Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 63 (2013) 318 – 326

Procedia Engineering

www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2013

A knowledge based application for industrialization design

A. Gómez[a,]* , F. Mas[b], J. L. Menéndez[b], J. Ríos[a]

[a]*Dept. of Mech. Eng. and Mfg., Universidad Politécnica de Madrid, Calle José Gutiérrez Abascal, 2, 28006 Madrid, Spain*
[b]*Dept. of PLM, Process and Tool Solutions, AIRBUS, Avda. García Morato, s/n, 41011 Sevilla, Spain*

Abstract

After being designed, a product has to be manufactured, which means converting concepts and information into a real, physical object. This requires a big amount of resources and a careful planning. The product manufacturing must be designed too, and that is called Industrialization Design. An accepted methodology for this activity is starting defining simple structures and then progressively increasing the detail degree of the manufacturing solution. The impact of decisions taken at first stages of Industrialization Design is remarkable, and software tools to assist designers are required. In this paper a Knowledge Based Application prototype for the Industrialization Design is presented. The application is implemented within the environment CATIA V5/DELMIA. A case study with a simple Product from aerospace sector illustrates the prototype development.

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion

Keywords: PLM; Assembly Design; Industrialization Design; KBE; Product Structures.

---

1. Introduction: Assembly process in aerospace

As mentioned by Mas et al. (2009), engineering projects in aerospace field are characterized by high investments and objectives in the long term. These projects require a thorough organization in the manufacturing processes design and planning. According to Mas et al. (2012), it is essential to improve the methods efficiency. As mentioned by Mas et al. (2008), the assembly process is a key step in any aerospace Product Lifecycle (PL) with near the 30% of the final project cost. As pointed out by Zha et al. (2001), it has high strategic importance because of its impact over the final quality and time to market. According to Mas et al. (2008), the assembly process must

---

* Corresponding author. Tel.: +34-91336 3124; fax: +34-91336 3003.
E-mail address: alejandro.gomez.page@alumnos.upm.es; fernando.mas@airbus.com; jose.rios@upm.es

1877-7058
Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion
doi:10.1016/j.proeng.2013.08.178

be carefully planned in the PL phase called Industrialization Design (ID), which includes tasks such as modeling the assembly system dealing with facilities and transport issues; and designing and planning the operations.

As mentioned by Rekiek et al. (2002), the utilization of Digital Manufacturing (DM) tools makes the developing time shorter and improves the Design process and the Assembly Process Planning. In Rekiek et al. (2002) and in Anselmetti and Fricero (2012), DM tools are named as a very useful mean to execute most of the tasks related with such stages. Several authors, Butterfield et al. (2005), Anselmetti and Fricero (2012) and Mas et al. (2012), point out as key characteristics in a CAD/CAM tool, an approach integrated in the PL and the possibility of quickly defining multiple scenarios. Literature shows that the current tools are still insufficient to satisfy the PL needs.

1.1. Definition of Product Structures during the Assembly Design

Several authors, such as Pardessus (2004), Hu et al. (2011) and Mas et al. (2012), maintain that Assembly Design requires a methodology that supports the simultaneous development of ID and Product Design, adequate to represent the Product structure and define the assembly process. As presented by Pardessus (2004), in AIRBUS Military, the methodology for the first steps of ID is based on sequentially defining structures known as Product Model views: As Design, As Planned and As Prepared.

According to Pardessus (2004) and Mas et al. (2012), from specifications, the As Designed view is created, as part of the Product Design. Components are settled according to their functionalities. The first task within ID consists on creating the As Planned view from the As Designed structure, by resettling components in subassemblies which will be made-up in a station in the Assembly Process. Then, Joints between components are defined. Each Joint connects two components that will be coupled in the Assembly Process. The As Prepared view is defined by ordering the execution of the Joints involved in the As Planned sub assemblies. It implies a sequence in the main assembly operations. Fig. 1 shows the most important ID tasks in an IDEF0 diagram.

1.2. Limitations in the Assembly Design using Product Structures Definition

The Assembly Design following the described method presents several improvable aspects. According to Mas et al. (2008), many important decisions are taken without considering some implications, i.e. during the As Planned definition, defining the fuselage and the wings as the first sub assembly to produce may imply transporting it, as a single product, between two locations instead of transporting a smaller subassembly to the first location and, separately, transporting the wings to be mounted. At plant level, if the wings are added firstly, moving the resulting subassembly to execute subsequent operations will require more powerful jigs and cranes.

