4

State-of-the-art on models, architectures and methodologies

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This chapter intends to give an overview on models, architectures and methods for the CIM systems design. We start from presenting the basic concepts and definitions of CIM, model, architecture and methodology, as well as the concepts of the economic and human aspects of CIM. Then we present some early work performed in the 1970–80s; ICAM, CAM-I, NBS, SADT, SSAD, GRAI, MERISE and SSADM. Following this there is a state-of-the-art evaluation of the work performed within the ESPRIT Program, particularly MMCS, E932 knowledge based factory model, PAC model, CIMOSA, IMPACS and FOF. We also give an overview on recent CIM architecture work in the USA, and in particular the Purdue Reference Model and Enterprise Reference Architecture and the EIP approach. Some IT vendor based approaches are also presented such as the IBM model and the Digital model. The CIM architecture work performed in the Asia and Pacific area is not ignored. Simulation models for manufacturing systems are also mentioned. The object oriented approach for CIM systems design performed by IPK Berlin, Germany and recent developments on the GRAI-GIM methodology and ECOGRAI at the GRAI laboratory in France are also reported.

4.1 BASIC CONCEPTS AND DEFINITIONS

The term CIM is usually used to describe the process of integration of all of the elements involved in manufacturing, by means of computer techniques, and has usually been confined to a purely technical interpretation. Today, the many difficulties encountered in the course of various implementations have shown that such a narrow outlook is not satisfactory: economic, social and human aspects must be taken into account. We consider that 'CIM refers to a global approach – in an industrial environment – which aims at

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improving industrial performance. This approach is applied in an integrated way to all activities, from designing to delivery and after sale, and uses various methods, means and techniques (computer and automatic techniques) in order to simultaneously improve productivity, reduce costs, meet due dates, increase product quality, secure flexibility at the local or global level in a manufacturing system, and involves every actor. In such an approach, economic, social and human aspects are at least as important as technical aspects' [1]. This broad definition shows that CIM cannot be bought; each firm must devise its own, which explains why methodologies must be made available so that CIM systems can be built.

The word 'methodology' means a set of methods which involve the use of: modelling formalisms and their associated graphic tools; models and reference architectures; and structured approaches.

A modelling formalism is a means to represent pieces of knowledge that have to be transmitted unambiguously. It allows one to build models according to a set of associated concepts. The theoretical basis for modelling formalisms can be found in the graph theory, the languages and logical structures theory, etc. The modelling formalisms that are used to model production systems are often associated with graphic tools. A good diagram is often better than a long speech.

A model is an abstract, simplified representation of reality. A model of a CIM system can only represent a set of selected elements concerning the domain studied, and in agreement with defined objectives. A good model amplifies the important characteristics and conceals the details which are considered to be of a low or no importance at a given abstraction level. In the CIM area, models are supported by mathematical formalisms, languages and/or graphical tools.

A CIM architecture can be defined as a structured set of 'models' which represent the invariant building blocks of the whole CIM system. It is considered as a basis for the design and the implementation of CIM systems. These models, which contain the invariant elements and the relations between these elements, describe respectively the 'what' (what a CIM system is conceptually composed of), and the 'how' (how a system technically works), and show how to transform the models into realities, i.e. the working system [1,2]. A reference architecture is the architecture for a class of manufacturing systems. One derives the architecture of the enterprise studied by adapting the reference architecture to the specifics of the enterprise.

Generally speaking, a structured approach defines a set of steps to be followed when applying a methodology to the solving of a problem. In a CIM design methodology, the structured approach should cover the whole life-cycle of the CIM project which is split up into several steps (analysis, design, development, implementation, operation). All these steps should be perfectly defined and based on the project type structure, consisting of particular actors whose roles are clearly defined. For each of these steps, models will be built and coherence and validation will be controlled between the various steps, and between the various models.

Talking about the economic issue of CIM one can find that in today's companies the economic factor is often not taken sufficiently into account in everyday decision making. Many of the management decisions are made without knowing their effects on costs. Recently, the GRAI laboratory has developed the ECOGRAI method which allows one to identify the economic decision centers of a production management system in order to implement performance measurement systems.

Implementing a CIM system in a company will inevitably cause large changes in its running style. During the ESPRIT Project 1217, the concept of HC-CIM (Human Centered CIM) was developed. Traditional functional system design considers the human as a mechanism basically equivalent to other resources like machines, etc. The HC-CIM approach provides an opposite understanding of the human role in the production process; not as a supplement to supervise the process and manage exception, but as the acting and interacting backbone supplemented and supported by technologies to make the human capabilities more productive. It requires the integration of the technical and the social domain and rejects a technology driven understanding of integration [3].

4.2 EARLY WORKS ON MODELS OF ADVANCED MANUFACTURING SYSTEMS

Between the end of the 1970s and middle of the 1980s, some work on models of advanced manufacturing systems was performed in the USA and in Europe. The ICAM model (Integrated Computer Aided Manufacturing) was elaborated within one of the major projects led by the US Air Force. The ICAM model [4], also called 'Model of Manufacturing' was especially designed for the aerospace industry. It displayed the functions of aerospace batch manufacturing and the detailed relationships between those functions. The ICAM model was supported by The IDEF (ICAM Definition) methodology. A more general model for a large variety of manufacturing enterprises was built within CAM-I (Computer Aided Manufacturing International). CAM-I is a nonprofit organization formed to promote cooperative R&D efforts in CADCAM. Over 100 large companies from around the world have joined CAM-I. A factory model was proposed with four levels of decomposition [5]. At each level we find seven main generic functions. Two levels of this model (shop and cell levels) were described in the 'Factory Management' project in which GRAI laboratory was involved. However, no associated tools were developed within CAM-I. The CAM-I model was found to be too conceptual and was not widely used.

Another initiative launched during the same period of time was the NBS model which later became a widely accepted reference model. It also the first model published as a CIM architecture. The NBS model aimed to have an extreme flexibility in order to emulate the wide variety of manufacturing cells which are typical of a small machine job shop in the domain of machining and assembly. It fits particularly well in a fully automated manufacturing environment with a highly complex computer based sensor system [6]. At the same period in Europe, the GRAI models [7] were developed to meet the needs of the modelling of decisional systems. The GRAI models consist of a macro conceptual reference model for manufacturing systems (Fig. 4.1) and a micro conceptual model for decision centers. Compared with the ICAM, CAM-I and NBS models, GRAI models are based on system theory and present the decision making aspect. The GRAI model is a reference through which various elements of real world can be identified. The macro conceptual model is used to express one's perception and ideas on the manufacturing system which is decomposed into a decision subsystem, an information subsystem and a physical subsystem. Particularly within the decision subsystem one finds a hierarchical decision structure composed of decision centers. Decision centers are connected by a decision frame (objectives, variables, constraints and criteria for decision making). The operating system is an interface between the decision system and the physical system. The micro conceptual model is used to represent the internal elements and structure of the decision center.

