Initial Approach to an Industrial Resources Ontology in Aerospace Assembly Lines

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Abstract. Industrial ontologies can support the Product Development Process (PDP) and the product and industrial system lifecycle, to have a seamless collaboration between actors. In this sense, an industrial resource ontology that supports an aerospace assembly line design process is key within the conceptual phase of the PDP. Industrial resources can have a different classification to support the design goal of the assembly line, in terms of process optimization, layout and space optimization, production time, costs, or even the assembly line capabilities definition. This work describes an initial approach to an industrial resources ontology, considering the notions that will describe these resources inside an assembly line design perimeter.

Keywords: Aerospace, Industrial Resource Ontology, Assembly Line Design, Knowledge-based systems, Models for Manufacturing.

1 Introduction

A Product Development Process based on collaborative engineering between different domains, requires strong and interoperable process, methods and tools, to develop an aerospace product and industrial system. Lack of interoperable tools to support this process in the conceptual phase, has strong influence in the maturity of the industrial system during production ramp-up phase.

Formal engineering ontologies are emerging as popular solutions for addressing the semantic interoperability issue in heterogeneous distributed environments and for bridging the gap between the legacy systems and organizational boundaries [1].

The design process of an aircraft assembly line is similar to a product design process. Assembly line design methods are discussed in the literature [2], but only few address an aerospace product industrialization with its inherent and non-negligible constrains (e.g. product complexity, industrial system complexity, long lifecycle, among others).

One of the most difficult steps in the assembly line design is to choose among different resources for each assembly process so that the work is done within given performance requirements, like cycle time, quality and minimum cost. Industrial resources play therefore a major role, and have to be correctly addressed to enable reuse or reconfiguration of existing assets, or design considering flexibility and target performance parameters.

Due to product functional requirements, some industrial resources or mechanical equipment may have to be designed specifically for a product or process. Often, a company outsources the design of its assembly lines and is at the mercy of the vendor regarding types of equipment [3].

This paper defines an initial approach to an industrial resource ontology, to support the assembly line design process during the conceptual phase of a PDP, and enable early design trade-offs against performance requirements. Next sections are organized as follows: Section 2 highlights related work and describes the motivations for a new industrial resource ontology applied to the aerospace industry; Section 3 presents an initial approach of this ontology supporting the assembly line design process; Section 4 covers the conclusions and further work. The paper ends with an acknowledgements section.

2 Related Work

2.1 Concurrent and Collaborative Engineering. Models for Manufacturing

Aerospace industry was pioneer designing and industrializing aircrafts using Concurrent Engineering techniques starting in the 90s [4]. With the introduction of PLM methods, processes and tools and the need to reduce time-to-market the industry pursues new working methods. Traditional Engineering works sequentially, Concurrent Engineering overlaps tasks between teams and Collaborative Engineering promotes teamwork to develop product, processes and resources from the conceptual phase to the start of the serial production. The authors proposed to implement the industrial Digital Mock-Up (iDMU) concept and its exploitation to create shop floor documentation in a framework of a Collaborative Engineering strategy [5].

In parallel, targeting to improve multidisciplinary design and simulation of complex systems, MBSE (Model Based Systems Engineering) methodology use graphical modeling authoring tools to specify data and behaviors of the systems and simulation tests systems behavior of complex products. Using the MBSE approach and based on the existing research for modelling manufacturing systems for the aerospace industry and the functional and data models published and deployed proposed by the authors [6], [7], a new approach for modelling manufacturing systems has been coined. Models for Manufacturing (MfM) is based in a novel architecture based on 3-Layers Model (3LM): a Data layer, an Ontology layer and a Service layer. Ontology layer is the core of the 3LM. The Ontology layer defines Scope model, Data model, Behavior model and Semantic model [8], [9]. A software tool to manage MfM in the collaborative process [10] and a framework was presented by the authors in [11].

2.2 Resources Definition in the Assembly Line Design Process.

Assembly processes, assembly planning and assembly system development are some of the elementary bricks of an Assembly Line Design Process. Most of the research efforts on this area have focused up to this day on the product and process definition, without a clear definition of the resources conforming the assembly system.

The term *"Resource"* has different definitions in the literature regarding the domain of applicability. For example, at enterprise level a "Resource" can be a mean to carry out an enterprise activity, at procurement level a mean to procure assets, and in different industries like telecommunications a node of a communications network. Some of the relevant work in the field of manufacturing is detailed next.

