An Innovative Methodology to Optimize Aerospace Eco-efficiency Assembly Processes

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Manuel OLIVA[1*], Fernando MAS[0000-0001-7230-9929][2,3], Ignacio EGUIA[0000-0003-3969-9958][3], Carmelo del VALLE[0000-0003-0155-4841][3], Emanuel J. Lourenço[4], Antonio J. BAPTISTA[0000-0003-2229-0101][4]

[1]Airbus, Avenida del Aeropuerto s/n, 41020 Sevilla, Spain
[2]M&M Group, 11500 Cadiz, Spain
[3]University of Sevilla, , 41092 Sevilla, Spain
[4]Institute of Science and Innovation in Mechanical and Industrial Engineering, Porto, Portugal
manuel.oliva@airbus.com*, fmas@us.es, ieguia@us.es, carmelo@us.es, e.lourenco@inegi.pt, a.baptista@inegi.pt

Abstract. Sustainability and eco-efficiency have been researched in multiple scientific papers since the last years. However the literature is not so abundant when applying those concepts to industrial assembly processes. This paper presents an innovate methodology to optimize aerospace assembly processes. Authors propose the introduction of a new element, the eco-efficiency, along with the traditional criteria, cost and time, currently used for optimization. Using a large Aero-Structure as an industrial case of study, the methodology analyzes the eco-efficiency of an assembly process in connection with a Life Cycle Assessment (LCA) to compute the environmental impact. Results are shown in a dashboard along with the relevant Key Process Indicator (KPI) to help the engineers to select the best assembly process.

Keywords: Eco-efficiency, Life Cycle Assessment (LCA), Aerospace, Assembly Processes, 3-Layers Model (3LM).

1 Introduction

In 1992 Schmidheiny [1] published an eco-efficiency concept defined as "The delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity." Or defined in a more simplified way by Moreira et al. [2], "creating more with less".

When taking this definition to industry domain, it can be understood as reducing the consumption of resources, raw material, energy, waste and air emissions while keeping or reducing the costs for manufacturing a product. For an assembly process, it is a question of balance of environmental and economic benefits in an integrated way.

There are several methods to measure impacts and evaluate environmental indicators and the authors selected Life Cycle Assessments (LCA), as it has been standardized according to the ISO 14040:2006 [3]. According to Ilgin et al. [4], "Life Cycle Assessment is a method used to evaluate the environmental impact of a product through its life cycle, encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal". The author proposes starting by compiling an inventory of relevant inputs and outputs of a production system followed by an assessment of potential environmental impacts associated to those input and outputs and interpreting of the results. Applied to an assembly processes, LCA should respond to questions such as:

- What are the resources used in an assembly process and their consumption?
- What are the main potential effects of an assembly process over the environment?
- Where within the assembly are those potential effects on eco-efficiency?
- What elements in the process are mainly responsible for these potential effects?
- In which stage of the process can we potentially improve the eco-efficiency?

Life Cycle Assessment is commonly used for product system life cycle environmental analysis but requires high expertise that brings complexity for decision-making process. Selection of the best design among a set of alternatives is an important step in the industrial design of a product [5]. And when considering also the production environmental impact, the analysis for decision making needs to consider not only traditional cost and functional performance requirements, but also additional constrains such as eco-efficiency in product manufacturing. This approach was presented in [6] by analyzing the energy efficiency impact in the CNC machine design as an additional constrain versus traditional. Developments for sustainable manufacturing have been reported in [7], [8].

Most industrial companies' practices are currently focused on traditional cost/time/profit models, maximizing benefits, and keeping costs low while maintaining product quality. The work presented in this paper is a proposal to bring the ecoefficiency and traditional cost/time/profit analysis together in a framework for optimizing product industrialization. Some Aerospace companies like Airbus, Comlux and others are researching these innovative methodologies to assemble green products.

