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ADDED VALUE PROCESS FOR COLLABORATIVE EARLY DESIGN USING SIMULATION MODELS IN AERONAUTICS AND AUTOMOTIVE INDUSTRIES

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1. Introduction

Engineering process modelling have been classified as a significant activity in most major companies around the word, making this methodology a crucial part of the company's management [Ould 1995]. Vehicle industry is not the exception. Process approaches have been largely applied to manufacturing and production phases. Then, more recently, these approaches started to be applied in engineering design phases. During the design phases, the utilization of simulation models in this industry has grown in importance in the last decades. These technics could be extremely accurate, bringing a quality/cost solution to test phase problems. The passing through a numerical era, where simulation models are used as the basis of the development process can often be referred to as a Model Based Systems Engineering (MBSE).

INCOSE defines MBSE as the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [INCOSE 2007]. This approach demands as well a new organization around the simulation models. Our research aims at understanding how people interact thanks to the models, and how they obtain the results in a context where team are large, spread and sometimes diverging objectives. In others words, how people collaborate in the design phases using simulation models.

In previous research [Roa-Castro and Cardinal 2014], [Roa-Castro and Cardinal 2015], the main features of the collaborative design using simulation models were identified. Nevertheless, no model exists today describing all the feature for a collaborative design in M&S context. The research presented in this paper is part of a larger effort on collaborative design modelling, and is focused in the modelling of three main features in collaborative design: Actors, activities and objects. To represent these three features, an added value process proposition for a collaborative design in early development phases using simulation models is suggested.

Section two presents the action-research methodology used in this paper, starting from industrial problems and literature gaps, passing through the added value process proposition, its implementation and later feedback. The observations of the industrial practices and the literature review are exposed in section three and four. Sections five to seven introduce progressively the added value process proposition, its implementation and its evaluation. Finally, conclusions and future work are presented in section eight.

2. Methodology

This paper follows a methodology in five steps. First, the observations in the industry pointed out the problem. Then, a literature review underlined the gap regarding the collaborative design process for simulation models, and suggested the need of guidelines in this context. After both, problem and literature analysis, an added value process for a collaborative design in early development phases using simulation models was proposed. Later, the implementation of the process in a project context was performed. Finally, a feedback regarding the newly implemented process was gotten through dynamics interviews. A complete view of the methodology is presented in Figure 1.

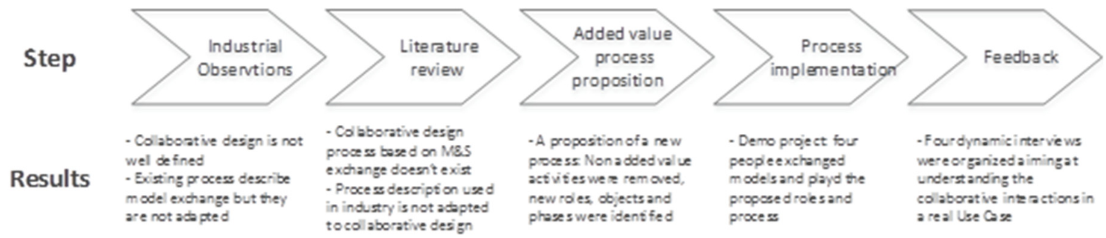

Figure 1. Methodology

3. Industrial observations

The industrial observations come from aeronautics and automotive industries. In order to improve the understanding, we triangulate by using two different data sources:

1. Theoretical observations: Based on the internal documentation for model exchange.
2. Operational observations: Based mostly on workshops.

Theoretical observations correspond to the analysis of industrial documentation about the support of model exchange. The outline of the guidelines is based on roles, process and model description. In total, eight main roles, three main stages containing about 30 detailed stages and ten documents to exchange are identified. Analyzing the roles, the stages and the documents, some facts can be highlighted:

- Some stages have undefined outputs
- All the described roles are not used in the process description
- All the described documents are not used in the process description, one of them concerning interfaces agreement.
- Additional undescribed supports are used but not documented
- No capitalization stage is described during the process
- The process considers only the model development situation, missing the re-use cases when a model already exists.