4.3 METHODS FOR DESIGNING ADVANCED MANUFACTURING SYSTEMS

In the middle of the 1970s, there was a need to deal with complex systems and structured analysis and design techniques began to draw attention. SADT (Structured Analysis and Design Technique) was developed by SOFTECH to analyze such complex systems [8]. SADT uses the Actigram (similar to IDEF0) and the Datagram for studying function and data aspects.

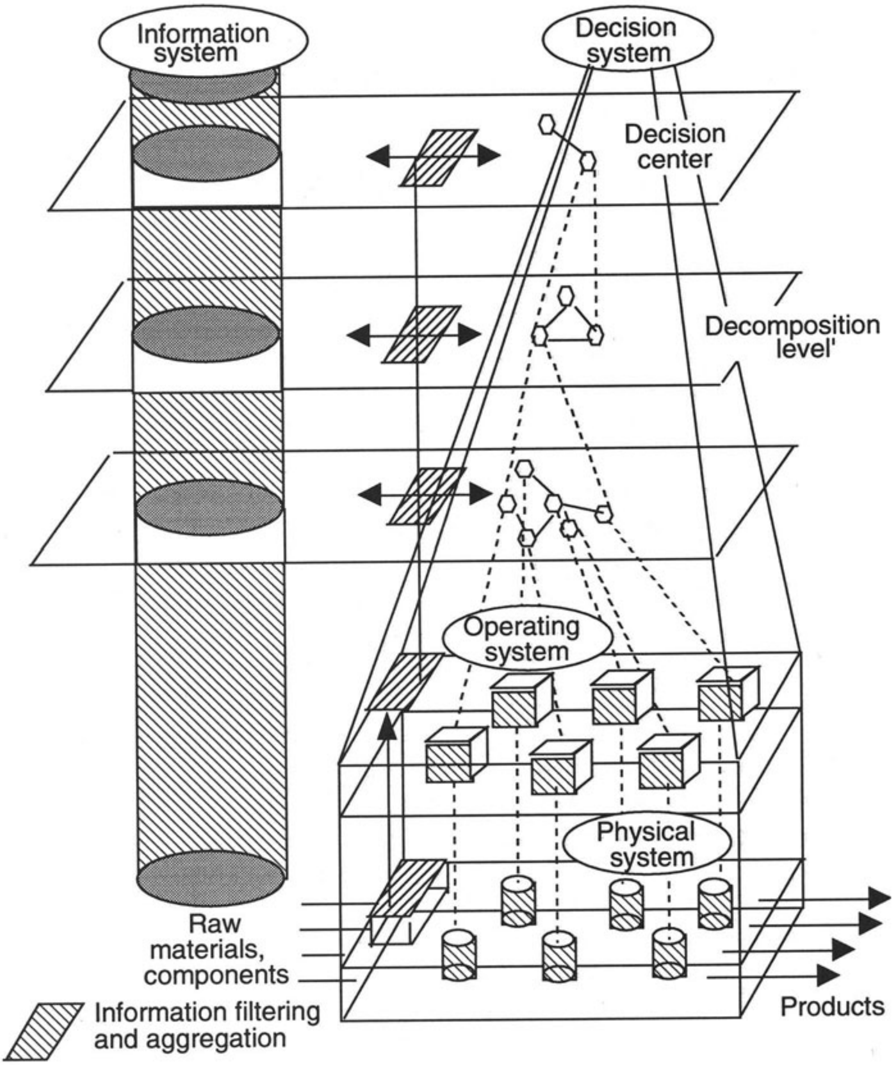

Figure 4.1 The GRAI conceptual model.

The method is supported by many computerized tools. SADT is not, properly speaking, a method to design manufacturing systems. However, it has the advantage of proposing a relatively general approach which can be adapted to a great number of applications. SADT turned out to be more adapted to the analysis and understanding of a complex system than to the technical designing of a manufacturing system. At the same period, the

SSAD (Structured System Analysis and Design) method was developed by Chris Gane and Trish Sarson [9] and marketed by Improved System Technologies Inc. (I.S.T.), now owned by Mac Donnell Automation. It is derived from the works of De Marco on the Data Flow Diagram [10]. The method consists of building a graphical (non physical) model of systems. Compared with SADT, SSAD is particularly well adapted to the analysis and design of computer supported information systems. However, SSAD cannot be considered as a method for designing CIM systems.

In order to cover various other aspects involved in the design of manufacturing systems, the ICAM project developed the IDEF (ICAM Definition) methodology to support the elaboration of ICAM models. IDEF in total consists of several different modelling approaches: IDEF0 is used to build a functional model, IDEF1 is used for the information model and IDEF2 for a dynamic model. Recently, IDEF1 was extended to become IDEF1x to help build a semantic data model. IDEF3 and IDEF4 were also developed to help deal with the topics of the enterprise scenario and object oriented modelling. In IDEF, structured approaches with well identified team works are defined. IDEF is the most used approach for CIMS design. IDEF0 is closely related to SADT.

Similar work on methods was also carried out in Europe, notably the GRAI method [7] and MERISE method [11]. Before developing the GRAI method, some existing works had been reviewed, notably SADT and SSAD methods. It was found that the decisional aspects were not very well taken into account in these methods. So, it was important for the GRAI method particularly to deal with the decisional aspects of manufacturing systems. Based on the GRAI models, two formalisms were developed to model the macro decision structure and the micro decision center; the GRAI grid and GRAI nets. A structured approach was defined to show how to apply the method. The GRAI method has been transferred to industry (over 100 industrial applications). Two ESPRIT-1 Projects (418 and 932) allowed some improvements of the method, and several ESPRIT-2 Projects are using it, such as ESPRIT 2338 and 2434, and an ESPRIT basic research Project FOF [18]. While the GRAI method focused its attention on the decisional aspect, the MERISE method was developed in France for the analysis and design of information systems. It is used for designing data models (static models) and data processing models (dynamic models) at three levels of abstraction; conceptual, logical, and physical.

A formalism, based on the principle of Petri nets, has been developed to build data processing models. The Entity/Relationship formalism has been chosen to model static data structures. The originality of the MERISE method probably lies in the fact that it considers the synchronization of data in the data processing model as a vital aspect in designing an information system, whereas quite a number of other methods (SADT, SSAD) do not regard the synchronizing aspect as a fundamental factor. In MERISE, abstraction levels are clearly defined, while in other methods, they do not exist.

Another method dealing with information systems design is the SSADM (Structured Systems Analysis And Design Method) developed in the UK by CCTA (Centre Computer and Telecommunications Agency) in the early 1980s. It is the UK government's standard method for carrying out the systems analysis and design stages of an information technology project. SSADM has been traditionally used for the development of medium or large systems. However, one variant of SSADM is 'Micro SSADM' which is for small systems. SSADM starts from defining the information system strategy and then develops a feasibility study module. These are followed by requirements analysis, requirements specification, logical system specification and a final physical system design.

4.4 RECENT WORKS ON MODEL/ARCHITECTURES WITHIN THE EUROPEAN ESPRIT PROGRAM

In the middle of the 1980s, the Commission of the European Community launched the ESPRIT research program. The GRAI Laboratory was involved in several ESPRIT Projects in the CIM area, particularly ESPRIT Project 418, Open CAM System; ESPRIT Project 2338, IMPACS; ESPRIT Project 3143, FOF; and ESPRIT Project 5288, CIMOSA.

