Concurrent Engineering in Virtual Enterprises: the Extended CIM-FACE Architecture

A. Luís Osório[1], Nuno Oliveira[1], L. M. Camarinha-Matos
New University of Lisbon, Faculty of Sciences and Technology
Quinta da Torre, 2825 Monte Caparica, Portugal
Tel: +351 1 3500227 Fax:+351 1 295 12 54
e-mail: {lo, no, cam}@uninova.pt

Abstract

The information technologies are commonly accepted as one of the keys to support the new enterprise paradigms emerging in the global market. Enterprises are not any more monolithic production infrastructures but rather nodes contributing to a wide spread production system. The intrinsic distribution aspects of the Virtual Enterprise paradigm brought new challenges to the research arena. The Internet and in particular the Web infrastructure used as a new information "highway" can link together distributed activity execution agents, persons or more basic computational processes. This paper presents the VCIM-FACE architecture as an integrating infrastructure to support concurrent engineering in the virtual enterprise. Co-operative product developments, grouping specialised teams spread through various enterprises, is fundamental to this new manufacturing paradigm. Issues like distributed execution of Business Plans, security and privacy, and execution control of concurrent engineering activities are some of the topics discussed in this paper.

Keywords

Concurrent Engineering, Engineering Information systems, Virtual Enterprises, Integrating Infrastructures, Distributed Systems.

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[1] Instituto Superior de Engenharia de Lisboa, Departamento de Engenharia da Electrónica e das Comunicações {lo, no}@deec.isel.pt

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The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: 10.1007/978-0-387-35390-6_58

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1 INTRODUCTION

The new trends in the global world market require fast answers from the engineering and production infrastructures. Factors like quality, on demand customisation, new stylistic designs, efficient delivery organisation, reasonable maintenance responses times, and other product-related aspects, are key requirements to achieve a successful industrial business. In order to support the complete product life cycle there is a need for a flexible, fast and as concurrent as possible set of co-operating processes running over distributed computational infrastructures. Fast and easy information access from the places where it is necessary, even considering mobile sites, and with high availability, are pre-conditions to achieve a new generation of competitive enterprises.

Markets are becoming more and more global. As a consequence, we can notice the emergence of a new group of enterprises organised around highly specialised multidisciplinary teams, working on the engineering phase of the product life cycle and outsourcing the production phase. The manufacturing itself can be done using production resources spread around the world. In the electronic sector, for instance, high-tech enterprises are using external production resources, keeping to themselves only the engineering, marketing, and quality control phase. On the other hand, companies offering the production infrastructures contribute with specialised production skills, usually centred on a restricted set of production resources. This specialisation trend is only viable if the participating companies can establish co-operation agreements and organise their co-operation around a strong distributed information system that allow them to behave as a single enterprise, following the virtual enterprise (VE) paradigm.

The main difference between the monolithic model of enterprise and the new virtual enterprise paradigm lies on the type of relationships among the life cycle support substructures. Independently of the enterprise model being more hierarchical or flat, a monolithic enterprise can be considered as a kind of island with all basic needs/resources centred in one place or even, if distributed, belonging to the same owner. Most of the specialised engineering and production resources belong to the enterprise. Even if the internal organisation is flexible, the decisions are always centred on the same management board. The ownership of the enterprise is clear and any strategic change is an internal enterprise decision.

On the other hand, in the new virtual enterprise paradigm, the engineering and production resources can be spread around a group of enterprises that find some common business interest on co-operation. This kind of arrangements does not have a centralised decision point. Each enterprise of the group has a commitment to some joint business goal, but the decision process at the virtual enterprise level, needs a common agreement from all or part of the management boards of the member enterprises.

