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Info Sim: Prototyping an Information System for Digital Factory management

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ABSTRACT

Digital Factory (DF) can be defined as a set of software tools and methodologies allowing the design, simulation, initiation and optimization of production systems, with regards to the Product Development Process (PDP). However, it remains not widespread in the industries, essentially due to the insufficient capability to communicate between the different entities and actors implied in the PDP and so to ensure a global consistency of the product and its production system definition. In this research work, we propose an information system dedicated to the management of data and information of product / production simulations, which allows the integration of different points of view and the communication between different actors that participate to the DF process. Such information system has been tested on a case study coming from an industrial context.

Key words: Information system, simulation, product development process, Digital Factory

1. Introduction

With the increase of worldwide industrial competition, being able to propose new products in a short lead time and with low cost is an important concurrence advantage for companies. In order to achieve such objective, companies should concentrate on effective ways to design products faster, minimising not just only cost and problems related to the design project phase, but also considering problems of others phases

of product lifecycle. Moreover, according to (Briggs et al., 2005), the increase of system complexity and of collaborations implies the needs for the concerned actors to share information through the frontiers of systems and organizations. In this context of collaborative engineering, the digital prototyping (based on the concepts of digital models representing the product, its physical behaviour, and its manufacturing process) is a solution to test and validate a product earlier in its lifecycle (Hoppmann, 2009). The simulation, associated to these digital prototypes, becomes an essential tool to avoid unexpected problems occurring during upstream phases of the product lifecycle, and so it allows reducing time spent in the product design project by helping the decision making process (Gedell et al. 2011).

In particular, *Digital Factory* (DF) was born to design and simulate production systems throughout the product design process (Bracht & Masurat, 2005), (Kühn, 2006). This approach, originating from concurrent engineering and from Computer Integrated Manufacturing (CIM), aims to reduce validation loops by ensuring, as early as possible in the product lifecycle, integration of the product manufacturability and productibility with business constraints. However, if simulation of the product physical behaviour (mechanical, electronic, etc.) can be considered well integrated to the product design project (Giudice et al., 2009) and if available technologies and systems in DF exist, such approach is still not widespread and they cannot meet business needs (Nagalingam and Lin, 2008). Several issues can explain such situation. DF is first intrinsically complex, due to the different levels of detail co-existing (from the operation on a specific station to the global supply chain) (Wiendahl et al., 2007) and to the variety of simulation types (prescriptive vs. based on events for instance) (Jahangirian et al., 2010), (Cheutet et al., 2011). Moreover, different actors in the company, with very different points of view are interacting in the DF scope: designer, production simulation responsible and manufacturer. The variety of views implies a complexity of communication and collaboration that interferes with the objective of best performance in terms of time, quality and cost. Finally, even if, according to the Moore's law, the computational power is currently growing roughly at an exponential rate, the simulation complexity and the amount of simulation data are approximately growing with the same rate, requiring new techniques of management (Hägele et al. 2010).

Management of information between the product and its production process including data related to resources is so essential. Indeed, the solution adopted for product development is to integrate different types of information (product, process and resources) as soon as possible to make the right decisions at the right time. This is possible through the implementation of simulated production process that integrates information resources in product design process. The aim of this paper is, therefore, *to provide an information system dedicated to the integration and the management of information related to the product/process simulation throughout the first phases of product lifecycle*. Such information system must be able to integrate different views (design, production and simulation), from different information systems used in design and production phases, and to provide a consistent view of information representing the state of the operating system for each actor in the organization.

The article is structured as follows. Based on an analysis of the intrinsic complexity of DF, we give details in section 2 on the requirements of the information system and we identify lacks of current information systems according to these requirements. Based on a MERISE methodology, section 3 presents the conceptual model of the DF Information system we propose. Section 4 details the implementation choices of the Information system and we discuss the validation of our approach on an industrial use-case. Finally, section 5 presents the conclusions and perspectives of our approach.

2. State of the art

Several works, like (Lin and Harding, 2007), (Mahesh et al., 2007) or (Nylund and Andersson, 2010), have proposed models that take into account some aspects of the diversity of simulation models and representations existing in the DF. Nevertheless, they do not provide a management of all generated information during the simulations.