The MMCS (Manufacturing Management Control System) [13] was developed within the ESPRIT Project 418 – Open CAM System, in which the GRAI laboratory was involved. This model is aimed at the problem of Shop and Cell planning and control with well defined interfaces (see Fig. 4.2). These interfaces transform, where necessary, the external data view into the MMCS view. Via a database, the system is able to interface with the available commercial MRP system at the factory level. The core functions of the MMCS are the Shop and Cell Controllers. Both the controllers have the same structure. They are responsible for the management of jobs, capacities and materials at Shop and Cell Levels respectively. While the MMCS model is very generic it is challenged by an even more generic model: the PAC (Production Activity Control) model. The PAC model was developed

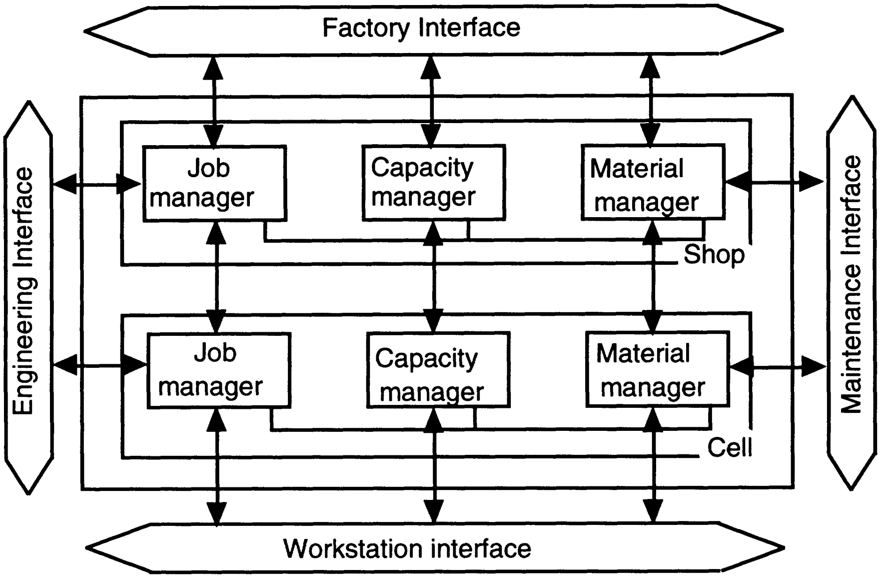

Figure 4.2 The MMCS model.

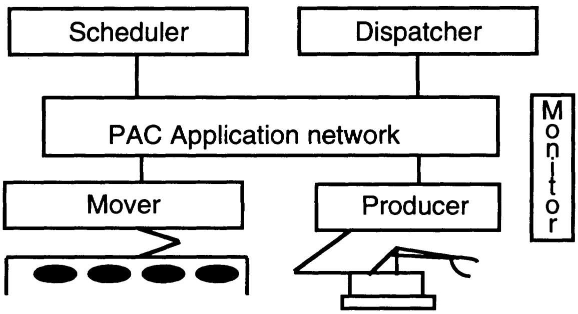

Figure 4.3 The PAC model.

within the ESPRIT Project 477 entitled COSIMA (Control System for Integrated Manufacturing) [14].

One of the basic principles of PAC as shown in Fig. 4.3 is the recognition of five basic building blocks representing the functions required for production control: Scheduler, Dispatcher, Mover, Producer and Monitor. Communication between these building blocks is facilitated through the use of the Application Network which was developed as part of the project. This

Application Network also supports message passing across different nodes thus providing the means to develop a distributed PAC system. MMCS and PAC models are limited to the shop and cell levels. A more global model for factory supervision and control was defined in the ESPRIT Project 932 to support decision making at all levels. This model is based on the NBS model and the GRAI model and uses an intelligent workcell controller concept. A controller (see Fig. 4.4) performs three basic tasks (Planning, Quality Control and Preventive Maintenance). Various expert system tools have been developed to support these controllers.

		PQM functions		
Organizational unit	*Time Horizon/ Time Period*	*Planning (P)*	*Quality (Q)*	*Maintenance (M)*
Factory	year/month			
Shop	month/day			
Cell	day/minute			
Workstation	minute/sec.			
Automation module	millisecond			

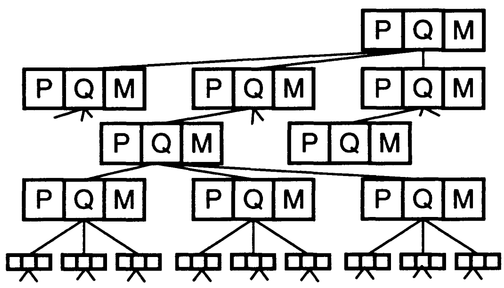

Figure 4.4 Knowledge based real-time model.

The knowledge based, real-time control, reference model enforces the decision making aspect by introducing some important concepts from the GRAI model, such as the Decision Horizon/Period and the Decision Frame, etc. The implemented system becomes totally goal oriented by means of the use of a 'decision frame'. The ESPRIT Project 932 finds its sequel in a new project; ESPRIT Project 2434 in ESPRIT 2.

The ESPRIT Project 2434 is concerned with real-time controllers for distributed factory supervision. The results achieved in ESPRIT 932 were used directly in ESPRIT 2434. The objective of this latter project is to make modern production philosophies (OPT, JIT, LOP, etc) available on the factory floor by delivering decision support to each relevant function of the factory using knowledge based software techniques.

During the same period, another initiative for developing an Integrated Manufacturing Planning And Control System was launched within the frame of the ESPRIT Project 2338 entitled IMPACS. It is probably the first attempt to design integrated planning tools that would bridge the gap between global planning and production control based on very long term strategic planning (3 to 5 years) and real-time control at the cell level [15].

IMPACS considers it very important to design all of the tools needed within an architecture context. A framework for an architecture [16] (see Fig. 4.5) and the IMPACS method also known as GRAI-GIM (General IMPACS Method) have both been proposed. The IMPACS architecture is

