Integrated Application Systems for Manufacturing

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Abstract: One of the main progress directions of Applied Information Engineering is to develop profession-specific application systems. Integration demand of Production Information Engineering is more than 30 years old. Why need is there for integration? The birth and evolution of CIM-paradigm. Progress of the functional modelling of production enterprises. The CIM-OSA concept. The results of EAI technique. Interfacing the applications to the enterprise environment. Experience getting from the modelling and integration tasks of the projects entitled "Digital factory" and "Information support to real time co-operative production structures" respectively.

Keywords: Production Information Engineering, IT for manufacturing, application systems, system integration

1 Introduction

Nowadays creation of integrated application systems has become one of the central problems of progress of Applied Information Engineering. As is known, *Information Science* deals with acquisition, transferring, storing, processing, understanding and using of information. Its theoretical background, above all, is of mathematical origin (Information Theory, Finite State Machines, Algorithms Theory, Formal Languages, Abstract Data Modelling, etc). *Information Technology* (IT) is a special technical scientific area, which deals with large areas of the research of hardware and software tools for information processing. Information Technology, however, is essentially a tool, by means of which it is possible to make applications realizing social benefit.

Applied Information Engineering is the science of computer applications. This is an interdisciplinary field of science expressively, because computer applications can be considered virtual model based transformations of physical, social, industrial, production, commercial, administrative, bank, etc. processes. *Production Information Engineering* (or: *Information Technology for Manufacturing* as it is proposed in [1]) is a specific area within the framework of Applied Information Engineering, which deals with computerized modelling, design, planning and control of production systems and processes, respectively.

The computer-aided applications used in the field of production processes in the beginning, were suitable for supporting well-defined engineering application areas (mainly for design and planning). They were, i.e., as follows: manufacturing automation, manufacturing systems, robots, product design and NC-programming. These applications used the models, database, graphics and interactive man-machine interface of their own and operated independently of each other. As a consequence of increasing the number of applications, demand appears for the integration of applications. *Integration is defined as a connection of those system-elements, which are capable for co-operation in interoperable, coherent and compatible way in order to create a complex technical system.* It is important to underline here that the three aspects of integration mentioned above (interoperability, coherency and compatibility) are in a close connection of the pragmatic, semantic and syntactical properties of information.

As a result of industrial demand, the CIM paradigm was born at the end of seventies of the last century [8], which set as an aim the integration of computer-aided applications for production. At the level of IT at that time, the main tasks were the connection of I/O interfaces of applications and accomplishing the standards required to this. It is interesting to recognize that integration started with connecting the control equipment and solving their program supply, i.e. at the nearest hierarchy level to technology processes themselves.

In the course of integration developments in the late eighties the MAP initiative of General Motors played an important role [6], which was concentrated to producing a shop-floor level computer network as the main tool of integration. Integration of technical design, planning and control systems can be denoted by the abbreviation CIM-E (Computer Integrated Manufacturing and Engineering). In the early nineties of the last century the ESPRIT project revealed the problems of connection of production information engineering applications in a more detailed and penetrating way. These problems can be summarized as follows [2]:

- surprising complexity of production tasks;
- heterogeneity and strong model-dependency of application systems;
- frequented incoherency of interfaces;
- communication network (protocol) problems;
- lack of standards;
- excessive being closed of applications;
- the lack of component-based approach and of the property "*reusable*", and as a consequence of the problems listed above:
- lack of readiness for co-operation, i.e., lack of *interoperability*.

Cumulated synergic effects of several factors have made it possible to solve the problems. Among them the most important is the extremely rapid development of IT, especially of hardware tools. Wide-spreading of the network technology and of the platform-independency oriented development connecting with Internet have also a significant role. Development of technical data base management is of great importance as well, in which the SQL standard and the consecutive generations of Oracle servers have got an outstanding role. These have made it possible to integrate technical and business processes.

Enterprise Resources Planning (ERP) systems have come into being (Computer Integrated Manufacturing and Engineering and Management = CIM-EM).