According to Butterfield et al. (2005), developing the same alternative with an increasing level of detail may make difficult to explore other alternatives to find the optimum configuration. Available CAD/CAM and Digital Manufacturing tools do not provide utilities or modules to guide and assist designers when exploring alternatives and making decisions. From the findings of Mas et al. (2012), the designer must create each alternative separately and manually, the comparison between alternatives must also be manually done.

Rekiek et al. (2002), Butterfield et al. (2005), Anselmetti and Fricero (2012) and Mas et al. (2012b), mention also the limitation related to the need of the product redesigns, which often implies repeating steps in the simulation and planning modules of the Digital Manufacturing tools.

2. Proposed solution

In this section, a solution for improving the Assembly Design is presented. The specific problem is described and then the adopted solution is proposed: the developed application.

2.1. Problem to be solved

The main target is to give the user a wider perspective of the whole project when creating a manufacturing solution for the industrialization of an aerostructure, so the designer can define several alternatives and know the decisions' consequences. A Knowledge Based Engineering (KBE) application prototype was developed to achieve this goal. It works as an assistant for the first steps of the Assembly Design. Based on the results from Mas et al. (2008), fig. 1 shows an IDEF0 diagram of the Product Industrialization context. The application focuses on the first task: Create Conceptual Assembly Process; and it is included as a mean to be used by the designer.

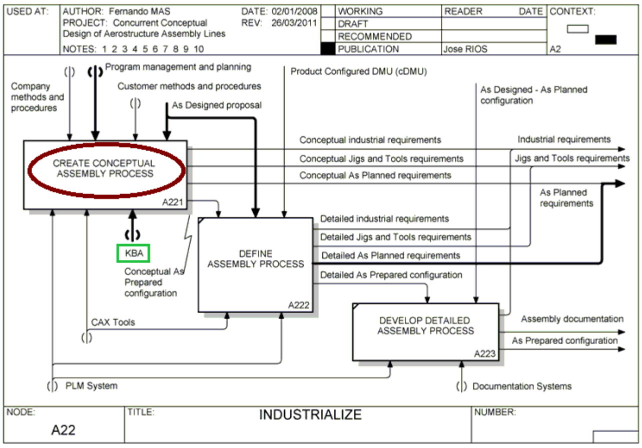


Fig. 1. IDEF0 diagram of the Industrialization Process tasks, with the application (KBA) as a mean for the first one.

2.2. The Assistant tool

An assistant tool was developed to aid in the Conceptual Assembly Design. It is implemented in the CATIA/DELMIA environment using VBA macros. Its main characteristics are described next:

- It allows easily designing several alternatives for the Assembly Process.
- It is executed following several steps, and each one of them generates a CATIA V5/DELMIA file. A session can start in any step with the adequate files.
- At any step, the session can be saved as a different alternative.
- Each alternative can be evaluated at any step, with different accuracy levels.

2.2.1. Structure and Implementation

As recommended by Chapman and Pinfold (1999) and Butterfield et al. (2005), a framework was used to develop the assistant application, and modules were gradually added on it. The Information Model presented by Mas et al. (2009) and (2012) was used as reference. The modules were implemented into the CATIA/DELMIA environment by programming a set of VBA macros.

The implementation made necessary to modify the Information Model used as reference, Fig. 2 shows the final model. Several new classes (shaded ones) were added, and also elements to store information between sessions. Those elements are files of type: CATPart, CATProduct and CATProcess.

2.2.2. Developed Utilities

Store the task data is a key role of the Information Model, to develop the application: methods for capturing that information are also required. The information can be input by two ways: by asking to the user, which is easily implementable; and automatically, from analyzing the CAD models.

A set of methods and functions were developed. The most important utilities relate to: calculating the dimensions of any component or assembly; getting the components structure within any assembly, represented by a CATProduct file; and getting the properties defined by users in a part or in an assembly.

