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Discipline Research Contributions to the Modelling and Design Of Intelligent Manufacturing Systems

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Abstract: This joint paper is the result of the work of cluster 3-4 within the Esprit WG No. 21955 on Intelligent Manufacturing Systems (IMS) working group. The paper conveys the results of a co-operative research effort between LAR Patras (Greece), DTU (Denmark), CRAN/GSIP (France) and Aachen WZL (Germany). It aims at highlighting the contribution of each of the partners to some common issues related to the modelling and control of an autonomous and co-operative system under dynamically changing conditions. Yet, it does not provide a global solution since this would require further investigations and research, but it stimulated us to continue working towards the integration of our individual approaches within the IMS perspective.

Keywords: Modelling, Control, Intelligent Manufacturing Systems

Chrysostomos Stylios, Ph.D, received his Ph.D. degree from the University of Patras, Greece in 1999, and the diploma in Electrical Engineering from the Aristotle University of Thessaloniki, Greece in 1992. He is currently a post-doctoral researcher at the Department of Electrical and Computer Engineering at the University of Patras, Greece. His interests include intelligent control, supervisory control, fuzzy logic, neural networks, Fuzzy Cognitive Maps and generally soft computing techniques. His research interests are Hierarchical Systems, Decision Support Systems and Intelligent Manufacturing Systems. He is a member of IEEE and of the National Technical Chamber of Greece.

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He is currently Assistant Professor at the University Henri Poincaré-Nancy I where he is involved in engineer school E.S.I.A.L. by ensuring the responsibility of the Manufacturing Engineering channel. He belongs also to the Automatic Research Centre of Nancy (CRAN) in the Production Integrated System Engineering team managed by Professor G. Morel. His research and teaching activity focused on the dependability and the maintenance of the Production System and, more precisely, of the Integrated – Distributed System based on Interoperable and Intelligent field components. In this way, he participated in different national projects (CIAME, CNRS-S3, GRP) and managed tasks in several European projects as ESPRIT DIAS, PRIAM, EIAMUG. He ensured also scientific co-responsibility for the CRAN participation in European and International Projects as ESPRIT REMAFEX, INCO-DC EIAM-IPE (with China), ESPRIT IMS-WG long -term research in the maintenance and intelligent system fields.

One objective of his current research is to apply the Multi Agent System modelling technique for the development of proactive maintenance intelligent system.

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Professor Groumpos is the Greek NMO representative to IFAC and he is the vice-president of the IFAC TC «Large Scale Systems».

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1. Introduction

The requirements for new generation manufacturing systems, which will be characterised by high autonomy and intelligence, have led to the investigation and invention of new techniques that will integrate and combine known advanced methodologies and will be the core of these sophisticated systems. Powerful computers, advances in communication and other technological and scientific areas would be integrated and utilised in the area of Intelligent Manufacturing Systems. It has become quite clear that the requirements in the modelling and control of systems cannot be met only with the existing conventional theories. It is necessary to investigate and use new methods that will exploit human experience, will have learning capabilities, will be supplied with failure-detection and identification characteristics and it will include imprecision and uncertainty. An Intelligent Manufacturing System should utilise effectively all the company resources, especially the insights and experience of front-line operators and experts, in order to achieve continuous improvements in productivity. One of the major objectives of the Intelligent Manufacturing System initiative [1] is to contribute to the development of new production systems that can fulfil technical, economic and environmental requirements for optimality and sustainability while maintaining their competitiveness. This necessitates enhancement of the flexibility, reusability, availability, dependability of the production system [2]. This leads to a system organisation that has to be a compromise between the current hierarchical enterprise architectures, which are inherently integrated, and the new distributed architectures, which are more flexible, reactive and agile [3].

2. Frame of Reference

Indeed an integrated organisation requires that information is made available for use by all the operational activities and throughout the entire business environment. In that way, "intelligence" embedded in the field components (e.g. devices such as actuators, sensors, PLC's, etc.) [4] and digital communication (e.g. field-bus) provide a solution to an informational representation of the production process as efficiently as possible. The resulting shop floor architecture is therefore constituted by a network of field components integrating a "technical form of intelligence" (local capacities) that offer a greater reactivity while interoperating among them to ensure the integration (co-ordination) of operational activities. These architectures advocated by the IMS initiative are characterised mainly by properties of flexibility and adaptability that are required to quickly face up with internal and external disturbances while preserving the global goals of the application.