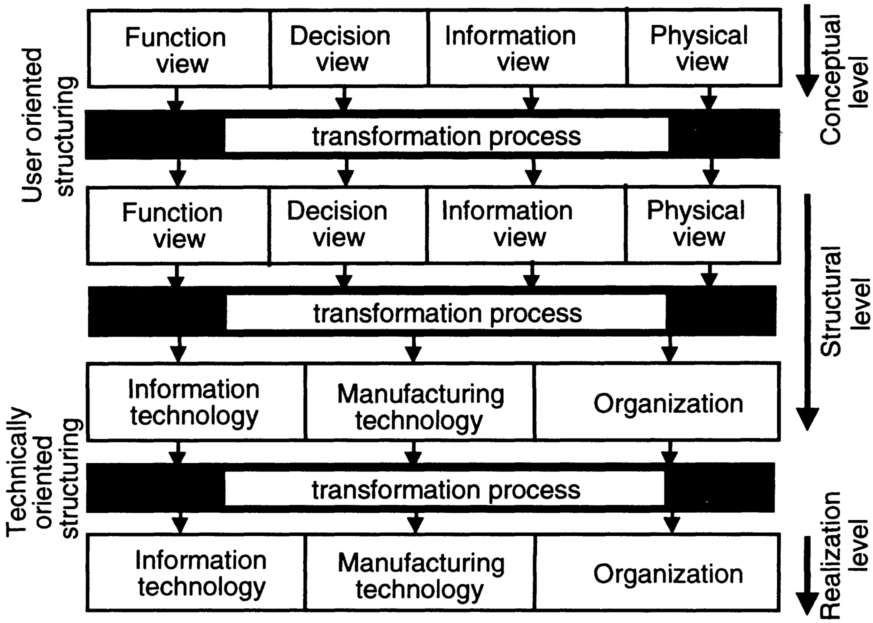

Figure 4.5 Framework for the IMPACS architecture.

defined at three levels of abstraction, conceptual, structural and realisational. The conceptual architecture allows one to define all the elements that are needed in an IMPACS system; the structural architecture defines how to structure the identified elements into the conceptual architecture, and the realisational architecture shows the final real tangible system.

It is generally considered that production in the future will be based on a one-of-a-kind system of product production. That's why the FOF Project (Factory of the Future – a Basic Research Action in the ESPRIT Programme) was launched. The ultimate goal of the project is to obtain a designer's workbench for the development of CIM in future production systems providing one-of-a-kind products (OKP) to the market, each OKP will require its own product design and process design [12].

There are many methods for describing the operations which occur in production systems. However, the methods are all fundamentally fragmented as they are all based on a set of scattered, theoretical notions (communication, organization, human point of view, decisional approach). Fig. 4.6 illustrates the various 'views' identified in the project, and points out

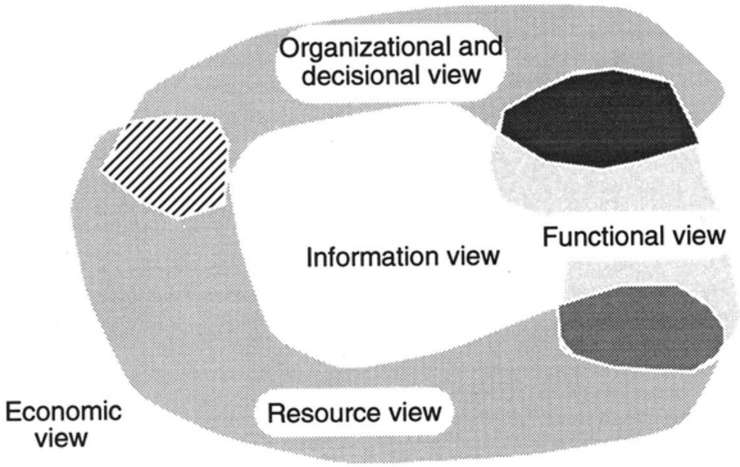

Figure 4.6 Views of the FOF model.

their relationships. As the views are presented separately, we need an integrated approach for PMS design. This integrated approach in the design phase was first based on an integrated model called REMBRAND. A set of Design Choice (DC) and a set of Performance Indicators (P.I.) were connected by a set of relations. The designs of the Production Management System (PMS) were done in agreement with the value of the P.I. and depending on the DC. See Fig. 4.7.

In some more specific areas of CIM, it is worth noting that the ESPRIT Project CNMA allows the extending of MAP. The ESPRIT Project CIM-ALIVE established a common project CIM reference model identifying cost effective reusable CIM concepts. ESPRIT Project CIM-Plato developed a prototype toolbox consisting of a set of computer-aided procedures and tools to design, plan and install FMS and FAS systems within the CIM environment.

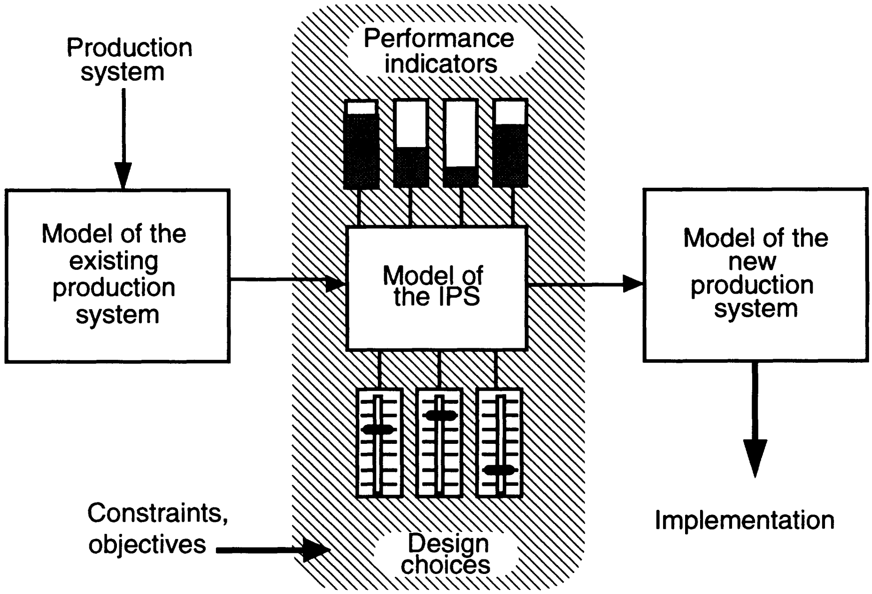

Figure 4.7 FOF workbench: relation between DC and PI.

In particular, in the methodology area, the ESPRIT Project 2706, MICIM (Methodology for the Introduction of CIM), considered that the methodology for progressing towards an integrated manufacturing environment has largely been neglected with most of the emphasis of current work being placed on the problems arising in technology. This project therefore concentrated on defining a methodology to remedy this. On the economic aspect, the ESPRIT Project CIMSIM intends to provide a methodology and associated tools for the economic and technical evaluation of various CIM solution options. An ESPRIT Exploratory Action 5603 is dealing with the problems of incorporating human factors into technology research and development along with techniques for the economic justification of CIM.

Lastly, we close this section by introducing CIMOSA [17], the well known CIM Open System Architecture developed by the AMICE Consortium, and the most important CIM initiative within the ESPRIT program. The term AMICE is a reversed acronym for 'European CIM Architecture'.

