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AN OVERVIEW OF COLLABORATIVE SIMULATION ON DESIGN PROCESS

Laura Roa Castro[1,2], Julie Stal-Le Cardinal[2]

[1]Institut de Recherche Technologique IRT SystemX
[2]Industrial Engineering Department

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ABSTRACT

This paper aims at defining *collaborative modelling and simulation* (M&S) and at fining the research gap on collaborative M&S domain. In order to give an overview of the collaborative work in product development process, and more exactly the work done in modelling and simulation field, the research done for this paper is presented in six main sections. Section 1 and Section 2 present the context and the motivation. Section 3 introduces the methods used in this paper. Section 4 explains how *collaborative M&S* definition has been built. Section 5 describes how the research gap concerning our research has been highlighted. And Section 6 presents the conclusions and the future work. Based on the analysis of the state of the art and on the results of the industrial audit realized, this document concludes with a proposed definition of *collaborative M&S* regarding four main dimensions: shared object, stakeholders, process and IT. Future work will be focused on the study of the four dimensions suggested and it will be also dedicated to the implementation of more industrials audits and the creation of the systematic analysis of our collaborative system.

1 CONTEXT

This research in complex system design takes place in Research Institute of Technology (IRT) SystemX in partnership with Industrial Engineering Laboratory (LGI) from Ecole Centrale Paris. IRT involves academic and industrial research teams and is located on the “Saclay Cluster” in France. This institute addresses the scientific and technological challenges on two main axes: *systems of systems* and *tools and technologies of numeric engineering*. The present work takes place on a project called SIM (French acronym for *Multidiciplinary Simulation and Engineering*) which is part of the second axis. The two industrial partners in this project are Renault and Airbus Group. LGI from Ecole Centrale Paris, ENSTA and SUPMECA are among academic partners.

2 MOTIVATION

In order to understand what a *collaborative simulation* is in design process for vehicle construction (aircraft or automobile), the work starts by analysing the whole lifecycle in automotive and aeronautic industry. In our case this is represented by the industrial partners of the project: Airbus group and Renault.

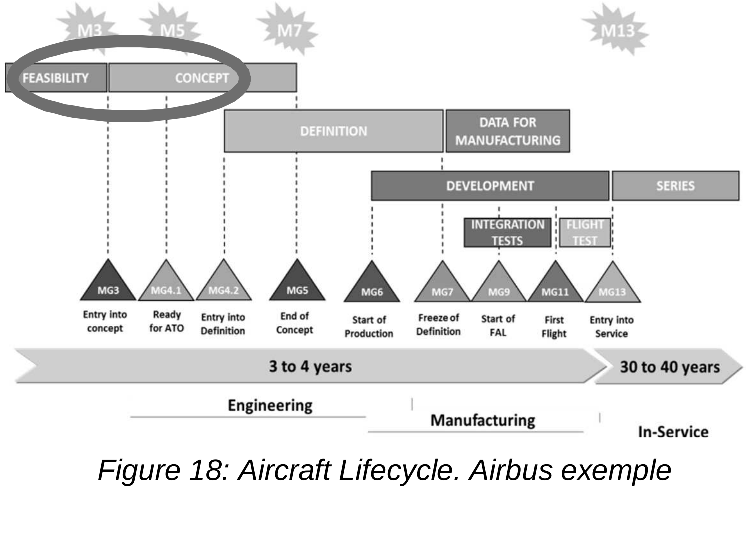

Figure 18: Aircraft Lifecycle. Airbus exemple

Starting from one of the IPD (Innovative Product Development) key success (M.M. and L, 1987) and the basis of the PLM (Product Development process) approach (Stark, 2004), having a lifecycle point of view seems essential to our research. Integrating IPD and PLM approaches into our work allows us to establish the context, the inputs and the outputs of simulation process.

The red circle in Figure 1 represents the positioning of our research. Our work is focused on the development phase, more exactly on the pre-project stage, where the modelling and simulation process (M&S) are used in order to establish concepts and definitions. Indeed, modelling and simulation technics are commonly used in product development process (Sinha, 2001, Bertsch et al., 2014) and the application of these methods has increased during the last decades.

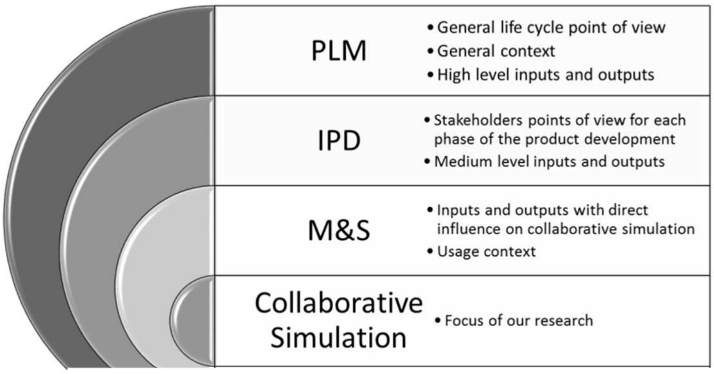

Figure 19: Research context

This paper aims at defining and fining the research gap on collaborative simulation domain. In order to give an overview of the collaborative work in product development process, and more exactly the work done in modelling and simulation field, this paper includes six sections. Section 1 and Section 2 present the context and the introduction. Section 3 explains the research methods used on Sections 4 and 5 of this work: the method used to build the *collaborative simulation* definition and the one used to find the research gap. Section number 4 is focused on the state of the art. The purpose of this section is to give a definition of collaboration based on collaborative features chosen from the literature and from the industrial audit. On the fifth section we will focus on the research gap, by placing the different work that has been achieved on this field in relation to the collaborative features found on section two and to the product development phases. The last section corresponds to recommendations, conclusions and further work.