Thus in order to portray and investigate the different researches described in this paper a frame of reference has to be established. This reference can then be used as a basis for comparison of the different researches, to reveal possible fields of collaboration for further research.

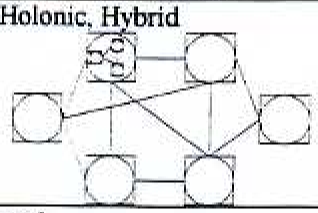
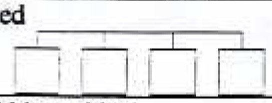
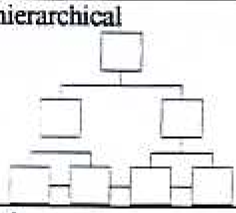
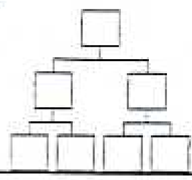
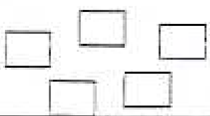
From a production point of view, a compromise has to be reached between:

- **Integration paradigm** that focuses on integrating the Operational domains (Control, Maintenance and technical Management: **CMM** concept [5]) at the shop floor level in accordance with the Business domains at the Enterprise level. Thus it comprises a coherent architecture in order to gain real business advantages, and requires the use of a well-known **CIME Enterprise hierarchical modelling framework** [6] as promoted by the EP 21859 "EI-IC" and the world-wide "Enterprise Integration" initiative [7]. The resulting "hierarchical" systems are optimised for performances and as a consistent whole but with considering the problems that unforeseen disturbances may cause.
- **Distribution paradigm** that focuses on embedding "intelligence" at the shop floor level producing an adaptable architecture that achieves hardware and software interoperability and adaptability. It requires the use of a prospective IMS (Intelligent Manufacturing System) **Enterprise distributed modelling framework** as proposed by the world-wide IMS initiative. The resulting "intelligent" systems (distributed, heterarchical) that enhance interoperability, adaptability, ability to react to disturbances, still have problems related with optimising global functionality.

This compromise asks for the definition of the expected characteristics of such type of production systems. This implies not only the need to characterise the architecture resulting from the engineering process, i.e. the model of the system (hierarchical, heterarchical), but also the engineering process itself. The engineering process can be formalised by use of meta-models, reference models, emergence mechanisms, etc. Finally a modelling framework (Cartesian, systemic, etc.) has to be used in order to provide a framework thereby the architecture can be implemented, based on the engineering process [8].

Kosanke and Nell [7] introduced **an Enterprise Integration Capability Model** in order to characterise architectures using five levels (interpreted as hierarchical, integrated, distributed, and intelligent by Iung et al [8]). Weston in [9] also proposed some

Table 1. Frame of Reference adapted from B.W. Hollocks et al [7] and by Iung et al[8]

Architectures	Modelling Frameworks	Structures
Adaptable	Intelligent *Kinetic:* *HMS, RCS4*	Agile: Holonic, Hybrid 
Interoperable	Distributed *Object oriented:* *UML, Ontology, DAI*	Distributed 
Visible	Integrated *Systemic:* *CIMOSA, GERAM, SAGACE*	Modified hierarchical 
Rigid	Hierarchical *Cartesian:* *SADT, IDEF, RCS3*	Hierarchical 
Fragmented Islands	Fragmented *None*	None 

classifications of the systems and system engineering process.

The relationship between architecture and modelling framework is illustrated in Table 1. It is based on the Enterprise Integration Capability Model proposed by Kosanke and Nell [7], and on a classification of modelling frameworks proposed by Iung et al [8]. The Table illustrates five levels, which are named Fragmented, Rigid, Visible, Interoperable and Adaptable, respectively. At the first level (Fragmented Islands) no integration exists and thus no modelling framework can be used. The Rigid level is characterised by purely hierarchical structures and the modelling framework is based on the Cartesian approach. This modelling framework results in structures that ensure optimal overall performances but are too rigid and respond only poorly to changes and disturbances. In order to loosen the hierarchy the Visible level allows communication between sub-units. However this structure is still too rigid and slow in responding to disturbances. The modelling framework approach is Systemic in such frameworks as GERAM.

the hierarchy and thus, to the IMS paradigm in general.

