking the manufacturing facilities with the business information systems and staying in the middle of automation pyramid. IEC 62264 standard supports the development and use of MOM, providing standard models and terminology for describing the activity models of manufacturing operations management and interfaces between the business systems of an enterprise and its manufacturing operations and control systems, in order to integrate them [6, 7]. Quality operations management is an important set of activities in the frame of MOM and is very suitable for a transition to IioT application.

The main aim of the proposed paper is to suggest some modifications to IEC 62264 based models and architectures in respect to the Quality operations management using RAMI 4.0 reference architecture in order to follow the basic principles of IoT and achieving the main advantages of IIoT.

The paper is organized in 4 parts. After the introduction, in part 2 the basic principle of IIoT are proposed. Part 3 discusses the ISO/IEC 62264 standard as a part in the IIoT architecture with a special attention on the quality operations management. In Part 4 of the paper the suggested approach is described. Finally some conclusions are made.

2. Basic Principles of Industrial Internet of Things

Tom Bradicich [8] defines 7 basic principles of IoT, as shown in Fig.1:

① *"Big Analog Data"* - The IoT will include vast numbers of heterogeneous predominately analog devices and sensors, generating enormous quantities of variable analog data that is the oldest, fastest, and biggest of all big data. Analog data needs to be treated differently than digital data, and the unresolved problem is the extraction of business value from big analog data.

② *"Perpetual Connectivity"* - the IoT presents perpetual connectivity to the product and user, supporting 3 main functionalities:

- Monitor - continuous observing and checking the progress or quality of products, users on the market or industrial settings, allowing their systematic review;
- Maintain – to keep equipment in a good condition trough convenient push of upgrades, fixes patches and management;
- Motivate – the ongoing connection to users or workers shows the way to force or motivate others to take some actions, purchase a product, accessories, etc.

③*"Really Real Time"*- IoT blends the world of Operational Technology with the world of Information Technology, following a 4 tier generalized solutions architecture for the IoT, and its related data flows:

- Tier 1: Sensor/actuator (wired, wireless);
- Tier 2: Internet gateways, Data acquisition systems (data aggregation, A/D, measurement, control actuation);
- Tier 3: Edge IT (analytics, pre-processing);
- Tier 4: Data center/Cloud (Analytics, management, archive).

④ *"The Spectrum of Insight"(Спектър на прозрение)* - Data analytics will be executed at 4 main domains

- At the sensor in the I/O channel;
- At the gateway or DAQ device;
- At the edge server or PC;
- At the data center or cloud.

⑤ *"Immediacy Versus Depth"* - Using advanced computer techniques and depending on the type of tasks solved, a compromise between speed and depth has to be found (so known "immediacy of insight vs. depth of insight"). Some tasks require immediate access to data and results from simple calculations, while others require more time to extract deep knowledge.

⑥ *"Shift Left"* - computation and data analytics will migrate to the lower tiers in the 4 Tier generalized solutions architecture of the IoT, enabling components and machines to gain self-awareness and self-predictiveness.

⑦*"The Next 'V'"* - The IoT eliminates time and place constraints allowing access from disparate geographic locations and representing the "Visibility" of Big Data. Such a way IoT adds a next "V" to the traditional "V's" of Big Data, which are: variety (mix of structures), volume (large amounts), velocity (high speed, high sample rates), value (importance of analysis, which was previously limited by technology).

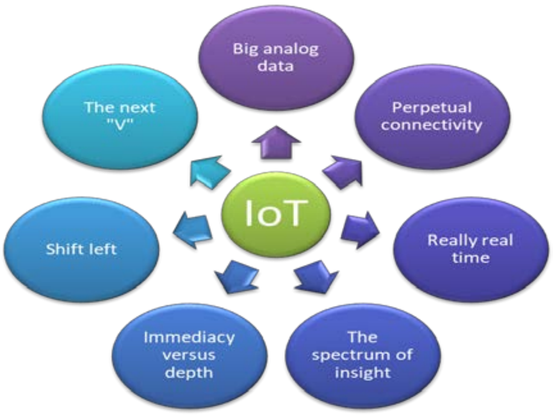

Fig.1: Basic principles of IoT

3. IEC-62264 standard as a part of IIoT

3.1. Short review and analysis of ISO/IEC-62264 Standard

ISO/IEC 62264 (ANSI/ISA-S95) series of standards [6, 7] offer the technology and a vendor independent way to exchange data and information. These standards are an agreement between leading companies (SAP AG, Eli Lilly, The Foxboro Co., Hewlett-Packard, Honeywell, Rockwell Automation, IBM Corp., Oracle Corp., ABB etc.) to create a common framework and guidelines for design and integration of systems. The standard ISO/IEC 62264 facilitate to separate business process from production processes and to separate the exchanged information from specific implementation of manufacturing systems and specific implementations of the business systems. The standard provides standard models and terminology for describing the interfaces between the business systems of an enterprise and its manufacturing-control systems (Fig.2). Activities related to manufacturing operations management (Level 3) integrate planning and logistics (level 4) and control functions defined on Level 2.