The aim of this project is to elaborate an open system architecture for CIM and to define a set of concepts and rules to facilitate the building of future CIM systems. An important aspect of the project is its direct involvement in standardization activities. The two main results of the project are the Modelling Framework, which is well known, and the Integrating InfraStructure (see Fig. 4.8). The Modelling Framework

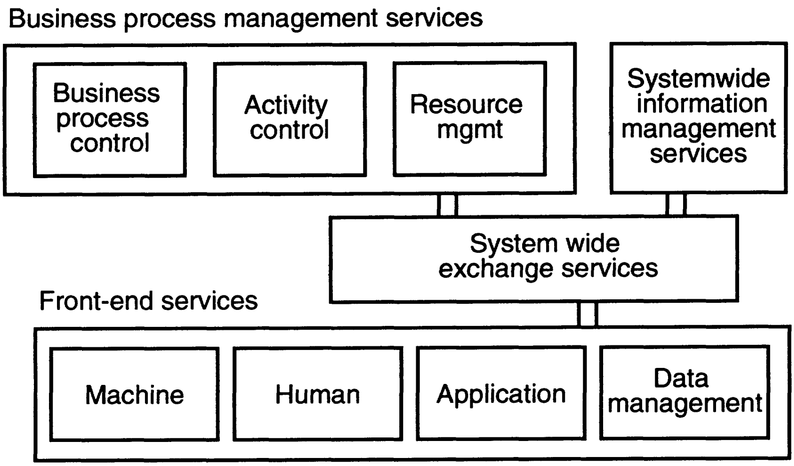

Figure 4.8 CIMOSA Integrating Infrastructure.

supports all phases of the CIM system life-cycle from requirements definition, through design specification, implementation description and execution of the daily enterprise operation. The Integrating Infrastructure provides specific information technology services for the execution of the Particular Implementation Model, but what is more important, it provides for vendor independence and portability.

CIMOSA insists particularly that the released model of the CIMOSA architecture should be processable or executable and evolutive, e.g., it can be modified easily during the run time. CIMOSA also intends to provide a methodology to show how to use the reference architecture to get a particular architecture of the studied enterprise. These are known respectively as the CIMOSA Model Creation Processes, and as the CIMOSA System Life Cycle. The CIMOSA modelling framework has been adopted by CEN/ CENELEC as the European prestandard for enterprise modelling, where it is known as ENV 40003.

It is worth noting that several ESPRIT projects are currently carried out to evaluate and validate CIMOSA, notably the ESPRIT Project VOICE (Validation OSA in Industrial CIM Environments), the ESPRIT Project CIMPRES (CIM Model and Implementation Concept in Precision and

Special Tooling Industry). Another ESPRIT Exploratory Action, 5605, is developing applications of CIM concepts, architectures and technology to Computer Integrated Agriculture based on CIMOSA.

4.5 RECENT CIM CONCEPTS AND DEVELOPMENTS IN THE USA

For several years, the distinct CIM architecture developments in the USA have been abundant, but each of them is based on its own architectural definition. No consensus has been achieved on what a CIM architecture is. There is no way of justifying an architecture proposal. The CIMCON 90 Conference at Gaithersburg showed that this situation had not been improved as of that date. Thus the USA parallels the situation in Europe.

CAM-I [5] considers the content of a CIM architecture was not intended to provide 'the answer' to the many complexities of CIM implementation, but rather was to be used to establish a common understanding of some of the identified elements comprising the CIM jigsaw puzzle. A CIM architecture should be viewed as a blueprint for the future, not as a detailed migration strategy or strategic planning road map to solve a current problem [18].

NIST considers it necessary to define a global architecture to integrate several separated architectures. They have argued that 'such an architecture has three interrelated management components, production, information, and communication' [6]. For each of these components, there must be an architecture. As for the Battelle Memorial Institute, they consider that there are many parts to defining an architecture for a CIM system. The following categories have been identified: functional relationships, information relationships, processing relationships, sequence relationships and control relationships [19]. The RAMP (Rapid Acquisition of Manufactured Parts) architecture which they developed is an aggregation of several perspectives of the RAMP system, including an IDEF0 functional model, a Yourdon-De Macro data model, a simulation model, a process control flow model, and physical models of the shop floor and hardware and software configuration [20].

From the point of view of Philips USA, a CIM architecture should describe a production organization as a configuration of interacting components. They assume that the purpose of an 'architecture' is to show how a production organization can be integrated, i.e. composed of closely coordinated components, and controlled. They indicate that a common, although not universal, denominator of CIM architectures is their hierarchical structure of 'controllers'. They have proposed that a CIM architecture should have a 'natural structure', e.g. a structure with the 'conceptual integrity that allows a human to master a production organization as a whole, despite its inherent complexity' [21].

The Sandia National Laboratories, a subsidiary of AT&T, considers that a CIM architecture is a formal representation which provides an integrated user interface over a very broad collection of application platforms, all from different vendors. There are several sources for obtaining physical and operational descriptions of computer and network architecture, but for a functional system architecture only the guidance exists and not the description available for the more specific system. They consider that there are only two useful viewpoints in the logical representation of a system architecture. These are the User View and the System View. The system view might be further represented by both a Designer's view and an Implementor's View [22]. They have discovered that one must not only base a new CIM architecture upon functional requirements and specifications, but that these must, in turn, rest upon well considered business and technical policies [22].

From Honeywell's point of view, 'the architecture does not provide a solution; it provides the discipline and the mechanisms needed to evaluate various alternatives, and to select a solution with reasonable confidence' [23]. The CIM reference architecture provides a common starting point for all the manufacturing units in an organization to use in developing their own organization specific architectures. They define the CIM architectures as a structured interrelationship of principles, functional models and guidelines.

The Purdue University group has proposed a 'Purdue CIM Reference Model' [24]. It was the oldest of the reference models but has recently been updated to meet the needs and requirements of CIM modelling specifically. They consider that a reference model is a previously agreed-upon or 'standard' definitive document or conceptual representation of a system. The reference model defines requirements common to all implementations, but is independent of the specific requirements of any particular implementation. In May 1988, the CIM Reference Model Committee of the International Purdue Workshop on Industrial Computer Systems completed this Reference Model for CIM: a Description From theViewpoint of Industrial Automation [25]. This reference model compiles a generic listing of those tasks which must be carried out by the integrated computer control system of a manufacturing plant in any industry to achieve CIM as understood today. The model arranges these tasks in a hierarchical functional framework to show their proper primacy and subordination to each other. It also shows the necessary data flow between these tasks, defines the relationship of the factory to those external entities which influence its operations, and develops a mechanism which allows the definition of the procedure for the carrying out of any one task [24].

The Purdue group has also very recently developed a major extension to their previous work to develop a full architecture called The Purdue Enterprise Reference Architecture. This has been published by the Instrument Society of America [25] and is becoming widely accepted in America particularly in process industries circles.

Another approach drawn to our attention is the CIM architecture studied in Carnegie Mellon University. It uses the intelligent networking concept as the element to facilitate the integration of the distributed heterogeneous functions of a manufacturing enterprise [26]. The integration is supported by having the network; first, play a more active role in the accessing and communication of information, and; second, by providing the appropriate protocols for the distribution, coordination, and negotiation of tasks and outcomes. The Enterprise Management Network architecture [27] uses the GRAI approach for its organization layer.