Operational observations aim at illustrating the As-Is situation. The situation studied refers to the engineer teams using simulations models in order to respond to a request during the early development phases. After analyzing the situation through ishikawa and five why's methods, a representation of the current situation was done in participation with the concerned engineers teams. The representation uses a flowcharts. Situations introducing a way back in the current process were identified and included into the diagram as a return flow using an arrow. The situations presented below were pinpointed during two workshops. Each workshop took two hours, and sixteen engineers were participating.

- Architecture changes are often requested during the simulation process. These changes, concerning the architecture evolution are difficult to take into account with the current process.
- Often simulation teams need to request for an additional information regarding the environment where their models supposed to be used.
- When the assembly of the models takes place, the accuracy of the models is not appropriate. This inaccurate results often lead to rework tasks as well as other imprecise specifications during the model request stage. In general, a better preparation upstream of the model request, is identified as an important need.
- A centralized vision of the entire model seems to be missing. As a result, a lack of organization aiming at the models convergence emerges.

Next section introduces the literature review (second step proposed in the methodology).

4. State of the art

Additionally to AP2633 [Airbus 2005], two other industrial initiatives propose model exchange processes: FEDEP and ProSTEP [ProSTEP 2014]. On the one hand, FEDEP [Defense 1999] is the acronym used for Federation Development and Execution Process. FEDEP document describes a high-level process where the activities are related to high level architecture federations. Nevertheless, FEDEP documentation does not include any role in its process ant it is mainly focused on task and documents identification. On the other hand, ProSTEP iViP Recommendations document aims at orchestrating different models of manufacturers and suppliers. ProSTEP initiative offers an interesting break down structure regarding the product lifecycle and different scenarios for joint product development phase. Regarding this phase, a significant description of the IT needs have been done. The ProSTEP reference process identifies three roles (Partner A, Partner b and All), three phases, thirteen activities and five elements of the behavior model specification. Nevertheless, the roles identified are still general and the outputs of each activity are not included in the process description but in other documents.
Some academic works propose approaches much more related to knowledge exchange by standardizing the simulation model interfaces. Sirin et al. [2015] suggest the standardization of the model interfaces trough a Model Identity Card (MIC). This work identifies as well three main roles in a collaborative design based on simulation models context: System architect, simulation architect and model provider. Another research in a similar context is presented in the work done by Badin et al. [2011] where KCModel methodology (Knowledge Configuration Model) is introduced. The purpose of the KCModel is to Capitalize, Trace, Re-use, and ensure the Consistency (CTRC) of technical data shared by several experts model, especially in the upstream step of design process. Other collaborative approaches mention the importance of the process but are much more based on user interfaces and IT improvements during the simulation models exchange [Ji et al. 2008], [Freedman et al. 2015].
Looking in the wider scope of collaborative design process in the literature, no commonly method, used specifically for collaborative design, was found. Though, both, traditional and relatively new process modelling approaches are used. Two interesting new approaches are Cooperating Correlative Map Based on Activity (CCM_A) and the Collaborative Architectural Design Processes. The CCM_A process modeling method [Cui et al. 2009] takes into account some of the important features of the collaborative design. Nevertheless, the roles and the interaction within the stakeholders are difficult to interpret. The Collaborative Architectural Design Processes is characterized by a collaborative engagement of all stakeholders. This approach structure different design tools and design events, as walkthroughs and design games, aiming at promoting creativity and facilitate common understanding of the design tasks [Binder et al. 1998].
To conclude, literature proposes different process modelling methods and different approaches to study collaborative design. However, none method is exclusively dedicated to collaborative design using simulation models. In addition, only very general processes describing Modelling and Simulation (M&S) specific interactions in the literature exists today. However, some process describing M&S exchange have been proposed by the industry, such the AP 2366 by airbus, FEDEP and ProSTEP. Those process descriptions are a valuable initiative nevertheless a significant improvement could be done, especially regarding the inclusion of hypothesis of model reuse and capitalization and the roles played during the process.
Section three and four have introduced the problem and the literature review analysis. In section five, the added value process for a collaborative design in early development phases using simulation models is presented in order to fulfill the gaps presented in previous sections.