As a scenario to clarify this new trend let us consider an investor that wants to produce a new toy. One option is to develop the idea considering the creation of an enterprise with all design/engineering and manufacturing resources to produce it. This option has a big risk and is not easy considering the global competition where other enterprises, taking advantage of structural situations, can produce the same kind of products at a lower price. Another solution is to organise a good design and engineering team to create the new products, plan their production and utilise the existing external production capacity to produce them. This new enterprise can select the production resources according to quality requirements and the proximity to the market. In some sense what is described here is the creation of an enterprise centred on an idea, taking control of what is essential to preserve the enterprise identity and outsourcing the activities that can be transparent to the customers. This scenario points to distributed engineering/production systems as a flexible infrastructure to make profitable existing or new specialised engineering and/or production infrastructures.

This new generation of enterprises need a flexible information support infrastructure integrating heterogeneous cultures, providing a holistic system based on differentiated components. The development of a single system to support the full product life cycle is a pharaonic task. The alternative solution is to provide an integrating infrastructure where various components can play specialised roles and interoperate accordingly. There is a set of emergent standards contributing to this trend. For instance, at the middleware level, the OMG is developing an infrastructure to integrate heterogeneous functional components based on the object-oriented paradigm. The problems associated to the computational platform heterogeneity and diversified operating systems are being surpassed by the Java computational infrastructure and language. Functional modules developed in Java can run virtually in any hardware requiring only the runtime Java support. Most of the Web browsers are able to run Java applets.

Some consortia are guided by market expectations and other works are being carried on in the context of research and development projects like the European ESPRIT program, the American Federal research projects, and other world wide innovation projects. At the European level, projects like PRODNET II (Camarinha-Matos, 1997), (Afsarmanesh, 1997), or VEGA (Zarli, 1997a), (Zarli, 1997b) are examples of the efforts in this direction. The American Federal Government has sponsored the NIIIP project (NIIP, 1995), (NIIP, 1996), whose main goal is to develop an integrating infrastructure to support the Virtual Enterprise concept. The NIIIP project is mainly addressing the infrastructure and not behavioural related aspects like the electronic commerce. Other specialised projects address restricted areas of the globalisation, like the Commerce.net centred on electronic commerce. The globalisation also brought to the international standardisation organisations an added importance on defining standards contributing to increase the interoperation and to reduce development risks. The development of STEP as a standard suit to deal with product model data in the body of ISO is a paradigmatic initiative illustrating this tendency.

In this direction the proposed VCIM-FACE architecture aims to contribute to the execution of engineering activities maximising the concurrency and providing a supervision architecture to control the execution of Business Plans. Problems like concurrency control, distributed execution of distributed Business Plans, easy user access to execute planned activities, privacy on the distributed environment, integration of emerging standards to maximise the interoperability among components and guaranteeing integration of legated systems, are some of the focused issues.

This architecture is based on a previous work of the authors (CIM-FACE) that supported concurrent engineering in a single enterprise environment. VCIM-FACE tries to extend this architecture towards the VE environment.

2 CONCURRENT ENGINEERING WITH CIM-FACE

The development phase of the product life cycle has received many research efforts to shorten its duration time. Product development needs the interdisciplinary contribution of engineers/designers and other contributors with diversified expertise, each one contributing with some added skill. The efforts to shorten this development phase led to the overlap of activities and to the introduction of mechanisms to co-ordinate/synchronise them. Depending on the characteristics of the products, some activities can be executed in concurrency. Therefore the concept of Concurrent Engineering (CE) is the result of the recognition of the need to integrate diversified expertise and to improve the flow of information among all phases involved in the product life cycle. Even if this was attempted before with the introduction of enterprise team structures, the results were somehow limited because the co-operation support tools were not enough to overcome the traditional sequential "throw it over the wall" operation paradigm. With the development of new computer-aided tools, contributing to different facets of product life cycle, it becomes more evident that some activities can effectively be realised in parallel. Evolving from earlier attempts, represented by the paradigms of "Design for Assembly/Design for Manufacturing", Concurrent Engineering is thus a consequence of the recognition that a product must be the result of many factors, including: marketing and sales; design factors; production factors; usage factors (intended functionalities/requirements); destruction/recycling factors; etc.