2 European Clean Sky 2 and DILECO Project

In the frame of the H2020 Framework Program, European Clean Sky 2 [9], DILECO (DIgitalization of ground-testing Life cycle with ECO design criteria) Project [10] aims to work on development and deployment of Product Lifecycle Management (PLM) tools for aircraft ground functional testing with eco-design criteria in order to improve the sustainability of the Final Assembly Lines (FAL) and the efficiency of the Ground System Tests (GST) process end to end.

DILECO research activities provide a comprehensive methodology and related software tools for the development, optimization and management of industrialization of aerospace assembly processes. The ultimate goal is to jointly improve productivity, cost-efficiency and eco-efficiency together.

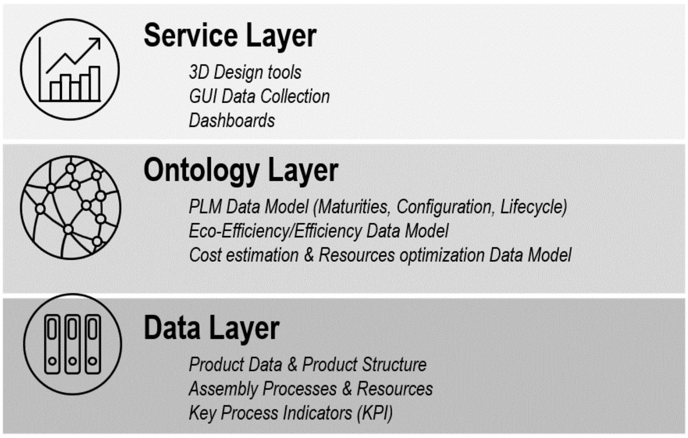
During the conceptual design of products and assembly processes, most of the analysis are preliminary with low data definition. The current research will help, at conceptual development phase, to have a qualitative measurement of the eco-efficiency and influence the product industrialization decisions for a better environmental industrial design.

3 Eco-efficiency Framework

As part of the DILECO research activities a framework was developed to connect design-oriented tools, basically PLM tools, and lifecycle assessment cycle tools to help aerospace engineers in their decision-making.

The framework 3-Layers Model (3LM) is a novel model proposed by [11] in the Models for Manufacturing (MfM) methodology, proposed as a new approach to apply MBSE [12] concepts to Manufacturing: Ontology layer is the core of the 3LM. It holds all the company knowledge in terms of processes and scope, data and semantics, and the associated simulations. Data layer collects all the databases and interfaces and Service layer holds the software services.

Fig. 1. Three Layer Model (3LM) framework



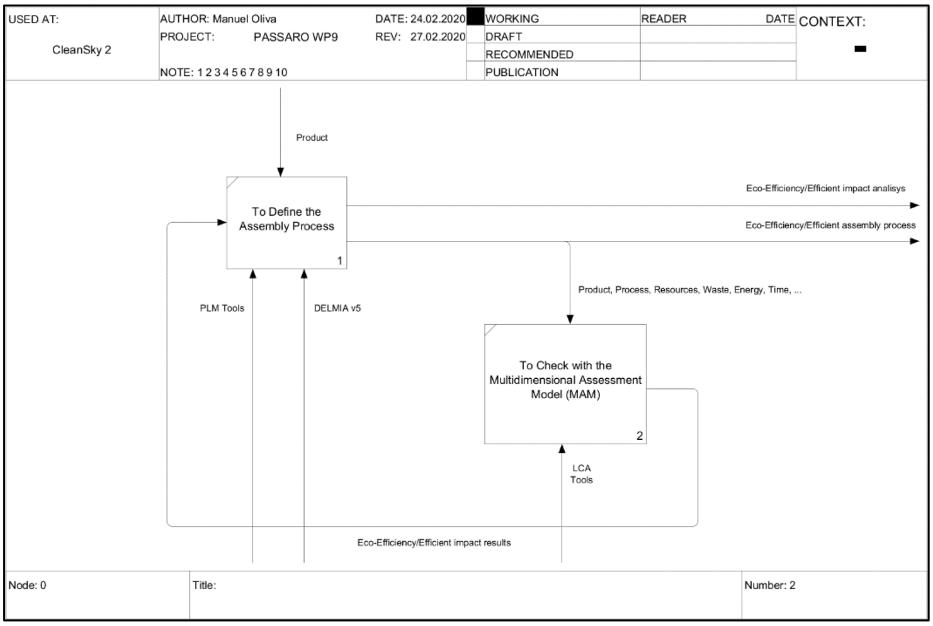
3LM framework is reused in this research and supports the prototype. It integrates the 3D engineering design environment with eco-efficiency and efficiency assessment. Framework 3LM is shown in the Fig. 1 particularized for the eco-efficiency approach and provides functionalities for:

- Design industrial assembly processes in 3D
- Manage eco-efficiency, efficiency and costs assessment for assembly processes
- Manage processes in a PLM
- Simulate and optimize

4 Eco-efficiency Conceptual Model

The Conceptual Model supporting the framework is showed in Fig 2. IDEF0 has been used as process analysis methodology. The following points explore in detail de different objects in the IDEF0 Conceptual Model.

Fig. 2. Eco-efficiency aerospace assembly process assessment conceptual model



Define the Assembly Process: Development of the 3D assembly process is performed using Dassault Systèmes DELMIA v5 [13] creating an iDMU (industrial Digital Mock Up) [14] and the related links. Industrialization model breakdown starts with the build assembly process that is performed in a Final Assembly Line (FAL) [15]. An Assembly Line may have stations with one or more manufacturing solutions processes decomposed in operations and elementary tasks with detailed technical instructions. The 3D environment provides a main point of access for end-users through user interfaces, including capabilities for extending with additional developments required, such as the eco-efficient attributes needed to compute the environmental impact.

Check with the Multidimensional Assessment Model (MAM): The multidimensional design assessment model will allow an innovative practical integration of eco-efficiency analysis, including LCA and cost analysis component alongside with assembly efficiency. This is done from the perspective of Lean Manufacturing, thus implicitly evaluating “value added” and “non-value added” (waste) actions and resource usage. The MAM holds and computes the eco-efficiency, efficiency and costs for each required level of a build assembly process. A detailed description of the module has been published in [16]. Environmental impacts are provided by the LCA database.

Life Cycle Assessment (LCA) Tools: LCA is the database with the impacts for each one of the elements that are part of an assembly process. The development of a specific LCA for aerospace is a project being carried out in Clean Sky1 Life Cycle Assessment Database Improvement LCA DATIM [17]

Product Lifecycle Management (PLM): It provides the technical infrastructure for the data management. It contains the current information of an assembly process in development, historical data, constrains, and KPIs. It also controls the synchronous communication flow with the MAM module. Typical functionalities offered by a PLM, like vaulting, workflow, maturity states, are still used for the project. The tool selected for this research work is ARAS Innovator [18].

Eco efficiency impact and results: A dashboard provides the comparative analysis of different versions for an assembly process: resource utilization, optimization, KPIs and visualization of results. The KPIs taken into consideration will mostly reflect eco-constraints. Inputs from the MAM will support the decision process, by simulating the potential evolution of relevant KPIs and allowing engineers taking decisions.