The evolution of modelling frameworks has not been consistent with the evolution of production system architectures. For instance, the Distributed Artificial Intelligence paradigm currently does not seem to be operational enough for modelling Intelligent Systems. It is however adequate for modelling and control of autonomous and co-operative system, since it considers the system as an interaction between autonomous and independent entities (**agents** or **holons**), which work together according to operating modes [10]. So, all these architectures can be implemented through modelling framework, but on the basis of an engineering process.

The engineering process can be characterised by the **Capability Maturity Model** (Table 2) used in software engineering [11]. This model of graded maturity (not a continuous maturity model), similar to the Software Capability Maturity Model proposed by the Software Engineering Institute of Carnegie Mellon University , suggests five levels of classification: Initial, Repeatable, Defined,

Table 2. Capability Maturity Model [11]

Quantitative	***Optimising***	*Continuous process improvement is enabled by quantitative feedback from the process.*
	Managed	*Both the software process and the software itself are observable.*
Qualitative	***Defined***	*It is documented, standardised, and integrated into a standard software process for the organisation.*
	Repeatable	*The software process is explicit and can be re-used from an application to another.*
	Initial	*Software is characterised as ad hoc, occasionally even chaotic.*

The Interoperable level represents a distributed structure, where all decision-making is carried out locally at each unit. This results in a flat structure, where the units co-operate. The modelling frameworks used are object-orientation and distributed artificial intelligence (DAI) methods. These systems are easy -to-re-configure and therefore they respond well to changes and disturbances. However , the decentralisation hinders the overview of the performance of the systems whereby sub-optimisation is likely to result. The Adaptable level corresponds to the ultimate "relaxation" of

Managed and Optimising. Moreover the model divides these categories into qualitative and quantitative ones, in order to clarify the "invariants" of the modelling process, such as the genericity, reusability and validity of the architecture. This reference model can be used to classify the architecture obtained as a result of the engineering process, specifically in terms of the research described in this paper.

The main goal of this paper is to use the frame of reference shown above to describe how any of the partners' research contributes to the modelling and control of autonomous and co-operative system. By clarifying issues related to the manner of implementation of the architecture at the adaptable level (Table 1) through the use of new modelling framework, these issues will additionally show the general shift from the Visible level (CIM) to the Adaptable level (IMS). It is important to note that this shift has to be realised at and between two levels, namely the shop floor level and the business level. This corresponds to realising the integration between the symbolic world and the physical one. Co-operation at the physical level is more difficult to achieve than it is at the symbolic one due to the difference between the hard constraints (time, physical location, variations, unexpected behaviour, etc.). The new intelligent systems will thus have to emerge from these special integration requirements.

3. Summarising Research Contributions

All four partners have different approaches regarding the modelling and design of Intelligent Manufacturing Systems; yet with the same aim namely an agile production system. The different approaches are presented in Figure 1, where the investigation of the borders between these fields is one of the goals of this paper.

The Laboratory for Automation and Robotics (LAR) proposes a hierarchical approach to describing the upper production level and the lower enterprise level. This modelling approach can be classified according to Figure 1, and it belongs to the hierarchical and integrated approaches class. This approach examines the shop floor system from a behavioural point of view and it utilises an abstract methodology in modelling this behaviour. This methodology is named Fuzzy Cognitive Map (FCM) and it belongs to the soft computing approaches, modelling the shop floor level from a behavioural point of view. Moreover a hierarchical structure is proposed, that establishes a shop floor level with supervisory control, which is linked with the business level in Figure 1 (see Section 4).

DTU has attempted to develop an architecture and methodology for the design of agile shop floor control systems and has focused their research on the holonic approach. By founding the control system on autonomous and co-operative entities (holons), a highly adaptable manufacturing system can be realised. The main interest at DTU is in developing a system architecture defining the functionality of the basic entities, structures of the entities and their co-operation mechanisms. This research aims at building a Holonic Multi-cell Control System (HoMuCS) architecture that can be used for the design and development of a multi-cell control system at the shop floor level (see Section 5).

