Applied Ontologies for Assembly System Design and Management within the Aerospace Industry

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Abstract. The aerospace industry is characterized by a low-scale manufacturing rate, producing mid to high level customized products, with high level of complexity. Factories, and the complete assembly system in charge to manufacture these products, are not efficiently flexible to new manufacturing scenarios or new product developments. This work shows a preliminary review of the literature and proposes the application of ontologies for the assembly system definition and management within the aerospace industry. The resources addressed are not only human or tools at factory level, but the complete capital set conforming the aerospace assembly system. This work will enable trade-off scenarios and re-configure the system to a new manufacturing scenario or product design.

Keywords. Aerospace Manufacturing Ontologies, Assembly Systems Ontology, Assembly Line Design, Knowledge-based systems, Models for Manufacturing

1. Introduction

The assembly system of an aerospace product, comprising all the resources that constitute it, represent 70% of the cost of a product development [1]. During the design process, a unique deliverable should be made including the product functional and industrial design, as well as the assembly system design, within a collaborative engineering process. This key deliverable is named industrial Digital Mock-Up (iDMU) [2,3]. Industrial requirements are gaining weight on the design conceptual phase, mainly driven by cost reduction targets on new product developments.

The complexity of the assembly system design lies in different factors: the resources that form an aerospace assembly system have a complex design process; the industrial setup is driven by contractual workshare agreements between the manufacturer and the customers or governments; the product size constrains impact logistic plans and means; product functional requirements force most of times the use of ad-hoc tools and means to support the assembly process; among other constrains.

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Moreover, assembly lines in the aerospace industry have particular characteristics that differ in other industries. They have a low-scale manufacturing rate, produce mid to high level customized products with high level of complexity, and are dedicated to only one product family. Other industries (eg. automotive) produce multiple standard products in the same assembly line, with a medium or high-scale manufacturing rate.

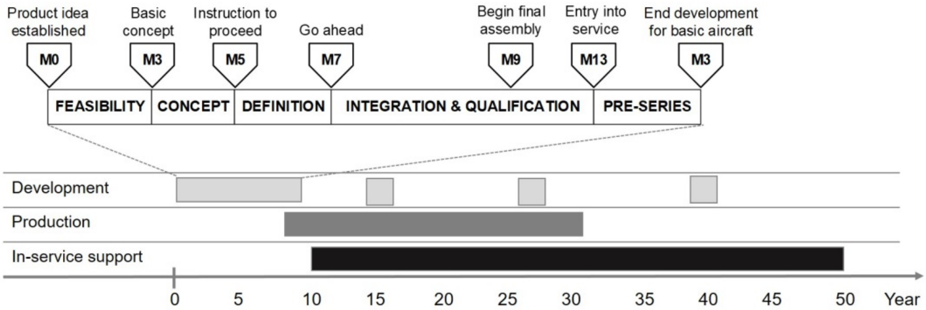

Figure 1. AIRBUS product lifecycle and development milestones.

As shown in Figure 1, Airbus product lifecycle is made of three stages: development, production and in-service support. The development process starts with a product idea, launching a feasibility phase both for the product and assembly system. Further development maturity gates are reached in a collaborative engineering process, creating a unique final deliverable, the iDMU. After development, the system has to be prepared for drastic ramp-up increases in the production phase. The same development process can be launched at different points of the product lifecycle when a new product version is created, or due to changes on the assembly system requirements.

In order to achieve the maturity gates, decisions on the assembly system are done sometimes with no detailed consideration of key assembly process constrains. This problem is due to a lack of tools that can support the assembly system conceptual design, and do it collaboratively with the product functional and industrial design.

This work shows a preliminary review of the literature on this field, and proposes the application of ontologies for the assembly system definition and management. The objective is to set the foundation to support this process considering the distinctive features of the assembly lines in the aerospace industry, making a first proposal of the product, process and resources structure relationship that would support this process.

2. Research work conducted on this field

This section describes a preliminary review of the state of the art on the assembly systems design process, and the way resources are described and managed inside this process. This is followed by a preliminary literature review on resource modeling, and a consideration on the evolution from Knowledge-based Engineering methods to Models and Ontologies applications.

2.1. Resources and their management in the assembly system design process

Following a collaborative engineering approach for the product and assembly system design process, once having a preliminary product design in the conceptual phase, the first step towards a preliminary assembly system design is to generate a product manufacturing breakdown. To support this step, a product structure management tool is needed to support the different product views generated.

The product design is split into components to be assembled, generating a product manufacturing breakdown structure made up of components and sub-assemblies. The work of Janardanan [4] proposes a web-based product structure manager based on STEP standard PDM Schema, to support designers in this phase.

This manufacturing breakdown defines the set of parts to be assembled, and the characteristics of this joint. Considering the assembly system requirements defined, a high level assembly process is sketched to carry out the joints of the components and sub-assemblies, considering technical precedence of the tasks to be performed, and initiating the assembly line or assembly system design process.