5. Added value process proposition

5.1 The process modelling method

Methods commonly associated in the literature to the keywords design process, modelling methods, and process modelling are: the flow charts, the IDEF, the Critical Path Method (CPM), the Design Structure Matrix (DSM), the Petri-net, the Data flow diagram (DFD), the Role activity diagram (RAD), the

Business Process Modelling Notation (BPMN), the Business Use Cases (BUC) and Business Object Interaction Diagram (BOID) among others [Huang et al. 2003], [Wang et al. 2006], [Yao et al. 2006], [Perrot 2008], [Aldin and De Cesare 2009]. The design process modeling methods mentioned before have different characteristics and are useful in certain cases. In order to choose the most appropriate representation for our problem a comparison of different methodologies is presented in Table 1.
Collaborative design features using simulation models have been identified in previous work [Roa-Castro and Cardinal 2014], [Roa-Castro and Cardinal 2015], [Roa-Castro et al. 2015] and also in others researches [Huang et al. 2003], [Cui et al. 2009]. A synthesis of the features is presented below:

- Lifecycle and stages: A basic time notion
- Simulation artefact: Includes simulation models to be exchanged as well as all the documents linked with the model (interfaces definition, scenarios, hypothesis, requirements, etc.)
- Stakeholders: Stakeholders and actors are included in this categories
- Activities: Succession of activities to achieve a simulation having different contributors
  - Parallelism and iteration: Characteristics of the activities
  - Decision: The final objective of any collaboration is to make a decision. At the moment the decision will be considered as an action
  - Traceability-reuse: Models can be reused when the modification is easier to handle than a new development. In addition, author information and model records are crucial in model exchange.
- Trade-off points: Different interest from different stakeholders
  - IP constraint: Intellectual properties constraints often linked the model utilization. Can be considered trade-off point.
  - Multidiscipline: People coming from different backgrounds working together. Can be considered as a trade-off point.
- Resources: Material resources needed for the activities
- Environment/context: Organizational context (e.g.: how people are organized, what is the company policy)

A comparison regarding seven features of collaborative design using simulation models is presented in Table 1. After the evaluation of the different characteristics, no method completely fulfills the needs regarding collaborative design for M&S modelling. In addition, collaborative process studies, presented in section four, tackles mainly the activities, the documents and the roles involved during the model exchange. As a result, in a first instance this work will be mainly focused on the information flow (Sim Artefact), activities and roles. Then, in a further research a more complete representation will be studied. Regarding these three criteria, three representations seem to be appropriated: IDEF, RAD and BPMN. After several attempts using the three methods to represent information flow, activities and roles, a mix of the three seems to be the most appropriated modeling process representations for our case.

Table 1. Comparative table: process modelling representations vs collaborative design for M&S features

	Lifecycle and stages	Sim Artefact	Actors	Activities	Trade-off point	Resources	Context	Score
Flowcharts	+			++				3
IDEF	+	++	+	++	+	++		9
CPM	++			+				3
DSM		+	+	+		+		4
Petri-net	+			+				2
DFD	+	++		++				5
RAD		+	++	+	+	+		6
BPMN	++	+	+	++	+	+		8
BUC			+	+			+	3
BOID	+		+	+	+			4

5.2 The added value

The collaborative design process for simulation models proposed in this paper contains fifteen activities, eight flows and eight data roles. The process is appropriated in early development phases context. Three roles among the eight presented are the proposed roles by Sirin et al. [2015] (System Architect, System Model Architect, Model Provider) as well as one of the data flows (Model Identity Card).

