HLA Supported, Federation Oriented Enterprise Interoperability, Application to Aerospace Enterprises

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ABSTRACT: *The field of research, which address distributed enterprises interoperability implementation with HLA (High Level Architecture), was initiated in the final report on future trends of INTEROP Network of Excellence [1]. This report presents fields of investigation to support large federation oriented enterprise interoperability and state the requirement of interoperability transition from concepts to implementation.*

In this paper, we present, in a first point, the enterprise modeling and the enterprise interoperability concepts. A unifying three dimensional framework has been proposed in [2] for enterprise interoperability to represent the ability of interactions between enterprise systems. In this approach, the interoperability is considered as significant if the interactions can take place at least at the three different levels of conceptual abstraction and if interoperability barriers can be bridged. Then, an interoperability approach can be proposed considering the degree of integration between the different enterprises.

After that, we give a review of ongoing researches using HLA to support enterprise interoperability execution. Indeed, the HLA standard, initially designed for military M&S purpose, can be transposed for enterprise interoperability at the implementation level, reusing the years of experiences in distributed systems.

Then, we conclude the state of the art part by presenting MDA (Model Driven Architecture) methodology that assists the transformation of enterprise models from conceptual level to models for execution or simulation and the emerging MDI (Model Driven Interoperability) methodology for considering the interoperability transformation.

We have recalled complementary levels of abstraction to describe enterprise models and a methodology to transform them, but there is no completed methodology for distributed Enterprise modeling, addressing interoperability consideration at each level. From that postulate, we propose to rationalize the development lifecycle of distributed enterprise models by merging the HLA FEDEP and the MDA / MDI methodology to a new unified lifecycle that will guide the development of distributed enterprises models from the conceptual level to the implementation of a solution.

We finish by illustrating interoperability problem on the complex problem of aerospace international cooperation.

1. Introduction

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In the globalised economic context, the competitiveness of an enterprise depends not only on its internal productivity and performance, but also on its ability to collaborate with others. This necessity led to the development of a new concept called interoperability that allows improving collaborations between enterprises. No doubt, in such context where more and more networked enterprises are developed; enterprise interoperability is seen as a more suitable solution to total enterprise integration.

Since early 2000, several European research projects have been launched to develop enterprise interoperability (IDEAS, ATHENA, INTEROP). Three main research themes or domains that address interoperability issues were identified, namely: (1) Enterprise modelling (EM) dealing with the representation of the internetworked organisation to establish interoperability requirements; (2) Architecture & Platform (A&P) defining the implementation solution to achieve interoperability; (3) Ontologies (ON) addressing the semantics necessary to assure interoperability [3].

This paper aims at investigating the contribution of Information Technology (IT) architecture and platform to develop enterprise interoperability, and in particular the interoperability of enterprise models which take place at higher level of abstraction.

In the first part, we present the various approaches of interoperability and the current consideration of interoperability stated as conclusion of the Interop Network of Excellence (FP6, 508011) [1]. Then, we recall the High Level Architecture (HLA) [4] that is a standard for distributed simulation. After that, we present a state of the art of the frameworks that already uses HLA in Enterprise interoperability. It gives a review of ongoing researches in using HLA to support enterprise interoperability development. We define then three ways of investigation. The first concerns the time management in enterprise interoperability, the dynamic aspects have to be tackled with sound techniques, the synchronisation can be considered as it was recently employed in Workflow management [5]. The second aspect concerns the definition of Enterprise ontology. Federation approach in interoperability requires high-level representation of data to be exchanged. Computer science ontology, Object, and Interaction in HLA can give key to this problem. The last way concerns the confidentiality of data. Indeed, enterprise must manage the confidentiality of the data they share with other entities. Sub part of enterprise data must be defined. The knowledge coming from information systems, databases and military experiences can be studied to find a way of keeping data safe. We finish by proposing to specialise the HLA Federation Development and Execution Process (FEDEP) [6] development cycle to the concern of enterprise modelling.

2. Basic Concept of Interoperability

Enterprise Interoperability refers to the ability of interactions between enterprise systems. The interoperability is considered as significant if the interactions can take place at least at the three different levels: data, services and process, with a semantics defined in a given business context [3]. A unifying three dimensional framework has been proposed in [2] for enterprise interoperability to represent the ability of interactions between enterprise systems. Interoperability extends beyond the boundaries of any single system, and involves at least two entities. Consequently establishing interoperability means to relate two systems together and remove incompatibilities. Incompatibility is the fundamental concept of interoperability. It is the obstacle to establish seamless interoperation. The concept 'incompatibility' has a broad sense and is not only limited to 'technical' aspect as usually considered in software engineering, but also 'information' and 'organisation', and concerns all levels of the enterprise [1].

Our goal is to tackle interoperability problems through the identification of barriers (incompatibilities) which prevent interoperability to happen. Basic concepts relating to enterprise interoperability are categorised into three main dimensions as described below.

2.1 Dimension of interoperability barriers

This dimension takes into account three categories of interoperability problems.

- *Conceptual barriers* are related to the problems of syntactic and semantic of information to be exchanged. This category of barriers concerns the modelling at high levels of abstraction as well as the level of coding.
- *Organisational barriers* are related to the definition of responsibilities and authority so that interoperability can take place under good conditions.
- *Technological barriers* are related to the problem of use of information technologies. This category of barriers concerns the standards that are used to present, store, exchange, process, and communicate data through the use of computers.

2.2 Dimension of interoperability concerns

This dimension identifies various levels of enterprise where interoperability takes place. These levels are based on ATHENA Architecture.