Mas [5] presents how to generate a product industrial breakdown (called "as-planned view") from a product functional breakdown (called "as-designed view"), and link it to a process structure, that includes process diagrams to consider process time, and a preliminary resource structure (both structures are called "as-prepared view"). All done with the purpose of a knowledge-based application to define aircraft final assembly lines at the conceptual design phase. Based on the previous research, Escalona [6] applies model-driven engineering in CALIPSOneo project to build an iDMU in practice.

Whitney [7] defines the assembly system or assembly line design process following these basic factors: capacity planning (available time and required number of units per year); assembly resource choice; assignment of resources to operations; floor layout; workstation design; material handling and work transport; part feeding and presentation; quality (assurance, prevention, and detection); economic analysis; documentation and information flow; personnel training and participation; and intangibles.

One of the most difficult steps in the design process is to choose among different resources for each task so that the work is done within the cycle time and the whole assembly system has minimum cost. Due to product functional requirements, mechanical equipment may have to be designed specifically for some steps. Often, a company outsources the design of its assembly lines and is at the mercy of the vendor regarding types of equipment.

Assembly process planning is the term used to describe this activity, in which the part assembly sequence and resource usage is determined in an iterative process, to minimize assembly costs and time [8]. Bukchin [9] work focus on station paralleling and equipment selection, minimizing the number of stations, and minimizing the total cost.

Complementing the work of Mas [5], Gomez [10] developed a methodology for assembly process design at the conceptual phase for aerospace products, including multi-criteria evaluation of possible alternatives using Ant Colony Optimization (ACO) metaheuristic method, and fuzzy logic theory for solutions evaluation.

DARPA iFAB program work [11] centered on two functions: providing manufacturability feedback to the designer, and configuring what they call a foundry (or assembly system) of networked manufacturing capabilities tailored to the final verified design. This configuration includes supply chain considerations, assembly planning, and automatically generated computer-numerically-controlled (CNC) and human work instructions.

2.2. Resource modeling in the literature

There is extensive work in the literature regarding assembly process modeling, to define assembly requirements, key characteristics, assembly variation, assembly parametrical models, mathematical or feature models, assembly or manufacturing planning, among others [12-14]. In these works, resource models are poorly considered, and mainly done in terms of workforce or means needed within the process.

Whitney [7] highlights the following points to be considered on resources within process modeling: what resources are applicable or available to a given task; time for transport from station to station; reuse of resource for several tasks; and reuse of tools at one station. He also distinguishes three basic types of assembly resources: people, fixed automation, and flexible automation.

Mas [5] define 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).

Research on manufacturing resource modeling conducted by Chengying [15], proposes an architecture of the general model of manufacturing resource as a 3D solid model composing three aspects: organization structure (divided in 5 levels each aggregating the lower level manufacturing behavior), capability status (properties of the manufacturing resource), and development activity (relationships between the product development stages and the manufacturing resource involved).

The ontological approach for modeling manufacturing resources presented by Sanfilippo [16] intends to lay down a conceptual framework with a representation of manufacturing resources, based in the idea that manufacturing resource relates to a manufacturing process plan as far as it is relevant for some goal specified in the plan. It proposes as well a high level classification of manufacturing resources based on three principles: agentivity, mode of deployment and control.

2.3. From Knowledge-based Engineering to Models and Ontologies applications

Capture and knowledge representation using Knowledge-based Engineering (KBE) has been a paradigm during the last decades. Huge efforts have been made by researches and industrials through different projects and initiatives like CommonKADS, MOKA (Methodology and tools Oriented to KBE Application) and other [17,18]. An interesting application using KBE to design and industrialize tools for High Speed Milling machines (HSM) was developed by the authors [19].

Lemaignan [20] propose a preliminary upper ontology for manufacturing named MASON (MAnufacturing's Semantics ONtology), aimed to draft a common semantic net in manufacturing domain, and exposing two applications of this ontology: automatic cost estimation and semantic-aware multi-agent system for manufacturing.

Traband [21] describes the work conducted in DARPA iFAB project on manufacturability, generating detailed formal models which represent the capabilities of various manufacturing machines and processes. By mapping these models into the same semantic domain as the product design, an automatic constrain on the design trade space can be made, such that designs that are not manufacturable in a given assembly system configuration are automatically discarded.

Models for Manufacturing (MfM) [22] is a recently proposed methodology to define manufacturing or industrial ontologies, by generating a set of interconnected models: Scope models, that defines the limits where the model works; Data models, that include the information managed in the selected scope; Behavior models, for the inherent behavior of the system within the given scope; and Semantics models, that considers generic objects for connection of data model instances to data location, and/or between models inside ontologies among the models lifecycle.

As described by Mas [23], the product lifecycle management infrastructure that would support the described type of model-based methodology for manufacturing, called "PLM generation 3", would have data models format based on international standards.

3. Open points on resource modeling and management

From the findings on the preliminary research review, the authors describe in this section the open points on resource modeling and management within the conceptual phase of the assembly system design process.

First point is the resources consideration. Most of the research is focused on the product structure, process structure and process optimization in terms of planning and scheduling. Resources are considered mainly as assembly or manufacturing operations enablers (eg. workers, tools, etc.), being limiting parameters inside a process optimization. The question of the resources structure, classes, key parameters, and assembly system overall optimization is slightly approached.