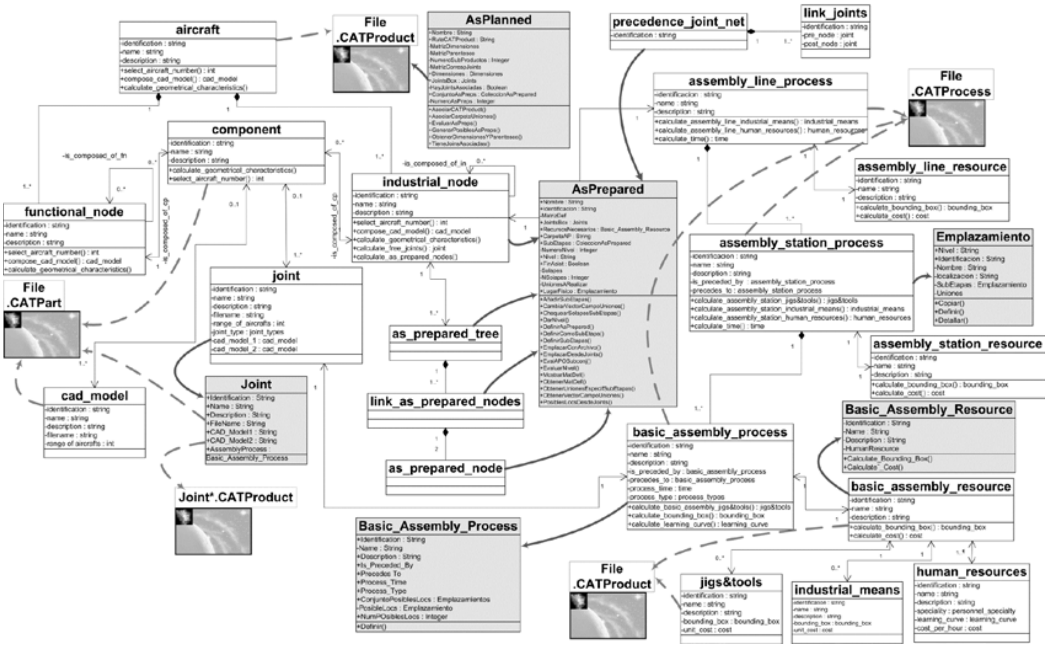


Fig. 2. The initial information model and elements added (shaded) for its implementation.

2.2.3. First Operative Prototype

Using the implemented Information Model, a first prototype of the application was created. It includes some of the design characteristics, to generate assembly design alternatives and their evaluation.

During the execution, the user defines feasible Assembly Process alternatives that are evaluated later. First, the ‘As Planned’ and the ‘As Prepared’ views are defined. After checking the components structures of the CATProduct files representing Joints and the ‘As Designed’ view, the assistant guides the user in defining the joints execution sequences, which defines the ‘As Prepared’ view, and distributing them into groups associated with sub assemblies, which defines the ‘As Planned’ view or structure.

Then, the industrial plants for the assembly stations are chosen. The ‘As Planned’ view means a distribution of components in sub assemblies, and each one is made at one location. The available facilities are part of the information that must be previously input. The existing joints may present some constraints about their location due to the use of resources, i.e. "Joint number 2 can only be executed in industrial plants number 1 or number 4".

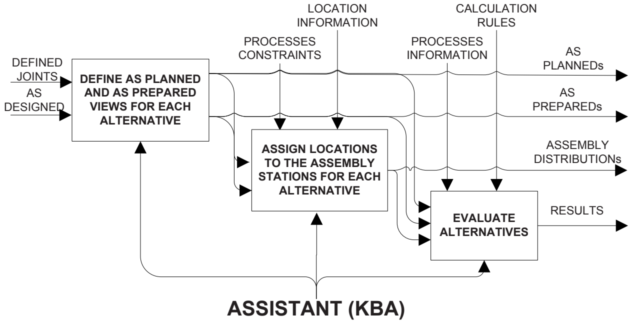


Fig. 3. Information and work flow within the assistant steps.

Several alternatives for the assembly process can be defined. For each one, the assembly sequence and the plants are established. Process requirements will probably change from one alternative to another, e.g.: space requirements depend on the number of Joints to be executed in a plant; transport requirements depend on the distance between the chosen locations and the dimensions of the intermediate products to be transported.

Finally, each alternative is evaluated following four criteria, dimensions and transport requirements, time and cost. At this early defined stage of the ID, it is impossible to do any high accuracy evaluation, but the application offers a comparison between alternatives attending to the defined parameters, and it allows choosing the more adequate one or at least discarding a number of them. The application involves an information flow between system and designers. Initial data must be filed before running the assistant and results are presented later (Fig. 3).