The CRAN-GSIP work is more dedicated to an engineering process based on reference models and dealing with the architecture of shop floor

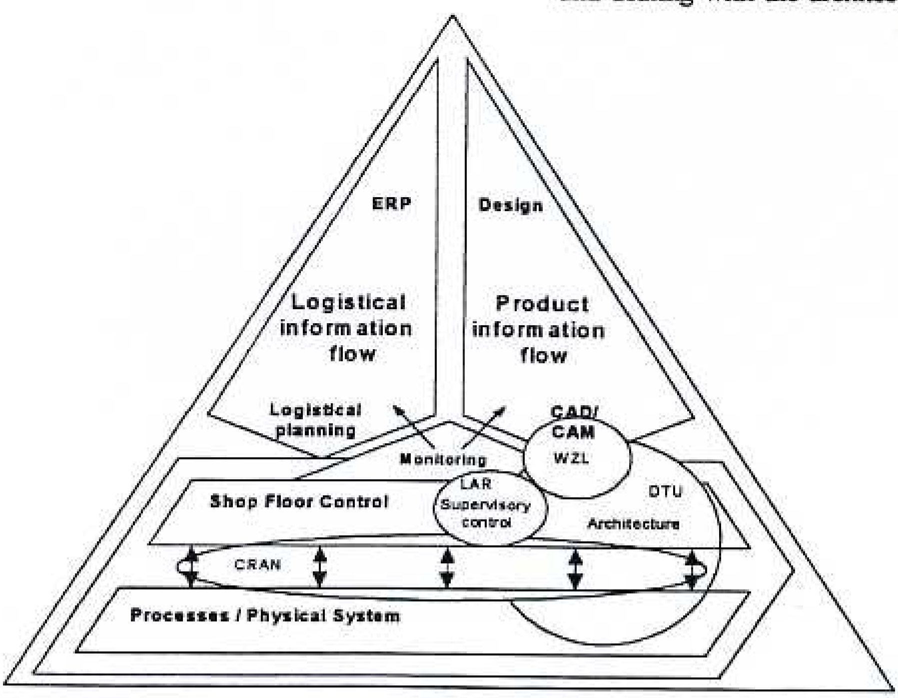


Figure 1. Enterprise Pyramid With Partners Research Fields

production systems. It means to provide solutions to the system structure change and adaptation as a dynamic organisation. The development of an operational system is based on the application of the reference models and leads to building a physical shop floor architecture, which is composed of co-ordinated and co-operating interoperable and reusable hardware/software field components (see Section 6). The co-ordination and the co-operation are required to form a functionally integrated and physically distributed shop floor architecture which is a first step towards a full intelligent manufacturing system using an engineering process based increasingly on emerging trends that would provide more adaptability (see end of Section 6).

In the development of new intelligent systems, the kinds of communication and information exchange between shop floor devices of the physical systems or agents that model the system have a great importance. In this framework Aachen WZL proposes a data and communication model, which can be used as a gateway between the shop floor and the business levels. The existence of a reliable means for exchanging information is a fundamental issue in all the research work described in this paper (see Section 7).

4. A Model Based on Fuzzy Cognitive Map (FCM)

4.1 Behavioural Model of Shop Floor Level

Hierarchical architectures are widely used and accepted in enterprise modelling. LAR is considering a general hierarchical architecture to model the shop floor level of the enterprise. Our research focuses on an abstract model that connects the shop floor level with the upper level at the enterprise pyramid (Figure 1) and thus it creates a more integrated modelling approach. In order to develop advanced modelling methodologies based on soft computing approaches, ideas and existing approaches from information theory, neural networks and fuzzy logic are investigated and utilised to represent and process information in a hybrid and hierarchical industrial system [12]. This hierarchical approach pays more attention, from a behavioural point of view, to the shop floor level and a new modelling methodology is resorted to in order to model the behaviour of the human operator at his level and of the system itself.