Based on an analysis of DF, the authors of (Ayadi et al., 2013) demonstrate the lack of interactions between the different DF simulation tools and the existence of a large information gap that will be complex to fill in order to ensure the continuity of information flow over all the PDP. As a consequence, the main issue is not the existence of adequate tools but their capability to communicate together and ensure a global consistency

of the product and its production system during the early stages of product design. Moreover, the integration of simulation information requires more than just data and information management and no current information system covers such field. This is why our main objective is to propose an information system that can manage and control DF information.

2.1. Requirements for a DF Information System

To solve such issue, the expected information system should include the following functions:

- Based on a PPR (Product, Processes, and Resources) philosophy, which is the structure of all DF simulation tools.
- Able to manage different points of view: DF is at the intersection between different actors of the PDP (Design, Production, Industrialisation, etc.) and aims at making them collaborate together. All these actors have specific needs in terms of data and information on the product and the production system, according to their own objectives (Gunendran & Young, 2006) (Drieux et al., 2007).
- Able to manage different granularity of products, processes and resources: (Bley & Franke, 2004) enlightens the need to define a simulation easy to develop and likely to obtain concrete results, according to the amount of information and its maturity known at a given time of the PDP. We based ourselves on a 5-level scale (Supply chain, plant, production line, workstation, task), coming from an aeronautical vision of the extended factory (Cheutet et al., 2011).
- Interoperable with the variety of DF simulation tools: a large diversity of simulation objectives, methods and tools exists within DF. Moreover, for each of these simulation types, a large number of tools exist, either in the scientific community or provided by software editors. The information system should be able not only to integrate the metadata of the simulation but also to interact with such data.
- Interoperable with the other information systems participating to the PDP: since several IS exist inside one organization, the data can be found in the information system then dispersed, with potentially high risk of redundancy and/or synchronization, knowing that for the same information system, the objectives and the functional area may be different from one company to another one (Houlihan, 2008).

- *Able to control simulation process with a project-oriented interface*: when complexity is growing, simulation activity is known to be managed as a project by itself, in order to ensure consistency between objectives, resources and deliverables.

2.2. Information System analysis

To support the PDP, information systems are becoming a crucial element for engineering. Indeed, any failure in the information management, any information loss can induce delays. The difficulty to manage information is explained by the intrinsic dynamics of the system. The main existing business information systems are actor-oriented, i.e. defined for a particular point of view. In the context of our study, we classified them into four families: ***Manufacturing Process Management*** (MPM) dedicated to production engineering (Fortin & Huet, 2007) (Kim et al., 2010), ***Product Data Management*** (PDM) dedicated to the product design process (Eynard et al., 2006), ***Enterprise Resource Planning*** (ERP) dedicated to the production process (Kelle & Akbulut, 2005) (Botta-Genoulaz, et al., 2005), and ***Simulation Lifecycle Management*** (SLM) dedicated to the simulation management (Popielas et al., 2010). Table 1 analyses these categories according to the criteria defined in the previous section.

PDM systems are dedicated to design data management. They integrate a multi-point of view system, and most of them are project-based. Some research works have succeeded to integrate simulation process management inside PDM, even if they are not defined for this (Buda et al., 2011). PDM systems can manage any files that may be generated during the PDP. Nevertheless, granularity is not managed but simulation of different granularity may co-exist. The same remark may be done concerning a PPR philosophy.

ERP systems are dedicated to production data management. They are based on a PPR philosophy, in which the production system is defined according different levels of granularity that are interacting, allowing a MRP 2 approach for instance. Several points of view exist in the ERP but for our concern only the production one, and not the designer and the simulation responsible. Moreover, the only simulation that the ERP may be interested is the one managed by the APS (Advanced Planning Systems). Finally, an ERP is defined for daily usage and do not incorporate a project vision.

SLM systems, by nature, are dedicated to simulation management. This is why they manage very well simulation processes and project and are interoperable with different simulation tools and other IS. On the other hand, they are defined to be used by simulation actor and manage only one point of view. Moreover, even if simulations with different granularity may exist inside the same PDP, a simulation project generally consider one level by itself and do not try to make them co-exist at the same time. Finally, a SLM only manages product simulations and no production ones, and so does not take in consideration a PPR organization.

MPM systems are dedicated to production engineering management. They are based on a PPR philosophy, with different levels of granularity defined. Most of the existing software tools are integrated with existing DF simulation tools from the same editor, allowing a very good interoperability. On the contrary, they are defined for only one type of user, like the SLM systems. And the simulation process is not defined by default and requires specific development.

Since no current information system perfectly fits to our requirements, we propose to develop a new one that can be integrated in the global information politics of the company. As a consequence, it should be interoperable with other information systems, whatever the ones that exist in the company.