3. Case study

Case studies were defined and executed to test the application. Next, one of the case studies is shown. For a simplified model developed in CATIA V5, several alternatives for the assembly process are defined, developed and evaluated. The study has two parts, in the first one, three alternatives for Industrial Distribution ('As Planned' and 'As Prepared') with the same industrial plants locations are compared. In the second part, different configurations of locations are compared for one of the previous alternatives.

3.1. Example of application: Simplified Aircraft

A very simple model was created to test the application. It represents an aircraft, with 7 components: right and left wings; three parts of fuselage, nose, rear and central; and vertical and horizontal stabilizers. The 'As Designed' view and 6 Joints were defined (Fig. 4). Initial information was defined and included, as it would be done in a real case: manufacturing processes, available locations, cycle times (Table 1). Rules and equations for evaluating alternatives were created also; an example is the equation (1). The data shown in Table 1 were estimated for demonstration purposes. Ultimately, a full process costs analysis would be necessary.

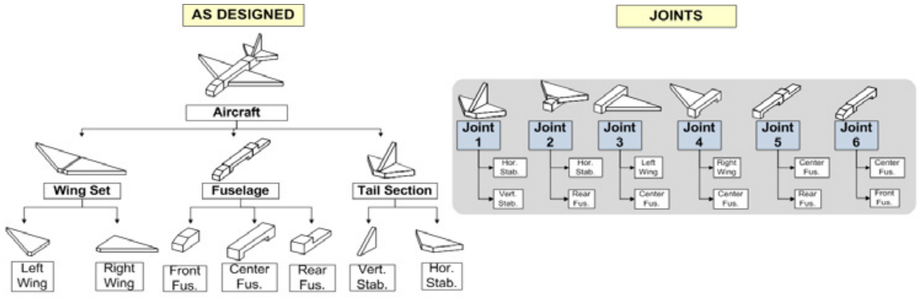


Fig. 4. 'As Designed' view and Joints defined for the example.

Table 1. Initial information about available industrial facilities

Plant	Location	Id.	Cost/ day	Available Surface	Distances (km)				
					T	M	S	B	SN
Main AB Plant	Toulouse	T	20 M€	30000 m^2	0				
EADS Getafe	Madrid	M	6 M€	20000 m^2	793	0			
San Pablo	Sevilla	S	4 M€	24000 m^2	1258	532	0		
AB Bremen	Bremen	B	4.25 M€	12000 m^2	1466	2062	2504	0	
AB Saint-Nazaire	Saint-Nazaire	SN	5 M€	14000 m^2	650	1103	1564	1227	0

$$\sum_{i=1}^{N_{SStages}} Cost_{Plant_i} \Big/ day \times \mathrm{Re}\,qDimens_{X_i} \times \mathrm{Re}\,qDimens_{Y_i} \Big/ AvSurface_i \tag{1}$$

3.2. Part 1: Alternatives for Structures and Industrial Distribution

Three alternatives for the assembly process, A1 to A3, were defined and compared. The aim was to find the best alternative when executing Joint 6, in the main plant, at the beginning or at the end of the process. Alternative A3 had no transport requirement, but location constraints forced to define an extra sub stage with the associated transport. The same locations were associated in the three alternatives: Sub stage SS1 in Madrid; SS2 in Bremen and SSMain in Toulousse. Alternatives A1 to A3 are described below and shown in figures 5 to 7.

Alternative 1

- It has 3 sub stages: SS1, SS2 and SSMain.
- It requires transporting sub assemblies 1 and 2 to the Main Plant.
- Joint 6 at the beginning, less use of Main Plant, the more expensive, but bigger Sub Assembly 1 to transport

Alternative 2

- It has 3 sub stages: SS1, SS2 and SSMain.
- It requires transporting sub assemblies 1 and 2 to the Main Plant.
- Joint 6 at the end, more use of Main Plant, the more expensive, less transport of Sub Assembly 1.

Alternative 3

All the Joints should be completed in Main Plant to remove transport, but Joint 1 cannot be completed in any location but plants in Bremen and Saint-Nazaire, so one extra sub assembly was added.

- It has 2 sub stages: SS1 and SSMain.
- There is only one sub assembly to transport.
- Most of the Joints are executed in the Main Plant, in Toulouse.