Resource is defined as *"Equipment"* by Graves [12] Rekiek [13]. Whitney [2] detail the equipment notion including tools, part presentation, sensors, transportation for the assemblies, and assembly aids like fluid dispensers, fixtures, and clamps.

One of the earliest manufacturing ontologies is the Process Specification Language (ISO 18629-1: PSL), designed to facilitate correct and complete exchange of process information among manufacturing systems [14]. With this goal, Lemaignan [15] proposes a preliminary upper ontology for manufacturing named MASON (Manufacturing's Semantics ONtology), with a *"Resource"* decomposition in geographical resource, human resource, and material resource.

ISO 15531 MANDATE, (ISO 15531-1) defines a *"Resource"* as any device, tool and means, excepted raw material and final product components, at the disposal of the enterprise to produce goods or services. Within it, the Resource Information model (ISO15531-31) defines a resource hierarchy (generic, specific, individual resource), resource characteristics (set of information about a resource), resource administration (administrative information), resource status (avail-ability or not of the resource), resource view (specific aggregation of resources), resource representation (physical values), resource configuration [16].

Mas [17] defined three different resource levels (line, station and basic), and within the basic level three types of resources: tools (ad-hoc mechanical equipment), industrial means (standard means or easily configurable that can be procured), and human resources (with defined set of skills).

The term *"Manufacturing Resource"* is used by several authors to clarify the scope of usage to manufacturing aspects. Manufacturing resource is defined by Chengying [18] as a 3D solid model composing three aspects: organization structure (5 levels each aggregating the lower level manufacturing behavior), capability status properties, and development activity. Manufacturing Service Description Language (MSDL) is an ontology developed for formal representation of manufacturing services primarily in mechanical machining domain [19].

Sanfilippo et al. [20], described a Manufacturing Resource as a physical object or amount of mater, which can be available/dedicated, agentive/non-agentive, or an input/output/mechanism. Järvenpää [1] defines a manufacturing resource as a device or factory unit as part of MaRCO ontology, with the goal of describing the capabilities and combined capabilities of manufacturing resources.

All the previous definitions suffer from lacks to have a holistic definition of industrial resources applicable to the aerospace industry. The assembly line design at conceptual phase, comprises strategic decisions of reconfiguration or redesign of industrial resources, which are different from operational decisions to be taken at production phase, where detailed capability information is needed to reconfigure in short time. This strategic decision level is poorly addressed in the literature.

Also, the aerospace industry has specific and non-negligible constrains for the Original Equipment Manufacturer and most of its Tiers (e.g. product size, complexity, long productive life of a same product), which drive the design of its industrial resources.

For example, the term *"Jig"*, widely used in the aerospace industry to refer to product dedicated industrial resources, seem not to be covered by the term *"Equipment"* used in other industries due to the complexity scale and associated costs.

Jigs can cover the full scale of aircraft (e.g. 75m x 80m x 25m dimension of A380 aircraft) to assure aircraft functional surfaces or mechanical requirements, with very high costs (up to 70% of total costs of an aircraft program). Equipment in other industries, even if dedicated for a product, have relaxed tolerances associated to product functional or mechanical requirements, rather than the ones of an aerospace product.

These deficiencies motivates the development of an industrial resource ontology for aerospace assembly lines at conceptual design phase. An initial approach is presented in next section.

3 Initial Approach to an Industrial Resource Ontology

This section approaches the role of the industrial resources in the assembly line design process of an aerospace product, as an initial approach to an industrial resource ontology. The assembly line design process defined by Mas et al. [17] is used as starting point for this work.

In [21] the authors defined a preliminary ontology to support the activity in charge of generating an *"As-Planned"* Product structure and a *"Build Process"* at industrial system network level, at the conceptual design phase of the PDP.

The *"Build Process"* at industrial system network level, describes for a given aircraft product the top-level sequence of manufacturing, assembly and logistics between plants, in a worldwide industrial network. It considers the product workshare to be made between countries or partners, before make/buy decisions for supply chain definition. This top-level sequence is the highest point of the process structure.

For a mono-configured product, the *"As-Planned"* is the industrial view of the product breakdown structure, created from a common layer of elementary objects to the *"As-Designed"* product structure, being this last one the functional view of the product. The *"As-Planned"* defines the product workshare between partners/contractors and their responsibilities, defining the *"product work package"* of each one of them, meaning aircraft components, interfaces definitions and joints to perform.

After this activity, an assembly line design process is launched for each assembly node of the *"Build Process"* and its corresponding *"product work package"*. This is the starting point of the work detailed next.