- *The business level* refers to working in a harmonise way at the levels of organization and company in spite of for example, the different modes of decision-making, methods of work, legislations, culture of the company and commercial approaches etc. so that business can be developed and shared between companies.
- *The process level* aims at making various processes working together. A process defines a sequence of services according to a specific need of a considered company. Commonly, in a company, several processes run in interactions (serial or parallel). In the case of a networked enterprise, internal processes of two companies must be connected to create a common process.
- *The service level* is concerned with identifying, composing, and making function together with various applications (designed and implemented independ-

ently) by solving the syntactic and semantic differences, as well as finding connections to various heterogeneous databases. The term `service' is not limited to computer-based applications but manual ones as well.
- *The data level* refers to making different data models (hierarchical, relational, *etc.*) and different query languages working together. The interoperability of data is related to find and share information coming from heterogeneous bases, which can moreover reside on different machines with different operating systems and databases management systems.

2.3 Dimension of interoperability approaches

This dimension takes into consideration the three admitted approaches to develop interoperability [7].
- Integrated approach: there exists a common format for all models. This format must be as detail as models. The common format is not necessarily a standard but must be agreed by all parties to elaborate models and build systems.
- Unified approach: there exists a common format but only at a meta-level. This meta-model is not an executable entity as it is in the integrated approach but provides a mean for semantic equivalence to allow mapping between models.
- Federated approach: there is no common format. To establish interoperability, parties must accommodate on the fly. Using federated approach implies that no partner imposes their models, languages and methods of work.

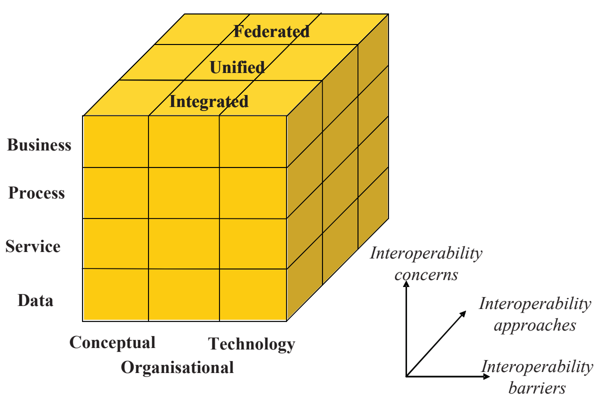

Figure 1. Framework for enterprise interoperability

Figure 1 shows the graphic representation of the interoperability framework.

Today, most of the approaches developed are unified ones such as for example in the domain of enterprise modeling, we can mention UEML (Unified Enterprise Modelling Language) and PSL (Process Specification Language) which aim at supporting the interoperability between enterprise models and tools.

Using the federated approach to develop enterprise interoperability is most challenging and few activities have been performed in this direction. The federated approach aims to develop full interoperability and is particularly suitable for an inter-organizational environment (such as networked enterprises, virtual enterprises, etc.). In the enterprise interoperability roadmap published by the European Commission [8], developing federated approach for interoperability is considered as one of the research challenges for the years to come.

2.4 Measuring Interoperability of Information Systems

In the more specific field of information systems, two methods have been proposed to evaluate the interoperability.

The LISI model (Levels of Information Systems Interoperability) [9] is the first approach having been exactly developed to measure the interoperability of information systems. The model LISI is defined according to five levels of maturity which have to allow the evaluation of the potential degree of interoperability between two systems. Every level consists of characteristics connected to the interoperability.

The model LCIM (Levels of Conceptual interoperability Model) [10] proposes a more abstract approach. It focuses on the quality of documentation of the data which are going to be exchanged, and on the quality of the interfaces between the interoperating systems.

3. HLA Recalls

The High Level Architecture (HLA) [4] [6] is a software architecture specification that defines how to create a global software execution composed of distributed simulations and software applications.

This standard was originally introduced by the Defense Modelling and Simulation Office (DMSO) of the US Department Of Defence (DOD). The original goal was Reuse and interoperability of military applications, simulations and sensors.

3.1 HLA concepts

In HLA, every participating application is called federate. A federate interacts with other federates within a HLA federation, which is in fact a group of federates. The HLA set of definitions brought about the creation of the standard 1.3 in 1996, which then evolved to HLA 1516 in 2000 [4].

The interface specification of HLA describes how to communicate within the federation through the implementation of HLA specification: the Run Time Infrastructure (RTI).

Federates interact using the proposed services by the RTI. They can notably “Publish” to inform about an intention to send information to the federation and “Subscribe” to reflect some information created and updated by other federates. The information exchanged in HLA is represented in the form of classical object-oriented programming. The two kinds of object exchanged in HLA are Object Class and Interaction Class. The first kind is persistent during run time, the other one is just transmitted between two federates. These objects are implemented with XML format. More details on RTI services and information distributed in HLA are presented in [4].

In order to respect the temporal causality relations in the execution of distributed computerized applications; HLA proposes to use classical conservative or optimistic synchronization mechanisms [11].

3.2 HLA Implementation Components

An HLA federation is composed of federates and a Run time Infrastructure (RTI) [4].

A federate is a HLA-compliant program, the code of that federate keeps its original features but must be extended by other functions to communicate with other members of the federation. These functions, contained in the HLA-specified class code of *FederateAmbassador*, make interpretable by a local process the information received resulting from the federation. Therefore, the federate program code must inherit of *FederateAmbassador* to complete abstract methods defined in this class used to receive information from the RTI.

The RTI supplies services required by distributed executions, it routes messages exchanged between federates. It is composed of two parts.

