An enterprise integration framework for manufacturing environments

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Abstract

Enterprise Integration (EI) deals with increasing interoperability among people, machines and applications to enhance synergy within an enterprise to better achieve business objectives. EI is both an organizational and a technological problem. An enterprise integration framework is presented in this paper for manufacturing environments based on works performed in projects of the European ESPRIT program (AMICE, AIT, OPAL). The framework relies on advanced technologies for systems and application integration (integration platforms, request brokers, electronic data and information interchange standards, workflow engines). It also includes an enterprise modeling framework to deal with business process and organizational aspects at the business integration level, with a special emphasis on human aspects.

Keywords

Enterprise Integration, Enterprise modeling, Manufacturing systems, CIM, Integration platforms, AIT, OPAL

1 INTRODUCTION

Enterprise Integration (EI) deals with increasing interoperability among people, machines and applications to enhance synergy within an enterprise to better achieve business objectives. This is a technological as well as an organizational problem. It can be limited to the scope of one enterprise or extended to several enterprises involved in a common supply chain (extended enterprise).

There is the need to develop frameworks for enterprise integration as well as technical solutions to achieve integration. Enterprise integration frameworks provide reference architectures and guidelines for business users to understand the purpose and scope of EI, position and compare potential solutions and explain relationships among these solutions. Examples of such frameworks are CIMOSA (AMICE, 1993), the European pre-norm CEN ENV 40 003 (CEN, 1990) or the GERAM framework of the IFAC/IFIP Task Force on Architectures for Enterprise Integration (Williams *et al.*, 1994; Williams, 1995). Technical solutions consist of methods, modeling tools, software packages, and standards as well as particular architectures. The bad news for business users is that they are characterized by their tremendous diversity and frequent incompatibility.

In this paper, EI is first defined with regards to the manufacturing context (including inter- and intra-enterprise integration). A global framework for enterprise integration is then presented as a result of a study conducted by AIT, a European initiative for advanced IT in design and manufacturing. The framework relies on advanced technologies for systems and application integration, including communication networks and protocols, distributed computing environments, shared databases, electronic data interchange and data exchange formats as well as hypertext. The business integration level addresses business process modeling at various stages of the enterprise life cycle (requirements, design, implementation) as recommended by reference architectures for EI (CIMOSA, ENV 40 003, GERAM). Emphasis is placed on the modeling of resource and organizational aspects of manufacturing enterprises, with a special emphasis on human aspects. The last section presents some conclusions.

2 ENTERPRISE INTEGRATION

Enterprise Integration (EI) is mostly concerned with breaking down organizational barriers and making the enterprise, or even a network of enterprises in the case of the extended enterprise, interoperable to improve enterprise efficiency and reactivity. It is essentially concerned with facilitating decision-making in distributed environments, simplifying business processes across the enterprise and providing the right information at the right place at the right time (Petrie, 1992; Vernadat, 1996).

Organizational issues: EI is first of all an organizational problem. If information and decisions are not properly transmitted, understood, managed or processed, then the enterprise will not operate correctly and its organizational structure has to be revisited before any technological change be made. Furthermore, the role of human resources remain central and essential in EI.

Interoperability: From a technological point of view, to make integration possible there is the need to facilitate communication exchange and sharing as well as inter-working throughout the company. This assumes the availability of an integrating infrastructure, i.e. a middleware facility with a set of computer services to support the exchange of messages, information or objects and to send requests to remote systems and receive responses.

Two types of enterprise integration problems can be distinguished: intra-enterprise integration versus inter-enterprise integration.

Intra-enterprise integration, or 'inside the four walls integration', typically refers to the CIM concept extended to the whole enterprise. Technologically, it could be achieved if company standards are imposed on the enterprise in terms of a limited number of compatible and interoperable pieces of equipment, standard interfaces and normalized procedures and data structures to be used. Although feasible, this would be a too rigid approach to meet the need for reactivity imposed nowadays by fluctuating market, business and technological conditions. The CIM concept must evolve towards EI to take into account agility, human factors as well as knowledge and decision-making distribution requirements.

Inter-enterprise integration concerns have emerged with the extended enterprise concept. The challenge is to face such realities as global markets, the rise of mass customization and the need to develop environmentally benign products and processes (Browne et al., 1995). The solution is to build networks of enterprises to look beyond 'the four walls of the manufacturing plants', i.e. control the whole value added chain to better serve the customer world-wide and have access to resources (human or technological) outside the enterprise. Inter-enterprise networking is the key. Again, this is first of all an organizational problem (e.g. choice of partners, business network, legal issues, intellectual rights, etc.) before being a technical problem (e.g. computer networks, distributed databases, EDI).