The proposed methodology is that of Fuzzy Cognitive Maps (FCMs), which can model dynamical complex systems that change in time following non-linear laws. Fuzzy Cognitive Maps use a symbolic representation for the description and modelling of the system [13]. A Fuzzy Cognitive Map consists of concepts that illustrate different aspects in the behaviour of the system and these concepts interact with each other showing the dynamics of the system. An FCM integrates the accumulated experience and knowledge on the operation of the system, as a result of the method by which it is constructed, i.e. using human experts that know the operation of the system and its behaviour. Experts represent the human accumulated knowledge on the operation and behaviour of the system, using concepts to stand for the main characteristics and factors of the system and they also express the causal relationship among factors connecting concepts with weighted interconnections [14].

At the shop floor level of the plant there is a common technical information system for the process control, the computerised and technical management systems that is shared between the production and the management teams [5]. This information could be unified and used to construct a Fuzzy Cognitive Map, which will represent a conceptual, organisational and operational model of the system [15]. The knowledge on manufacturing plants includes the layout of the plant, the expected behaviour of some parts of the plant, an aggregation of attributes or quality variables that are important. This information is captured using a Fuzzy Cognitive Map structure that exploits human operator's experience and knowledge. An expert relates a process or a succession of processes to a concept, or a concept can stand for a specific production procedure or a process can represent the operation or malfunction of a machine or the desired output, etc. All these concepts are closely connected to each other with a degree of cause and effect that is expressed by the weighted interconnections.

The development and design of the appropriate and efficient Fuzzy Cognitive Map model for the description of a system requires the contribution of human knowledge and experience on the operation of the system. Experts and operators of the system, who know the behaviour of the system, have created a mental model of the system and, according to this, they monitor, supervise, control and make decisions and take actions on the operation of the system. This model can easily be constructed as a Fuzzy Cognitive Map that is a conceptual model. Experts are asked to determine the concepts that best suit the model of the system. An expert knows which factors are the key principles - functions of the system operation and behaviour and he expresses a concept for each one of the factors or the elements. Moreover, during the operation of the system, he may observe which of the elements of the system influenced the others and he could determine for the corresponding concepts the negative, positive or zero effect of one concept on the others. For each interconnection, it is assigned a fuzzy value, since it is assumed that there is a fuzzy degree of causality between concepts. Knowledge and experience are stored in the structure of the Fuzzy Cognitive Map and the corresponding interconnections that summarise the cause and effect correlation among concepts. The selection of the different factors of the system, which must consist the FCM, is the result of a close-up on system's operation and behaviour under the operator's supervision and control, as experts have acquired them. Causality has a great importance for the Fuzzy Cognitive Map design, as it indicates whether a change in one concept causes change in another, and it must include the possible hidden causality that could exist between several concepts.

4.2 A Fuzzy Cognitive Map Model for Process Industry

The characteristics, development methodology and features of Fuzzy Cognitive Maps have already been presented. In this Section a Fuzzy Cognitive Map model for a simple part of a chemical plant will be developed in order to illustrate the procedure of developing an FCM model for a system and how FCM would look like. The examined example consists of two chemical processes, which take place in two tanks, and the product of Process 1 continues its processing in tank 2 whereas Process 2 takes place. A pipeline connects the two tanks and its

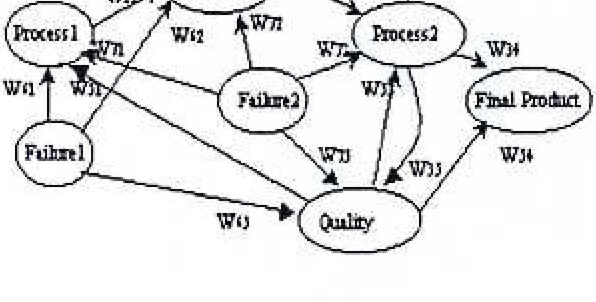


Figure 2. A Fuzzy Cognitive Map Representing the Behaviour of A Chemical Plant

status influences both processes as it takes the output of the first and provides the input to the other. Conventional controllers are used to control these two processes and human operators will supervise and control the whole system.

For this chemical plant a Fuzzy Cognitive Map can be developed that will model human supervision. This FCM is illustrated in Figure 2. This FCM consists of seven concepts that represent the main factors, states and variables of the plant. The FCM is developed by a group of experts who supervise the process and know the operation of the system:

Concept 1: the state of Process 1;

Concept 2: it represents the state of Pipeline, which connects the two processes;

Concept 3: the state of Process 2;

Concept 4: the Final Product of the two chemical processes;

Concept 5: the Quality of the Final Product;

Concept 6: the occurrence of Failure 1, mostly related to Process 1;

Concept 7: the occurrence of Failure 2, mostly related to Process 2.