3 METHODS

The methods used in this paper are explained in the two following Sub-sections. The Sub-section 3.1 explains how *collaborative simulation* definition has been built. The second Sub-section 3.2 describes how the research gap concerning our research has been highlighted.

3.1 Construction of *Collaborative simulation* definition

In order to build the most complete definition of *Collaborative Simulation* this work has been organized as follows. Firstly, *Collaborative Simulation* features should be established. In order to choose those features, different collaborative works in a simulation domain and in other domains have been studied. Then, the same work for the industrial projects and for the research work developed in industrial context has been done. Comparing gradually all the features *the elements to keep first list* and a list of the *elements to discuss* are created (see Figure 3). In order to validate *the elements to keep first list* and to decide which elements, from *the elements to discuss list*, have to be added to the *elements to keep final list*, an industrial audit has been realized. The elements from the industrial audit found on the *elements to discuss list* were added to the *elements to keep final list.* Figure 3 gives a better understanding of this approach.

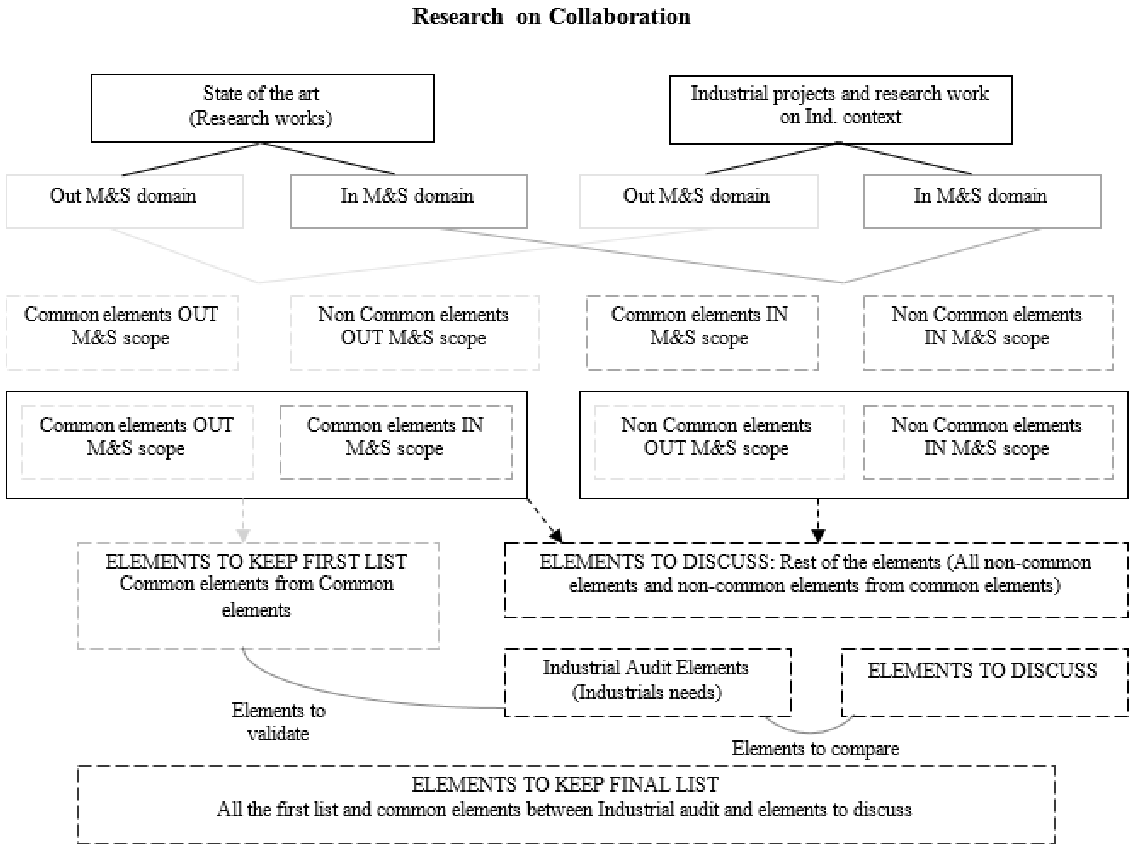

Figure 20: Method used to decide final list of collaborative simulation features

3.1.1 Industrial Audit

From the different research methods proposed in (Creswell, 2014), focus group was chosen as the most appropriate methodology to carry out the industrial audit. Between March and July 2014, five focus groups took place at Renault *Technocentre*. Those sessions were focused on understanding the current situation on collaborative M&S process. For each session, between 10 and 15 participants from M&S department at Renault participated. On the first meeting, brainstorming session (Osborn, 1979) was suitable in order to generate ideas of their collaborative problem on M&S context. The ideas generated during this session were classified using an Ishikawa diagram (Conner, 2009, Hohmann, 2012). Throughout the second session, the most important problems were selected and by using the five why's method (Hohmann, 2012), we performed further searches to determine the cause of the problems.

3.2 Looking for the gap

A table used to compare the works done on collaborative M&S field is proposed in Section 5. (See Figure 4) Vertical axis of the table is composed of collaborative simulation features from Section 4. Horizontal axis represents different phases of the product development process. Finally the collaborative M&S works were placed in this table in order to highlight the research gap.