3 ENTERPRISE INTEGRATION FRAMEWORKS

3.1 General EI framework

Traditionally, three levels of integration are differentiated: physical or system integration, application integration and business integration (AMICE, 1993). Table 1 provides an indication of integration aspects covered by each level while Figure 1 provides an indication of technologies involved. Physical system integration is mostly concerned with system interconnection and message passing using computer communications networks. Integration services, distributed computing environments and object request brokers can then be implemented on top of these. Application integration builds on physical systems integration and is more concerned with application interoperability and distributed co-operative applications and requires data and information exchange using integration platforms (such as CORBA, AIT-IP or OPAL). Finally, business integration goes beyond application integration in terms of business process co-ordination and enterprise networking. It must take into account organizational issues and human factors and requires enterprise-wide knowledge sharing. This assumes a precise modeling of intimate enterprise details concerning enterprise procedures, organization, knowledge and know-how in the form of a shared enterprise model. Part of this model can be enacted using workflow engines and computer support for collaborative work (CSCW).

Table 1 Integration levels and aspects

Integration levels	Integration aspects	
Business	Business process coordination Enterprise-wide knowledge sharing Interworking; enterprise internetworking	Organisation and human issues
Application	Distributed cooperative applications Data/information exchange Application interoperability	Technological issues
Physical	Basic computer communication Message passing Interconnection

Figure 1 Integration levels and related technologies

Figure 1 shows the diversity and complexity of technologies involved in EI. These are briefly discussed in subsequent sections. Historically, they have been tackled from the bottom level, i.e. from a technical point of view because of technology evolution reasons. However, from a methodological point of view and taking advantage of recent technology advances (concerning high speed networks, distributed computing environments, object-oriented technology, hypermedia technology, workflow management and CSCW), EI must be addressed first at the business level (concentrating on business process and organizational issues) and then at the technological levels (application and system levels).

To illustrate parts of the general framework, two examples (AIT-IP and OPAL) are discussed from our experience in integration platform development for integration in manufacturing, and especially from the ESPRIT program and its AIT initiative.

3.2 AIT-IP

AIT is a European initiative launched in 1993 for Advanced Information Technology in design and manufacturing activities. It is sponsored jointly by all major European manufacturers of the automotive and aerospace industries and by the ESPRIT Program of the Commission of the European Communities (CEC). Its aim is to identify industry requirements for future IT solutions and influence IT product development on the basis of a consensus built among IT users.

Among major requirements identified by AIT there is the need for an integration platform making the business support applications or BSAs (CAD/CAE, CAPP, MRP, CAM, SFC) independent from the IT basic infrastructure proposed by IT vendors, thus allowing their independent evolution (principle of application isolation). The integration platform must enable integration of business support applications using a 'plug and play' strategy to guarantee IT vendor independence and protection of previous investments (principles of modularity and interoperability).

To specify the requirements for such an integration platform, a reference model, called AIT ITRM for AIT IT Reference Model, has been defined (AIT, 1995). The AIT ITRM is an open, standard-based, non proprietary reference model defining middleware requirements for integration in large distributed manufacturing environments. The ITRM envisions integration as a set of interoperable integration platforms being installed at different user sites and providing a number of integration services. The ITRM is organized around a software bus (which could be CORBA-like object request broker) as depicted in Figure 2. Integration services include generic execution services (GESs), application front-ends (AFEs), machine front-ends (HFEs), human front-ends (MFEs), data server front-ends (DFEs) and communication front-ends (CFEs). In addition, system-wide actor directory management services record all functional entities (humans, machines or applications) used in the enterprise architecture and system-wide information management services access information models containing the enterprise model are mandatory.

These integration platforms with the necessary services can be installed on various sites of a company to integrate specified application systems. They can then be interconnected to one another to form an enterprise-wide network forming an integrating infrastructure for some part of an enterprise or for a group of enterprises (extended enterprise).

3.3 OPAL

OPAL is a software platform for integrated information and process management dedicated to design and manufacturing environments (OPAL, 1996). OPAL is developed as an ESPRIT project as part of the AIT initiative. OPAL takes advantage of modern technologies for information management and sharing including object request brokers, object-oriented database technology, neutral product and process data exchange formats such as STEP, workflow engines and hypermedia technology such as the HTML and the world-wide web (WWW).

The global system architecture of OPAL is presented by Figure 3. It consists of a data repository, an execution environment based on a workflow engine as well as a middleware layer (based on the CORBA object request broker) and central services for system-wide message and object exchange and interoperability.