3. Conceptual model for information management in DF

In the proposed article, we choose the MERISE method (Avison, 1991) to design the information system. We first propose a data conceptual model, defined with a set of UML diagrams. We after suggest the physical model that leads to the prototyping of an information system dedicated to Digital Factory information management named **Info Sim**.

To define the conceptual model with regards to the constraints defined in the previous section, we base ourselves on existing models that describe views and attached information of the product and/or the process and the resources. Such models are known to be consistent and interoperable with the classical models used in the actor-oriented information system detailed in section 2.2 and with international standards (ISO/CEN 19439, ISO 10303-49, ISO 15531-1, ISO 18629-1, etc.).

In (Ayadi et al., 2013), we enriched two information models, one in the context of product information model proposed by (Costa & Young, 2001) and the other one in the context of manufacturing information model proposed in (Molina & Bell, 1999). Such results allow to encapsulate product and manufacturing information needed to make a simulation and information relating to four major aspects of the enterprise, i.e. the processes, resources, strategies and views.

Once these information classes defined, we develop the conceptual model to detail the relationships between the information inside the DF context, by developing a set of UML models. More formally, we first defined a use case diagram for our proposition, in which we defined a set of 4 actors interacting in the DF context (*DF project leader, designer, manufacturer and DF analyst*) and 3 main functions (*DF Project creation, DF Project simulation and DF Project control*). Thereafter, we defined the structure and the behaviour of the system, with the use of class diagrams and activity ones.

3.1. Structural view of the conceptual model

In figure 1, we first define a *DF entity* that encapsulates all the attributes of the main classes of the model (Product Component, Process Component, Resource and Simulation), like a identify number, a creation date, a description and comments. This class can also be associated to a file (technical documentation, 3D model, plant plan, simulation videos, etc.), and to an experience that can be shared for future projects. Finally, since a DF project is often based on try-error approach, a first modelling attempt of versioning is also attached to this class we define a very simple versioning modelling, by specifying the number of the version with an attribute and by defining the relation *has for version*.

In order to model the tree structure of a *Product* and a *Process*, and the specific semantics of the leaves (a part for a product, a task for a process), we use the same assembly template, creating two fictive classes (*Product component* and *Process component*) that are specialized (*Product* and *Part* on one side, *Process* and *Task* on the other side) and with the aggregation relation between the fictive class and the non-leaf one. Moreover, a part can be associated to a material. For the *Resource* modelling, we do not make the same

choice since we define the complete tree structure of the resources and its semantics on the basis of the 5-level structure defined in (Cheutet et al., 2011).

On the other side of Figure 1, a *DF Project* is an aggregation of one or numerous *Product*, *Process*, *Resource* and *Simulation*. *Product* is the input of *Process*, and as the *Process* modifies it, *Product* is also the output. It is important to note that the integration process of different information involved in a *DF Project* is initialized by the insertion of product information. The *Process* uses one or more *Resource*, and the *Simulation* simulates one or more *Process*. This *Simulation* is performed on a *software tool*. One or more versions of *Product*, *Process*, *Resource* and *Simulation* can be considered in a *DF Project*.

A *DF Project* is associated to a control *Graph*, which the attributes are the date and the hour that information is inserted in the project and the category of information (product, process or simulation) it represents. Finally, we propose the *Validated* attribute for the *Simulation* classes, in order to keep a traceability of the decisions taken in the project life and that will be displayed in the control graph.

3.2. Behaviour view of the conceptual model

Hereafter, we develop a set of activity diagrams that represents the expected dynamics of the information system, based on the function defined in the use case diagram. In particular, we propose the definition of the *DF Project creation* activity (Figure 2). In this activity, three different actors are implied, the DF leader, the designer and the manufacturer. Once the DF project created by the DF leader, the designer defines all the final products that are in the scope of the project, with the possibility to reuse previous products that have already been defined in previous projects or to create specific products. After that, the manufacturer can select or define the manufacturing processes and/or the associated resources. At that moment, all the required data and information on the PPR dimensions are defined in the project.

4. Physical model and Info Sim validation

Based on the conceptual model presented before, a data physical model of Info Sim has been developed considering a Three-tier architecture and on WinDev¹ of PCSoft. WinDev allows the development of data-oriented applications. This physical model will be presented in this paper through its application to a use-case, which allows us to validate its functionalities. Thus, we will first introduce the case study context and then we will explain how Info Sim works. We will present a screenshot of Product Information Tab in Info Sim (Figure 3). The others information tabs (Manufacturing, Simulation and Consultation) will be presented in a global representation of Info Sim (Figure 4).