3.1 Generate Assembly Line Activity - Black Box View.

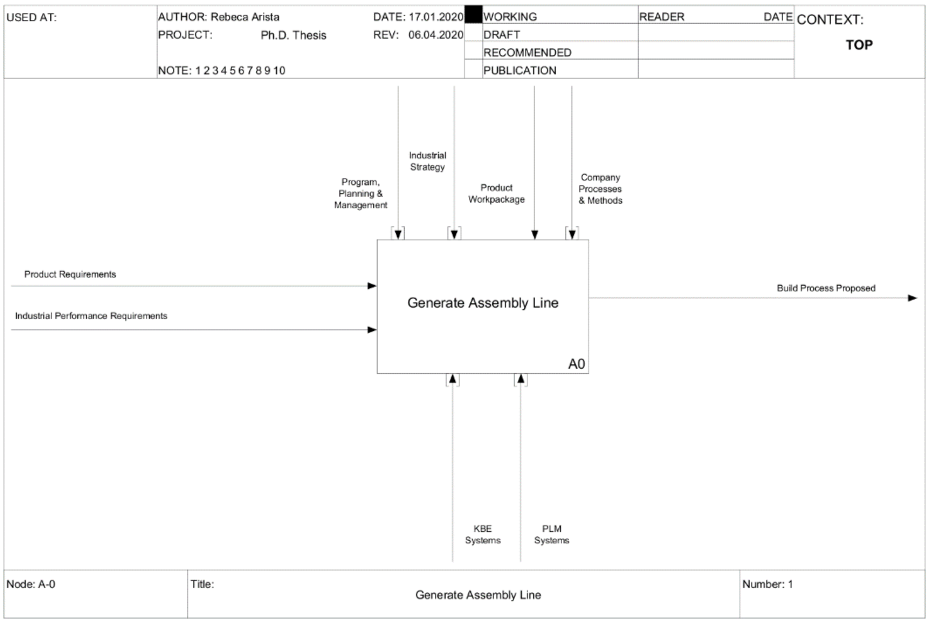

Fig. 1. Activity Generate Assembly Line – black box view

The assembly line design process is launched in the conceptual phase with the *"product work package"* definition, being controlled by the program planning & management, the industrial strategy and the company process, methods and tools. Figure 1 describes this activity in IDEF0, called A0 *"Generate Assembly Line"*.

This activity is in charge of generating a *"Build Process Proposed"* at assembly line level, which goes back to *"Define As-planned and Build Process"* activity to reevaluate both, the "As-Planned" product breakdown and "Build Process" at industrial system network level. This activity has as inputs: the product requirements (e.g. aerodynamic performance and weight), the industrial performance requirements (e.g. production time, costs and CO2 emissions), and supporting mechanisms KBE and PLM systems.

3.2 Generate Assembly Line Design Activity - White Box View.

Figure 2 shows the activities inside A0 "Generate Assembly Line". A "Build Concept" is a work-in-progress "Build Process" at assembly line level, containing a general description of the assembly line with the aircraft components flow, an estimation of the number of stations and sequence between stations. It includes as well a preliminary sequence of the main activities to be performed at each station.

With the product work package (components and interfaces) and the product requirements, activity A1 "Generate Build Concept" defines a Build Concept containing the components flow, stations and main stations activities. It defines as well the first needs of industrial resources related to this Build Concept (e.g. logistic system between stations, positioning systems and test system), and specifies the product tolerances that have to be fulfilled by the given industrial resources (e.g. aerodynamic shape and functional interfaces).