The results are shown in the Table 2. Alternatives 1 and 2 require the same number of days to be completed, but Alternative 1 is almost 50 million € cheaper. A3 is the more expensive and time consuming.

Table 2. Results of applying the assistant tool for the first analysis

	Sub-stage	Location	DIMENSIONS (m)						TRANSPORT		COST		TIME	
			X1	X2	Y1	Y2	Z1	Z2	Dims. (m)	km	M€		d	
A1	SS1	M	80	30	110	100	20	10	80x200x20	793	118.65		36	
	SS2	B	42	30	100	20	40	20	42x100x50	1466	46.22	**TOTAL**	29	**TOTAL**
	SSMain	T	80	42	200	100	20	50	110x200x50		81.5	246.38	6	42
A2	SS1	M	55	30	110	100	20	10	55x200x20	793	61.68		26	
	SS2	B	42	30	100	20	40	20	42x100x50	1466	46.22	**TOTAL**	29	**TOTAL**
	SSMain	T	85	25	200	20	50	20	110x200x50	0	188.23	296.14	16	42
A3	SS1	B	42	30	100	20	40	20	42x100x50	1466	46.22	**TOTAL**	29	**TOTAL**
	SSMain	T	85	25	200	20	50	20	110x200x50	0	285.50	331.72	32	45

3.3. Part 2: Alternatives for Industrial Plants Locations

The aim was to find the best set of locations for the involved factories. To do so, variants from the best alternative were created. Alternative 1 was evaluated with different configurations for the industrial plant locations.

Alternatives A1a, A1b and A1c

Alternative 1 has 3 sub stages and one of them is always located in the main plant, in Toulouse. The other two have two possibilities each, so there are four total possibilities. However a study with the first two possibilities, A1a and A1b was used to create only one more variant from the cheaper of them, A1c was created by this way.

The possibilities, for the sub stage SS1, were Madrid and Sevilla. Madrid is closer to Toulouse, the next stop in the process, but using its plant is more expensive. For sub stage SS2, Bremen and Saint-Nazaire (SN) are the possible locations. SN is again closer to Toulouse but more expensive (Table 3).

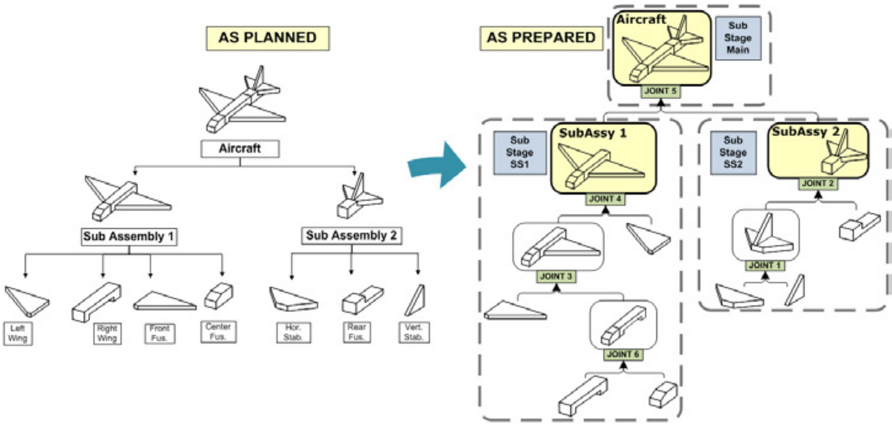


Fig. 5. Industrial Distribution in Alternative 1 for the first case study.

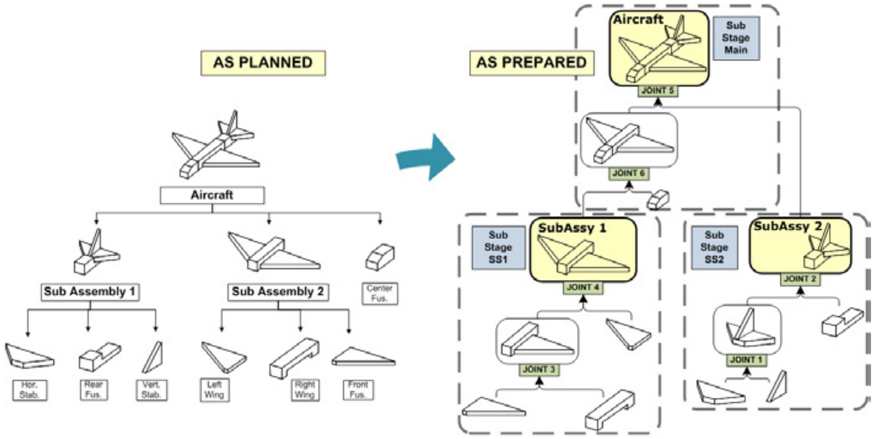


Fig. 6. Industrial Distribution in Alternative 2 for the first case study.