The group of experts know the correlation among these concepts and so they can describe the influence of one concept on the other and their causal relationship with a fuzzy degree. First of all, they determine which concept will influence which other. So they describe that Process 1 influences positively the concept of Pipeline. Pipeline influences positively the state of Process 2 and Process 1. Process 2 influences positively the Final Product, the Pipeline and the concept for the Quality of the Final Product. The state of the Quality has a positive effect for Process 1, Process 2 and the concept of Final Product. Experts know that when Failure 1 occurs, this event influences negatively the state of Process 1, and consequently the state of Pipeline, which is depending on Process 1, and the Quality of the Final Product, is influenced negatively. When Failure 2 comes up, there is a negative effect on Process 2 and it influences negatively the operation of Process 1 and of Pipeline, as they are pre-processors of Process 2. In addition to this, Failure 2 influences negatively the Quality of the Final Product.

When experts determined the concepts that consisted the Fuzzy Cognitive Map and the positive or negative influence of one concept on the other, they also had to determine the degree of this causal influence. Every causal relationship among concepts can be represented by a weight. Experts describe the influence of one concept on the other with a linguistic variable. Every expert describes each interconnection with a fuzzy variable and then the corresponding fuzzy weights are combined and integrated into one, which is defuzzified into one numerical weight. The followed methodology is that proposed in [16]. When the Fuzzy Cognitive Map was constructed, it could be used to model the behaviour and to simulate the operation of the system. The values of concepts stand for some variables and states of the system and so their corresponding concept values represent values of states and variables in the real system.

4.3 A Hierarchical Two-level Supervisory Structure

The general characteristics of Manufacturing Systems are their complexity and their large scale construction that make researchers use structural models such as hierarchical, heterarchical and other models, in order to model such systems. In Manufacturing Systems framework the human operator offers and supports Supervisory Intelligent Control through the use of a vague control methodology, within which he takes into consideration different factors and their relationship. On the other hand, there is a high requirement for more sophisticated systems with advanced characteristics such as the possession of human-like expertise within a specific domain, their adaptation and learning to do better in changing environments. Fuzzy Cognitive Maps are symbolic representations for the description and modelling of complex systems, revealing different aspects in the behaviour of complex systems in terms of concepts; and the interactions among concepts show the linear and non-linear dynamics of a system. The supervisor of a system can by means of this abstract methodology model the Fuzzy Cognitive Map. It is assumed a hierarchical structure where the lower level consists of conventional control methodologies and the supervisor is modelled with this symbolic abstract methodology and the whole structure follows the principle of "decreasing precision and increasing intelligence" [17].

The supervisory model is developed as an augmented Fuzzy Cognitive Map. FCM is constructed with a methodology that describes the supervisor directly from the knowledge and experience of experts who are monitoring, supervising and controlling the process manually and successfully. Within this procedure primary attention is paid to the human's behaviour and experience rather than to the process being controlled. This distinctive feature makes Fuzzy Cognitive Maps be applicable and attractive for dealing with the supervised problem where the process at the lower level is quite complex and on the other hand this process is supervised and controlled satisfactorily by human operators.

It is suggested a hierarchical two -level structure, where the lower level system is sufficiently controlled by local conventional or non conventional controllers and the supervisor at the second level. The proposed structure is depicted in Figure 3, where the supervisor is modelled as a Fuzzy Cognitive Map and consists of five sub-FCMs. Each one of these sub-FCMs accomplishes a special action for the plant at the lower level; one FCM is monitoring the plant, another one is used for failure diagnosis, the next one is used for decision-making, the other for planning actions on the plant and the last FCM describes the execution commands and sends them to the plant. These five FCMs are interconnected and they may have common concepts. The plant at the lower level has its own local controllers that perform usual control actions and the supervisor is used for more general purposes: to organise the overall plant in order to accomplish various tasks, to help the operator make decisions, to plan strategically the control actions and to detect and analyse failures. This supervisor with an augmented Fuzzy Cognitive Map attempts to