The “Local RTI Components code” (LRC, e.g. in Figure 2) supplies external features to the federate for using RTI call back services such as the handle of objects and the time management. The implementation is the class *RTIAmbassador*, this class transforms the data coming from the federate in an intelligible format for the federation. The federate program calls the functions of *RTIAmbassador* to send data to the federation or to ask information to the RTI. Each LRC contains two queues, a FIFO queue and a time stamp queue to store data before delivering to the federate.

Finally, the “Central RTI Component” (CRC, e.g. in Figure 2) manages the federation notably by using the information supplied by the FOM [4] to define Objects and Interactions classes participating in the federation. Object class contains object-oriented data shared in the federation that persists during the run time, Interaction class data are just sent and received.

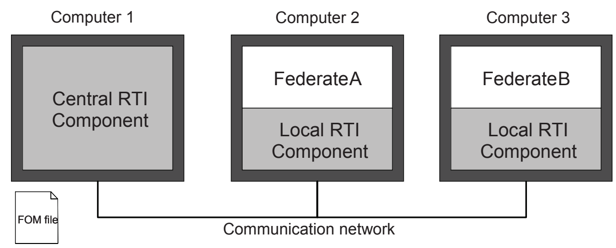

Figure 2. HLA implementation components

A federate can, through the services proposed by the RTI, "Publish" and "Subscribe" to a class of shared data. "Publish" allows diffusing the creation of object instances and the update of the attributes of these instances. "Subscribe" is the intention of a federate to reflect attributes of certain classes published by other federates.

4. Existing Interoperability Approach Implemented in HLA Federations

We propose in this section a state of the art of the previous approaches using HLA to support the implementation of interoperability solution at the level of company components.

4.1 Multidisciplinary Collaborative Design of Virtual Prototyping

The development of complex products requires a multi-field knowledge and requires the computer designers assisted cooperation. The multi-field collaboration M&S technologies are effective approaches for specification and development of complex product. Authors in [12] and [13] suggest applying M&S multi-field techniques at the level of the complex products development.

The key issue of this approach consists in integrating various, autonomous software tools into a distributed environment. In this work, the authors propose a structure based on HLA and Web services for developing interoperability solution in a multi-field collaboration and distributed environment context. The process of project management in multi-field collaboration is, in particular, deeply analyzed. An M&S platform centered on conception making in multi-field collaboration is presented. The question of interoperability of this research is also discussed.

4.2 Common Enterprise Modeling Framework's for Distributed Organizations (CEMF-DO)

CEMF-DO mission is to supply, in distributed organizations, a common structure into which the modeling, the simulation, the analysis and the management of the models for development of interoperability solutions are investigated and integrated. The implementation is done by integrating each distributed subpart of a considered process as a HLA federate (e.g. Figure 3).

The authors [14] activities are related to the Unified Enterprise Modeling Language (UEML) and to the management and synchronization of Enterprise Models, this research was executed as a working package in the INTEROP Network of Excellence (508011) [1].

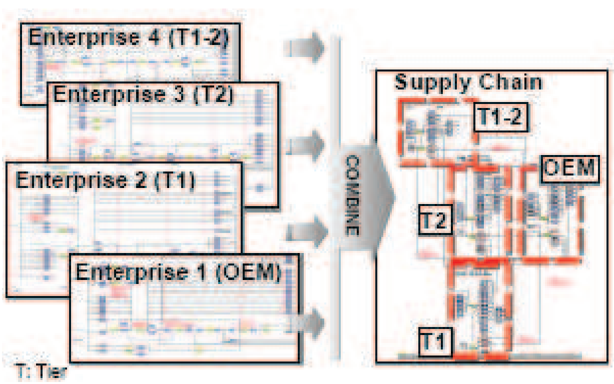

Figure 3. Distributed supply chain

4.3 Modeling and Simulation Environments for Design, Planning and Operation of Globally Distributed Enterprise (MISSION)

The works of [15] present a HLA federation approach of Supply Chains Distributed Simulation. Multinational companies have to face the new ways of distributed work. In this vast domain, the approach proposed by the authors concentrates on the distributed, decentralized simulation and, in particular, on the process of supply chain. The global concept is based on the results of the European Module of MISSION [16] and on an extension of the IEM (Integrated Enterprise Modeling). The approach includes the modeling aspects that describe how a user can collect the necessary data for the distributed simulation. Besides, it describes how different models of simulation can be connected starting from a library of models, via a model of company until the automatic generation of the required files of interface. The approach extends HLA to support an industrial use of the distributed simulation. We can consider this approach as a specific enrichment to the application of the HLA standard.

In this approach (i.e. Figure 4), a simulation tool manages the definition and the interoperability of simulation models by exchanging objects. It proposes an intuitive graphical tool to define simulation scenarios of process chains. The simulation manager tool guarantees the coherence between the federation configuration files for distributed simulation scenario and generates all files necessary for the RTI.

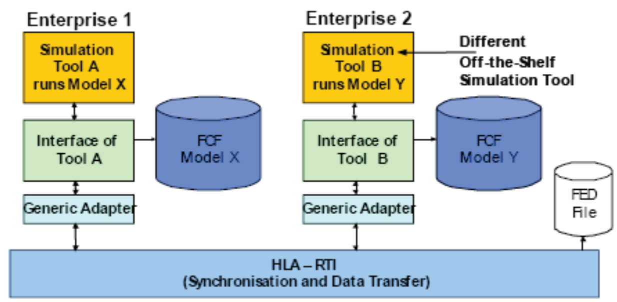

Figure 4. Interoperability model approach

4.4 LSIS - Workflow Model Editor (LSIS-WME)

In [5], an “open” M&S platform is proposed to create and execute models of production flow in the field of Micro Electronic industry manufacture. HLA allows in this platform insuring interoperability of the M&S environment with other heterogeneous software components of the company, notably specific professional applications previously standing alone.