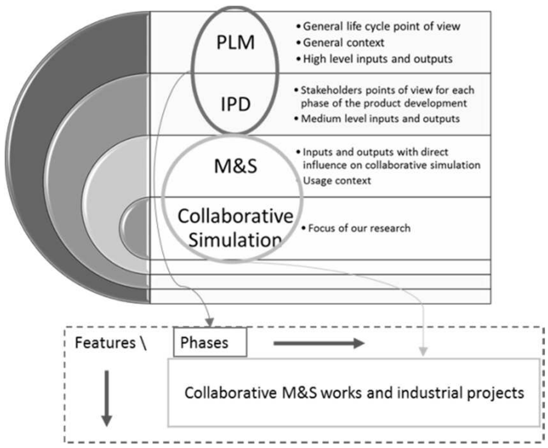

Figure 21: Construction of comparative table

To conclude this section and in order to develop and validate our research, our study is positioned regarding Design Research Methodology (DRM) proposed by Lucienne Blessing and Amaresh Chakrabarti (Blessing and Chakrabarti, 2009). The work described above corresponds to stage one and stage two of DRM: Research clarification and descriptive study I. Even if the construction of the collaborative system has not been started yet, the goal of the research and the criteria to be included in our reference model have been defined based on the analysis of the literature and the empirical data.

4 LITERATURE REVIEW: CONSTRUCTION OF A COLLABORATIVE SIMULATION CONCEPT

In order to achieve a definition of *Collaborative Simulation,* the research done on collaborative domain presented in this literature review is separated into six Sub-sections: in Sub-section 4.1 an introduction to M&S context is presented. Then, the collaborative research is broken down into: research works on collaboration out M&S domain (Sub-section 4.2), research works on collaborative M&S domain (Sub-section 4.3), industrial projects or research works with industrial context on collaboration out M&S domain (Sub-section 4.4), industrial projects or research works with industrial context on collaborative M&S (Sub-section 4.5) and industrial audit (Sub-section 4.6). Each sub-section finishes with a *Collaborative features list*.

The conclusion of this section is the *Collaborative Simulation* concept (presented at the end of Sub-section 4.6). This definition is based on the *Elements to keep final list* (See Figure 3).

4.1 Introduction to M&S context

The literature on M&S domain suggests three key words in this field: system, model or simulation model and simulation. Most of the definitions from literature of ***System*** refer to a *collection of elements or entities where the whole is more than the sum of individual parts*. NASA handbook (NASA, 2007) defines a system as "*a construction or collection of different elements that together produce results not obtainable by the elements alone*". In his modelling and simulation book, Kai Velten (Velten, 2009) describes a system as "*an object or a collection of objects whose properties we want to study*".

Moving forward ***Model*** definitions, in (Velten, 2009) model is call a "*simplified description of a system under considerations, in order to simplify its complexity*". In a theory of modelling and simulation (Zeigler et al., 2000), a simulation model is characterized as a "*set of instructions, rules, equations, or constraints for generating I/O behaviour*". Overall, a model can be defined such as *representation of something (system) employed to understand the reality (behaviours), built on a solid scientific basis*.

Finally, ***Simulation*** definitions are very often related to models.. In (Shubik, 1959) simulation of a system is interpreted as "*the operation of a model or simulator which is the representation of the system*". Similarly, P. Fritzson (Fritzson, 2011) defines the simulation as "*an experiment performed on a model*". Others definitions includes the objective of the simulation process (help in decision making process). B.A.P Calderon (Calderón) defines simulation as a "*numerical tool on decision making process. It is based on logical and mathematics models describing the system behaviour*". Likewise, in (Velten, 2009) simulation is presented as an "*application of a model with the objective to drive strategies that help solve a problem or answer a question pertaining to the system*".

4.2 Research works on collaboration out M&S domain

The works on collaboration out M&S context suggests many definitions of ***Collaboration.*** Nevertheless, those definitions are strongly related to the authors and its domain. In that way, the same term could have different meanings. Some definitions and concepts proposed on this literature field are presented in the next paragraphs.

The work done on (Bedwell et al., 2012) suggests a conceptualization of collaboration by discipline, and taking this constraint into account they manage to define collaboration as an "*evolving process whereby two or more social entities actively and reciprocally engage in joint activities aimed at achieving at least one shared goal*".

From a business process point of view, Mathew G. E (Mathew, 2002) describes the collaboration as *a process implying a technology component which enables to collaborate*. In the same work, ***Enterprise Collaboration*** is defined as "*the partnering of activities, knowledge and assets by multiple* *stakeholders in a dynamic environment, with the objective of gaining business advantage*". A stakeholder is a group or individual who is affected by or is in some way accountable for the outcome of an undertaking. (NASA, 2007). Wood and Gray (Wood, 1991) take into account the stakeholders issue in their definition saying that a collaboration takes place when a "*group of autonomous stakeholders of a problem domain engage in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain*" (Wood, 1991).

According to Bedwell et al. (Bedwell et al., 2012) ***Effective Collaboration*** often *depends on the capability of managers to select, training and evaluate the employee activities for which he was hired.* In the same work, 5 underlying assumption of collaboration are suggested: *collaboration is an evolving process, collaboration requires two or more entities, collaboration is reciprocal, collaboration requires participation in joint activities and collaboration is aimed at achieving a shared goal.*

Other terms referring to collaboration process are presented below. A ***Cooperation***, from a game theory point of view (Cooperative Game Theory-CGT-) aims at ensuring *that the total cost of the team is less than any other non-cooperative optimal solution obtained* (Semsar-Kazerooni and Khorasani, 2009). An additional term, ***Horizontal Cooperation,*** found in literature (Cruijssen et al., 2007), corresponds to *identifying and exploiting win–win situations in order to improve performance*. In both cases, cooperation refers to a trade-off between different parts.