In the development strategy, we made the choice not to focus on the interoperability requirements at the first stage. It implies that the current version of Info Sim cannot communicate with the other information systems and that all data are created/copied by a user inside Info Sim. Such choice can be explained by our objective to first validate the integration of different points of view inside one common DF framework.

4.1. Presentation of the case study

FALSIM project was leaded by EADS group in 2010, and it concerned the assembly line of four types of aircraft sections (left Framing Door Passenger – FDP, right FDP, boat, and pavilion). This project aimed to design, simulate and improve this Aeronautics assembly line, whose production rate would increase from 7 to 13 aircraft per month in two years (Cheutet et al., 2011).

The project team proposed a solution to this situation, minimizing the investment in workstations and patterns. Thus, the assembly process was modified, without changing the routing or resources, in order to improve the material flow, the production rate, the work space or the resource usage. The simulation was applied to validate the new production rate. More than 15 simulations and 300 files have been generated during this project, for 2 types of simulation and 2 levels of granularity. Each of the files has been modified several times by different actors, according the interrelation between the results.

The information of this project was implemented in Info Sim in the same chronological order that they were used or generated during the project. But in order to be clearer, we will here present the very beginning of

¹<http://www.windev.com/>

information implementation in Info Sim. The objective here is not to discuss about the results of the proposed solution by project stakeholders, but to demonstrate that Info Sim is able to integrate different information of product, manufacturing process and simulation which can be generated by different design tools or software (as CATIA, DELMIA DPM, Quest, etc.) during the PDP phases, with different point of view associated to each information.

4.2. Method

As noted in section 3, the integration of different information involved in a *DF Project* is initialized by the insertion of product information. Thus the first information to be inserted in Info Sim, when we create a new project, is information about product. In the *Product information* tab, we primarily insert information of all different materials used in the different parts of the product (through *Material* bottom), then the information about these parts (through *Part* bottom) are introduced associating these parts with their corresponding materials. Finally, information about product can be inserted (Figure 3-1), associating it with correlated parts. At this stage, the assembly order of these parts must also be informed (Figure 3-2). Note that in the beginning of the project no production process is associated to the product (Figure 3-3).

As proposed in the conceptual model, the material, parts and product information mentioned above concerns identify number, name and designation; and attached files, as 3D models can also be associated to these different aspects of product (through *Attachment files* bottom). Also, when a file is attached, the user can insert comments about this file, and it can be viewed by other actors of the project.

Once product information exists in Info Sim, the manufacturing process information associated can be introduced. In the *Process information* tab, we first select the product that concerns this process (Figure 4). Then, the routing to assembly the product can be inserted in *Manufacturing process list*, attaching a file that explains the routing. After this operation, this production process will appear in the *Product information tab – List of production process*. Different files can be inserted because alternative routings can be considered in the project. In this window, the information about the resources used in the production process can also

be inserted attaching files. Four types of resources are taken into account in Info Sim in function of the granularity required by the project: plant, line, station and task.

Thereafter, all these information can be associated to propose and test different simulation scenarios. In the *Simulation Information* tab, we must first select which product concerns the simulation, then chose one of the assembly process introduced in Info Sim and one of the resource associated to; and finally insert simulation information, attaching a file of the executed simulation.

The last tab proposed in Info Sim, named *Consultation*, was created to support the project management and it is associated to the control *Graph* (which is very close to a GANTT representation), and simulation *Validation* proposed in the conceptual model. Through the *Validation* bottom, users find the information about all simulations associated to the project. The responsible of each simulation can validate it and add comments if it is necessary. When all simulations are validated by the respective responsible, Info Sim automatically validate the DF project. By the way, in this window, the user can have access to different file versions associated to product, process and simulation.

Also in the *Consultation* tab, user can view a plan presenting the chronological generation of information during the project (Date and hour – *Graph* bottom). Considering the order that information is displayed in the graph, users can find respectively product, manufacturing process, resource and simulation information. In this graph, resource information is displayed separately from manufacturing process information in order to better represent PPR philosophy, and the different colours of resources represent different granularity (plant, line, station and task). This graph allows a better analyse of the project proceeding. The leader of the project can verify if the project follows a concurrent engineering approach, and if information are generated in a consistent way. Indeed, it illustrates how project is organised between different actors, highlighting the overlapping of activities or the re-works.