On the one hand, the distributed simulation is used to simulate new road of production to anticipate wrong changes that can concurs to dysfunctions or wrong performance in the production. The workflow models of production route are graphically represented referring to key concepts enounced in [17] [18]. A Workflow process model is composed of tasks components that treat items (by calling resources), and controllers components that route items between tasks. Items pass over a sequence of these components. These components are linked by directed arrows in order to define a graphical component based model specification.
On the other hand, the environment is employed during real time to manage the flow of data associated to the flow of products, to trigger autonomously and right in time specific applications (previously manually called).

The figure 5 illustrates interoperability, orchestrated by a HLA RTI, between LSIS-WME environment and enterprise software components. The applications communicate by publishing and subscribing to information maintained by the RTI, the access to data is restricted regarding to rights defined in publish/subscribe to information regions.

This representation illustrates also the capacity of the environment to be plugged to other heterogeneous HLA compliant software components. Other enterprise models can communicate by becoming HLA compliant in order to insure interoperability also at a higher level.

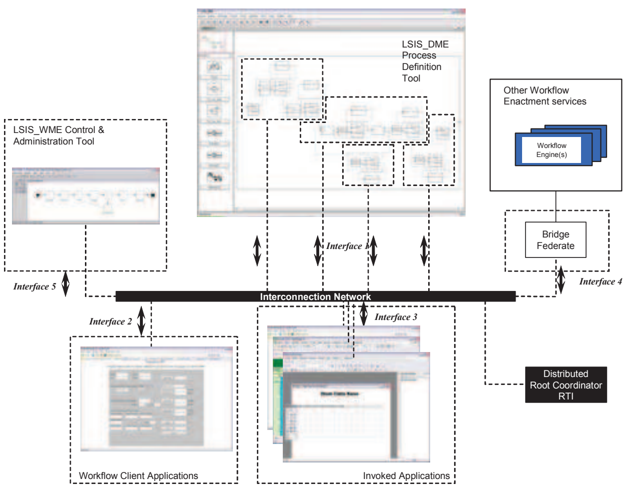

Figure 5. Components interoperability in microelectronic components manufacture

5. Perspectives to Remove Conceptual Barriers

From the state of the art of the Interoperability in federation domain and implementations experiences presented in the preceding points, we can define several directions of almost natural matching with HLA concepts in the following domains.

The first direction concerns the definition of commonly recognized paradigms and data structure because order and clarification is required to propose a sound paradigm. The second requirement not addressed at the enterprise modeling level is the synchronization of data. The order of data exchanged is important, ignoring this can lead to misunderstanding and wrong functioning of the model. Finally the enterprise modeling must consider the confidentiality management of data. The interoperability can be considered between concurrent enterprises in that context, a strategy of data sharing/not sharing between these must be defined. We present in the next points propositions to address these requirements.

5.1 Defining Ontology in XML

The development of a federation interoperability solution requires the creation of ontology at a meta-level, to be collectively admitted by the various federates components. At the implementation step, the choice of XML allows the definition of DTD (*Data Type Definition*), this data structure is a grammar verifying the consistency of a XML document. An inventory of XML enterprise ontology is done in [19].

The WfMC (Workflow Management Coalition) chose XML as the representation of Workflow standard [18], this standard defines the keys concepts required in the definition of a workflow model of document, physical product or data. In [5], a subset of this whole standard was used to define models of products flow. These models were able to be automatically transformed by an algorithm into a model able to be simulated (i.e. not ambiguous and with explicit notion of time). For these requirements, DEVS formalism [19] was selected since its strong expression power to specify systems. Thanks to HLA standard compliance, this flow application is able to communicate with different levels of abstraction applications if we consider a mechanism of data aggregation.

On the one hand, main corpuses of ontology are implemented in XML. On the other hand, this format is also used by HLA that defines objects and interaction in this common format. These data defined according to a classic structure of object programming allow facilitating the reuse and the constitution of libraries of data to be shared. Moreover, the possibility of transforming XML data structure by the use of a XSL processor (*eXtensible StyleSheet Language)* gives consistency and robustness to data. The data can be transformed according to the level of abstraction required from the enterprise level to the implementation level by defining automatic mechanism of transformation as presented in LSIS-WME project [5].

5.2 Temporal Enterprise Interoperability Management

The current researches expressed in [1], [19] and [25] identify the necessity of a space management but also of time to remove at best the conceptual barriers. The domain of the Modeling and Distributed Simulation may propose today mature solutions in these domains. In particular, the respect of temporal causality of exchanged information is addressed since the end of the

70s with the introduction of synchronization algorithms [11]. Later, standards e.g. [4], implying these algorithms have been introduced, to support and to facilitate the development of application platforms of distributed M&S. In [21], the interaction between distributed DEVS models [19] is detailed. These solutions can be transposed into an upper level of abstraction, in particular at the enterprise interoperability level. Therefore, the synchronization of enterprise models can be considered within the experience of lower level constraints (e.g. M&S level). For instance M&S enounces time related rules (i.e. causality) to be considered for more real-world accuracy of the upper level model. At the end, it is also interesting to envisage trans-level interactions between enterprise models, models for simulation, and data resulting from real world sensors to define a multi level, real time execution, application for enterprise interoperability.

5.3 Data Sharing Management (Confidentiality)

Another main issue of interoperability is the data confidentiality management. The standard [7] states on the requirement for an enterprise to share some selected sets of data in the situation of interoperability but to keep confidentiality of others. Directed by military goals, the HLA address this problem. HLA based its approach on set theory, it sub sets of data to share by interoperability and some other data not to be revealed to others components. In more details, data of enterprise need to be partitioned into classified sets with levels of confidentiality. This field is well developed in military interoperable war games [4] and could be transposed to enterprise purpose.