5 Eco-efficiency Data Model.

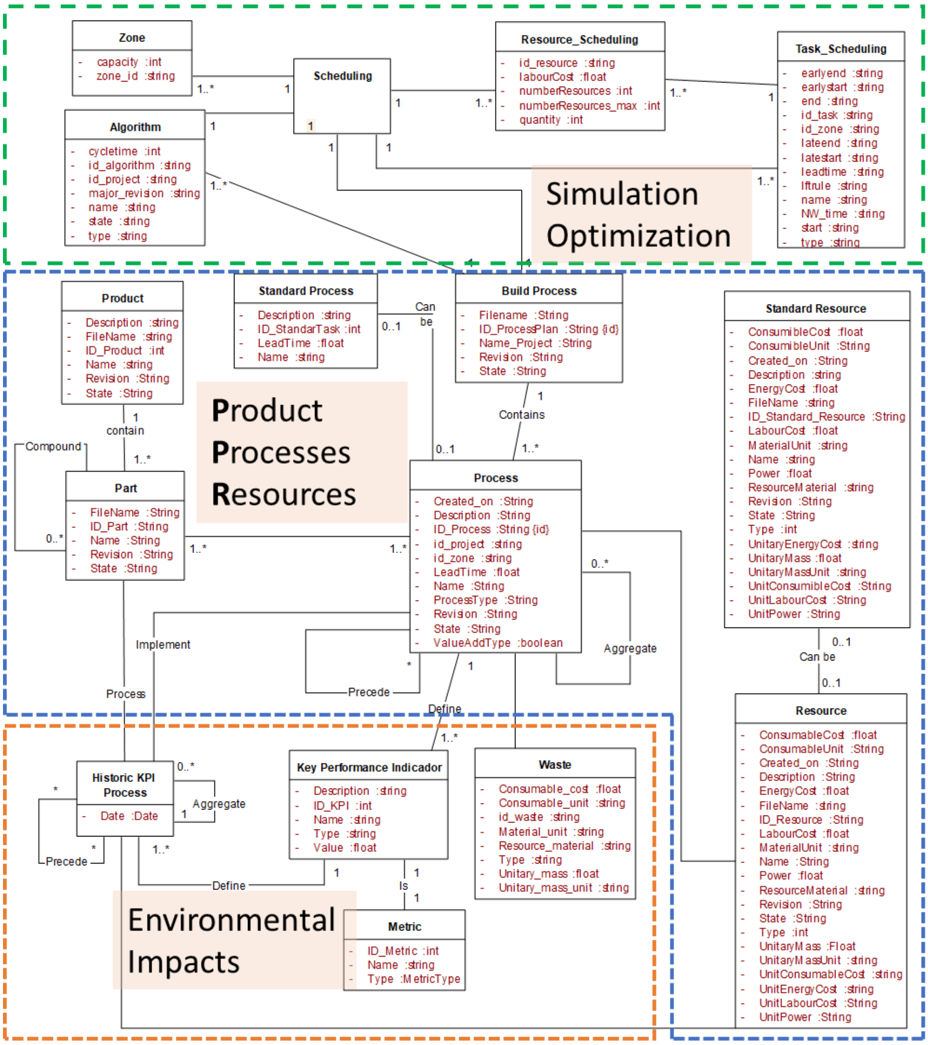
The development of the Data Model requires the consideration of two conditions: the assembly process definition and the eco-efficiency/efficiency of it. The literature review shows many different solutions for a Data Model for aerospace assembly processes. In this research the authors take as input the proposed model in [19], [20], [21] and adapt it to the eco-efficiency requirements.

Aerospace assembly processes are characterized by intensive human labor with low automation. Several research work in eco-efficiency, efficiency and KPIs propose Data Model for single parts, but it not so much solutions for aerospace assembly with intense human labor. Main inputs used as starting point for the Data Model developed in this research are described in [22], [23].

Definition of the Data Model is shown in Fig. 3. The iDMU Data Model is extended to include the environmental concepts and is implemented in the PLM. Other additional functionalities are included such as vaulting and configuration management for assembly process development maturity.

Zone 1 (iDMU. Product, Processes and Resources): It holds most of the concepts commonly used in an iDMU structure with the particularity of adding the standard process and standard resources. The definition of standard processes and resources are functionalities developed to have a library of processes and resources commonly used in assembly. Such functionalities will help engineers to speed up the process definition and save on continually introducing the same information.

Fig. 3. Eco-efficiency Data Model



Zone 2 (Environmental Impacts): It includes the concepts needed to extend the iDMU with an environmental impact dimension, particularly the ones for eco-efficiency, and the associated metrics and KPIs. The *Key Performance Indicator* object defines every KPI for each process in the *Build Process*. The attribute value has the impact of the process for every KPI. Associated to each KPI, the *Metric* object defines the magnitude the KPI (meters, kg, liters, etc.). Additionally, the *Historic KPI Process* object holds the calculated value of different versions allowing decision-making comparing them.