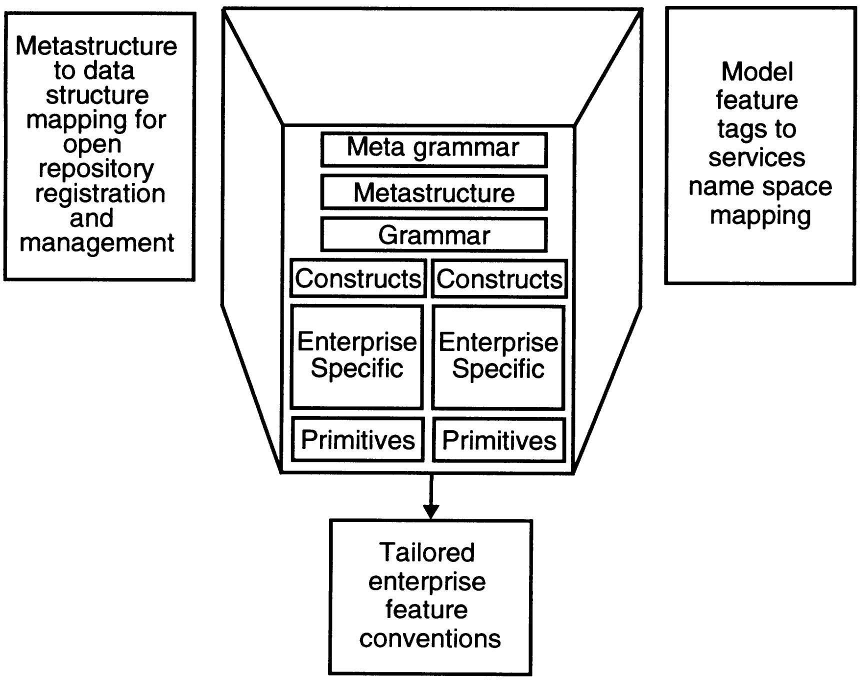

Figure 4.9 Unified model strategy.

Besides the university and company developed architectures, the EIP (Enterprise Integration Program), a research and development program composed of several projects, is being carried out in the USA. The Program Manager is the US Air Force and the Prime Contractor is SOFTECH. The EIP has four phases (framework, 18 months; commercialize, 24 months; pilot sites, 14 months; round up, 4 months). EIP considers that there is a global race for the technology to be first to market with the best. The range from the strongest to weakest will be decisive. The best performers will be those who excel at coordination. Specific improvements in process or product yield will only give temporary advantage. The source of a sustainable advantage will be the ability to continually improve.

EIP believes that Enterprise Integration is concerned with getting the right information, parts, processes, people, cash and products to the right places at the right times, and with reacting rapidly to changes in market demand, resources, technology and organization. The EIP seems to be the most important program in the US for the time being in the area of CIM. Close cooperation with the European AMICE Consortium (CIMOSA project) has been established in order to seek the complementary advantage which may exist between EIP and CIMOSA.

It seems that EIP addresses a broader scope than that of CIMOSA. EIP intends to integrate any and all models in an enterprise, all running in a heterogeneous and open environment (See Fig. 4.9). The US had sponsored two studies on an Enterprise Integration Framework (EIF) which focused on the applicability of CIMOSA to the US definition of the EI problem space. Cooperation between AMICE and US would emerge in a more internationally harmonized framework.

4.6 MODELS DEVELOPED BY IBM AND DIGITAL

The two biggest IT vendors in the United States, IBM and Digital, early realized an enormous market potential for CIM products and started to concentrate on the development of CIM solutions in the early 1970's. Presented below is only an overview of part of their known work.

In the early 1970's, IBM begun to develop a general CIM philosophy named Communication Oriented Production Information and Control System (COPICS) which comprised all the major planning and control activities of manufacturing. The emphasis was made in communication, database management and presentation as shown in Fig. 4.10. Originally IBM intended to promote their software and hardware solution within the framework of COPICS. No general CIM architecture was developed. Due to the

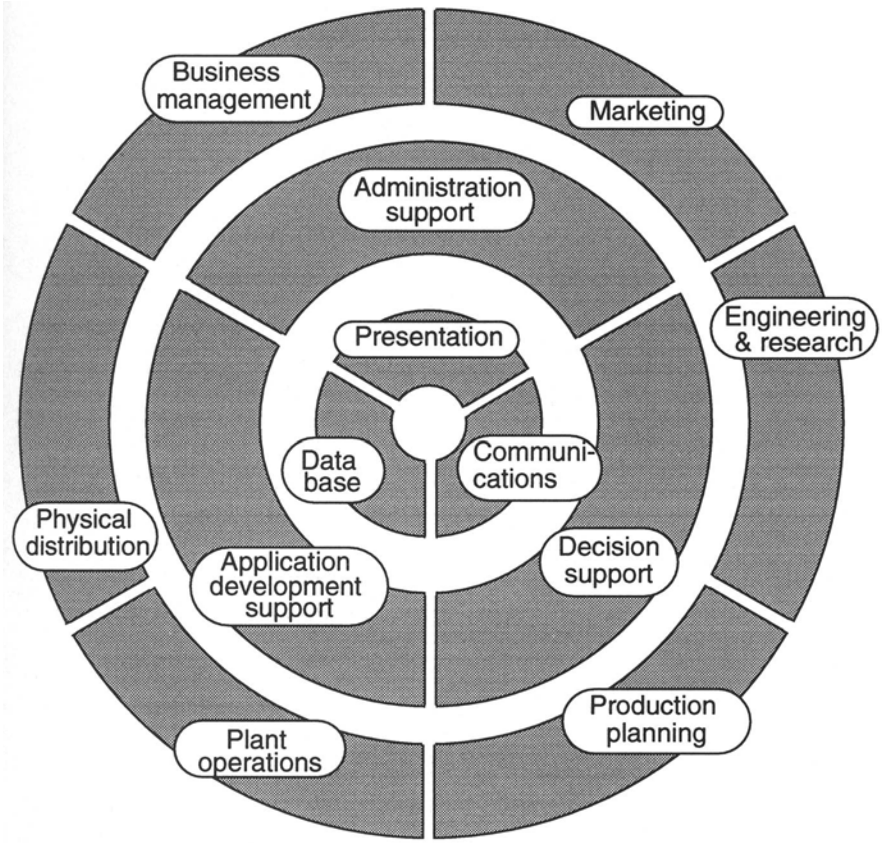

Figure 4.10 CIM architecture elements as defined by IBM.

more and more concurrent software and hardware solution for CIM coming from other IT vendors, IBM was asked by their clients to make its products compatible with the others. The approach adopted by IBM in answer to this was to offer general interfaces to integrate other products into their concepts, by using communication systems based on mainly LAN and MAP [29].