Communication was found as another term used in collaboration context. ***Communication*** can be simply defined as a *message delivery*. Nevertheless, Burstein et al. (Burstein et al., 2010) distinguish communication from ***Effective Communication*** defining this one as a *communication that produces the intended effect in the recipient*. The last two terms often related to collaboration are *Coordination* and *Synchronization.* (Salas et al., 2000) define ***Coordination*** as a "*process by which team resources activities and responses are organized to ensure that tasks are integrated, synchronized and completed within established temporal constraints*". Finally, (Wooldrige, 2009) characterizes ***Synchronization*** as "*the problem of design the interaction between process, typically to ensure that they do not destructively interfere with one other*". Table 1 summarizes all the features of collaborative work and their related references.

Features of Collaborative Work OUT M&S domain	References
Technology component	(Mathew, 2002)
Sharing of artefact, Shared goal, Join activities	(Cruz, 2014) (Bedwell et al., 2012) (Mathew, 2002)
Entities, Stakeholders, Level of analysis	(Bedwell et al., 2012) (Mathew, 2002) (Wood, 1991)
Process orientation	(Bedwell et al., 2012) (Mathew, 2002) (Wood, 1991)
Knowledge	(Mathew, 2002)
Rules, norms	(Wood, 1991)
Management capabilities	(Bedwell et al., 2012)
Teamwork, Cooperation	(Bedwell et al., 2012) (Salas et al., 2000), (Cruz, 2014) (Semsar-Kazerooni and Khorasani, 2009)
Coordination and Synchronization	(Salas et al., 2000), (Wooldrige, 2009)
Communication, Interaction, Awareness	(Benford and Fahlén, 2014) (Burstein et al., 2010) (Cruz, 2014)

Table 5: Features of Collaborative Work

4.3 Research works on collaborative M&S domain

For years, the computational power available to Engineers has grown exponentially. Nevertheless, the collaborative dimension of the workspace has been largely under developed (COSPACES). However, this situation is starting to change. In his work, MacCormark (MacCormack, 2008) claims that collaborative approach becomes part of cross-industry initiatives when the re-use of development data was considered as a major factor for cost savings and, the improving of transparency of the design process could reduce the risk of having unplanned situations on the test phase.

Searching through the literature of collaborative M&S, different research axes are proposed. As an example Wang et al. (Wang et al., 2010) propose three main topics on collaborative simulation: collaborative and distributed product development, collaborative simulation and its model paradigm and collaborative simulation in a distributed environment. Those topics treat respectively the problems related to availability of information; tool integration and modular approach; and multi-client access and services.

After analysis of general literature on collaborative M&S this work suggests three main work axes: the first one concerns a technology component and it is mostly addressed to interfaces, tools interoperability and integration problems on M&S field. The second axis is related to sharing, monitoring and visualization capabilities of the system. The last one addresses a lifecycle product development problem focusing on different phases using simulation models. A brief literature review for each axis is presented below.

4.3.1 Axis 1: IT and mathematical problems concerning: interfaces, modularity, tools interoperability and integration.

The two main problems addressed to collaborative M&S concern mathematics problems and IT tools integration. In order to answer precise needs of the specialists in different domains, very specific M&S tools have been developed for years. As design of complex systems has increased in the last decades, the multi-physics and multi-level integration needs, appear more and more frequently in design engineering teams and software becomes the major bottleneck in modern computer modelling (Portegies Zwart et al., 2013). As a consequence, there have been many developments of collaborative platforms aiming at solving: interfaces model problems, compatibility and interoperability tools problems and mathematical model integration problem.

In Corunua et al. (Cornua et al., 2012) ***Interoperability*** is considered a *major factor conditioning the success of deployment*. This work suggests four interoperability types: maturity model, conceptual interoperability, organizational interoperability and technical interoperability. Next paragraphs present some works related to technical interoperability problems (data exchange and modularity). Works related to conceptual and organizational interoperability problems are presented on axes two and three of this literature review.

Data exchange problem could be supported on different ways. As an example, MuPIF integration tool (Patzák et al., 2013) supports exchange between codes (different discretization technics and specific field transfer operators) by using a channel that calls individual codes at appropriates times, handles the exceptions and requests and updates data applications. Meanwhile, Zhaia et al. (Zhaia et al., 2010) work aims to supporting data exchange by adopting an external/internal unit system. This system allows the understanding of internal units by seeing the changing on external ones. Finally, in order to support data exchange issues and to facilitate model plug-in, FMI/FMU tools have standardized the model interface (Bertsch et al., 2014). Finally, Ming et al. [31] use a control data flow graph (CDFG) on functional verification and validation in order to create a collaborative verification flow.

Patzak et al; et Portegies Zwart et al. [27, 29] also tackle ***Modularity Problem*** by building their frameworks from separate components or modules. On MuPIF tool [29], this construction allows abstract access to solution domains and creation of specialized applications which enables to handle multi-physics problem in an easier way. The framework presented on [27] is built from different modules, this characteristic allows parallel and serial execution and permits to combine existing simulation codes or develop the new ones using the modules. Lastly, modularity concept on FMI/FMU is more related to withe box and black box in model exchange context. Using the black box model exchange FMI defines interfaces only and deals with know-how protection.

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4.3.2 Axis 2: Sharing, monitoring and visualization capabilities

Since a common language does not guarantee interoperability (Ruggaber et al., 2006), sharing and monitoring features on collaborative work have grown on importance especially due to long execution time for a large scale simulation. In addition, worldwide work and spread teams make those features necessary. Most of the works on this axis treat the ***remote work problem*** and the ***understanding between specialists problem***.