4.3. Discussion

The presented use-case demonstrates that Info Sim is an information system that manages necessary information to create and follow-up simulations, as well as information generated by simulation execution.

Also, it drives actors to associate different types of information, such as product, resource, process and simulation. These associations allow Info Sim to guarantee the integration and the reliability of information in a DF project. Otherwise, the possibility of attach any format of files in the different windows allows the exchange of technical information between actors: documentation of the product development, exchange database files of other systems (as calculation tools, simulation of production processes, etc.). So, it allows to keep a continuous information flow between PDP actors, to avoid information duplication through version management redundant and to improve the process quality. As a consequence, Info Sim environment provides a better communication between different PDP actors and ensures a global consistency of information in a DF project context.

Considering the requirements for a DF information system identified in section 2.1, we verify that Info Sim respect all criteria (based on PPR philosophy; able to manage different granularity of product, process and resources; interoperable with the variety of DF simulation tools; able to control simulation process with a project-oriented interface) excepted for the ability to be interoperable with the other information systems participating to the PDP. Indeed, in the present version of Info Sim, we cannot directly transfer information from another IS to Info Sim. But we consider that Info Sim guarantees consistent information for short and medium duration projects. The interoperability with other SI is the next and important step of Info SIM improvement, and as it was developed according to international standards (mentioned in section 3), this work should be facilitated.

Thus, in this study, we validated Info Sim from an operational and information integration point of view. Also, a larger scale validation requires changes in the design methodologies of companies. Indeed, the implementation of information systems requires changes on the organization of design team and of PDP.

5. Conclusion

After identifying information management as one of the main difficulties for DF implementation in an industrial context, we decided to propose an appropriated information system to this activity. Indeed, DF projects require an information system able to handle and integrate information of different actors, generated

by different tools. To achieve it, we have based on MERISE methodology to propose a conceptual model of the information system, then an activity model to finally develop a physical model named Info Sim. The conceptual model allowed us to define how these different information should be integrated in Info Sim, and the activity model allow us to define how Info Sim should works.

Thereafter, Info Sim was developed and applied in a use-case. This application allows us to validate its main functionalities:

- integration information provided by different actors: product, process, resource and simulation information (following a PPR philosophy).
- management of different levels of granularity of simulation information
- storage of any format of files generated by different tools supporting PDP (as Delmia, 3D models)
- project view, through a graph presenting the chronological generation of information during the project, which allows a better analyse of the project

It is important to note that Info Sim is not responsible for the generation of information and knowledge necessary to a good project proceeding, but it provides a better visibility of the project advancement and the access of different information, which will help to take better decisions earliest during the PDP.

The future work concerns the development of the interoperability between Info SIM and the others information systems participating to the PDP. This ability is very important to guarantee consistent information in long duration projects. Furthermore, “lesson learned” functionalities will also be developed in Info Sim, in order to capitalize past experience that can be useful in future projects. In this stage, specific metadata about the PPR and the simulation process will be also capitalized in order to be more precise and efficient in the capitalization. Finally, since simulation is a process, specific lifecycle can be added to improve the management of simulation objects. As a long term perspective, we intend to extend the versioning functionality into change management functionality, considering the propagation of changes either made in a part of the product to the simulation or in the opposite. Also, to ensure a large scale validation of Info Sim, a methodology must be proposed to the implementation of Info Sim in a company.