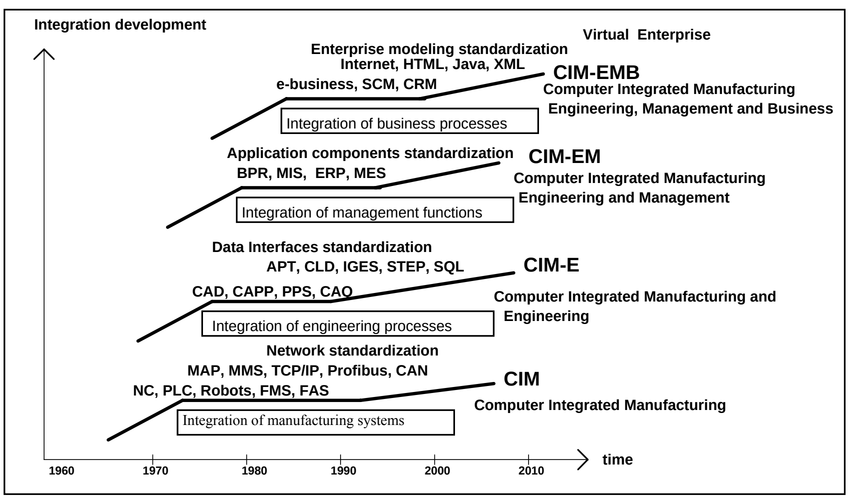


Figure 1

Progress of CIM-paradigm

At this level of integration syntactic adaptability is the main requirement no longer but semantic compatibility and pragmatic (object-oriented) interoperability have become the most essential aspects.

In the field of Information Technology for Manufacturing the most significant venture for development of integration tools was the SIMA program, within the framework of which the NIST (National Institute for Standard and Technology) set as an aim to support integration of industrial computer applications [4]. The SIMA program was concentrated to elaborate reference architectures, models, standards and integration methodologies. The ESPRIT project of EU was established in order to achieve similar objectives [2]. The main objective declared was to create a new integration platform. The CCE-CNMA (**C**IME ***C****omputing* ***E****nvironment* – ***C****ommunication* ***N****etwork for* ***M****anufacturing* ***A****pplications*) project built its conception on those IT-results, which were created by object oriented programming and networking technology in the nineties. The strongest point of the proposed platform was to elaborate and introduce open applications and protocols. However, these efforts were in certain contradiction of the interests of system manufacturers.

Networking technologies and reliable large bandwidth communication conduced to realization of the functions of Virtual Enterprise (VE). In addition, supply chains, distribution logistics systems and electronic commerce resulted in the integration of business applications. Integration of technical management and of business applications made it possible to apply such technical-economic models, which improved the adapting capabilities of firms in the global environment to a great extent.

This level of integration has been supported by a new software technology. After the turn of the millennium, the further development of IT conduced to a new paradigm named *Enterprise Application Integration* (EAI) within the framework of which integration tasks can be solved by means of *multi tier* applications, network and integration servers, as well as Java 2EE (Enterprise Edition) language technology [1], [5].

2 The Structure of Application Systems in Production Information Engineering

The structure of IT applications for manufacturing has developed in parallel way to the results of modelling for production processes. Of the late years, *Enterprise Modelling* has become a new area of science. Numerous results achieved in the CIM-OSA project have a great influence to the progress of the area [2], [14]. In the modelling as a whole, functional model was separated both from resource and organization model, as well as from information infrastructure model and application model, respectively. The CIM-OSA project distinguished and defined three model types, they were as follows: *general*, *specific* and *individual* models, as well as the three viewpoints of requirements, design and implementation.

Integration of applications has 3 dimensions at least [12]:

1 Integration of applications for the functions subordinated hierarchically to one another. Here the main criterion is that the system at the higher hierarchy level transports constraints to determining the solutions of the lower hierarchy level.

2 Integration of the activities at the same hierarchy level, which can be carried out in parallel way. The methods are given by the principles and tools of Concurrent Engineering.

3 Integration of the functional systems having a fixed sequence in time and providing data to one another. Here the main task is to ensure coherency of data.

The earlier aspect based on networks and hierarchy has been succeeded by a new approach based on the model oriented components of applications. In the course of this changing, the application systems demonstrated in Figure 2 have formed. An ERP system is built on the common data model of business and management functions. The most powerful software developing firms (SAP, People-Soft, Oracle, etc) have developed those solutions in step-by-step way, which are able to adapt to the products and technology of the enterprise in question, including the component-oriented, individually scalable and functionally adaptable solutions.

The basis of integration of product design and technology process planning is a common geometrical-physical entity model. The leading applications (AutoCAD, CATIA, ProEngineer etc) use such reference models that facilitate integration.