SIMON (Simulation monitoring system) proposed in (Yasuaki et al., 2008) aims at assisting simulation studies in which collaborators are spread on geographically different places. Using a trigger method the process consists in transmitting a request for up-date processing (from the client) to ongoing simulation. The results are available at any place and at any time. The "easy-to-integrate" platform suggested on (Belaud et al., 2014) is not only based on common environment for different partners, but also it aims at sharing high performance computing (HPC) resources and at being a generic platform. Offering web-based technologies, remote access, HPC capabilities, 3D visualization, common bandwidth and highly modular architecture this platform seems to offer very interesting collaborative facilities. Nevertheless for now, the application has been developed for the chemical process engineering only.

The work done by Dong et al. (Dong et al., 2013) and by Walker and Chapra (Walker and Chapra, 2014) is more focused on a common understanding of one concept from different users. Actually, on (Dong et al., 2013) avoiding the misconception is essential to prevent correction on validation phase. Then, the contextual information for the user becomes a key factor for the performance of the task. In addition, they affirm that visualization improves communication and is useful on interpretation results. On the other hand, (Walker and Chapra, 2014) confirm the importance of understanding of the model for stakeholders because the model is the key on decision making process. Their application is accessible and intuitive and helps to reduce the bottleneck between the specialist and the decision-maker.

As a final point, Siampou et al. (Siampou, 2014) propose a study so as to compare online and face to face collaboration, both have their advantages and disadvantages. However, it seems to be useful to practice both methods depending on the project phase.

4.3.3 Axis 3: Lifecycle Product development problem

Two interesting works on M&S lifecycle product development are presented below. On the one hand, Jordan and Schmitz (Jordan and Schmitz, 2014) propose a library for scalable modelling of aircraft environmental control systems. This library avoids rebuilding simulation models on different phases of design process. By supporting scalable systems, the models can be modified during four different phases defined on the paper: system design, component design, component test and system test.

On the other hand, Mas et al. (Mas et al., 2013) introduce the transition between traditional, concurrent and collaborative engineering. They arrive to define those three engineering in function of five main characteristics. This work (Mas et al., 2013) characterizes collaborative engineering as a share timeframe, an unique team, a customer focus, with a virtual manufacturing goal and delivering an "iDMU for all"(Industrial Digital Mockup). iDMU provides a common virtual environment for all the aircraft development stakeholders. Table 2 summarizes the features on collaborative M&S and their related references.

Features of Collaborative Work IN M&S domain	References
IT and mathematical problems (interfaces, modularity, tools interoperability and integration problems)	(Portegies Zwart et al., 2013) (Cornua et al., 2012) (Patzák et al., 2013) (Zhaia et al., 2010) (Bertsch et al., 2014) (Ming et al., 2006)
Sharing, monitoring and visualization capabilities	(Belaud et al., 2014) (Dong et al., 2013) (Ruggaber et al., 2006) (Siampou, 2014) (Walker and Chapra, 2014) (Yasuaki et al., 2008)
Lifecycle Product development problem	(Jordan and Schmitz, 2014) (Mas et al., 2013)

Table 6: features on collaborative M&S

4.4 Industrial projects or research works with industrial context on collaboration out M&S domain

Collaborative projects in the industry have been largely developed on the last years. One of the most important motivation is the geographically dispersion of people and teams. Grids technologies make face to this problem. Projects as BEinGRID (Dimitrakos, 2014), BRIDGE (FP6-ISTprogramme, 2007), and SIMDAT (IST, 2007), have worked on grids tend. Those projects have as a common objective the use of computer resources from multiple locations to reach a common goal. Grids allow work on more loosely coupled, heterogeneous, and geographically dispersed context. Grid projects tackle also with the computer resources issue. This is one of the most common problems in collaborative context. In this way, other projects as ECOLAD and CoSpaces (COSPACES, 2010) recall this aspect.

Another approach from the industry is the collaborative environments or systems as proposed on DiFac (Sacco et al., 2007), VOSTER (VOSTER, 2002) and CLOCK projects. The respectively technics used by those projects to supports the stakeholder's points of view were: virtual reality for the representations, work on virtual organization systems and cultural issues.

An additional aspect is the organizational structure and collaborative reference process approach that have been treated by projects as DiFac(Sacco et al., 2007) and CoSpaces(COSPACES, 2010). The last approach found on these industrial projects is the product lifecycle vision. On VIVACE (Homsi, 2008) project for example, the aircraft design is seen as a whole. Table 3 summarizes all the features on industrial projects or research works with industrial context on collaboration out M&S domain and their related references.

Features of Collaborative Work OUT M&S domain	References
IT and mathematical problem (interfaces, modularity, tools interoperability and integration problems)	(ECOLEAD, 2008) (Dimitrakos, 2014) (FP6-ISTprogramme, 2007) (IST, 2007) (COSPACES, 2010)
Sharing, monitoring and visualization capabilities	(Sacco et al., 2014)
Lifecycle Product development problem	(Homsi, 2008)
Stakeholders points of view and organization	(VOSTER, 2002) (c-rural, 2007) (AMI@Work, 2008) (ECOLEAD, 2008) (Sacco et al., 2014)
Collaborative process and workflows	(Sacco et al., 2014)
Extended enterprise: multiple locations problems	(Dimitrakos, 2014) (FP6-ISTprogramme, 2007) (IST, 2007)
Extended enterprise: Intellectual property (IP) constraints	(Sacco et al., 2014)

Table 7: Features from collaborative projects out M&S

4.5 Industrial projects or research works with industrial context on collaborative M&S domain

Moving to the industrial projects concerning M&S, about ten features were found. First seven properties are the same as those showed on Table 3. A briefly summary of different projects is presented below. Then, Table 4 sum up the collaborative features for collaborative M&S Industrial projects or research works with industrial context.