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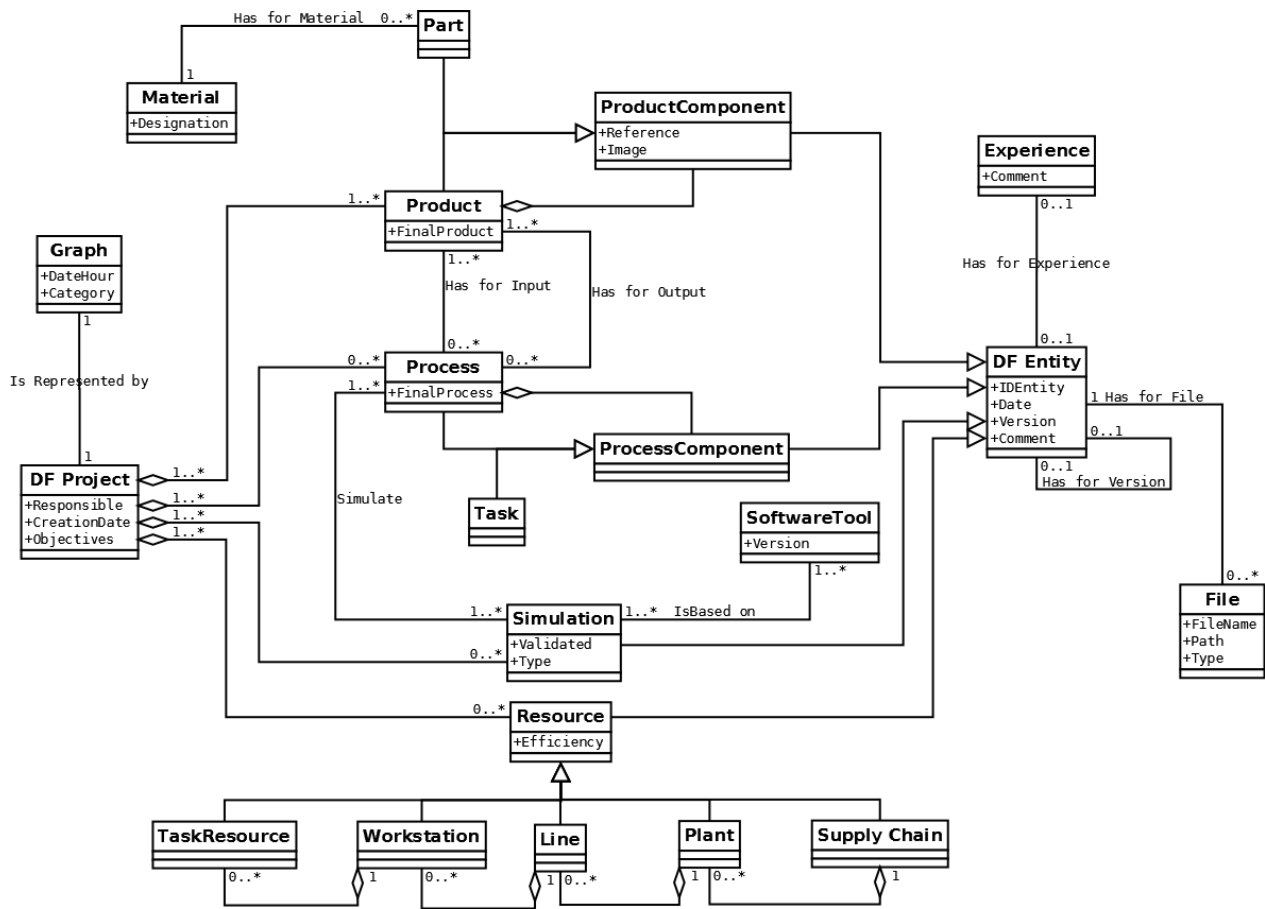


Figure 1. Info Sim conceptual class model.