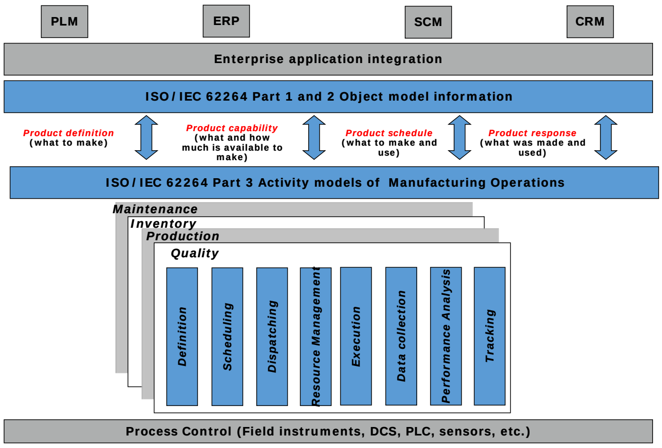

Fig.2: ISO/IEC 62264 Manufacturing Architecture [9]

According ISO/IEC 62264 the activities in manufacturing operations management are divided into four main areas: Production operation management, Maintenance operations management, Quality operations management and Inventory operations management. For all areas a common activity model of 8 activities (definition, planning, dispatching, resource provision, implementation, data collection, tracking and analysis) is suggested. The interrelationships between the four areas of MOM and the links with the main categories of information exchange defined in the standard are presented in Fig.3.

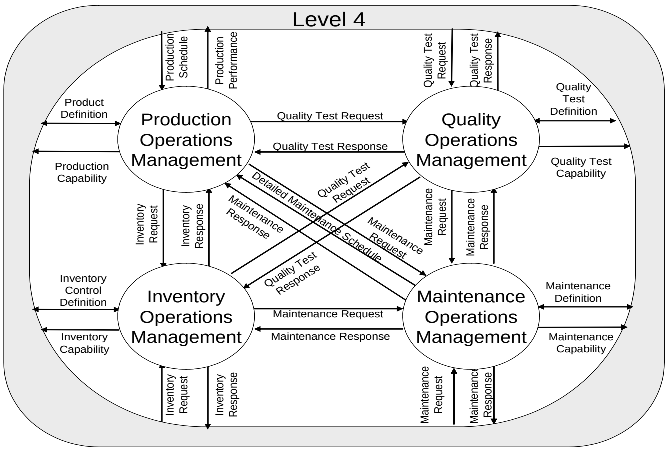

Fig.3: Interrelations between the areas of manufacturing operations management [7]

3.2. Quality operations management according ISO/IEC 62264

Quality operations management in the ISO/IEC 62264 standard is defined as a set of activities, which coordinate, manage and track the functions that measure and report quality. Quality operations management activities include: assessment of raw materials, intermediate and finished products, collection and maintenance of data records, use of analysis, real-time decision making, classification and certification tests, validation of measurements, maintenance of statistics for quality management.

The activity model for quality operations management, presented in Fig.4, defines what quality verification activities should be performed and the relative sequence of activities without specifying the way they are to be performed. The information related to the quality operations management according to the activity model is associated with the level 2 functions in the following categories: parameters and procedures, automatic commands for performing tests and obtaining results from them. Information flows from and to level 3 are classified as test definitions, resources, queries, and quality test results. The standard defines 8 types of activities related to the functions of the operations management systems for quality testing (Fig.3): Quality test definition, Quality test resource, Detailed quality test scheduling, Quality test dispatching, Quality test execution, Quality test data collection, Quality test performance analysis and Quality test tracking.

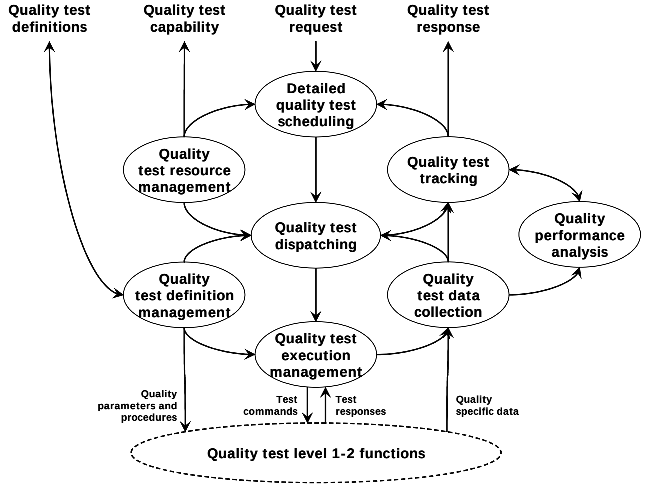

Fig.4: Activity model of quality operations management [7]