Many computer-aided tools have been developed to fulfil the product life cycle needs from the point of view of business and engineering. Most of the tools address specific functionalities and, when coming from different providers, their interoperation is, in most cases, very difficult. Therefore a platform that supports the integration of such tools (information and knowledge sharing) as well as the interaction among their users (teamwork) is a computational requirement for CE. A realistic approach to design an architecture that supports Concurrent Engineering has to take into account results and tendencies emerging from various research fields of the advanced manufacturing area. The definition of a platform for Concurrent Engineering involves, in our opinion, four related sub-problems: interoperable computational and communication infrastructure, common information models, engineering information management, and process execution and supervision (workflow management).

The platform for integration and concurrent engineering CIM-FACE (Federated Architecture for Concurrent Engineering) (Camarinha 1993), (Osório 1994) addresses these three issues in the context of a single enterprise.

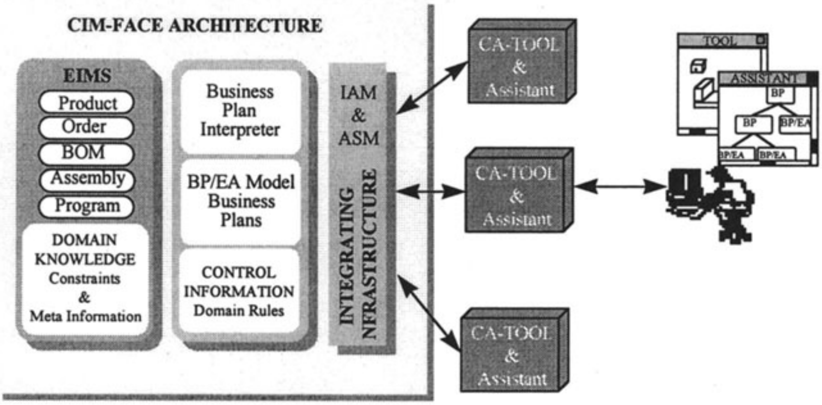

Figure 1 - CIM-FACE Architecture.

In **Figure 1** the main blocks of the CIM-FACE architecture are shown. Application computer-aided tools are integrated via the integrating infrastructure, which provides access to the common Engineering Information System (EIS). In the first implementation of CIM-FACE, a client-server model using RPC to access the CIM-FACE services, was used (Camarinha 1993), (Osório 1994).

Recent developments in integrating infrastructures point to object based integration as a flexible approach to cope with heterogeneity, and to guarantee easy reutilization of existing implemented functionalities and integration of legacy systems. The integrating object oriented OrbixWeb is used in the current implementation. The OrbixWeb integrating infrastructure is CORBA compliant and provides bindings to C++ and Java from IDL interface language. As a CORBA compliant architecture, the new VCIM-FACE implementation enables a federation of heterogeneous software CA-tools to access its published services.

As a support to the execution of concurrent engineering activities the CIM-FACE architecture has four main components: the STEP/Express model base, the set of business/workflow plans, a knowledge base to support intelligent execution and business process/workflow interpreter. All these components are interrelated and guarantee the realisation of the planned activities by team members interacting through a set of CA-tools with the assistance of an assistant software module. The selection of a standard architecture as CORBA to integrate the hybrid CA-tools facilitates the reutilization of existing tools.

To enable the integration of information models generated by legated systems, a "STEP door" is available. STEP neutral files can be loaded into CIM-FACE through the provided loose connection mode.