Zone 3 (Simulation and Optimization): It contains the objects to help simulation and optimization; the *Algorithm* object associated to a build process together with the

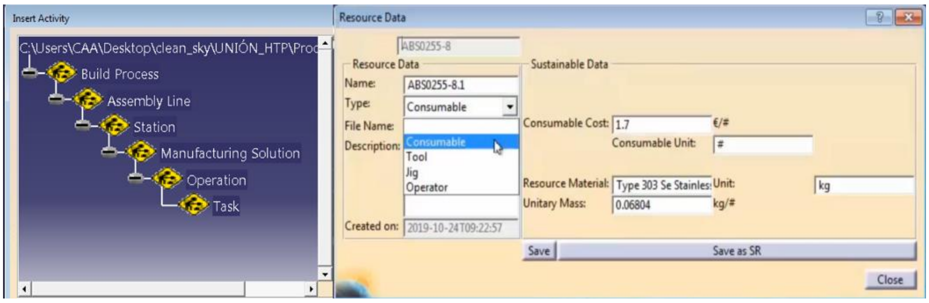
Task Gantt and *Resource Gantt* objects are defined to apply the selected algorithm to an assembly process. The *Schedule* object together with the *Task Scheduling* and *Resource Scheduling* objects are defined to store the calculated schedule for a particular *Build Process*.

6 Application Methodology

The application methodology presents how to use the prototype software tool created to support the Conceptual Model and the Data Model presented. It follows the steps defined in the LCA methodology to create more value with less environmental impact. The main steps in the methodology are:

Compiling inventory of input and outputs: The first step consists of defining the assembly process in a PLM 3D virtual environment using Dassault Systèmes DELMIA v5. The assembly process is modelled and all information needed to calculate the environmental impact is provided by resources and materials used during the process. Fig 4 shows assembly product structure and data entry interface window.

Fig. 4. Inventory of inputs and outputs



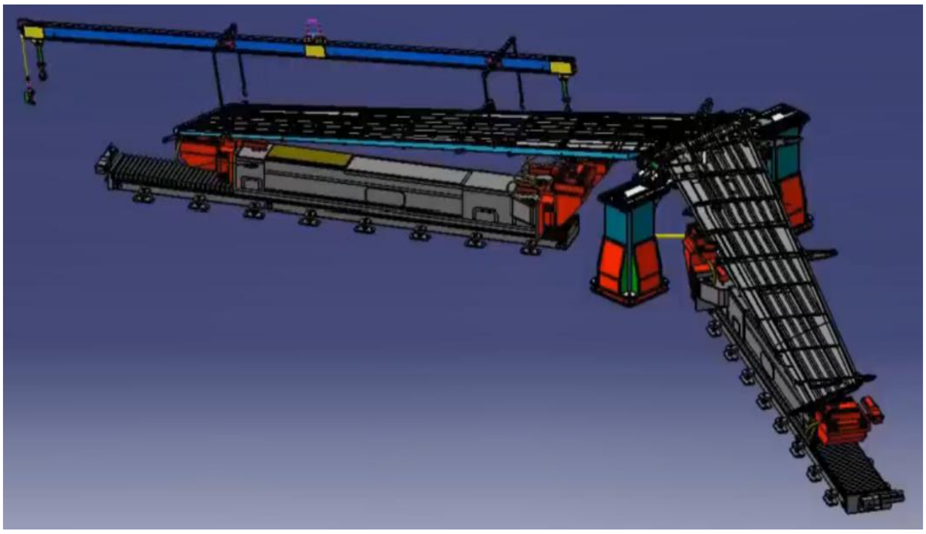
Assessment of potential environmental impacts associated to input-outputs: This event consists of the identification of all assembly means and their characterisation. Assembly processes data collected in the previous phase is sent to MAM to compute the eco-efficiency and efficiency. Most of the functionalities of this phase are developed in PLM. The process engineer inquires the application through the interface developed in Dassault Systèmes DELMIA v5, while most of the functionalities are orchestrated by ARAS Innovator. Communication to and from PLM and MAM to compute the process eco-efficiency is managed in this phase, and results are stored in the database.