Figure 2 The AIT integration platform

Figure 3 OPAL general architecture

The enterprise repository containing business process, organization and data models to be used to control business support applications. Process models and data models are stored using a common object-oriented structure. Each application package (e.g. CAD, PDM or MRP system) must be encapsulated using its application program interface (API) to become an agent in the integrated system (encapsulation services). It can then be accessed by other modules via the middleware layer (based on CORBA) and the central services (naming services, time services, communication services and information services). Since this integrating infrastructure is dedicated to engineering and manufacturing data management, it also provides so-called virtual folder system services and WWW-browser facilities to deal with product data. The virtual folders are used to collect and transmit technical documents (e.g. CAD drawings, bills-of-materials, product documentation, simulation data, text files, etc.) put together as one document and to be exchanged by users or application systems across the system. Hypermedia web browsers facilities provide users with the ability to navigate through the product and process data to which they have access wherever they are located in the system.

The specification of OPAL took place in 1996 and a prototype is planned for the end of 1998. Two industrial pilot test cases are under development at PSA in France and Robert Bosch in Germany.

4 SYSTEMS INTEGRATION

The system integration layer has been the focus of tremendous research efforts over the last two decades both from the traditional EDP standpoint and the CIM standpoint. OSI (MAP/TOP) and non-OSI communications protocols (Ethernet, SNA) are now widely available both for local and wide area networks. The current trend is on one hand improving the performance of computer networks (bandwidth and speed) and on the other hand having simple, fast, low-cost communication at the equipment level.

The state of the art in manufacturing environments is to use field-buses (based on FIP or ASI protocols) at the equipment level, local area networks based on TCP/IP at the station, cell or plant levels and ATM technology at the cell, plant and enterprise levels.

Furthermore, Internet and web technology are rapidly penetrating the manufacturing area from design offices to shop floors. This is made possible by the emergence of the object-oriented technology and distributed computing environments such as OSF/DCE and OMG/CORBA.

5 APPLICATION INTEGRATION

For many companies it is important that their applications can inter-operate, i.e. work together and not in isolation whatever the operating systems, database systems or communication network regardless of the systems. Therefore, application integration concerns data/information exchange and sharing as well as application interoperability. Three complementary trends are currently under development in this area:

Data exchange formats and data and knowledge manipulation languages: Manufacturing and engineering data appear in various forms in an enterprise, including text, drawings, images and signals. Central to these are product and process data. Application integration thus relies on standards such as EDI for administrative data exchange, STEP for product and process data exchange and SGML for technical document exchange. In addition, access to data can be made via SQL to relational databases, OQL or ODMG for object-oriented databases and QKML/KIF can be used to exchange knowledge. PIF is a language developed as a process interchange format while WPDL is the workflow process description language of the Workflow Management Coalition (WfMC).

Integration services and integration platforms: The client/server architecture provides a basic model for the communication between two (remotely located) interacting or co-operative agents: the client and the server. The infrastructure linking agents in a client/server architecture is called an integration platform. AIT-IP and OPAL are examples of such platforms for the manufacturing industry. An

integration platform is a set of computer services together with a middleware layer built on top of communication systems to facilitate message and request exchange among agents (or functional entities or actors) of a system. These services can deal with data transmission, data access security, transaction management, concurrency control, clock synchronization, binding a name to an object, tracing a request to a client, data presentation to an application, computer network access, to name a few.

Workflow management and enactment: Application packages are often used according to predefined business procedures called business processes and made up of a chain of activities to be executed in a given order to perform a business task. To control the execution of these processes, they can be modeled in the form of a workflow which can then be executed under the control of workflow execution engines.

To learn more about basic principles and techniques for application integration, the interested reader is referred to (Vernadat, 1996).

6 BUSINESS INTEGRATION AND ENTERPRISE MODELLING

So far the discussion has concentrated on the technological aspects of EI, essentially because this is the facet of EI which is best understood although still incompletely solved. In this section, we focus on logical aspects, and especially the organizational and human aspects, of EI. In practice, these are the concerns which must be addressed first.

From the experience gained on the development of CIMOSA (AMICE, 1993), it is the author's opinion that enterprise modeling (EM) plays a crucial role in EI. In fact, EM is a pre-requisite to EI (Vernadat, 1996).

Reference architectures for EI (CIMOSA, ENV 40 003, GERAM) suggest modeling business entities or enterprise domains according to four views (function, information, resources and organization views) and three modeling levels (requirements definition, design specification, implementation description).

Various methods have been recently published for enterprise modeling in manufacturing (IDEF suite of methods, GRAI/GIM, CIMOSA, IEM, ARIS, OMT). Users of the above modeling methods must make sure that in addition to modeling functional and information features other features such as resource and organization aspects, and especially human factors in terms of competencies and skills as well as decision-making abilities in terms of responsibilities and authorities, are correctly represented.