Digital has developed an Information Technology model (IT model) to support communications between two subsystems. This IT model is an extension of the OSI model, as shown in Fig. 4.11. It has adopted a layered approach.
Four layers have been defined as follows:

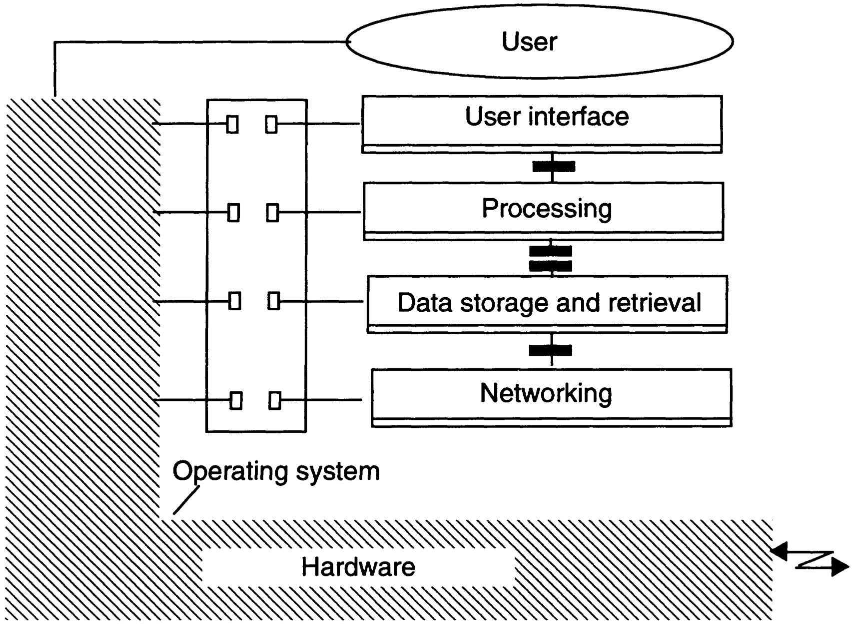

Figure 4.11 Digital IT model.

1. User (man/machine) Interface, which facilitates the transfer of data to and from the system and application;
2. Data processing, which performs the instructions requested by the user, via the user interface;
3. Data storage and retrieval, which provides services to the application to store and retrieve data;
4. Communication, which provides network links to other services and applications.

The role of the IT model is to support the interconnection of heterogeneous systems.

Another Digital CIM initiative is the NAS architecture (Network Application Support) which enables application integration and portability across a distributed, multivendor environment [29]. NAS is considered as a Digital strategy for a unified software environment allowing open and standard implementation of CIM applications.

4.7 ARCHITECTURE WORKS PERFORMED IN THE ASIA AND PACIFIC AREA

Nippon Steel Corporation reported an Industrial Automation System Model. More recently, Mitsubishi Electric Corp. has developed an object oriented approach to model factory automation systems [30]. This system architecture adopted a three level hierarchical distributed system architecture. The three levels are: factory management level or factory host-computer level; area level or FA-computer level; and Cell level or FA-controller level. As for networks, the following three kinds of networking are involved: OA-(Office Automation) networking; FA-networking; and factory backbone networking which is for interconnecting OA-networking and FA-networking. Logical modelling is based on an object-oriented approach resulting in an object oriented and class structure diagram and a message flow diagram. A case study was done on the logical modelling of the automatic assembly line control system of automobile manufacturing factories.

China launched a ten year government CIM research program in 1986 with five key reference sites for implementation. The CIM architecture and methodology projects are led respectively by the East China Institute of Technology associated with the Shenyang Automation Research Institute and the Tsinghua University. The methodology works are mainly based on an IDEF like approach. Partial implementation of IDEF0 and IDEF1x were performed at the reference sites. The architecture works are mainly based on CIMOSA. Efforts were made to develop partial models for the mechanical industry at the shop floor level. A method to create a functional model was also developed [31]. A Cooperative Program between the EEC (European Economic Community) and China in the area of CIM started in early 1992 and will run for three years. The GRAI Laboratory was chosen by the EEC as the Program Coordinator and has been involved in the methodology work.

Last but not least, the work performed at Griffith University and CSIRO Manufacturing Technology on CIM architecture and methodology should not be ignored. They consider that architecture, modelling techniques and development method are closely related. A distributed integration platform is being developed to integrate applications [32] based on an object-oriented approach. They believe that the object-oriented data models and object-oriented implementation environment can help to overcome the difficulties encountered when using a traditional top-down functional analysis and design in a heterogeneous computing environment [33].

4.8 SIMULATION MODELS

Simulation is a computer technique which consists of reproducing the dynamic behavior of a system on a computer in order to model it. This is done to get a better idea of the evolution of the system with time in a given environment and to assess its performance. Getting a good dynamic model for the simulation is difficult. Although some designers work directly with the dynamic system, one of the most often used working methods advocates a transition through a static model (see Fig. 4.12) which describes the

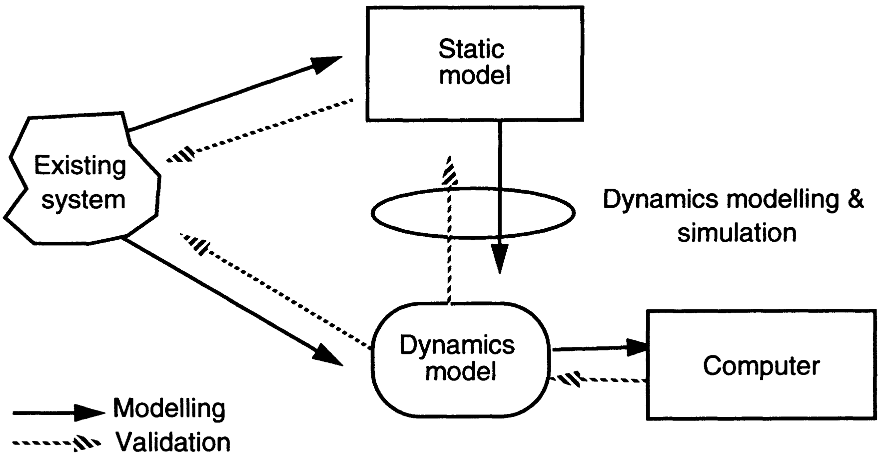

Figure 4.12 Simulation approach.

entities and their links without any notion of time (i.e. steady state). This step is essential since it allows the researcher to take into account the static aspects of the system. It also makes it possible to develop the dynamic model only when the static model has been validated. Several approaches for modelling a discrete system can be distinguished:

1. Event oriented approaches (SLAM, SIMAN etc) consist in modelling a system by describing the succession of events in the course of their evolution.
2. Activity-cycle oriented approaches (CAPS/ECSL, SIMGRAI, etc) consist in defining the activities by describing the conditions needed for their beginning and end.
3. Process-oriented approaches (SIMULA, QNAP2, etc) consist first in defining adequately the current processes, in order to cover the maxi-

mum number of current configurations. Second, it will then be enough to assemble all of the processes as needed for the elaboration of a given model.

4. Object-oriented approaches (OASYS, HOCUS, etc) consist in modelling the system by means of a set of objects which communicate between themselves by sending appropriate messages. This approach allows one to reduce the life-cycle to the steps of modelling, simulating and analysis of the results [34].

4.9 OBJECT-ORIENTED APPROACHES FOR CIM

An object-oriented approach was initially developed at IPK Berlin [35] as a programming approach. Later on it was extended to the modelling of information systems. Recently, some further work has been performed to use an object oriented approach for the modelling, the analysis and design of global CIM systems. Early work such a MOOD (Methodology for Object Oriented Design for CIM systems) was performed jointly by Digital Munich and IPK Berlin.