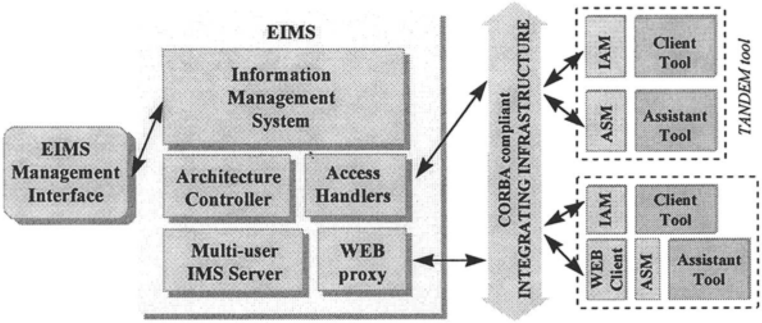

Figure 2 - Engineering Information Management System (EIMS)

The basic integrating infrastructure presented in Figure 2, works as an information management system providing concurrent and distributed accesses from CA-tools to shared information models.

As a general strategy, CIM-FACE considers that each enterprise owns a set of heterogeneous CA-tools able to be integrated through a specialised interface that implements CIM-FACE services access. Each co-operating CA-tool has to access CIM-FACE information services through the Information Access Methods (IAM). Through these methods, a CA-tool will access and/or update shared information models with the results of the activity execution. Furthermore, there exists a dedicated protocol enabling the CIM-FACE kernel to know who are the users realising activities and the business plan for which they are contributing to. For CA-tools that cannot have a tight integration with CIM-FACE, a client proxy could be implemented to play as a bridge between the integrated infrastructure and the legated tool. In any case, it is always possible, for the CIM-FACE manager, to download external STEP neutral files with contributions generated by that class of loosely connected CA-tools.

Considering the extensibility of Internet services to the internal infrastructure of an enterprise, referenced as Intranet infrastructure, EIMS has been extended with access capabilities via Web browsers. This feature enables the extension of CIM-FACE architecture to the virtual enterprise world.

Another important component of CIM-FACE architecture is the role of the business plan assistant. This special tool provides the engineer with a window to the set of business plans he/she is contributing to. Through the Business Plan assistant a user can browse a business plan, check the execution status of each activity, receive and send messages to other co-operating team members, and guide the engineer informing him/her when some exception happens.

This environment based on team members and the CA-tools used to realise activities, is the base of a framework interconnecting autonomous agents co-operating on the resolution of complex tasks. It is up to the business plans execution supervisor, (Camarinha-Matos 1995), (Osório 1994), the co-ordination of these agents.

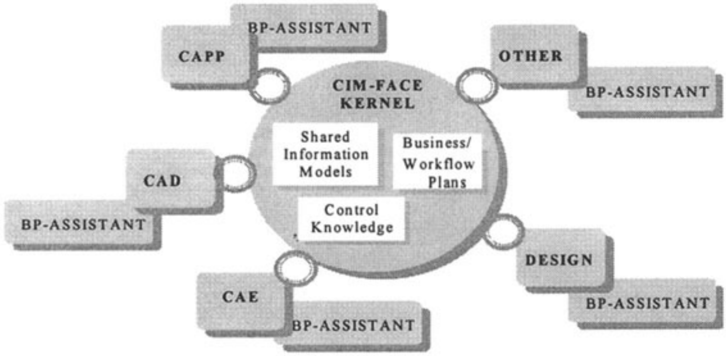

Figure 3 - CA-tools as a federation of autonomous software agents.

As shown in Figure 3, each CA-tool contributes to the execution of planned activities operated by team members and guided by the BP-assistant. The Business Plan Assistants provide a front end to the human experts facilitating their co-ordination in the execution of the business processes. An agent in this community is therefore formed by a tandem software structure: the CA-tool plus the BP-assistant and the human expert.

Each agent may have its own data models (partial views of the world) and its decision making capabilities. The decision making is centred on the couple, team member (expert) and CA-tool. The HOW and WHEN each activity is performed depend on the team members' decision. The CIM-FACE controller is responsible for the overall workflow co-ordination, terminating some activity if some pre-conditions are not satisfied, i.e., actions resulting from procedural rules violation, incomplete information models, or violation of constraint rules (control knowledge).