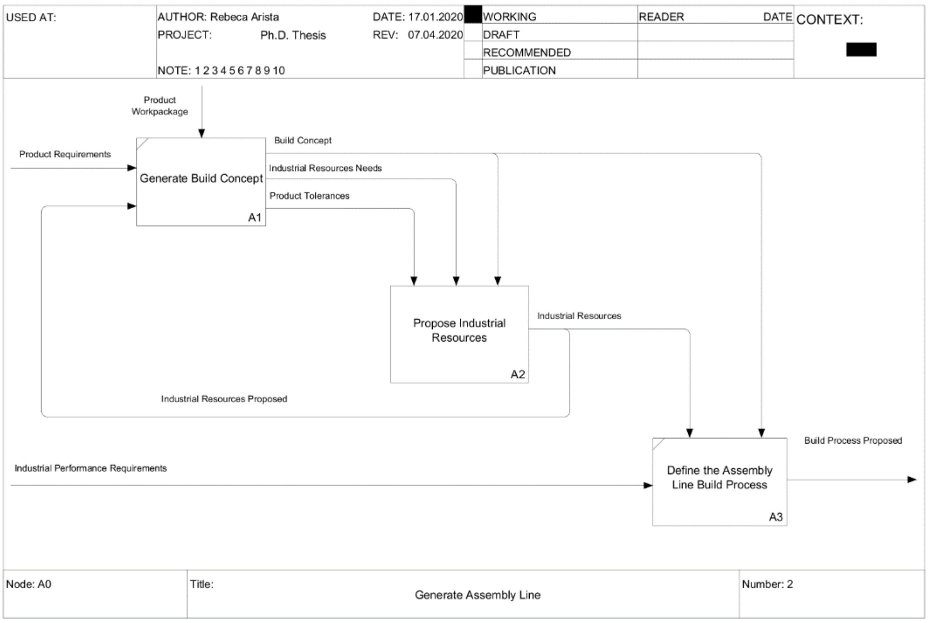

Fig. 2. Activity Generate Assembly Line – white box view

An example for a Final Assembly Line: a Build Concept is generated defining the joints between the components to be made one-by-one in different stations, and the flow of the aircraft components from one station to another. Taking the station where the wing and the fuselage joint will be made, in order to achieve the product requirements, the manufacture engineer defines the industrial resource needs at this station as a high precision positioning and alignment system for the components (wing and fuselage), a measurement system to check alignment and a machining system to perform the junction. The Build Concept would include the components flow in/out of this station from stations sequence with associated logistics resources needs, and the activities sequence, meaning positioning of component one, positioning of component 2, alignment of both components using alignment & measurement system, and perform joint with machining system.

The Industrial Resource Needs are then given to A2 *"Propose Industrial Resources"* activity, which proposes a set of possible industrial resources that could cover the needs defined, and with the given product tolerances. The Industrial Resources Proposed are given on a feedback loop to A1 "Generate Build Concept" activity, to review with it the Build Concept defined, adjust or change Industrial Resources Needs, and even change the Build Concept or the Product Tolerances if no industrial resource solution is found. This activity is described in detail in the following subsection.

Finally, the activity A3 *"Define the Assembly Line Build Process"* takes the Industrial Performance Requirements, analyzes the Build Concept and the Industrial Resources options with the parameters of each industrial resource (like cost, energy consumption and CO2 emissions), choosing the most suitable option that fulfills the Industrial Performance Requirements. The Build Concept and Industrial Resources chosen conform the *Build Process Proposed*.

3.3 Generate Industrial Resources Activity.

Figure 3 shows the details of A2 *"Propose Industrial Resources"* activity. The first activity A21 *"Detail needs per resource type"* analyses the industrial resources needs defined in the activity A1, and details the Resource Needs per type, considering the flows and sequences defined in the build concept. Three types of industrial resources are proposed.

The term *"Jig"* is used to define an industrial resource specifically designed to fulfill an aerospace product functional and assembly tolerances (e.g. product functional requirements and aerodynamic shape). Jigs have no universal applicability, and can be dedicated (if its design parameters match to only one product tolerances), semi-dedicated (if some of its design parameters can be reconfigured for different products of a family), or flexible (if its design parameters can be reconfigured to achieve different product tolerances). Jigs can be among others: fixing or positioning elements, referencing elements, test elements, hoisting elements, transportation elements and machines.