3.3. ISO/IEC 62264 as a part of RAMI4.0

The reference architectural model RAMI 4.0, proposed for Industry 4.0 and shown in Fig.5, is three-dimensional and describes the crucial aspects of Industry 4.0 [3]. The "Hierarchy level" axis includes the hierarchy levels defined in the ISO/IEC 62264 standard, including all different functionalities in the factory. In the RAMI 4.0 the functionalities are extended to the "product" according IEC 61512 standard and to "connected world". The left horizontal axis represents the life cycle of the facilities and products, based on the IEC 62890 standard and the vertical axis represents the six layers for decomposing into its properties. The reference model allows a step-by-step migration from present into the world of Industry 4.0. RAMI 4.0 integrates different user perspectives and provides a common understanding of Industry 4.0 technologies. It is a foundation for the following next steps towards Industry 4.0: thing identification, unified semantics and common syntax for data, defining of QoS components, communication connections and protocols.

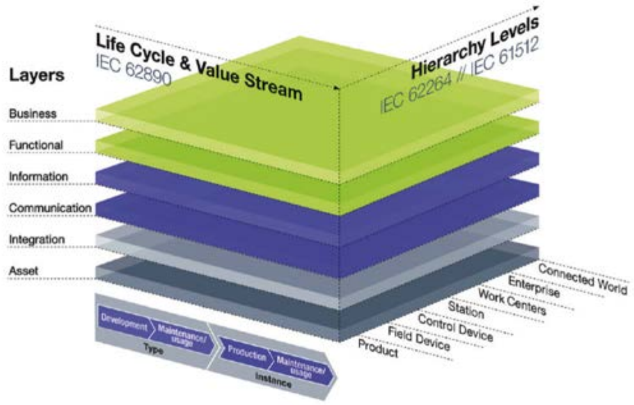

Fig.5: Activity model of quality operations management [3]

4. Quality operations management as IIoT application

For achieving an IIoT application of quality operations management system, a smooth migration path from existing deployments to emerging future internet technologies is needed. There is a consensus on the main steps to be taken [9], namely:

- Transparent (visible) factory - In his role as a central information and data hub, the MOM systems connect the business level in the form of the ERP system to the shop floor, thus ensuring mutual understanding and ultimately more transparency.
- Reactive factory (decentralization and autonomy) – based on identification of disturbances, detailed scheduling and reactive control
- Self-regulating factory - achieve more control loops and decentralization of tasks, control and the corresponding responsibilities. However, central synchronization is essential.
- Functional networking factory – based on interface between product development and production that is between PLM (product lifecycle management system) and MOM system, as well integrated quality assurance, a production-oriented energy management as well as the broadening of the viewing space to suppliers and customers - that is, to the complete supply chain.

The analysis of the above steps shows that paramount in building IIoT applications is the implementation of IEC 62264 based MOM system that supports the realization of three from all four steps. However, in order to achieve Step 3, it is necessary to solve the task of decentralizing the hierarchical model proposed in IEC 62264 standard according to the idea, presented in Fig.6. There are different approaches to successful decentralization in order to enhance integration and collaboration between decentralized components and to achieve self-X features of the system. The most successful and reliable approaches are those of Service Oriented Architecture (SOA) [10] and multi-agent systems (MAS) [11], as well the emerging infrastructures for fog or edge computing [12, 13]. MAS are widely used in the design of distributed manufacturing control systems with the purpose to enhance the horizontal and vertical integration of the enterprise systems. A short survey of the applied approaches is given in [14]. The fog computing extends the cloud computing closer to the enterprises network and is a horizontal, system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum [12]. Very often the fog and edge computing are used interchangeably, but between them there is a difference in respect to the involved pushing intelligence and processing capabilities [13]. While the fog computing pushes intelligence down to the local area network level of network architecture, processing data in a fog node or IoT gateway, the edge computing uses for this purpose edge gateway or appliance directly into devices like programmable automation controllers.