In detail, HLA employs mathematical set theory to define subsets of data to be exchanged and confidential data regarding to federates right status to share, update, handle and to receive data. These definitions can be generalised at an upper level. Finally, at the lower level, these concepts will be implemented from entity relation and data object model specified from data sets.

6. "From Enterprise Model to Execution" Methodology

The preceding points give evidence of no existing unified methodology to go from enterprise model to the implementation of a solution or to the model simulation (to obtain validations). We propose to explore existing methodology of model transformation.

6.1 MDA (Model Driven Architecture)

The first methodology studied is MDA (Model Driven Architecture®). This methodology defined and adopted by the OMG (Object Management Group) in 2001, (updated in 2003 [22]) is designed to promote the use of models and their transformations to consider and implement different systems. It is based on architecture defining four levels (i.e. Figure 6), which goes from general to specific:

Level CIM (Computation Independent Model): focusing on the whole system and its environment. It is also named « domain model », it describes all metiers models (functional, organisational, decisional, process…) of the system with an independent vision from implementation.

Level PIM (Platform Independent Model): model the sub-set of the system that will be implemented.

Level PSM (Platform Specific Model): that takes into account the specificities related to the development platform.

Coding Level: The last level consists in coding or more generally enterprises applications (ESA: Enterprise Software Application).

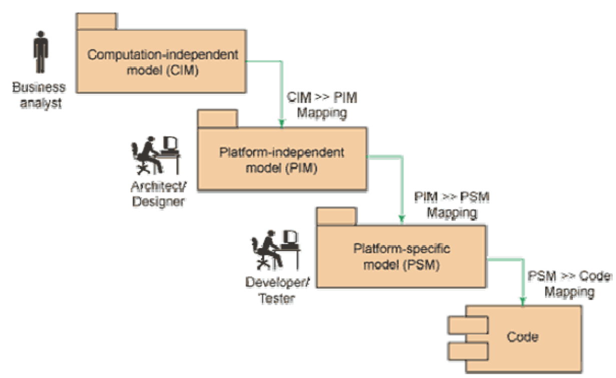

Figure 6. MDA method reference framework

To complete this description, a Platform Description Model used for the transformation between PIM level and PSM level is added to these four kinds of models corresponding to four abstraction levels.

6.2 MDI (Model Driven Interoperability)

The approach "Model Driven Interoperability" (MDI) consists in considering interoperability problems from enterprise models level instead of only at the coding step.

These works realised in the Task Group 2 (TG2) of INTEROP-NoE state at defining an approach inspired from OMG MDA® [23]. The goal is to tackle the interoperability problem at each abstraction level defined in MDA and to use models transformations techniques to link vertically the different levels of abstraction or horizontally to ensure each models of the level interoperability. The general framework of the approach proposed in TG2 is presented in Figure 7. The main goal of this methodology, based on model transformation, is to allow a complete follow from expressing requirements to coding of a solution and also a greater flexibility thanks to the automation of these transformations.

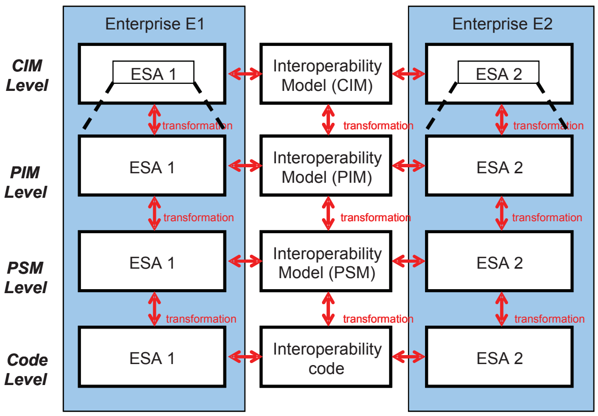

Figure 7. Cadre de référence pour la méthode MDI

In the context of TG2, experimentations have been realized and in particular the feasibility study to transform GRAI Methodology [24] [25] Models to UML between CIM and PIM levels [23]. These works are additional works realised in the context of ATHENA to define UML profiles to take into account Service Oriented Architectures at PIM level [26]. These results have consolidated by results presented by J. TOUZI [27] that have proposed an interoperability transformations method from BPMN to UML in the context of services oriented architecture.

Nevertheless, if the soundness of the methodology has been demonstrated, no full industrial scale validation have been yet realised. A project ISTA3 [28] has especially for goal to demonstrate these concepts in an industrial real world significant application. The different methodological propositions will be tested and refined by focusing on model interoperability and their interoperability. It will consist in particular to improve the flexibility of the MDI transformation process in the way of obtaining dynamic interoperability in the context of federated approach.

6.3 HLA FEDEP

HLA proposes a development life cycle of federate and federations based on the waterfall software engineering cycle. This life cycle is named FEDEP [6].

From the very beginning of the elaboration of the HLA standard, a need was identified in the HLA federations development. This need is characterized by a high degree of flexibility in the process of composition and execution of HLA applications that realize objectives of a “compound” application. The purpose of FEDEP is to avoid the reiteration (every new federation construction) of already treated questions dealing on the way the HLA applications were built and how they run. Indeed, it was recognized that the process of development and execution of HLA federations can vary significantly between applications create by various designers.