The process starts by a request (solicitation in the Figure 2) from the System Architect. This request is often a question, such as: What if a new technology is introduced in the system? This request is followed by a solicitation package (first information flow), where other important elements are presented, for instance, the scenarios to be studied, the hypothesis, the possible architecture to be studied etc. All this information is delivered to the model architect. He will technically specify the simulation architecture(s). Then a check loop with the system architect is done in order to verify the needs. This step is very important in order to avoid the rework tasks later in the process. The final agreement will be formalized using a MIC Simulation model (Simo) agreement. The MIC Simo agreement is a high level Model Identity Card [Sirin et al. 2015] for the global simulation.

Then the simulation architect will define every interface within the architecture elements by using a MIC (MIC Simo interfaces in the diagram). The next step is the search. The search step is essential in the process. Contrary to industrial existing process, in the present research we assume that the enterprise can already have the models or the results. As well as the verification of the needs, the search activity avoid rework tasks. The search is done by the librarian role. At that moment four possible scenarios could happen:

1. The architecture of the simulation and its raw results exist already. In this case, the raw results are transferred to the model architect who will see if the results need a post-treatment or not.
2. The architecture to be simulated exists but there are no raw results available. In this case, the simulation model is transferred to the model architect who will contact the model executor to run the simulation. Then, the graphic designer will be requested to make the post treatment (Visualization).
3. The architecture to be simulated does not exists but the subsystems models compounding the architecture exist. Then the model integrator will be requested to integrate the subsystems. After integration, the model architect will ask the execution of the simulation and visualization of the results.
4. The architecture to be simulate does not exists and the subsystems models neither. In this case, the model architect will ask to adapt or develop new models to the model adapter or model provider. In both cases, after development or adaptation, the model integrator will be requested to integrate the subsystems. The model executor to run the simulation. And the graphic designer to make the post treatment.

In all the cases, after post treatment, a capitalization will be requested to the librarian. The capitalization activity is key in the whole process. Without it, every situation will be automatically treated as the situation number four mentioned above. A complete view of the added value process proposition for a collaborative design in early development phases using simulation models is presented in Figure 2.

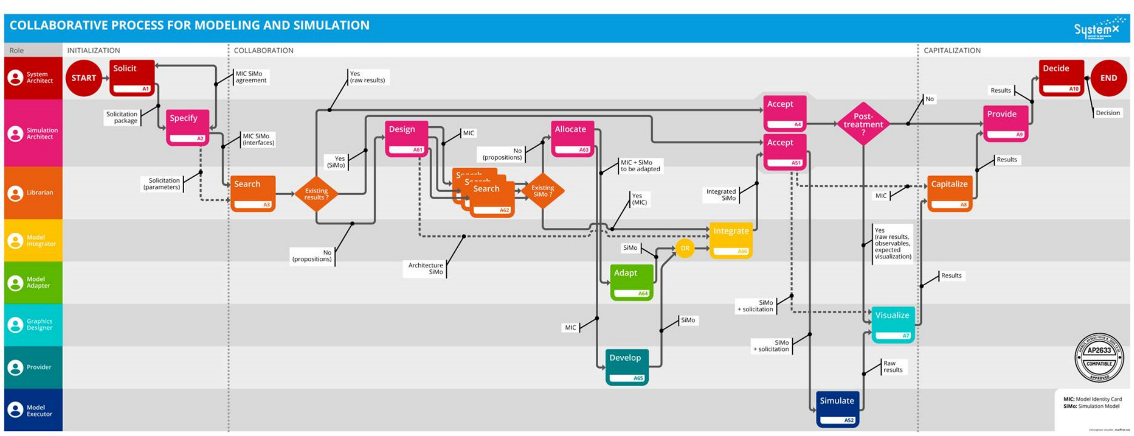

Figure 2. The added value process proposition for a collaborative design in early development phases using simulation models