INTEROP, FP6-IST-508011(Panetto et al., 2004) treats interoperability issues in inter and intra enterprises systems. This project aims to capitalize the knowledge and make it open to all interested actors. In this project a common framework is created, where modelling, simulation, analysis, management for designing interoperability solutions are explored and integrated. INTEROP goals include: enable a real-time collaborative sessions, share knowledge, impact modelling techniques and improve intra and inter enterprise connectivity.

SPACE CODE (Haerens et al., 2012), this project from Airbus Space and defence. The project proposes a concurrent engineering approach. Collaborative platform, systems engineering data model and specialty engineering data repository are among the methods and tools proposed on SPACE CODE project.

ARCADIA (Voirin, 2014) project suggests a model-based architecture approach and a multi-view point method to allow collaborative validation. This project considers the interoperability trough standards problem also. Since our research aims to help in decision-making process for architecture, this project seems interesting. Nevertheless, ARCADIA project is still under development.

ADN (DPS, 2013) is part of System@tic projects where Airbus group is also partner. This project is focus on four main items: 1. Parameters and rules to construct a generic and collaborative information baseline, 2. Information sharing by providing different views to each use, 3. Knowledge reuse 4.Consistence assured between knowledge used in several models and save new knowledge.

CRESCENDO FP7 (CRESCENDO-FP7, 2009) Project introduces a Simulation Processes & Data Management (SPDM) for collaborative product development. In addition some collaboration capabilities were developed, those capabilities are: information sharing, knowledge sharing and decision-making. One of the results of CRESCENDO project was MoSSEC: capability to share Modeling and Simulation information in a collaborative Systems Engineering Context. MoSSEC BOM templates support the specification of data exchange standard (DEX). Three items are out of DEX scope: Collaborative model templates, requirements and studies.

On ATHENA, FP6-IST-507849 (Ruggaber et al., 2006) a modelling platform for collaborative enterprises (MPCE) and a framework, called EKA (Enterprise Knowledge Architecture) were developed. Those developments were focus on views, models and meta-model format and language. The main work of the project was a repository and five different modelling clients (Software).

FEDEP (Office, 1999) for Federation Development and Execution Process proposes architecture to facilitate interoperability among simulations and promote the reuse of simulations and their components. This project describes a high-level process and activities related to the process by which HLA federations are developed and executed to meet the needs of a federation user. FEDEP model gives an interesting idea to how can be handled model exchange process.

Airbus Procedure 2633 (AP2633) (Airbus, 2005) for Integration and execution of simulation models is applied to functional simulations and system simulations. It is focus on: model exchange problem, integration of partner models (plug and play) problem, improvement of Validation &Verification (V&V) quality and support and the actors in terms of production and use of integrated simulation models. In addition to those processes, AP2633 document develops the concepts corresponding to: interface requirements, model requirements, distribution of models to partners, configuration control, intellectual property rights and compatibility with existing models.

ProSTEP (ProSTEP and Association, 2014) Smart Systems Engineering Project is a set of recommendations that aims at orchestrating different V-models of manufacturers and suppliers in order to joint development projects. FMI provides the technical basis for model exchange. ProSTEP suggests a flow of information and data between the contracting entity and the supplier during the various phases of product development by using scenarios allowing the description of a comprehensive and representative spectrum of the exchange of behaviour models. This recommendation includes process, use cases, scenarios, element to define and describe. Table 4 sums up the collaborative features for the industrial projects or research works with industrial context on M&S domain.

Features of Collaborative Work IN M&S domain	**References**
IT and mathematical problem (interfaces, modularity, tools interoperability and integration problems)	(Panetto et al., 2004) (Haerens et al., 2012) (DPS, 2013) (CRESCENDO-FP7, 2009) (Ruggaber et al., 2006) (Office, 1999) (Airbus, 2005) (ProSTEP and Association, 2014)
Sharing/monitoring/ visualization	(Panetto et al., 2004) (DPS, 2013) (CRESCENDO-FP7, 2009) (Ruggaber et al., 2006)
Lifecycle Product development problem	(ProSTEP and Association, 2014)
Stakeholders points of view and organization	(Haerens et al., 2012) (Voirin, 2014) (Airbus, 2005)
Collaborative process and workflows	(Office, 1999) (ProSTEP and Association, 2014)
Extended enterprise: multiple locations problems	(DPS, 2013) (Airbus, 2005)
Extended enterprise: Intellectual property (IP) constraints	(Panetto et al., 2004) (CRESCENDO-FP7, 2009)
Degree of reuse/ traceability	(DPS, 2013) (CRESCENDO-FP7, 2009) (Office, 1999)
Standards constraints	(Voirin, 2014)
Decision making process	(Voirin, 2014) (CRESCENDO-FP7, 2009) (Office, 1999)

Table 8: Collaborative features of industrials projects in M&S domain

4.6 Industrial audit

From industrial audit, three main roles were identified: *system architect*, *model architect and model supplier*: *System architect* is in charge of decision at the architecture level. *Model supplier* is a simulation model supplier from one or several parts of the architecture. Finally, *model architect* is the bridge between system architect and model supplier. His role is basically a “translator role”. A model architect is capable of understanding and making communicate both system architect and model supplier. In the present work we focused on model architect role. Figure 5 illustrates *model architect* work, seven main activities are linked to model architect functions: choice of operation mode (automatic, manual, real time…), consolidation of validation plan, choice of modelling level and the interfaces, distribution of inputs tied to each sub-model of the architecture, sending the related inputs to each model provider, assembling the models coming from different model providers and running the whole architecture model. The shapes over activities boxes represent some of the problems found in the process, those problems represent a set-back for the development. From those observations, the table *Industrial Audit Elements* from Figure 6 summarizes the industrial needs on collaborative work in M&S domain. After comparison between all the features, a final list of features is presented on the same figure.