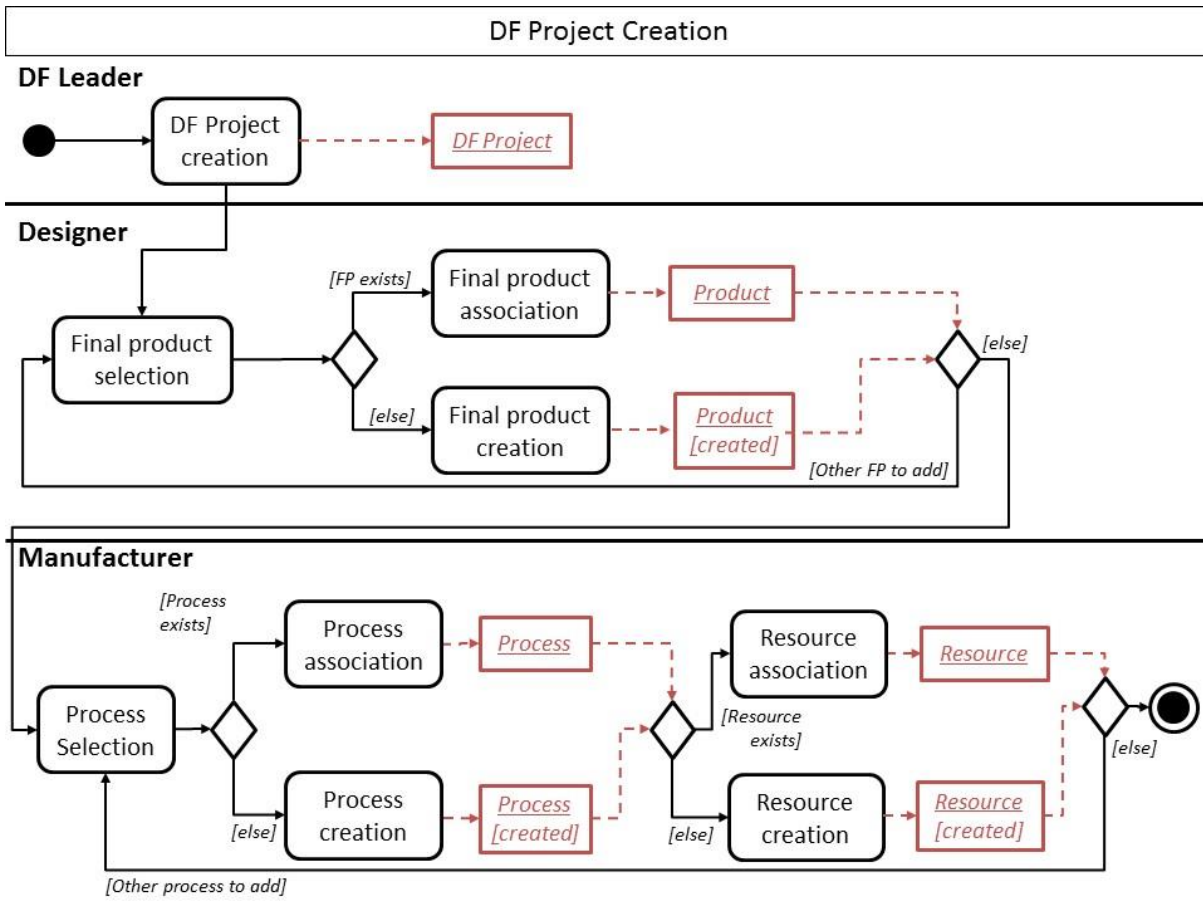


Figure 2. Definition of the *DF Project creation* activity.