Another point is the resources scope within the assembly system. Resources should not be limited to the scope of an operation, but should include all production processes at the different scales. This means primary resources (e.g. power supply, water supply, raw materials), logistic resources (e.g. worldwide logistic means, logistics means within a facility), and all which conforms the product manufacturing and industrial footprint.

One point to be addressed is the assembly system baseline definition and flexibility, which needs to be correctly modeled as starting point for a new conceptual design. Even when a completely new product development process is launched, the assembly system design starts with the baseline information of an existing assembly system setup for an aircraft product under production phase or other predecessor.

The existing assembly system setup should be considered both, inside the manufacturer and the extended enterprise. A potential reuse of this setup might be an industrial requirement or can reduce development costs, relocating available human resources skills, coping with existing customer workshare agreements, and getting easier access to needed elementary resources.

Last point is the relationship between the product, process and assembly system structure (including process time relationship), as well as the application of industrial ontologies for knowledge-based decision making during the conceptual design phase.

4. Proposed Ontology for product, process and assembly system relationship

Based on the previous research [5], [10] a proposed schema to present a complete framework for ontology of product, process and resources is presented in Figure 2. Product structures "as-design" and "as-planned" include the common layer of parts/subassemblies and joints. For each joint an assembly process plan is developed giving a collection of assembly plans. Modelling product and assembly processes and use ontologies in manufacturing has been developed by the previously mentioned research and by the MfM methodology [22].

When the manufacturing engineers develop the assembly plan, a set of resources are involved and modelled as part of the industrial solution. Resources are picked-up from a pool of resources where they could be seen as separate products by others. Initially the assembly plan makes use of infinite capacity of the resources and the pool of resources provides models to build the iDMU [3]. Now every assembly plan fits a joint with a complete industrial solution.

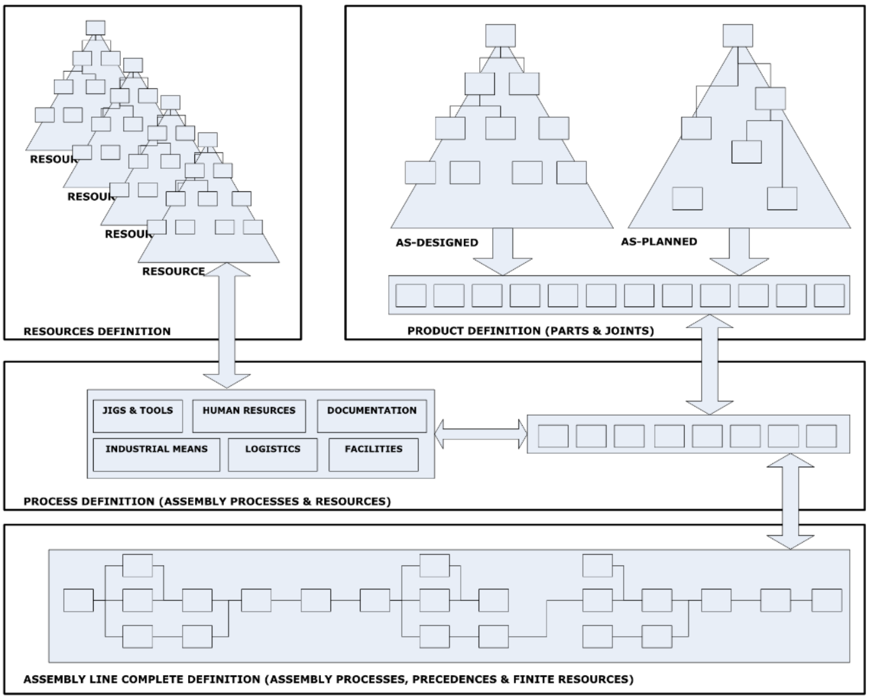

Figure 2. iDMU model with Product, Processes and Resources.

Despite the definition of the assembly processes fulfilling the joints defined in the Functional definition of the product, assembly processes are arranged as a net linked by precedence (start-to-start, finish-to-start, etc.) or left as free processes. The net with precedence defines the complete assembly line. By assigning precedence to every assembly process and balancing the assembly line against criteria [24], the manufacturing engineers define the quantity of the resources based on the real resources constrains and the use of shared resources in the net.

5. Conclusions and further work

This work aims to set the framework for ontologies applications in the aerospace industry, to support the assembly system design process and management in the conceptual phase: in particular, the framework to define resources modelling and the relationships with product and process.

The paper shows a preliminary review of the literature of the assembly system design process, and how resources are managed within this process. It describes the open points on resource modeling and management within the conceptual phase of design, and proposes the application of ontologies including an early stage proposal of product, process and resources structure relationship to support this process.

Further work will address the ontology detailed definition to support the assembly system design process in the conceptual phase, with the aim of supporting trade-off scenarios, decision making and flexibility of the assembly system to re-configure in new manufacturing scenarios (rate, resources available, structure, etc.) or new product design.

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