Interpreting the results: Following the characterization of the process, it is possible to create the assembly scenarios, and evaluate their global performance and performance for each domain in a virtual environment. After the virtual evaluation and comparison between the different assembly scenarios, the assembly sequence with better global performance takes place. This phase is performed in the Dassault Systèmes DELMIA v5 interface with the KPIs represented in a dashboard.

7 Aerospace Industrial Case of Study

The selected Case of Study to test and demonstrate the application methodology is based on the assembly processes for a large aerospace structure, a Horizontal Tail Plane (HTP), of a typical commercial aircraft. The structure is shown within the industrial environment in Fig 5. below This large aero-structure is composed by two main subassemblies, both HTP left box and right box, assembly together to produce the final product.

Fig. 5 HTP and Manufacturing Environment



The HTP assembly process is decomposed into manufacturing solutions and then in operations and elementary tasks. The Case of Study will be focused in the final assembly station dedicated to the assembly process between left box and right box. In the initial conceptual assembly process approach, five manufacturing solutions have been considered, with the associated resources and the related information: material, resources, energy, waste, etc. With the information collected, the MAM executed the impact analysis and returned the results.

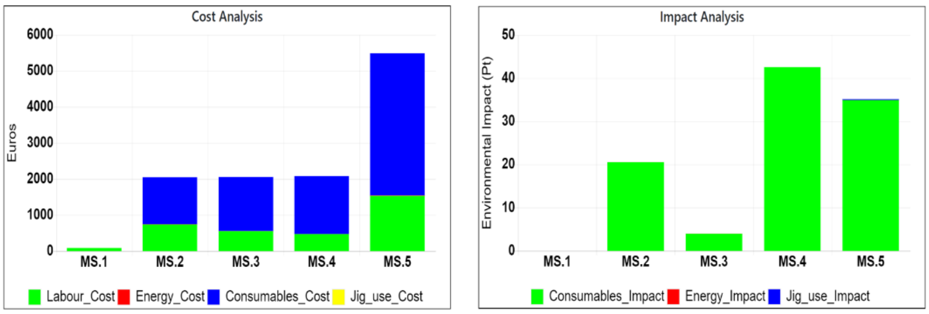
Presenting the complete LCA data analysis results is very helpful for a specialist in LCA, but too complex for engineers and designers, since they need to consider many parameters to decide. The use of a representative emission of kg of CO_2 equivalent, which is easy to understand for engineers, is unsatisfactory since environmental problems can be obscured by redesigns which then shift the problem towards other classes of pollution.

The option selected is to keep one single indicator indicating points for emissions and waste. It can be done considering impact scores broken out into categories, with no weighting at all. To reduce complexity and to have an easily understandable and comparable environmental impact value the model considers a weighted single score. Such approach has the advantage of generating one, single and easy-to-communicate, impact number. The number is expressed as Eco-Points according to the ReCiPe method to normalization and weighting [24].

Different dashboards have been developed to present and manage the correct, most understandable information to the engineers and to help them in the decision-making for the selection of the best assembly process. The prototype incorporates a dashboard where the KPIs associated with assembly processes, used resources and associated products are displayed. Likewise, the dashboard allows comparisons between processes and variations showing versions or historical data of the same assembly process. The dashboard module shows KPIs previously computed in MAM.