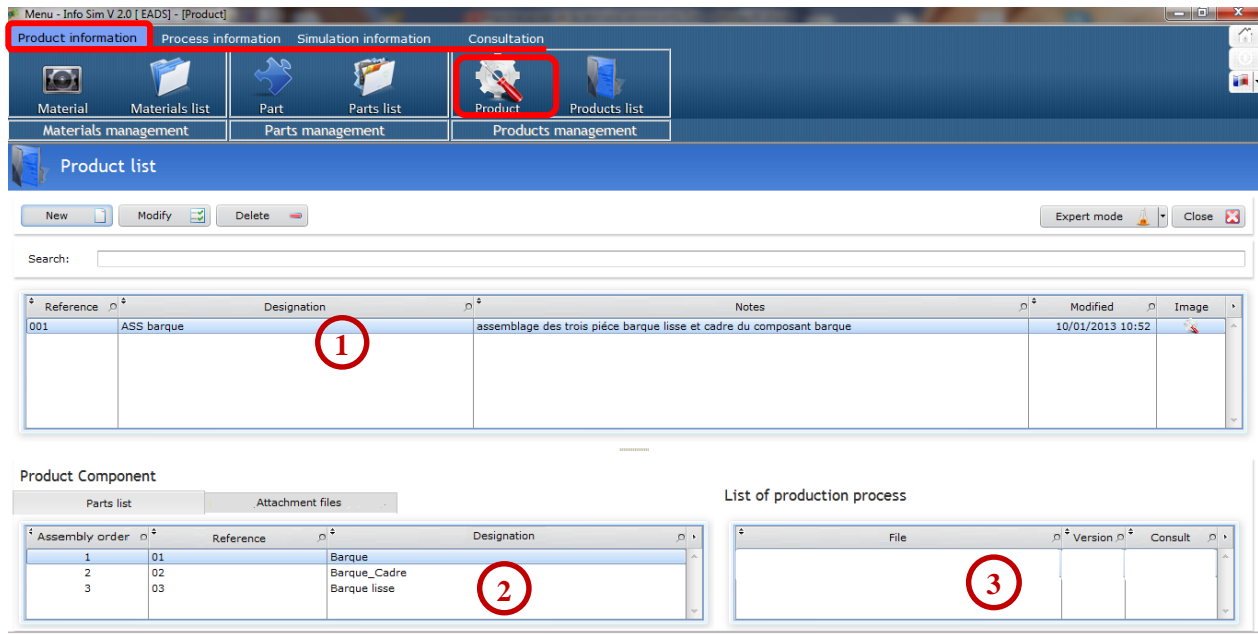


Figure 3. Product Information in Info Sim

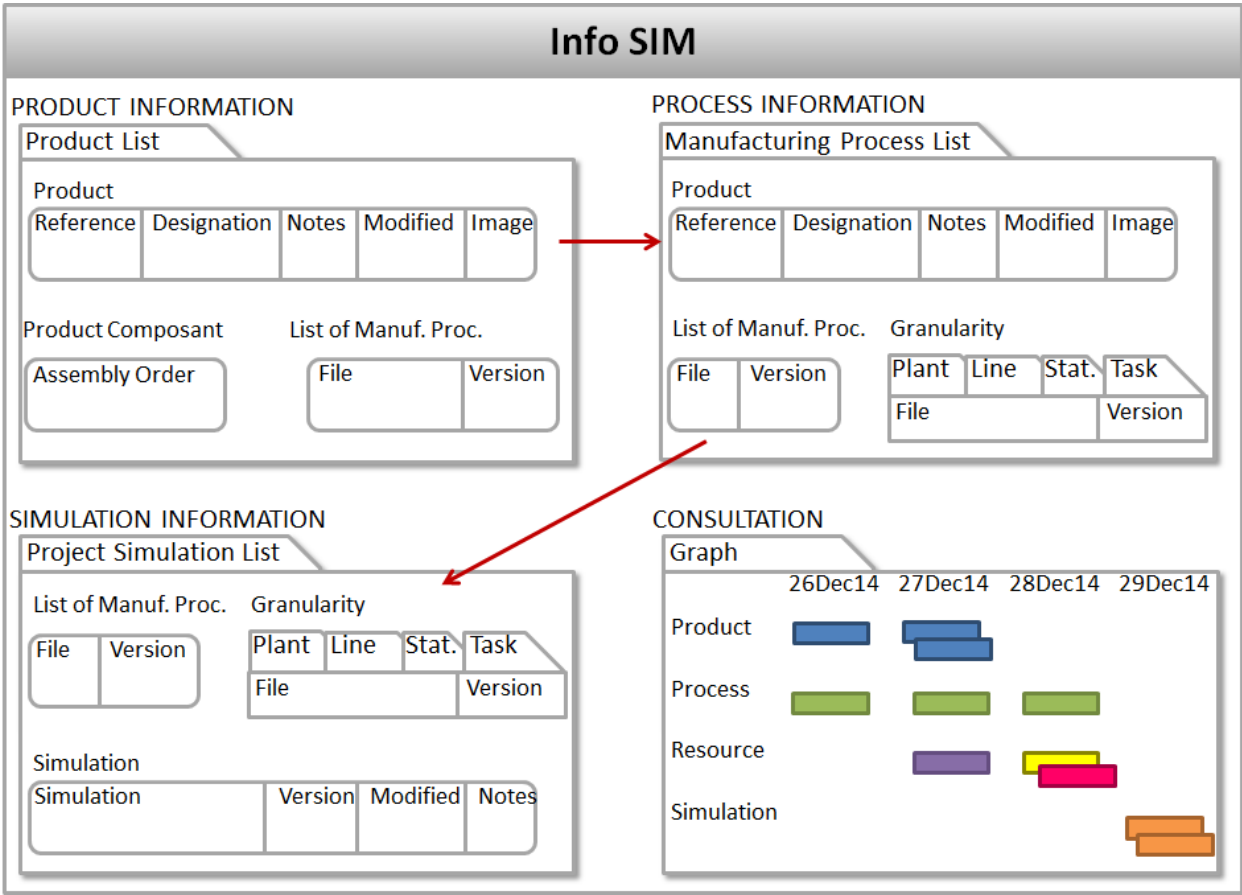


Figure 4. Global representation of Info Sim

	Simulation process	Points of view	PPR granularity	Simulation tools	IS interop.	PPR-based	Project-based
PDM	+	++	0	+	+	0	++
ERP	-	+	+	-	+	++	-
SLM	++	-	0	++	+	-	+
MPM	0	-	+	++	+	++	+

Table 1. Analyse of information systems according to DF point of view.