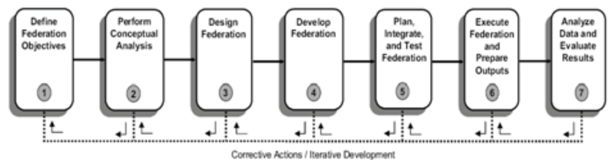

Figure 8. Federation development and execution process (FEDEP).

For the reasons enounced previously, the DMSO has identified, a cycle of seven steps that all HLA federation designer should follow to develop and execute their federations. Figure 8 illustrates each of these steps and the following summary is detailed in the next point. We specialise then the methodology for enterprise modelling.

Step 1: Federation Objective Definition: the user of the federation and the development team of the federation define and agree a set of objectives and inform what must be carried out to realize these objectives.

Step 2: *Conceptual Analysis Realization:* based on the space characteristics of a problem, an appropriate representation of the domain of the real world is created.

Step 3: Federation Design: federates, reusable in the considered federation, are identified. The activities for the modification of the federates and\or the creation of new federates are executed. The features required by the federation are assigned to the federates and a plan is defined for the development of the federation and its stake in work.

Step 4: Development of federation: the Federation Object Model (FOM) is developed. Agreements between the federates are established on the basis of data to be shared and the algorithms which will run it. Finally, new federates and\or the modifications of existing federates are implemented.

Step 5: Planning, Integration And Test Of The Federation: all the activities of integration necessary for the federation are executed and tests are realized to insure these conditions of inter-functioning.

Step 6: Federation Execution And Outputs Preparing: the federation is executed and the data produced by the execution of the federation are pre-treated. This step is an addition with regard to the former standard; it marks the necessity of a phase of calibration of the classification of the results.

Step 7: Data Analysis And Results Appraisal: the data produced by the execution of the federation are analyzed and estimated and the results are presented in a report to the user.

6.4 Conclusion on Existing Model Transformation Methodologies

Similarity appears by comparing the steps of the various methods. Nevertheless from our consideration a lack of distribution consideration in MDA/MDI and not enough specificity to enterprise interoperability in HLA have been also identified. From these statements, we propose to define an enterprise model specific development methodology based on the HLA Federation Development and Execution Process (FEDEP) [6]. It will clarify and systematise the development process of enterprise models. We precise that we have restricted our methodology to address transformation of enterprise models of distributed enterprises interoperating in unified or federated manner and when the coding will be done respecting the HLA standard.

The proposed unified methodology for development of interoperating enterprise model follows the HLA FEDEP that proposes seven steps in the federation creation. This formalization will help also the reuse of the development knowledge. It will also give a common metric to compare solution developments and refer to HLA standard to ensure heterogeneous components interoperability.

6.5 Enterprise Model Unified Transformation Methodology

We presented in §4 various enterprise models implementation using HLA, each has followed its own development cycle. In order to be able to compare these methods and models, besides to clarify and rationalise the implementation; we propose a common method by the convergence of HLA FEDEP MDA, MDI steps. This life cycle propose to standardise the steps to reach simulation or implementation from a conceptual enterprise model, it is depicted in Figure 9.

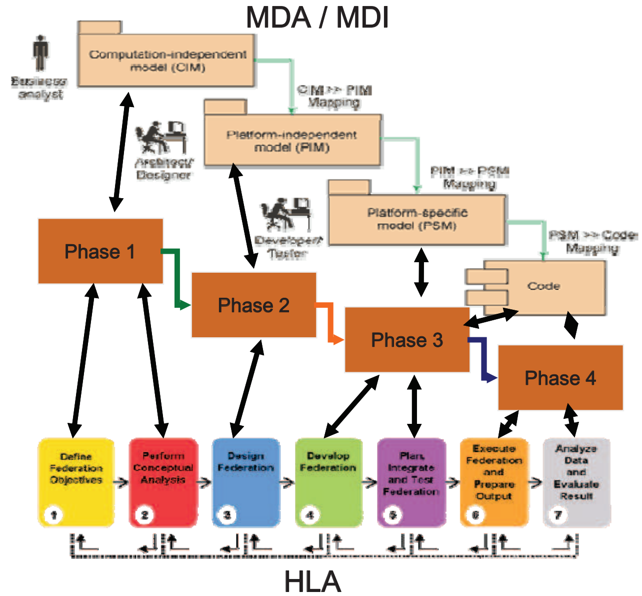

Figure 9. New convergent Methodology

Phase 1: In a first step, the objectives of the federation of enterprises have to be defined. Basically, the common goal of all federation created by this methodology consists in defining federation of interoperating enterprise models. This step is also considering the domain model of MDA CIM level.

Phase 2: As described in the FEDEP second step, a conceptual model is required. In our case, this model contains enterprise models represented as entities and actions that represent external information exchanged between enterprises. This representation can naturally use the typical enterprise relation model elaborated in the enterprise model interoperability field (e.g. UEML models [29]). We address in that step what are the information to exchange, in others terms, what is the structure of the distributed ontology. This level is considering the MDA PIM level.

Phase 3: As FEDEP third step, the mapping of enterprise models into HLA federates is realised, in detail the way models handle received information and how they send information to the federation is addressed, these mechanisms can conform to synchronisation algorithm proposed in [21]. We pay here attention to reuse already existing enterprise models. Not existing enterprise models federates are created.