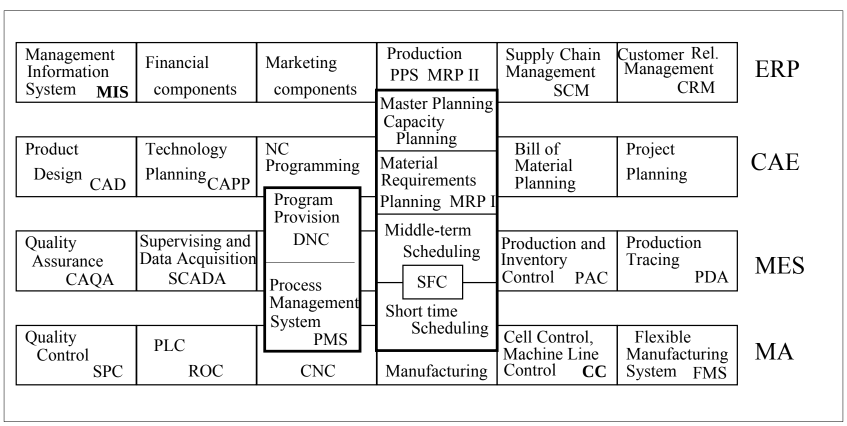


Figure 2

An integrated application system for manufacturing

Component oriented approach of manufacturing control and execution systems is a product of results of the last ten years. The big MES (Manufacturing Execution System) manufacturers (CIMNET, Wonderware, Matrix etc) and their alliance (MESA) elaborated a functional element-set of 11 elements that is suitable for solving the overwhelming majority of tasks. Of late years EU has done several attempts to form open embedded application systems of automation on the basis of component approach (e.g.: OSACA project) [2]. The big manufacturers of control equipment (Siemens, Fanuc, GE, etc) have broken development to a certain extent because of hardware-nearness.

Application systems are distributed network systems. In this field integrated application systems for manufacturing have adapted fast to the results of information and communication technique. From the point of view of functions there are five separated levels of networks at present, too. They are as follows: wide area network (WAN) between enterprises; local area network for offices (LAN1) inside a given enterprise; LAN2 for shop-floor level; LAN3 for cell level; LAN4 for the level of sensors and actuators (see: Figure 3). The main tendencies are unifying the protocols and wide-spreading the wireless technology.

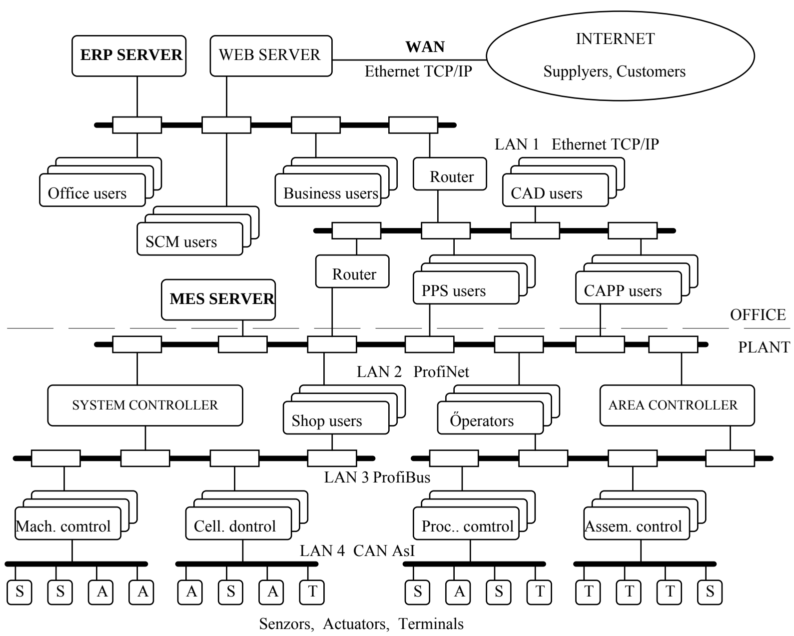


Figure 3

Network architecture for manufacturing applications

It is worth emphasizing here that the hierarchical structure of the computer-aided systems based on distributed network applications follows the natural model-based hierarchical structure of the manufacturing, design and planning systems considering its networking tools, too [11].