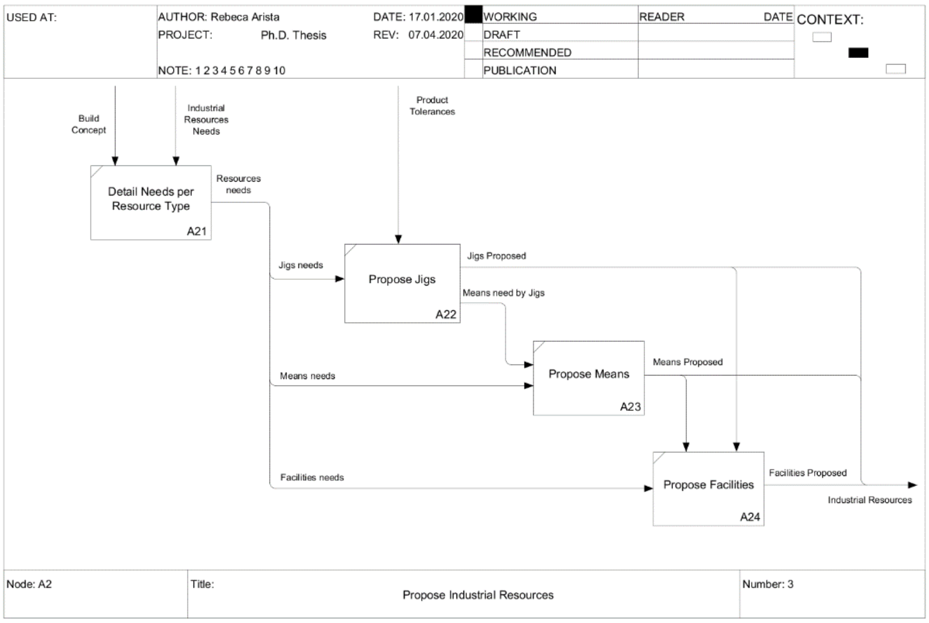

Fig. 3. Generate Industrial Resources

The term *"Mean"* is defined as any element needed to complete the processes and activities defined in the Build Concept, which are not *"Jigs"* or *"Facilities"*. Means can be among others: grades, platforms, tools, test means, consumables, human resources, documentation and racks.

The term *"Facilities"* as defined in the facility ontology proposed by Tomašević et al. [22], is from a physical and topology perspective a site infrastructure, installations and supplies. Facilities can be among others: buffer areas, warehouses, buildings, hangars, water supply and power supply.

The Resource Needs per type, outcome of activity A21 *"Detail needs per resource type"*, will launch activities to propose as applicable industrial resources, which match the product and process requirements defined in the Build Concept: new industrial resources design, reconfigure existing in-house resources, and/or use standard resources form catalogs.

The activity A22 *"Propose Jigs"* proposes in a first step a set of Jigs, from the Jigs needs defined, and considering the product tolerances. It defines as well the needs of Means associated to these Jigs, like human resources skills, tools, among others.

Activity A23 *"Propose Means"* proposes different Means that can fulfill the needs from the Jigs and from the Industrial Resources requirements defined in the Build Concept.

The Jig Proposed and Means Propose control the last activity A23 *"Propose Facility"* where Facilities options are proposed considering the Jigs and Means constrains (like space and power/water supply) and the needs defined from the Build Concept (like logistic flow spaces, hangar accesses and warehouses).

4 Conclusions and Further Work

An initial approach to an industrial resource ontology to support the assembly line design process is presented, considering the specificities of the aerospace industry and aerospace products. An overview of related work is presented, describing the motivations for this industrial resource ontology.

An Assembly Line Design process is modelled in IDEF0, as continuity of the design activities defined by the authors in [21] at industrial system network level. The role of industrial resources in this process is emphasized; three types of industrial resources are defined. Further work will mature the industrial resource ontology, as well as its management and use in the conceptual phase of the Product Development Process.