3 INTRANET/INTERNET BASED INTEGRATING INFRASTRUCTURES

The WEB infrastructure is increasing in importance for co-operation support systems by the information presentation facilities it offers. To provide dynamic information access, an extended protocol based on a gateway process was defined. The WEB server activates this gateway each time a client makes a reference to a special URL. This special process, named CGI process, receives the client information via the WEB server and answers in HTTP, providing a HTML page generated "on the fly." With the CGI infrastructure it is possible to build dedicated proxies to legacy information systems or to other specialised information sources like real time information acquisition systems. The main limitations CGI has are related to the type of connection between clients and the CGI process itself. The CGI process is launched each time a WEB client makes a reference to the respective URL. In order to have a memory state, it is necessary to use environment variables or else a named file to guarantee the persistency beyond the CGI process life cycle. The WEB client does not have execution capabilities what makes difficult the implementation of complex graphical client interfaces. Some flexibility can only be obtained through JavaScript, plug-ins or else Java applets. However its access needs always the implementation of a dedicated CGI process to deal with this special access door. Therefore CGI is mainly used to browse dynamic information embedded into HTML pages and to let users to enter information through dedicated forms. One advantage of maintaining CGI access doors is the relative openness against security mechanisms like those provided by firewalls. All CGI based messages are exchanged in HTTP what makes client access independent of constraints imposed by the server and/or client Firewalls. Therefore VCIM-FACE reserves to CGI a promotion/contractual role. For instance, VCIM-FACE provides an access registration service to team members that are candidates to realise enterprise business plan activities. The candidates can enter their curriculum through CGI forms, and if they are accepted, later on they will receive VCIM-FACE full access through the co-operation infrastructure.

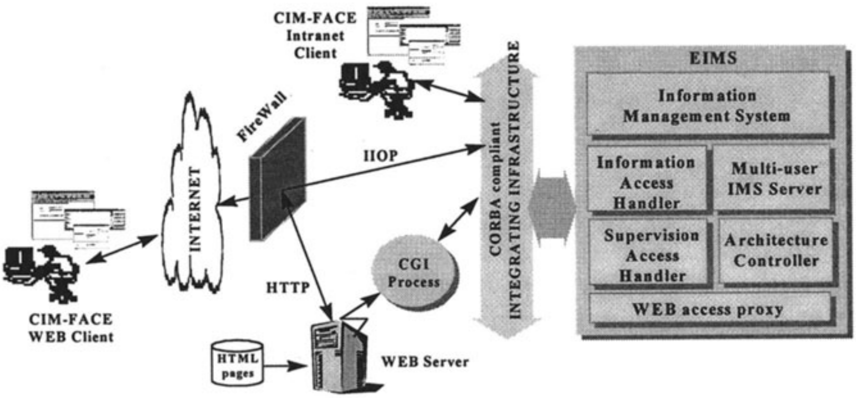

Figure 4 - Extended CIM-FACE architecture to Intranet and Internet

Another important aspect of the extended VCIM-FACE architecture is the utilisation of Java to access tool assistants. The implementation of business plan assistants in Java, which are directly loaded from the enterprise WEB infrastructure, facilitates the access to the last version of the assistant tool and avoids special client configuration. The team member only needs a general purpose WEB browser and to know the VCIM-FACE enterprise URL entry point. As soon as the client tool assistant is loaded, the team member can remotely access EIMS like if he/she was inside the enterprise. Besides the Java-based execution infrastructure in the client side, the basic communication protocols and languages are maintained. Even in Java, the tool assistant and any computer-aided tool continue to access EIMS through the access protocols and languages IAM and ASM. The main advantage of the extension to support tools download based on the Java infrastructure is on the flexibility they provide.

From the team members point of view, the main purpose is to present a flexible environment to access EIMS. A team member based at home only has to overpass the security doors to be co-operating with some enterprise business plan.