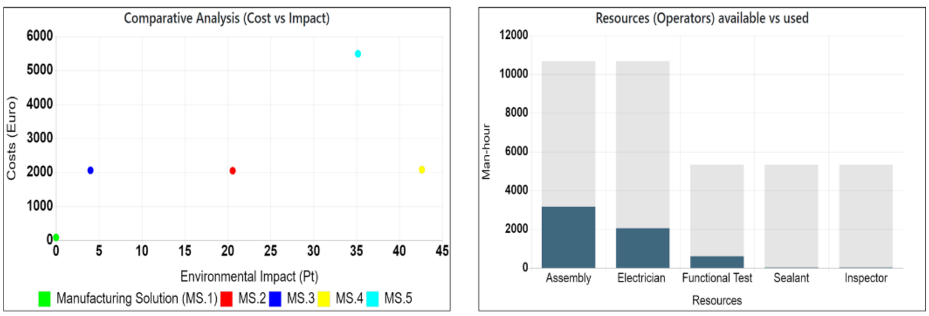
The dashboard and graphics are intended to answer the initial questions from the introduction section of this paper; what are the elements that have an environmental impact, in what intensity and where during the assembly process. Since cost is one of the main drivers for an industrial company, the evaluation of the environmental improvement cost needs to be assessed.

Fig. 6. KPI Cost analysis and eco-points impact



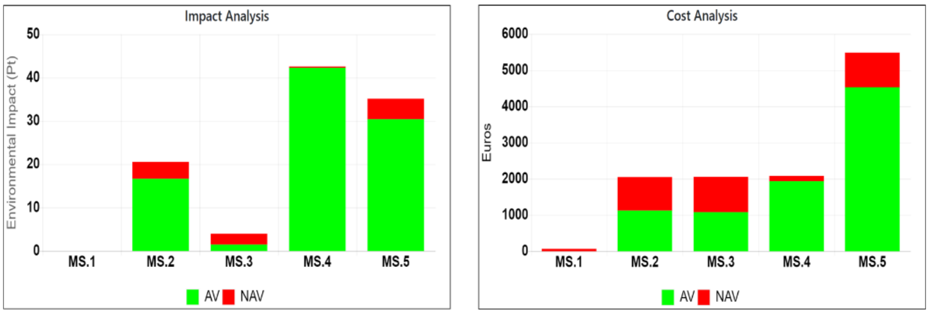
The Fig. 6 represents the cost and eco-points for each of the five considered manufacturing solutions. In the cost analysis, a decomposition of the elements (labour, energy, consumables and jigs) which affect the cost of a manufacturing solution are depicted. Similarly, for the impact analysis, the elements with environmental impact (consumables, energy and jigs) are also depicted.

Fig. 7. Costs versus Environment Impact for manufacturing solutions and Resources utilization



The dashboard also offers analysis to check cost versus impact and optimization of resources, like labor time. Fig. 7 shows a first utilization for each operator skills used during the assembly process. During the optimization process is possible to smooth the curve of number of operators per assembly station.

Fig. 8. Environmental Impact analysis filtering AV versus NAV, and Cost analysis



In terms of process efficiency and in relation to the environmental impact, Fig. 8 shows the eco-points for each manufacturing solution in relationship to Added Value (AV) versus Non Added Value (NAV) activities and similar comparison for the cost analysis.

8 Conclusions

The main conclusion of this research and the main results after the application can be resumed as:

- In this research the eco-efficiency analysis is proposed at the conceptual level, in a top-down approach, but the solution was also validated in performing detailed analysis in a bottom-up approach, gathering information at tasks level.
- The proposed framework solution and the methodology have been demonstrated in an industrial case study for a large aero-structure assembly process. Company organization should be aligned and software tools consolidated before including eco-efficiency as an additional criteria for selecting aerospace processes.
- The results in eco-points as a single measurement to ease the decision-making has become useful for process engineer although their first input was why not using CO_2 equivalent. This observation will be taking into consideration in the next development.
- It is necessary to make visible to process engineers that the assumptions taken when introducing data have direct impact in results. If design is at conceptual level with low detail, the impact can only be used as a first approach.
- The authors are still doing more tests to comprehend results in process engineering and how to be able to compare results of different versions of a build process. Although still in early tests of the solution, an extrapolation of results from the assembly

of a product to other similar one for a new development can be of a high interest for industrial companies.

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