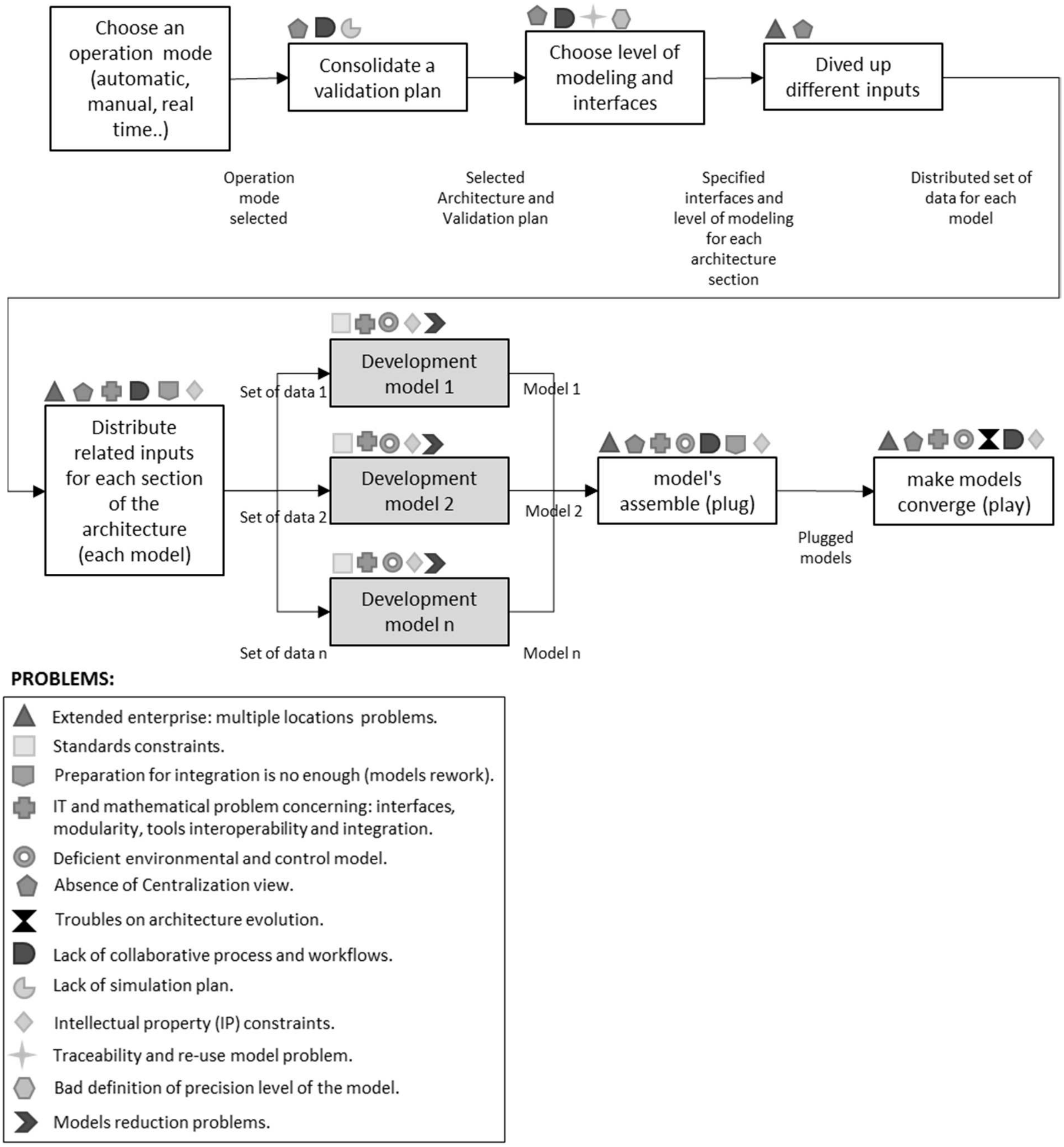

Figure 22: Model Architect work

From the elements presented on *Element to keep final list*, **Collaborative modelling and simulation** is defied regarding four main dimensions (object, stakeholders, process and IT) in the decision making context. **O*bject dimension*** is related to the object to be shared within the simulation process. Since this point forward, we will call this object S*imulation Artefact.* The simulation artefact integrates the simulation models to be exchange but the models will be not the only one component of the artefact. The ***Stakeholders dimension*** is linked to stakeholder points of view, but it is also associated to the actors performing the collaborative simulation, their interests and their behaviors. The ***Process dimension*** is more focus on the added value process, the impact of its different configurations and the flows in between. Finally, ***IT dimension*** makes reference to the IT tools carrying out the simulation itself but also making part of the M&S context. Collaborative simulation shall also consider the constraints concerning the intellectual property problem and the use of the current standards.