3 Theoretical Background of IT-based Application Systems

Of late years theoretical background of IT-based application systems has enlarged to a significant extent. In accordance with the interdisciplinary character of tasks, the results of several large scientific areas have built into the computer-aided applications. The most important new results have come into being in the connecting fields of Mathematics, Information Science, as well as in design and control of manufacturing systems.

Mathematics has given utilizable new results to IT-based application systems for manufacturing, mainly in the following fields:

- Operations Research
- Theory of Optimization
- Theory of Graphs
- Theory of Computation and Algorithms
- Numerical Methods.

It is worth stressing the importance of Linear Programming in the field of the Theory of Optimization, in which very effective new results have been obtained recently, especially for solving mixed integer problems. Numerous big software houses (e.g. ILOG) elaborated such "solver machine" components that have become software components of the IT-based application systems for manufacturing. More and more applications have built on the results of Mathematical Programming, Game Theory and Theory of Graphs.

The three great theoretical fields in Information Science, Engineering and Technology, where the most intensive development can be observed, are as follows:

1 Artificial intelligence methods (e.g. evolutionary algorithms, fuzzy logic, simulated annealing and constraint programming technique);

2 Data base management (object-based data models, data mining, and transaction theory);

3 Software engineering and technology (distributed applications, Java 2EE, CORBA, .Net, etc) [5].

These results have made a radical alteration in the performance of application software. In the field of design and control of manufacturing systems the effects of systems-theoretical novelties can be observed. Hierarchical modelling has become a general approach for production processes. The hierarchy of models means that a higher level model in hierarchy supplies constraints to the optimization tasks of the lower level. In the early nineties *Goldratt'*s activity called attention to the outstanding role of constraints [7]. Stochastic character of production, however, has become manageable in mathematical form on the basis of *Buzacott'*s mathematical models [3].

On the basis of our own investigations we summarize the features of models of the system based upon multi-level application components in Table 1. [11].

In the theoretical models of IT-based application systems for manufacturing the rate/intensity of state variables has more and more important role. The reason of this fact can be found in the specific cumulative nature of production processes [13]. These rate-type variables can play an integration role among the models.

Table 1 (continued)

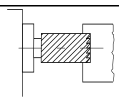
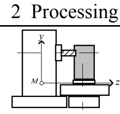
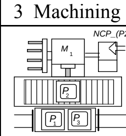
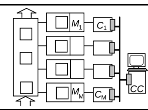
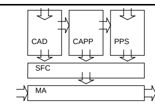
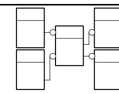
System level	1 Procedure	2 Processing	3 Machining
Model			
Example for field of theory	Cutting theory	Part Tool Fixture	Theory of machining
Objects of models	Material stream Tool edge Chip root	τ - tool type $\mathbf{r}$ - tool path V - volume of rem.	Machine Pallet Tool store
Control data structure	d - depth of cut f - feed rate v - cutting speed	F - cutting force P - cutting power T - tool life	$\sigma(\varepsilon)$ - sequence of o.e. $\Pi(\varepsilon)$ - relation of o.e. $D(\tau)$ - tool size
State variables	k - specific force R_a - surface rough. Q - removal rate	$F < F_{\max}$ $P < P_{\max}$ $T > T_{\min}$	$\delta\ (p)$ – quality of part Q – operation rate $C(p)$ – machining cost
Constrains	$b < b_{\max}$ $h > h_{\min}$ $f < f_{\max}$	$F < F_{\max}$ $P < P_{\max}$ $T > T_{\min}$	{Error}<{Tolerance} $\{\tau_o\} \subseteq \{\tau_s\}$ tools in store $R_o(\varepsilon) \subseteq R_m(\varepsilon)$ allowable relations
Objective function for optimization	u -specific time $u = 1/(f \cdot d \cdot v)$ $Q = 1/u$	t_{ijk} -op. el. time $t_{ijk} = u \cdot V_{ijk} + t_{k,aux}$	t_{ij} - operation time $t_{ij} = t_{j,prep} / n + \sum_k t_{ijk}$

Table 1

System level	4 Manufacturing	5 Producing	6 Delivering
Model			
Example for field of theory	Optimization theory Information engineering	Operation research Design theory	System modelling Relational data processing
Objects of models	Machining system Transporting system Controlling system	Design and planning Production planning Activities	Business processes Data entities Transactions
Control data structure	$\{J\}$ - jobs $\{S\}$ - schedule $\{n\}$ - batch size	Orders Master plan Material requirement plan	Demands Delivery date Cost
State variables	$W(J)$ – work in process $U(m)$ – utilization of machine $L(J)$ – lateness or slack	POS production order status RS resource status D demand rate	Slack of orders Service level Stock level Margin
Constrains	Actual priorities Actual capacities Actual material stock	Due dates BOM Routing	Cash level Supply level Market level
Objective function for optimization	t_i – item time Makespan=$max[t_i]$ Lead times	Tardiness WIP level Delivery capability	Profit Assets return Share on markets