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References

1. Järvenpää, E., Siltala, N., Hylli, O. et al. The development of an ontology for describing the capabilities of manufacturing resources. *Journal of Intelligent Manufacturing* **30** (2019) pp. 959–978. DOI:10.1007/s10845-018-1427-6.
2. Whitney, D. E., Mechanical assemblies: their design, manufacture, and role in product development, *Oxford University Press, Inc., New York* (2004). ISBN: 0-19-515782-6.
3. Su, B. Q., Smith, S. S., An Integrated Framework for Assembly-Oriented Product Design and Optimization, *Journal of Industrial Technology* **19** (2) (2003).
4. Pardessus. T., Concurrent engineering development and practices for aircraft design at Airbus. *Proceedings of the 24th ICAS meeting.* Yokohama (2004).
5. Mas, F., Menendez, J.L., Oliva, M., Rios, J., Gomez, A., Olmo, V., iDMU as the Collaborative Engineering engine: Research experiences in Airbus, *Proceedings of IEEE Engineering, Technology and Innovation International Conference* (2014). DOI: 10.1109/ICE.2014.6871594.
6. Mas, F., Ríos, J., Gómez, A. and Hernández, J., Knowledge-based application to define aircraft final assembly lines at the industrialization conceptual design phase. *International Journal of Computer Integrated Manufacturing*, **29** (6), pp.677-691 (2015).
7. Mas, F., Oliva, M., Rios, J., Gomez, A., Olmos, V., PLM Based Approach to the Industrialization of Aeronautical Assemblies, *Procedia Engineering* **132**, pp. 1045-1052 (2015).
8. Mas, F., Racero, J., Oliva, M., Morales-Palma, D., A preliminary methodological approach to Models for Manufacturing (MfM). In Chiabert, P., Bouras, A., Noël, F. and Ríos, J. (eds.). *Product lifecycle management to Support Industry 4.0*. (2018).
9. Mas, F., Racero, J., Oliva, M. and Morales-Palma, D., Preliminary ontology definition for aerospace assembly lines in Airbus using Models for Manufacturing methodology. In Sanfilippo, E.M., Terkaj, W. (eds.). *Formal Ontologies Meet Industry: Proceedings of the 9th International Workshop, within the Proceedings of the International Conference Changeable, Agile, Reconfigurable and Virtual Production (CARV)* (2018).
10. Arista, R., Mas, F., Oliva, M., Racero, J., Morales-Palma, D., Framework to support Models for Manufacturing (MfM) methodology, *Proceedings of 9th IFAC Conference on Manufacturing Modelling, Management and Control* **52**, pp. 1584-1589 (2019). DOI: 10.1016/j.ifacol.2019.11.426.
11. Arista, R., Mas, F., Oliva, M., Morales-Palma, D., Applied Ontologies for Assembly System Design and Management within the Aerospace Industry, *Proceedings of the Joint Ontology Workshops JOWO 2019, 10th International Workshop on Formal Ontologies meet Industry* **2518** (2019). http://ceur-ws.org/Vol-2518/paper-FOMI1.pdf
12. Graves, S. C., Whitney, D. E., A mathematical programming procedure for equipment selection and system evaluation in programmable assembly, *Proceedings of the IEEE Decision and Control*, pp. 531-536 . IEEE Press (1979).
13. Rekiek, B., Alexandre., D., Del-Chambre, A., Bratcu, A., State of art of optimization methods for assembly line design. *Annual Reviews in Control* **26** (1), pp. 45-56 (2002).
14. Grüninger, M., Menzel, C., The Process Specification Language (PSL) Theory and Applications, *AI Magazine* **24** (3), pp. 63-74 (2003).
15. Lemaignan, S., Siadat, A., Dantan, J. Y., Semenenko, A., MASON: A proposal for an ontology of manufacturing domain. *Proceedings - DIS 2006: IEEE Workshop on Distributed Intelligent Systems - Collective Intelligence and Its Applications* pp. 195-200 (2006).
16. Cutting-Decelle, A., Young, R., Michel, J., Grangel, R., Le Cardinal, J., Bourey, J., ISO 15531 MANDATE: A Product-process-resource based Approach for Managing Modularity

in Production Management, *Concurrent Engineering* **15** (2) (2007). DOI: 10.1177/1063293X07079329.

17. Mas, F., Rios, J., Menendez, J.L., Gomez, A., A process-oriented approach to modeling the conceptual design of aircraft assembly lines, *The International Journal of Advanced Manufacturing Technology* **67** (1-4), pp. 771-784 (2013). DOI: 10.1007/s00170-012-4521-5.
18. Chengying, L., Xiankui, W., Yuchen, H., Research on manufacturing resource modeling based on the O-O method, *Journal of Materials Processing Technology* **139**, pp. 40-43 (2003). DOI: 10.1016/S0924-0136(03)00179-1.
19. Ameri, F., Urbanovsky, C., McArthur, C., A systematic approach to developing ontologies for manufacturing service modeling. *Proceedings of the workshop on ontology and semantic web for manufacturing* (2012).
20. Sanfilippo, E., Benavent, S., Borgo, S., Guarino, N., Troquard, N., Romero, F., Rosado, P., Solano, L., Belkadi, F., Bernard, A., Modeling Manufacturing Resources: An Ontological Approach, *Proceedings of the 15th IFIP WG 5.1 International Conference PLM 2018* **540** (2018). DOI: 10.1007/978-3-030-01614-2_28.
21. Arista, R., Mas, F., Vallellano, C., Morales-Palma, D., Oliva, M., Towards Manufacturing Ontologies for Resources Management in the Aerospace Industry, *10th International Conference on Interoperability for Enterprise Systems and Applications I-ESA 2020,* Tarbes, France (2020). (in press)
22. Tomašević, N., Batić, M., Blanes, L., Keane, M., Vraneš, S., Ontology-based facility data model for energy management, Advanced Engineering Informatics **29** (4), pp: 971-984 (2015).