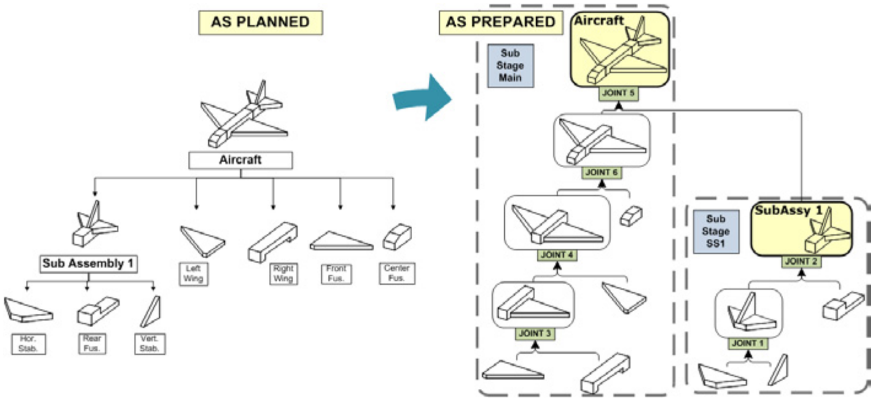


Fig. 7. Industrial Distribution in Alternative 3 for the first case study.

Table 3. Locations in the alternatives evaluated in the second study.

	Sub Stage	Location
A1a	SS1	M
	SS2	B
	SSMain	T
A1b	SS1	S
	SS2	B
	SSMain	T
A1c	SS1	¿? (S)
	SS2	SN
	SSMain	T

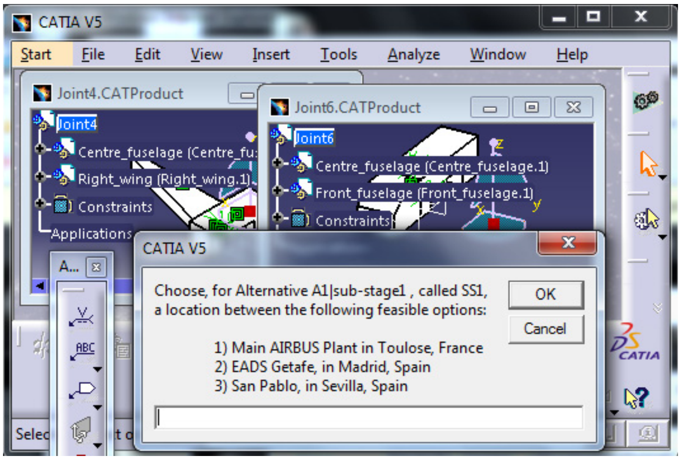
After the third execution of the assistant, results shown in Table 4 were obtained. As can be observed, the cheaper option is using the plants in Sevilla and Saint-Nazaire, Alternative A1c. This one consumes more time, about 6 more days, than A1a. Locating sub stage SS2 in Bremen or Saint-Nazaire do not change the total time because that sub stage is carried out in parallel with SS1, which is longer.

Table 4. Results of applying the assistant to choose the location for the industrial plants.

	Sub-stage	Location	TRANSPORT	COST		TIME	
			km	M€		d	
A1a	SS1	M	793	118.65		36	
	SS2	B	1466	46.22	**TOTAL**	29	**TOTAL**
	SSMain	T	-	81.5	246.38	6	42
A1b	SS1	S	1258	92.75		42	
	SS2	B	1466	46.22	**TOTAL**	29	**TOTAL**
	SSMain	T	-	81.5	220.48	6	48
A1c	SS1	S	1258	92.75		42	
	SS2	SN	650	33.28	**TOTAL**	19	**TOTAL**
	SSMain	T	-	81.5	207.54	6	48

3.4. Discussion

Results show that the cheaper alternative is A1 in variant c, with sub stages SS1 and SS2 located, respectively, in Sevilla and Saint-Nazaire. The less time consuming is A1a, with industrial plant in Madrid for sub stage SS1.