The proposed process contributes to an added value solution at three different levels:

- Operational level: At the operational level, the suggested process can be considered as an improved input for the vehicle industry. This new input has a major focus on the preparation phases, trying to converge the actor's perspectives as soon as possible and avoiding numerous changes during the process. The new process avoids the rework tasks at the development level and fulfills the gap concerning capitalization activity, which is a primordial need [Roa-Castro et al. 2015]. In addition, the interfaces definition is addressed all along the process by using Model Identity Card formalism.
- Three main improvements regarding the existing guidelines can be highlighted in Figure 2:
    - Eight roles are defined and used in the process. Additionally, the roles proposed in Figure 2 are compatible with the current industry guidelines.
    - A new task sequential logic for model exchange is suggested.
    - Information flow between the tasks has been identified.
- Tactic level: A clear vision of how and who does what is given at management level. Likewise, people involved in the process have a larger vision of how their work is valuable for the organization. In addition, the missing capitalization stage in the guidelines, proposed in the new process, could improve the knowledge management in the organization.
- Strategic level: The new process is compatible with the existing industry process mentioned in the state of the art. This process can be easily integrated in the organization and match with the others process. Furthermore, the hypothesis of model reuse proposed in the process could enhance the know-how of the organization and could eventually reduce the time of development during the design.

6. Process implementation

The process implementation took place in the Future@SystemX project. During Futur@SystemX four people exchanged models and played the proposed roles and process. This project took place between December 2014 and February 2015 at the Research Institute of Technology IRT SystemX. They exchanged 10 single simulation models, for a total of 6 different configurations of the global simulation. At the end of the project, four dynamic interviews were organized aiming at understanding the collaborative interactions in a real Use Case.

Figure 3 shows the process implementation. The use case deals with the thermic aspects of the cabin in the airplane. There is an air conditioner system (Environment control System ECS) in the cabin, and the question is: what kind of control model is better to use between two options (On/Off controller or PID controller)? The question is given during the solicitation stage. In this stage, other elements such as flight profiles and cabin architecture are provided. After an agreement between the system architect and the model architect, the specifications are provided. Those specifications establish the general simulation architecture to be studied. The elements composing the architecture are the cabin, the regulation system and the ECS system. Likewise, the elements of the solicitation package are established: the objectives (temperature comfort), the item to be observed/measured (temperature mean) and the scenarios (pressurization and temperature).

At the search stages, no result for a precedent simulations were found. Then, the design of each sub-system item was done using a Model Identity card (MIC). In total, six subsystems were described: an ECS, two kinds of control models (On/Off and PID) and three cabin models (surrogate model, 2D model and a nodal network model). After a second search (this time at sub-system level), one model has been found and it needed to be adapted (cabin surrogate model) the rest of the models were not found in the storage system, then a development stage was necessary. Once the models were ready, the integration and simulation phases took place. By combining the models, six different reconfigurations of the architecture were integrated and simulated. Finally, the results were visualized using the curves to compare the results. At the end all documents and models exchanged during the process were capitalized. The Results were useful and the decision could be done. The preferred configuration was PID as a control model, surrogate as a cabin model and of course the ECS model.