However, according to the PERA methodology (Williams, 1992), first it is fundamental that any integration project be preceded by a master planning activity to define the scope of the EI project, the mission to be achieved and the policies and strategies to be deployed. Second, during system development, it is essential to define the role and place of humans within the information and control architecture as well as in the manufacturing equipment architecture.

Therefore, enterprise modeling methods and tools must pay special attention to three fundamental aspects of industrial systems: business processes, agents and organizational aspects.

The modeling of business processes covers the modeling of the control, information and material flows within an enterprise. The control flow is represented by a workflow depicting the sequence of activities to be performed as an event-driven process chain. The information and material flows are defined by the inputs and outputs of activities involved in a business process. IDEF3 (Mayer et al. 1993) and the CIMOSA (Vernadat, 1993) process model are state-of-the-art methods in this field.

Agents represent the functional entities or actors of the system, i.e. any entity able to send, receive, process requests or even store information. They may represent autonomous devices, software applications or humans. Because of their dynamic nature and autonomy in terms of behavior, they need to be modeled separately from processes and be binded to processes only at run-time. Agents are usually characterized by their set of provided services (or interface), their set of offered capabilities, location, availability and sometimes capacity. In the case of human resources, important characteristics are skills and competencies. Once defined, these can be used to define a user's profile to fulfill a role as required by the execution of some activities of a process. Human skills are defined in terms of capabilities that a person can have or exhibit. Competencies are defined in terms of knowledge trees which describe domains of expertise and know-how possessed by users. The elaboration of knowledge trees requires the help of knowledge engineers.

Organizational aspects can be modeled in terms of organization units and organization cells. An organization unit is any functional entity or agent having some responsibility and authority. In other terms, it has some decision-making power on some part of the enterprise. Its area of responsibility and job profile must be known. Knowledge and know-how required for this duty can be modeled using knowledge trees and compared with knowledge trees of employees qualified for this job. Organization cells are aggregations of organization units or smaller organization cells to form a decision center within the enterprise. Each organization cell must be placed under the responsibility of an organization unit which must be a person. Decision centers can be organized into decision levels to construct the organization structure of the enterprise (be it hierarchical or decentralized).

While a lot of work has been done on the modeling of business processes and information systems of an enterprise, further work remains to be done on resource and organization aspects, and especially human factors, to build human-centered integrated manufacturing systems.

7 CONCLUSION

Enterprise Integration should be a target for any industrial company either struggling in a competitive environment or contributing to a network of partner companies. The benefits of EI should be increased efficiency and competitiveness

by means of better communication, co-operation and co-ordination of the functional entities of the enterprise (in terms of co-ordination of business processes and enterprise-wide information sharing) and better reactivity to changing business conditions by a controlled management of change.

Nevertheless, business users must keep in mind that first EI is not a technology but a goal. It is first of all an organizational problem before being a technological problem. Moreover, EI is a never ending process. Even the best integrated manufacturing system can always be further integrated. New technologies and management principles can be constantly used to push integration boundaries forward. However, the real challenge with EI remains to be able to provide humans with the right tools, information, decision support or empowerment they need to perform their work more efficiently and in symbiosis with the rest of the enterprise.

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9 BIOGRAPHY

François Vernadat is a French and Canadian citizen. He holds a Master degree (1979) and the Ph.D. degree (1981) in Electronics and Automatic Control. He has been a research officer at the Division of Electrical Engineering, National Research Council of Canada, Ottawa (1981-1988) and then at INRIA, a French research institute in computer science and automatic control (1988-1995). He is currently a professor in automatic control and automation at University of Metz, France.

His research interests include CIM, database technology and information systems, enterprise modelling, enterprise integration, manufacturing systems specification, formal description techniques, Petri nets and workflow enactment. Beside his work on the M* methodology for CIM information systems, he has headed the development of a main-memory database system (DBS/R) and was one of the chief architects of CIMOSA, an Open Systems Architecture for CIM developed as a series of ESPRIT projects (AMICE). He is the author of over 120 scientific papers in journals, conferences and books. He is the author of "*Enterprise Modeling and Integration: Principles and Applications*", a co-author of the book "*Practice of Petri nets in Manufacturing*" and a co-editor of the book "*Integrated Manufacturing Systems Engineering*", all published by Chapman & Hall. He has been a co-chairman and invited speaker of several conferences on CIM. He is the European editor for the *International Journal of Computer-Integrated Manufacturing* and a member of the scientific committee of other journals and conferences.

Dr. Vernadat served several times as a technical expert for the CIM programme of the Commission of the European Communities (CEC). He is the vice-chairman of two IFAC Technical Committees (Manufacturing Modelling, Management and Control and Architectures for Enterprise Integration) and a member of the IFAC/IFIP Task Force on Architectures for Enterprise Integration. He is a member of the IEEE Computer Society, ACM and SME.