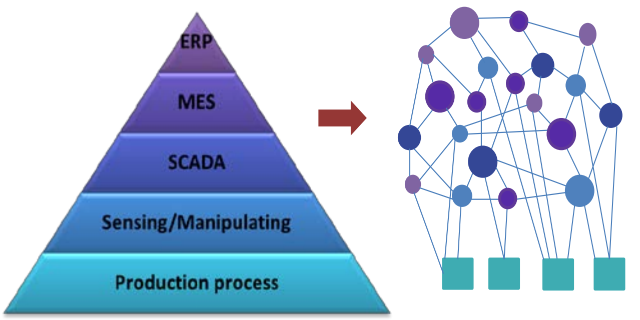

Fig.6: Transformation of automation pyramid

The IT structure of an IIoT components according RAMI 4.0 is represented on the vertical axis and consists of six layers. This layers help to visualize business processes, functional descriptions, data mappers, the communication behavior including Quality of Service (QoS), and the linking of assets via an integration layer. The data generated during production and in some cases customer-specific data for a specific instance is also considered as an asset.

The structure and sequence of operations at the functional level for Work Centers follows the proposed IEC 62264 based activity model, and in Fig.7a the activities and operations realized at this stage of development are presented. These are mainly related to checking and evaluating the quality of intermediate and final products, collecting and maintaining records, reporting on classification results, using "at-time" analysis for decision-making in real time in terms of technology mode and specific technology map. According to the information from the business level for the quality of raw materials and product requirements, an intermediate quality assurance procedure for intermediates has been established with the help of the resource database. The information stored in the database can be analyzed using various means of information processing and decision making. Tracking the change of information is essential for the future implementation of the detailed scheduling of quality assurance procedures.

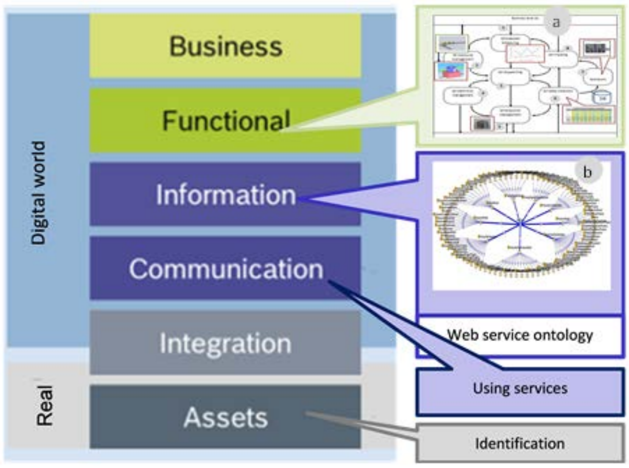

Fig.7: IT structure of quality operations management system based on RAMI 4.0

The quality operations management systems use a large amount of data from different data models. These models address different problems, have different users, may have been designed at different times, or may have come from different plant areas. In order to integrate and use these models, semantic technologies are used, based on the development of IEC 62264 based meta-ontology (Fig.7b) and different domain ontologies, as well an ontology for quality operations management, according to the standard model in ISO/IEC 62264 Part 4: Object Models and Attributes of Manufacturing Operations Management [16] and integrate it with the meta-ontology. In this way the quality management information, structured by the basic classes in the meta-ontology: “Material”, “Equipment”, “ProcessSegment” is connected with the five main interface classes, defining the relations Production-Process-Product: “ProductDefinition”, “ProductionCapability”, “ProductionSchedule”, “ProcessSegmentCapability” and “ProductionPerformance” ensuring the main tasks in quality operation management: Quality test definition management. Quality test resource management, Detailed quality test scheduling, Quality test dispatching, Quality test execution management, Quality test data collection, Quality test tracking, Quality performance analysis. The ontological approach allows the creation of a knowledge-based system able to identify changes in the quality and to support decision-making through the integration of domain ontology and semi-structured data, including data from laboratory analyzes of raw materials and end products. Integration of different models and data ensures flexible communication between enterprise information systems by ensuring interoperability and mutual exchange of information. The aggregate model provides data sharing capabilities and the ability to retrieve information from distributed heterogeneous sources for decision making, Key Performance Indicators (KPIs) calculations, and optimization of manufacturing and business processes.

5. Conclusions

The transformation of MOM systems and especially quality operations management systems according to the basic principles and reference architecture of IIoT for their integration into the structure of IIoT applications is an important step in achieving high quality of end products and efficiency of manufacturing system. The use of IEC 62264 based models and terminology shorten the development time and reusability of models and architectures. The transition from object-oriented models to semantic models enhances the interoperability of IIoT components at the different levels of RAMI 4.0 reference architecture. The use of reasoning mechanisms and the creation of rules based on the formalism of descriptive logic support the creation of a knowledge-based system capable of responding to changes in the product quality and quality assurance procedures. In addition the quality operations management systems comprise quality analysis functionalities and are a source for new information; they can assist with optimizing the quality parameters. The systems offer a rational functional supplement for detailed scheduling of quality assurance procedures and controlling all quality parameters in real time for ensuring process and product quality transparency.

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