4 EXTENDING CIM-FACE TO THE VIRTUAL ENTERPRISE

To some extent, the concept of virtual enterprise is not completely new. Since long ago entrepreneurs have established bilateral agreements for cooperation on mutual enterprise resources optimisation. However, the recent and fast evolution in communications in particular and information technology in general, sped up the global co-operation forcing enterprises to tight their inter-relations in a shorter time. This leads to the need of an infrastructure to support such enterprise agreements, some of them presenting complex relational behaviour. As a motivation to establish enterprise agreements we can mention:

- Resource sharing among enterprises (engineering, production, quality control, etc.);
- Production close to the market - world dimension;
- Minimise investment risks distributing production world wide;
- Find competencies (regional expertise);
- Production of alternative models under the same logo / brand name to present to the market a complete range of products and in competitive amounts.

This list represents a sample of the motivations to establish enterprise networks co-operating to some common goal. All of these motivations point to a new structure, above the classical enterprise, with a special structure to link them around a network as a set of enterprises having some common interest. Many kinds of arrangements can be established among enterprises belonging to the same network:

- Engineering resources sharing (stylistic design, structural evaluation, CAD design, etc.);
- Total or partial production of engineered products;
- Sharing a special operation implemented by an expensive machine (resistance tests, quality measurement control, special chemistry operation, etc.).

Established the motivation, the problem is to define an architecture general enough to support this kind of enterprises. The ESPRIT project PRODNET II (Camarinha 97) has proposed an architecture to support the virtual enterprise paradigm. However PRODNET II is centred on production planning and control and even if some problems would be similar, the concurrent engineering at virtual enterprise level creates special problems not addressed by this project.

***Extended CIM_FACE architecture*.** Using the concept of business plan to model a group of activities as a common goal, the proposal is to extend this concept to the virtual enterprise world. Let us consider that a virtual enterprise is a co-operative structure organised upon a group of enterprises connected through a network. Once established, all enterprises of the group know each other, have defined rights over the resources belonging to the virtual enterprise, and depending on their registered skills, they can contribute to the virtual enterprise business plans according to some assignment strategy. This strategy may depend on the business interests or expertise the enterprises have in some knowledge domains.

To better understand the main differences between the classical enterprise model and the virtual enterprise one, let us consider a business plan Pi whose execution is performed by a set of collaborators from the engineering, and the production sectors, as shown in **Figure 5**.

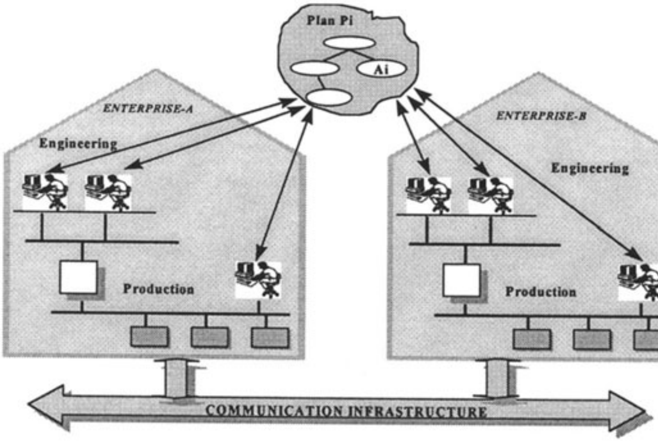

Figure 5 - A Business Plan executed by teams belonging to different enterprises.

The Business plan Pi is supported by the VCIM-FACE infrastructure of the owning enterprise. In a classical situation the execution infrastructure is confined to the enterprise borders. When it comes to the virtual enterprise, there is a need for the Business Plan to be located above any enterprise member. Any collaborator of any enterprise member can potentially contribute to the execution of this business plan. **Figure 5** illustrates a scenario where different users, located in different enterprises, are contributing to the execution of a common business plan. From the architectural point of view this new scenario raises the following questions:

- A business plan originated in an enterprise modeller, has now to be exported for execution by users from other enterprises.
- Considering that team contributors are spread around enterprise members, the execution architecture needs to locate shared and control information.
- The promotion of a business plan to a virtual space, which is an open space, requires the inclusion of security mechanisms guaranteeing privacy, integrity and authenticity of intervening users.
- It is necessary to guarantee the consistency of a virtual business plan execution.