Phase 4: In the FEDEP fourth step, the methodology maps enterprise interoperating connections between models into HLA interactions and objects. Then, these data are structured to generate the associated FOM. The strategy concerning the confidentiality of data problem is also explicitly addressed in that step. In details, on the one hand, an enterprise model that owns an incoming relation with an influencer enterprise "publishes" on an Interaction Class defining the coupling relation by *publishInteractionClass()*. On the other hand, an enterprise model possessing an interoperability outgoing relation "subscribes" to the Interaction Class published by the enterprise which influence it by using *subscribeInteractionClass*(). The methodology may also propose to generate, in the FOM, objects that define various shared elements of local enterprises; for instance, enterprise performance measurement tracking. Tracked enterprise federate publishes using *RTIAmbassador publishObjectClassAttributes()* and tracker enterprise federate subscribes using *subscribeObjectClassAttributes()*. To respect the time causality, the interactions among enterprise federates are defined "Time Stamped Order". They are emitted with a timestamp related to the local logical time of supplier enterprise federate in order to the RTI handles them respecting the causality (we address here the time management of the data).

At the end, the enterprise model federates generated by this methodology can be reused and interfaced with heterogeneous HLA-compliant models. For instance, "client models" federates can be upstream connected to enterprise federates and "enterprise subcontractors" federates can be downstream connected. The results obtained by simulation are used for validation of the models by test and analyse; in case it does not fulfilled the specification the methodology must allows doing feedback correction as described in the FEDEP last step.

6.6 Complex Problem of Aerospace International Cooperation Interoperability

The design of a new launch vehicle is a strongly complex task. The creation of a huge number of unique new parts, the involvement of a legion of engineers from several domains, countries, the need for frequent and intensive collaboration among them, the length of the development cycle, and the consequent expenses, are all on a scale that few other industries approach [30].

In military and aerospace community, the interoperability has been historically tackled at the technological level to facilitate reusing. Efforts in the way of standardisation have been instigated.

In particular, on the US side, the National Institute of Standards and Technology (NIST) leads programs for Systems Integration and Interoperability. NIST offers a variety of technological assistance to U.S. aerospace firms to enhance their competitiveness in the global marketplace [31]. In detail of the technical aspects, computer-controlled manufacturing processes need to speak the same language. Computer-aided design systems need to be able to receive and hand-off product data accurately within and between shops. NIST research means aerospace manufacturers spend less time solving systems integration and interoperability problems and more time building planes [31].

The NIST Manufacturing Interoperability equips U.S. manufacturers with the technical guidance and testing support needed to interoperate in today's global, heterogeneous manufacturing world. Systems Integration for Manufacturing Applications coordinates NIST research efforts to improve interoperability and data integration in the areas of manufacturing e-commerce, product data, and scientific data.

The NIST Manufacturing Engineering Laboratory (MEL) [32] has for goal assisting aerospace manufacturing through measurements and standards; it is a good example of what can be done in aerospace manufacturing technical interoperability. MEL is one of the seven NIST measurement and standards laboratories. MEL works with the American manufacturing sector to develop and apply technology, measurements, and standards. MEL provides industry-needed engineering tools, interface standards, systems architectures, and traceability.

This study stresses the fact that efforts to make specific aerospace sector converge with the industrial sector on unified standardization points are strongly considered. However, most of the standards are dedicated to technical interoperability, and we believe that aerospace need to explicitly consider other abstraction level of interoperability: business and also organizational (i.e. Figure 1). In particular, for European multi-countries projects, the following aspects are relevant but complex to handle and not clearly integrated in projects: human organizational working, cultural aspects, communication, working laws, costs, etc. We are at the beginning of new challenging considerations on the conceptual level of aero-spatial programs that still need to be addressed. We state that this field can learn experience from interoperability seen from the Enterprise-Modeling research field point of view; e.g. the new life cycle we propose in § 6.5 tackles interoperability at the different abstraction levels of enterprise model conception. In addition, interoperability association, Interop V-Lab [33], supplies deliverable on multi countries projects led in the field of Enterprise Interoperability that can turn out helpful experiences and resources.

7. Conclusion

This article has given a state of the art of model transformation methodologies and illustrated the use of HLA standard for the implementation of enterprise applications federations.

Three main concerns of interoperability barriers have been identified at the conceptual level and ways of solutions relative to the use of the HLA standard have been envisaged at the coding level. More detailed solutions that answer to specific enterprise modelling are under our scope of research and will guide our future works. In the way back the exploitation of the modelling and simulation level knowledge gives some keys from the data exchange point of view concerning time, confidentiality and organisation.

After this statement, we propose the first release of a clear and systematic methodology, specialised from the HLA FEDEP, MDA/MDI methodologies, to develop models of simulation from conceptual enterprise models. This methodology of model transformation and implementation seems to be really promising regarding to actual requirement of distribution, federated interoperability and information systems dynamic behaviour of enterprises. At the end, it tries to bridge a gap from concepts to implementation in the field of enterprise modelling by offering a new standardised and systematic way.

8. References

[1] Chen D, Dassisti M, Elvesæter B, 2007. Enterprise Interoperability Framework and Knowledge Corpus – Final report Annex: Knowledge Pieces, Contract no.: IST-508 011, Deliverable DI.3-Annex, May 21.

[2] Daclin N., Chen D., Vallespir. "Enterprise interoperability measurement - Basic concepts". EMOI-INTEROP 2006 (Co-located with CAiSE 2006): Luxembourg.

[3] IDEAS Consortium, 2002. Thematic Network, IDEAS : Interoperability Development for Enterprise Application and Software – Roadmaps, Annex 1 – Description of work, May 13.

[4] IEEE std 1516.2-2000. IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Federate Interface Specification, Institute of Electrical and Electronic Engineers.

[5] Zacharewicz G., M. E.-A. Hamri, W. Trojet, C. Frydman and N. Giambiasi, 2006a. G-DEVS / HLA Environment for Distributed Simulations of Workflows. Proceedings of the International Conference on Modeling and Simulation - Methodology, Tools, Software Applications (M&S-MTSA'06), SCS, pp. 206 - 211, Calgary, Alberta, Canada, July 31 - August 2

[6] IEEE std 1516.3-2003. IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Federation Development and Execution Process (FEDEP) The Institute of Electrical and Electronic Engineer.