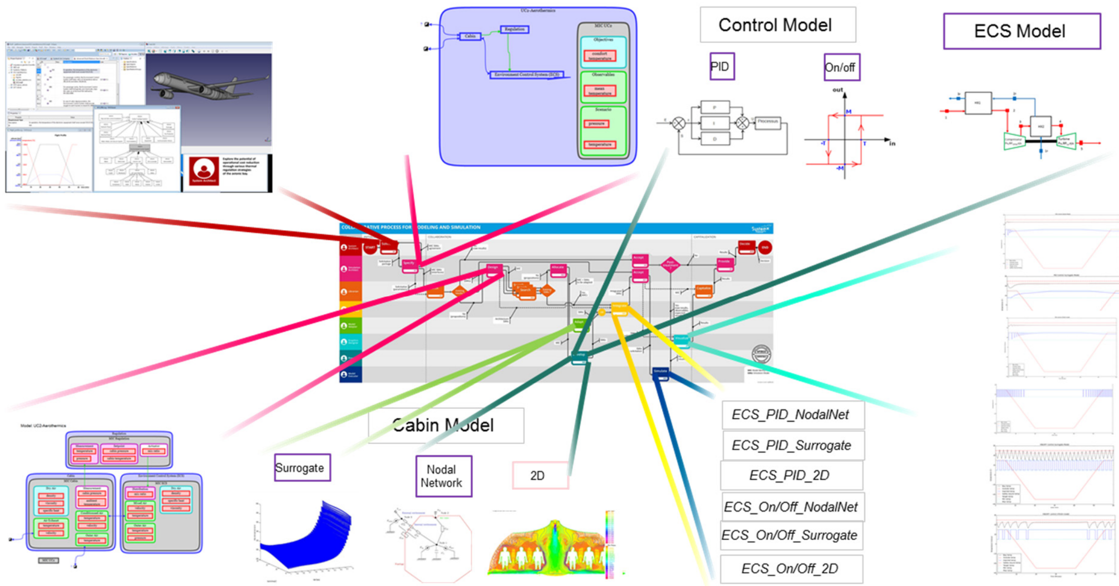

Figure 3. Process implementation illustration

7. Feedback

At the end of the project four dynamic interviews were organized aiming at understanding the collaborative interactions in a real Use Case. The results suggest some clues regarding the link between some of the collaborative features studied in this work: the stakeholders and actors of collaborative simulation process, the process itself (activities sequence), the Objects to exchange/share during the process and the tools supporting it (resources).

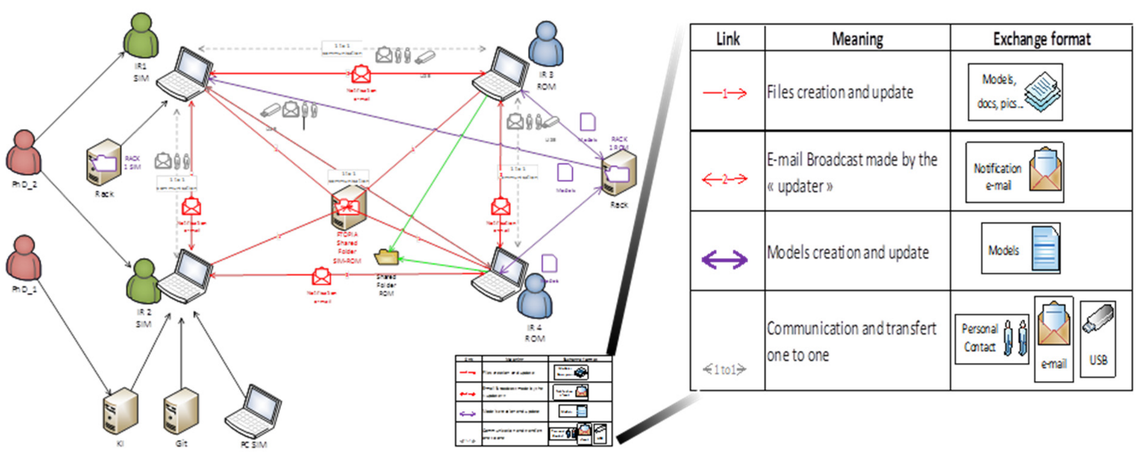

Figure 4. Interactions between actors at Futur@SystemX

The interaction between the actors and the object exchanged are represented in Figure 4. This representation illustrates another view of a collaborative design situation and is one of the results of the interviews. In the diagram, the IT elements, the team members and the exchanges objects are represented. The arrows between the character figures symbolize the interactions between the engineers working in the project. The arrows contain the exchange format of the documents as well. The colors and the ends have different meanings. For example, a red arrow with only one end represents the files

creation and updates in the server. A red arrow with two ends, represents also an update but in a broadcast communication between the team members. Purple arrows with double ends represent the simulation models creation and update. And the black arrows represent communication one to one.
Regarding the three main elements studied in the process: the sim artefact, the actors, and the activities some improvements are presented below:

- The Sim Artifact (ensemble of exchanged objects): The proposed objects seem to be appropriate, all of them were used. MIC object seems to be appropriate to model exchange, nevertheless, since this object has been developed for a specific company, some parameter are still very specific to it. Though, a difficulty related to the parallel work in the same model was highlighted. The sharing of an intermediate model looks delicate. This problem generates several intermediary files and transfers. Defining the best length of the milestones and the appropriated maturity level of the object to be shared could be helpful to solve this problem. Moreover, a platform for the documents management is necessary. PLM solutions can be a good alternative if the appropriate parameters and data model are used. Regarding the simulation models, other solutions must be explored.
- The actors: All the roles were played by someone during the project and no missing role were identified. However, a more specific role definition would be appropriate. This description could include some information regarding their rights, links, objectives, etc. Even if the representation is not completely adapted for representing the whole characteristics and complexity of the collaboration, it is very helpful to understand the chosen aspects such as task, exchanges and linear vision. In a future research more complete model will be suitable. This model must either expose as much as possible collaborative features at the same time or have different views. Finally, the implementation of the process brought to light the important part of human behavior in the collaborative problem as well. Most of the time, people collaborate because they want to and no because they have to. This raises a new research question: What are the factors motivating people to collaborate in this context and how can we measure them?
- The Actions: The representation was appropriate for the actions. Everyone understood their role and tasks very easily. The interfaces with other people are less evident to understand since one person can actually play different roles. The coordination tasks played a crucial role and they are not indicated as a task in the process, because most of the time coordination tasks arrive between the actions. In general, the project used the proposed guideline without any particular problem, but they use several parallel and iterative paths which is normal in design process, but is not represented in the process. As a guideline, the process seems to be adapted if everyone collaborates.

8. Conclusions and future work

The suggested process is an added value solution proposition to the current industrial needs and to the literature gap. The process modelled three of the main characteristics in collaborative design: Actors, activities and Sim Artefact (objects).
The proposed process contributes to an added value solution at three different levels in the organization: the operational level, the tactic level and the strategic level. At the operational level, the new process avoids the rework tasks at the developing level and fulfills the gap concerning capitalization activity. In addition some recommendations to industrial guideline are suggested. At the tactical level, a clear vision of how and who does what is given at management level. Likewise, people involved in the process have a larger vision of how their work is valuable for the organization. At the strategic level, the process can be easily integrated in the organization and match with the other process. Furthermore, the hypothesis of model reuse proposed in the process could enhance the know-how of the organization and could eventually reduce the time of development during the design.
After implementation and evaluation of the process, we conclude that collaboration in M&S activities is not a linear problem at all, but the proposed representation is highly appropriated to improve global comprehension of the objectives and the context understanding in the first instance. Concerning the actions, process representation describe them satisfactorily in terms of task and flow. Concerning the Sim Artefact, the proposed objects seems to be appropriate, all of them were used. Nevertheless, some

formats are still specific to a company and need to be improved. In addition, links between the object deserve to be studied as well. Finally, concerning the actors, no missing role were identified. However, a more specific role definition would be appropriate. The implementation of the process brought to light the important part of human behavior in the collaborative problem as well, pointing out the actors as the key element on the collaborative design and raising a new research question: What are the factors motivating people to collaborate in this context and how can we measure them?
Further research will explore on the adaptability and the flexibility of the process. And will mainly focus on a model with more collaborative features, based in the interaction between the actors and their motivation to collaborate. In addition, a data model describing the links between the different objects will be included.

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