MOOD (see Fig. 4.13) allows the integration of two views (planner and designer). The planner and designer will be guided in the way used for mapping their objects onto a uniform object frame. The object oriented paradigm considers a system as a collection of objects and their relationships. MOOD will provide the developer with a set of generic object classes. These classes are suitable for the modelling of arbitrary CIM systems, production activity systems, etc.

As for the advantages of the object oriented approach, they consider that existing approaches (in particular, functional design and structured analysis) are partial life-cycle methods, i.e. they either focus on the analysis or on the design of the system to be developed. The requirements captured in the analysis phase cannot be mapped directly into software design. There is a 'semantic gap' between what users require and what they get. Software development requires, independent of the applied approach, that the units of the problem domain are mapped onto a software structure. In the object oriented approach, this mapping is considered to be very natural.

More recently, an IEM-GAM model (Integrated Enterprise Modelling – Generic Activity Model) was developed at IPK Berlin. The IEM approach distinguishes the objects of the manufacturing enterprise by their intended purpose into: (1) products, (2) orders and (3) resources. The kernel of the enterprise model is derived from the definition of the classes of the objects in relation to their process description with the generic activity model (IEM-

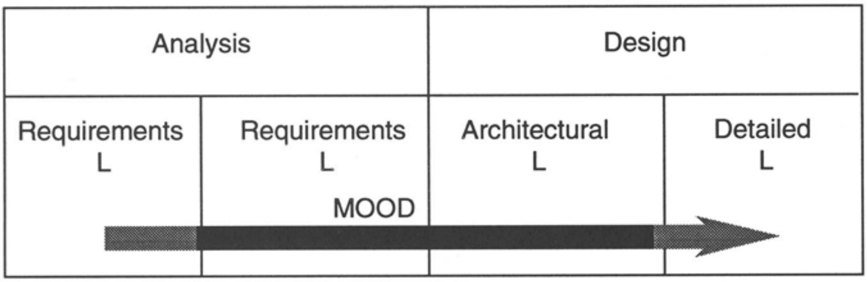

Figure 4.13 MOOD Approach.

GAM). It contains the description of two main views of the manufacturing enterprise, (i) the function model and (ii) the information model. Both views are interlinked by using the same objects and activities but looking upon and representing them in different views, ways, grades of detail, and context [35].

4.10 RECENT METHODOLOGY DEVELOPMENT AT THE GRAI LABORATORY

The ECOGRAI method developed in the GRAI Laboratory allows an investigation to design and implement a set of performance indicators for the PMS. In fact, an indicator is, first of all, a piece of information, but a special type of information, of which decision makers want to control the value. An indicator should be related to a set of decision variables which are the means for a decision maker to influence the evolution of that indicator. Implementing indicators leads to the specification of a set of potential answers for the decision makers of the production management system.

ECOGRAI uses a structured approach of four phases. Phase 1 consists of the decomposition of the project objectives. The global objectives of the production system will be decomposed into the objectives of the individual functions. Phase 2 consists of analysing the management system structure. In this phase, one identifies economic decision centers and the objectives and decision variables of each decision center. An economic decision center is a decision center which itself has a significant effect on cost. Phase 3 consists of building a set of control panels with various performance indicators displayed. The consistency between these indicators and the objectives/ decision variables must be checked at this phase. One also checks the consistency between different functions and within each function. Phase 4 is the specifications of the information system, e.g. identification of the data and data processing needed by the indicators. ECOGRAI was successfully applied in the SNECMA factory in France, and there are now other implementations.

Another work performed at the GRAI laboratory was the extension of the GRAI method to GRAI-GIM (GRAI Integrated Methodology) within the framework of the ESPRIT Project 418, Open CAM system and ESPRIT Project 2338, IMPACS [36,37]. GRAI-GIM contains a user-oriented method and a technically-oriented one (See Fig. 4.14). The user-oriented method

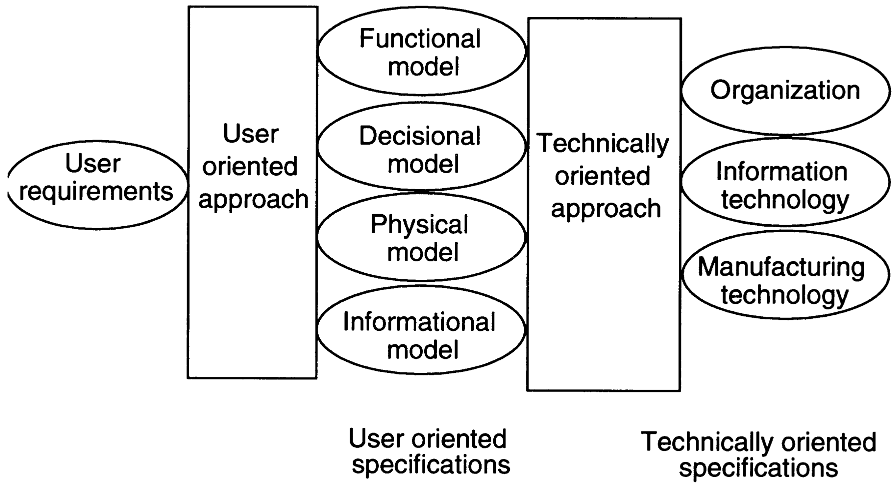

Figure 4.14 The GRAI-GIM methodology.

transforms user requirements into user specification in terms of function, information, decisions and resources. The technically-oriented method transforms the user specification into technical specifications in terms of information and manufacturing technology components and the organization. The technical specification must allow the implementor to choose (buy, commission, or develop) all the components needed to implement the system. A computerized support tool known as CAGIM (Computer Aided GIM) is being developed at the GRAI Laboratory within the framework of the IMPACS project on Unix systems with X-Windows, to support the GRAI-GIM method.

4.11 SUMMARY

Generally speaking, most of the work discussed here has concentrated on models and architectures. A few projects deal with methodologies. These were particularly IDEF and the GRAI based work. Models and methods developed in the 70s and early 80s (ICAM, CAM-I, NBS, SADT, SSAD, etc) are being challenged by new models, architectures and methods currently being developed within the ESPRIT Programme and in the USA. Particularly, CIMOSA has the most potential importance as it is striving to be the future generally-accepted CIM architecture. GRAI and ECOGRAI methods allow the user to study the decisional and economical aspects of CIM systems. GRAI-GIM (GRAI Integrated Method) provides an integrated methodology for the analysis and design of decisional, physical and information systems. Object oriented approaches currently developed at IPK Berlin have opened a new way to deal with CIM systems design. Simulation will be more and more involved in the global CIM system design. The work performed within the IFAC/IFIP Task Force has started to evaluate these major CIM models, architectures and methods, and will identify the generic requirements for a CIM architecture. All existing architectures and models are found to be heterogeneous, and the general impression is that the lack of a universally accepted CIM reference architecture can easily become the bottleneck in CIM industrial applications. System openness, portability and interoperability will progressively become a reality only through worldwide standardization.

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