Choose, for Alternative A1|sub-stage1 , called SS1, a location between the following feasible options:

1) Main AIRBUS Plant in Toulose, France
2) EADS Getafe, in Madrid, Spain
3) San Pablo, in Sevilla, Spain

Fig. 8. Screen capture of the location selection step of the assistant tool.

In conclusion, the results obtained with the assistant for this model mean that, if information shown in Table 1 is taken as correct, and following calculation rules as shown in equation (1), the assembly process for this simplified aircraft is cheaper and less time consuming if Joint 6 is completed at the beginning. Fig. 8 shows a screen capture of the assistant tool when selecting the location for the sub stages of an alternative.

4. Conclusions

A KBE Application for Product Industrialization Design is proposed. It is supported by a system composed by an Information Model and the CATIA V5/DELMIA PLM environment.

The Information Model was completed with information exchange methods and new elements and implemented. An operative prototype was developed using it.

The use of the prototype proves that an information exchange can be done automatically between a KBE system and CAD/CAM files to assist in Industrialization Design tasks. The execution of the case studies allowed confirming the main advantages of using the developed application:

- Generating several Assembly Process Design feasible alternatives following a methodology. Exploration of a higher number of alternatives enriches the process
- Defined alternatives can be quickly evaluated and compared, using criteria included and or defined by users. Each alternative's implications can be known from very early stages and the more convenient one can be chosen from the beginning.
- Every change in these stages of Industrialization Design can be evaluated, and its impact estimated.
- Time saving in design, prevention of errors in later stages and automation of repetitive work.

The initial theoretical information model is now validated by the results of this work.

Acknowledgements

The authors thank their colleagues from AIRBUS Military and Polytechnic University of Madrid that kindly helped and contributed to this work.

References

Anselmetti, B., Fricero B., 2012. Aid tool for the design of process and aircraft assembly lines. Aerospace Science and Tech. 23, 387-398.

Butterfield, J., Mawhinney, P., Crosby, S., Price, M., Curran, R., Armstrong, C.G., Raghunathan, S., 2005. An integrated approach to the conceptual development of aircraft structures focusing on manufacturing simulation and cost. In: Proceedings of the American Institute of Aeronautics and Astronautics 5th Aviation, Technology, Integration and Operations Conference.

Chapman C.B., Pinfold, M., 1999. Design engineering—a need to rethink the solution using knowledge based engineering. Knowledge-Based Systems 12, 257-267.

Hu, S.J., Ko, J., Weyand, L., ElMaraghy, H.A., Lien, T.K., Koren, Y., Bley, H., Chryssolouris, G., Nasr, N., Shpitalni, M., 2011. Assembly system design and operations for product variety. CIRP Annals – Manufacturing Technology 60, 715-733.

Mas, F., Ríos, J. Menéndez, J.L., Hernández, J.C., Vizán, A., 2008. Concurrent Conceptual design of aerostructures assembly lines. In: Proceedings of the 14th Intl. Conference on Concurrent Enterprising – ICE 2008, pp. 783-790.

Mas, F., Ríos, J., Menéndez, J.L., Hernández, J.C., 2009. Information Model for Assembly Line Design at Conceptual Phase. In: Proceedings of the 3rd Manufacturing Engineering Society International Conference, MESIC'09, pp.288-295.

Mas, F., Ríos, J., Menéndez, JL, Gómez, A., 2012. A process-oriented approach to modeling the conceptual design of aircraft assembly lines. Intl. J. of Advanced Manufacturing. Technology 62, (in press, available on-line).

Mas, F., Ríos, J., Menéndez, J.L., 2012b. Conceptual Design of an Aircraft Final Assembly Line: A Case Study. Key Engineering Materials Vol. 502, 49-54.

Pardessus, T., 2004. Concurrent engineering development and practices for aircraft design at Airbus. In: Proceedings of the 24th ICAS Conference, pp. 1-9.

Rekiek, B., Dolgui, A., Delchambre, A., Bratcu, A., 2002. State of art of optimization methods for assembly line design. Annual Reviews in Control 26, 163-174.

Zha, X.F., Du, H., Lim Y.E., 2001. Knowledge intensive Petri Net framework for concurrent intelligent design of automatic assembly systems. Robotics and Computer Integrated Manufacturing 17, 379-398.