Development of application systems has become more and more complex task, which can be decomposed into several consecutive phases. The most important phases are as follows:

- Requirement analysis
- Functional design/planning
- Mathematical modelling
- Design/planning of algorithms
- Data model design/planning
- Input/output specification
- Elaboration of a project for the system, platform selection
- Programming work (Java, C++, MSVB, .Net)
- Testing, verification, validation.

The complex activities listed above require such specific knowledge from the developing experts that an effective team of co-operating specialists is only able to produce a competitive software product. A consequence of this fact is that the competitiveness of big software houses has been increasing. Their solutions have become quasi-standards.

4 Implementation and Operation of Application Systems

Nowadays implementation and operation of application systems also require multi-functional and well-organized work. There are great deals of firms on the market, which deal with auditing, selling, implementing and up-grading of IT-based application systems. Without using their services, implementation of applications involves serious consequences. Because of the strong model-dependency of IT-based application systems for manufacturing it is obvious that selection, scaling, parameterization and data-filling of the appropriate application require very careful and time-consuming work.

To operate application systems, special methodologies have been worked out. The persons who must be involved into introduction of these methodologies are as follows: users, co-workers of IT-department, system-master, integrating expert, maintaining IT-expert, developing experts, application experts and counsellors.

Information Technology Service Management (ITSM) as a whole is so complex that partial implementation and operation can only be realized even in the case of multinational firms.

The most important services for application systems are as follows:

- Configuration management
- Up grade, release management
- Change management
- Solving the operation problems
- Incident management
- Security management
- Alert system operation
- Audit
- Further developing, extension, integration.

Conclusions

In the course of the last 5 years we have participated in several industrial R&D projects. The main aims of these projects were: development of information technology in enterprise environment with new applications and their integrations. Our experience is that modelling the production processes plays central role in the applications development. In the most practical cases there is no possibility to use only one analytical model at the same level of different firms because of complexity of the production process.

In order to develop a fast, reliable and user-friendly production system there are the following issues: 1. Decomposition of the model and activities to suitable hierarchy levels; 2. Decomposition of optimization tasks into smaller models suitable for solving and developing effective solver algorithms and programs to solve them; 3. Introduction of feedbacks and interactive handling of uncertainties at several decision levels to maintain stability and to avoid losses.

One of the Hungarian factories of a multinational firm carries out customized mass production. It is characteristic of this factory a large scale of product types, uncertainty of market demands, as well as rigorous conditions of the adaptation to the demands of customers (specification, packing, delivery dates). In the focus of the production policy, high level meeting the requirements of the customers is standing. Performance of production are measured by the quantity of products, the stock level, keeping the deadlines according to the contracts, the number of setups and loading the manpower capacities. It is also characteristic the variety of material demand, parallelism of machine capacities and the controllable lot size. In the course of planning and scheduling of customized mass production three important and easy-to-characterize uncertainties must be taken into account. They are as follows:

1 Uncertainty of market orders, both in quantity and urgency;

2 Uncertainty of materials supply because of the risk of services of the suppliers;

3 Uncertainty of production lines and, from time to time, uncertainty of the available skilled labour.

These conditions together make production planning and scheduling more difficult to a great extent. The R&D project, in which we are participants, started in January, 2005. Within the framework of the project the tasks are ordered in three clusters.

The three cluster deals with three different areas of computer aided production management area. They are as follows:

1 Detailed scheduling of production orders on one week time horizon with a lot of machine, material, BOM and routing alternatives.

2 Managing the uncertainties and revealing the possibilities of "behaviour" – based control of the production system.

3 Developing a new co-operative supply-chain, as well as increasing the availability of the materials and decreasing unusable components.

The project demonstrates those efforts well, which the producing enterprises operating in the competitive sphere make in order to achieve the strategic goals in the fields of planning and control for production systems and processes. These tasks, in majority of cases, can only be solved by means of a new approach, new models and new applications of information engineering and technology.

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