[7] ISO, 1999. 14258 - Industrial Automation Systems - Concepts and Rules for Enterprise Models, ISO TC184/SC5/WG1.

[8] IST, 2006. Enterprise Interoperability Research Roadmap, Final Version, (Version 4.0), 31 July. http://cordis.europa.eu/ist/ict-ent-net/ei-roadmap_en.htm), Accessed Sept 30 2007

[9] C4ISR 1998. Architecture Working Group, « Levels of Information Systems Interoperability (LISI) », USA Department of Defense.

[10] Tolk, A., Muguira, J.A., 2003. The Levels of Conceptual Interoperability Model. Fall Simulation Interoperability Worshop. Orlando, Florida, September.

[11] Fujimoto R. M. 2000. Parallel and Distributed Simulation System. Wiley Interscience, NY.

[12] Zhang H; Wang, H; Chen, D, 2007. A Multidisciplinary Collaborative Design System in a Distributed Environment, 11th International Conference on, Computer Supported Cooperative Work in Design, (CSCWD 2007), 26-28 April. p. 233-239.

[13] Zhang H, Chen, D. 2006. An approach of Multidisciplinary Collaborative Design for Virtual Prototyping in Distributed Network Environment, 10th International Conference on Computer Supported Cooperative Work in Design, 2006. (CSCWD '06), Nanjing, p 1-6.

[14] Berio, G.; Mertins, K.; Jaekel, F.W. 2005. Common Enterprise Modelling Framework for Distributed Organisations. In: Horáček, P.; Šimandl, M.; Zítek, P. (Eds.): Preprints of 16th IFAC World Congress. Praha

[15] Jaekel F-W, 2005. Distributed Federated Simulation of Supply Chains, in Deliverable D6.1 of Network of Excellence - Contract no.: IST-508 011 (editor: David Chen), Practices, principles and patterns for interoperability, May 20.

[16] Rabe M., Jaekel F.W., 2002. The MISSION Project, Proceedings of the IFIP TC5/WG5.12 International Conference on Enterprise Integration and Modeling Technique: Enterprise Inter- and Intra-Organizational Integration: Building International Consensus, p.235-242, April 24-26.

[17] Workflow Management Coalition. 1999. Terminology & Glossary. WfMC-TC-1011, 3.0.

[18] Workflow Management Coalition. 2005. Workflow Process Definition Interface -- XML

Process Definition Language (XPDL). WFMC-TC-1025, Oct.
[19] Chen, D., Doumeingts, G. 2003. European Initiatives to develop interoperability of enterprise applications - basic concepts, framework and roadmap, Journal of Annual reviews in Control, Volume 27, Issue n°2, pp.151-160.
[20] Zeigler B.P., 1973. Theory of Modelling and Simulation. Ed. John Wiley, New York.
[21] Zacharewicz G., N. Giambiasi and C. Frydman, 2006b. Lookahead Computation in G-DEVS/HLA Environment. Simulation News Europe Journal (SNE) special issue 1 "Parallel and Distributed Simulation Methods and Environments", 16, (2), 15-24, ISSN 0929-2268
[22] OMG: MDA Guide Version 1.0.1. Object Management Group. Document number: omg/2003-06-01 edn. (2003)
[23] Bourey J.P., Grangel Seguer R., Doumeingts G., Berre A.J "Report on Model Driven Interoperability". Livrable DTG2.3, INTEROP Network of Excellence, 91 pages, http://interop-vlab.eu/deliv/tg2-model-driven-interoperability/, Avril 2007
[24] D. Chen, B. Vallespir, G. Doumeingts "GRAI integrated methodology and its mapping onto generic enterprise reference architecture and methodology" September 1997, Computers in Industry, Volume 33 Issue 2-3.
[25] Doumeingts G., Ducq Y. "Enterprise Modelling techniques to improve efficiency of enterprises" in International Journal of Production Planning and Control - Taylor & Francis – Vol. 12, number 2, Mars 2001, pp 146-163Mars 2001, pp 146-163
[26] Benguria Gorka, Xabier Larrucea, Brian Elvesæter, "A Platform Independent Model for Service Oriented Architectures" Tor Neple, Anthony Beardsmoreand Michael Friess, (2007), In Book: Enterprise Interoperability, (Ed, London, S.), pp. 23-32. ISBN 978-1-84628-713-8
[27] Touzi « Aide à la conception de Système d'Information Collaboratif support de l'interopérabilité des entreprises », Phd Thesis INPT, 9 Novembre 2007
[28] Pôle Grand Sud-Ouest, « Projet ISTA3 Interopérabilité de 3ème génération, pour les Sous-Traitants de l'Aéronautique », 2007
[29] UEML 2003. Public Web for UEML. EU Project IST–2001–34229. www.ueml.org . Accessed Sept 30 2007.
[30] Klapproth, Ken "Sky CAD: design interoperability streamlines aerospace R&D" DesignFax *10 january 2002*
[31] NIST National Institute of Standards and Technology Website; accessed on 2 May 15, 2008, http://www.nist.gov/public_affairs/aerospace.htm#Systems
[32] The NIST MEL: assisting aerospace manufacturing through measurements and standards Stieren, D.C. Page(s): 7-3660 vol.7 Digital Object Identifier 10.1109/AERO.2001.931450
[33] The European Virtual Laboratory for Enterprise Interoperability Portal: http://www.interop-vlab.eu/, accessed May 2008.

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