Some of these questions are answered by the proposed extended CIM-FACE architecture (VCIM-FACE). However, the complexity of a distributed system suggests it is advisable to forget, for the moment, some of them. For instance, the availability of VCIM-FACE infrastructure could be improved by replication of some of the strategic services. However this strategy would require the solution of other complex problems, like the maintenance of information consistency.

Business plans at virtual enterprise level. In the envisaged scenario each enterprise will have its own information system, and an instance of the VCIM-FACE infrastructure. Internally all users have access, through the BP-assistant, to the active business plans and, for each one, to the activities they are authorised to perform. A business plan can be a local one or else a virtual enterprise business plan. When an enterprise user starts some planned activity in a virtual business plan, the interactions among the virtual enterprise nodes' information systems are transparent. For an enterprise user, the contribution to a local business plan or to a virtual one is similar.

The main changes are in the interactions among enterprise information systems and the execution/supervision architecture. Each business plan is owned by the enterprise that has created it (via the enterprise modeller) or has acquired its ownership (have received it from another enterprise). Each business plan has a virtual identification containing the enterprise's node identifier followed by the plan identification. To be known at the virtual enterprise level, a business plan needs to be exported during a negotiation phase. Finished this phase, the business plan acquires the same visibility to the users as a local plan.

The main necessary enhancements in the execution architecture of CIM-FACE towards VCIM-FACE are:

- Infrastructure to provide a virtual space to allow the sharing of a business plan among virtual enterprise nodes.
- The consistency of execution and control information needs to be maintained over the network.
- Bring in to the virtual space the shared data models representing the activity inputs and outputs.
- It is necessary to guarantee that a terminated activity can be validated independently of the enterprise node on which it is being realised.

To fulfil these requirements, the initial CIM-FACE execution and supervision architecture needs to be extended. Even if the establishment of an integration infrastructure is not easy, the main problem is however on the definition of an interaction protocol conducing to the desired transparent behaviour.

Extended execution architecture. The VCIM-FACE basic execution components are the Shared Data models, the Supervision Knowledge and the Execution models. Each one of its components is also sub-divided into smaller information structures supporting the execution of concurrent engineering activities. Besides the VCIM-FACE execution architecture components, Figure 6 presents also the extended components to enable CE at virtual enterprise level.

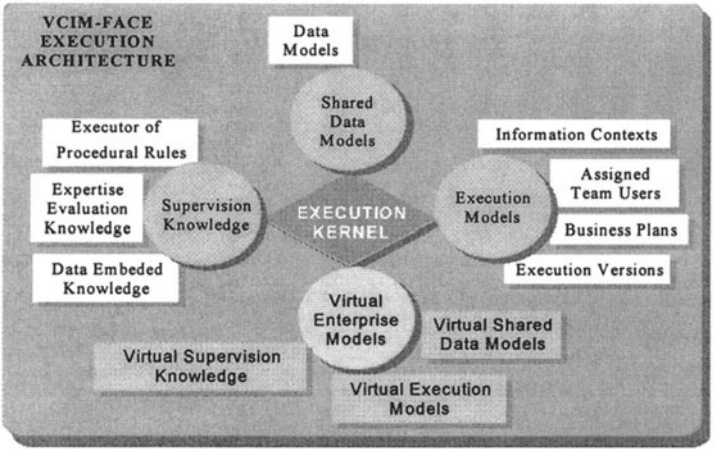

Figure 6 - The VCIM-FACE execution architecture

One of the main problems here is to maintain the consistency of the virtual enterprise business plans. In order to guarantee a complete transparency, the execution infrastructure is extended with a new protocol connecting all EIMS participating in a VCIM-FACE consortium. The EIMS of each enterprise node will guarantee the virtual space with the execution and supervision information in order to support the business plan execution life cycle when team users are co-operating from different enterprise nodes.