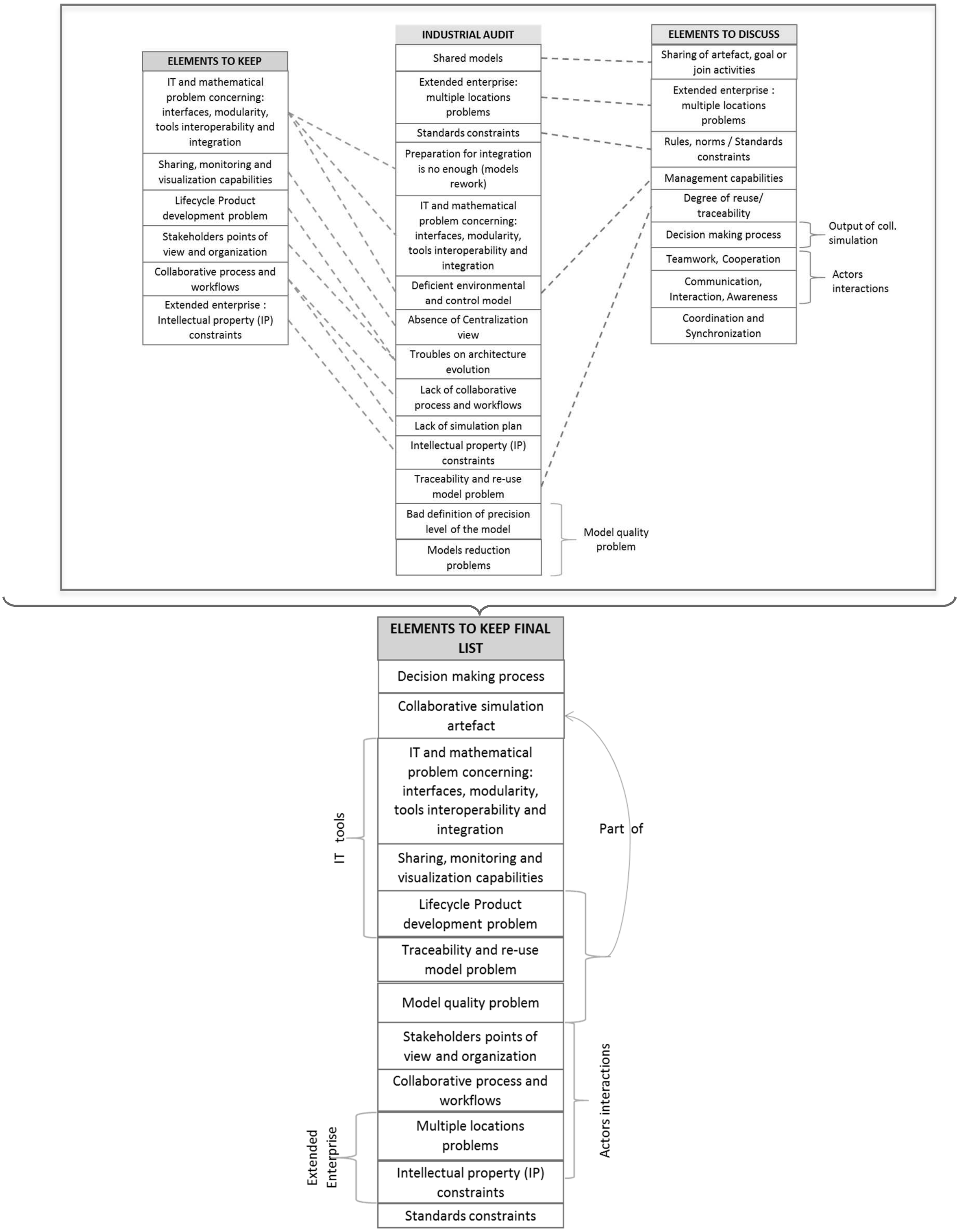

Figure 23: Elements to keep final list

5 LOOKING FOR THE GAP

As explained on Section 3 (methods), Table 5 summarizes the M&S works and projects presented before and highlights the research gap. The blanks on the Table 5 represent the research gap for some features in a particular phase. The first two features on the table have been significantly treated in the literature. The rest of the features has been treated at least once on phases two and three, but there is still a lot of work to do.

6 RECOMMENDATION, CONCLUSIONS AND FURTHER WORK

The changing world context leaves computer simulation facing diverse problems. The introduction of a collaborative approach can solve some of those problems. Today more and more collaborative platforms are addressed to heterogeneous environment problems, the re-use model problem and traceability problem. However, those platforms deal only with a part of the model exchange problems and some aspects still being untreated.

As the problems linked to the shared object, actors and process were found to be the main untreated problems, and taking into account the gap found on the literature review, we decided to concentrate our effort on the study of the four dimensions proposed in this paper for a collaborative M&S.

Future work will be also dedicated to more industrials audits and to systematic analysis of our collaborative system. This analysis will be validated by the industrial partners of the project.

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Table 9: Research gap for M&S works and projects

Features/ Prod. Dev. Phases	Concept studie	Concept and Tech. Dev.	Preliminary design and tech. Comp.	Final Design & fabrication	Assembly, integration and test	Operations & Sustainment	Closeout
IT and mathematical problem (interfaces, modularity, tools interoperability and integration	(16)	(2)(5)(15)(16)(18)(19)(20)(21)(22)(23)	(1)(2)(3)(4)(5)(6)(16)(18)(19)(20)(21)(22)(23)	(6)			
Sharing, monitoring and visualization capabilities		(15)(18)(19)(20)	(7)(8)(9)(11)(12)(18)(19)(20)	(8)(12)			
Lifecycle Product development problem	(13)	(13)(23)	(13)(14)(23)	(13)(14)			
Stakeholders points of view and organization	(16)(17)	(16)(17)(22)	(16)(17)(22)				
Collaborative process and workflows		(21)(23)	(21)(23)				
Knowledge management / Intellectual property (IP) constraints		(15)(19)	(19)				
Extended enterprise and multiple locations problems		(18)(20)(22)	(18)(20)(22)				
Standards constraints							
Decision making process	(17)	(17)(21)	(17)(21)				
Degree of reuse/ traceability	(17)	(17)(18)(19)(21)	(17)(18)(19)(21)				

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Contact:

Laura Roa Castro
Institut de Recherche Technologique IRT SystemX
8 Avenue de la Vauve
91120 Palaiseau
France
laura.roacastro@irt-systemx.fr

Julie Stal-Le Cardinal
Ecole Centrale Paris
Industrial Engineering Department
Grande Voie des Vignes
92 295 Châtenay Malabry Cedex
France
julie.le-cardinal@ecp.fr