Engineering development privacy. One of the key factors that can contribute to the success of any virtual enterprise supporting architecture is its degree of privacy. As a distributed system, the VCIM-FACE architecture needs to be trusted, guaranteeing that engineering developments are maintained secret and they are only known inside the virtual enterprise consortium. By trusted architecture it means that it guarantees information privacy, information integrity and authentication of enterprises and team participants.

5 CONCLUSIONS

As a distributed system, VCIM-FACE presents a set of features to support co-operation among engineering teams when they are contributing to the engineering phase of the product life cycle. Extensions to the basic CIM-FACE system, from an enterprise-limited architecture to its integration in Intranet and/or Internet infrastructure, were presented. These extensions can provide VCIM-FACE with extended capabilities facilitating the integration of new and more flexible CA-tools and based on common accepted developing infrastructures like the new Java environment.

The adoption of CORBA to play the role of a wide software bus provides an open integrating infrastructure in order to facilitate the integration of new CA-tools. Furthermore it facilitates the development of proxy processes playing as bridges between legated systems and the VCIM-FACE architecture.

Another important factor in the VCIM-FACE architecture is its openness to the WEB infrastructure, providing both advertising and task assignment negotiation and support to the Telework. The CGI infrastructure was adopted to provide WEB access to VCIM-FACE public information and as a mean to register a new team member. A team member can contribute to the planned activities from home likewise the contributions made from inside the enterprise. This Internet/Intranet parallelism can contribute to the distribution of engineering teams be it by inter enterprise agreements or else by contracting individual experts working outside any enterprise space.

Besides the openness to the Internet through the adoption of Java and CORBA to provide WEB client access to VCIM-FACE, a new protocol was questioned to interconnect different enterprises' EIMS infrastructures in order to provide the execution of virtual business plans. This inter-enterprise co-operation at engineering level can greatly improve development resources and shorten product development cycle when the production is also spread by a number of enterprises.

As a consequence of the openness of CIM-FACE to the WEB space, the problem of security has emerged. The most recent achievements in this field are being applied to VCIM-FACE architecture to guarantee a private co-operation space based on the Internet.

6 ACKNOWLEDGEMENTS

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7 BIOGRAPHY

António Luís Osório is Adjunct Professor at the Polytechnic Institute of Lisbon – ISEL (Instituto Superior de Engenharia de Lisboa) in the Electronics and Telecommunications Department. He his writing his PhD. thesis in Information based Control for CIM Systems: a Concurrent Engineering platform. He is a founding partner of the ESTEC Company and is co-responsible for the R&D department of the same company. His main research areas are Concurrent Engineering and CIM, Operating Systems, Distributed Systems and Systems Integration, Data Communication Systems and Security.

Nuno Oliveira is a MSc student in the Computer Science department of the New University of Lisbon (UNL). He received the B.S. degree in electronics and telecommunications engineering in 1991 from Instituto Superior de Engenharia de Lisboa (ISEL) - Polytechnic Institute of Lisbon. He's graduated also in Computer Science from UNL in 1994. He joined the Department of Electronics and Communications Engineering at the ISEL where he is currently an Assistant Professor. His main interests are: Operating Systems, Distributed Operating Systems and Internet technologies.

Luis M. Camarinha-Matos is associate professor at the New University of Lisbon where he co-ordinates the Robotics and CIM group. He has been involved, both as researcher and has technical co-ordinator, on several international research projects in the areas of virtual enterprises, multiagent systems, intelligent manufacturing systems and machine learning. He has served in the Program Committee of many conferences and was one of the founders of the BASYS conference series.