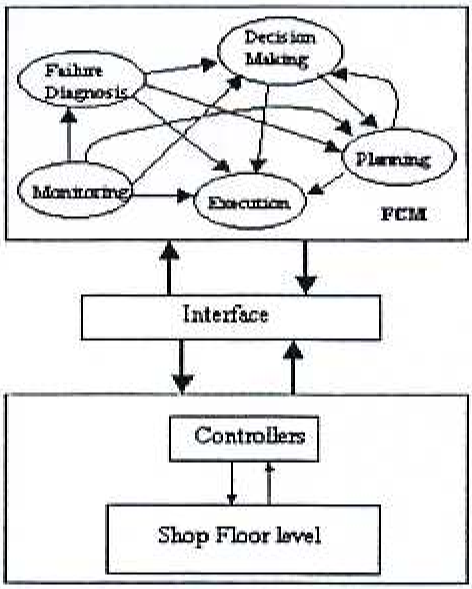


Figure 3. The Proposed Hierarchical Two-level Structure With the Supervisor FCM

emulate the human control and supervision capacity for the plant.

The two-level structure and separately its two levels have been described. These two levels interact and there is an amount of information that must pass on from one level to another and vice versa. Thus there is an interface between the two levels, which consists of two parts, one part will pass information from the controller at the lower level to the augmented Fuzzy Cognitive Map at the upper level and the other part will transform and transmit information in the opposite direction.

The supervisor Fuzzy Cognitive Map interacts with the upper enterprise levels on the general enterprise pyramid (Figure 1). The Fuzzy Cognitive Map model of the supervisor can easily interact, communicate and be integrated with the other elements of this pyramid.

5. A Holonic Multi-cell Control System Architecture

The research performed at DTU contributes to the development of autonomous and co-operative Shop Floor Control (SFC) systems and is part of the on-going international research in the area of Holonic Manufacturing Systems (HMS). The aim of the Holonic theory is to realise manufacturing control systems that inherit the best characteristics of the integration and distribution paradigms as described in the introduction (see Table 1). These manufacturing systems are able to simultaneously perform as both a hierarchical and a heterarchical control system. Thus in order to obtain adaptable manufacturing systems a hybrid approach is adopted in which the best characteristics of the rigid, visible and interoperable architectures are combined (see Table 1). The resulting structure of the control systems can be dynamically changed based on the demands forced in by the environment, thus enabling a highly adaptive behaviour.

The contribution includes an architecture (HoMuCS architecture) which makes highly adaptable shop floor control systems be designed and developed. It includes a methodology prescribing how to develop and implement shop floor control systems based on this architecture. HoMuCS is an acronym for Holonic Multi-cell Control System. The term Holonic points at the special characteristics of this type of a control system, which are the inherent traits of autonomy and co-operativeness. Thus the system consists of elements that are Holons structured in a holarchy, yielding a behaviour that gives the whole system an agile nature, in terms of both performance and reconfigurability.

The term multi-cell implies the extent of this class of control systems in a manufacturing enterprise. An HoMuCS is designed for the control of what would be the cell and area levels of a manufacturing enterprise in terms of traditional hierarchical control models. In popular terms, an HoMuCS refers to a highly agile shop floor control system from the workstation level and up to the factory level according to the enterprise pyramid illustrated in Figure 1. The HoMuCS architecture consists of a set of functional models, an object -oriented model and a meta-model for the integrated database of the system, called the Product State Model (PSM) [18]. These models describe the generic system functionality, the generic building blocks of the system and the internal structure of a holon respectively. The structural elements and their relationships are described based on a set of object-oriented models using the UML modelling standard. This modelling approach is a hybrid of the modelling methods classified as distributed, integrated and hierarchical architectures respectively (see Table 1). It has been adopted as a result of the need for a new modelling method at the Adaptable level. At this point it is uncertain if it will do, but it serves as a first attempt to model the future adaptable and intelligent manufacturing systems.

The elements of the architecture are abstract meaning that they have to be customised, as part of the engineering process in order to obtain the holons and other strucural elements necessary for implementation. Each Holon in the architecture describes a generic component of a shop floor control system. The system architecture is implemented using the Java programming language and can be viewed on the HoMuCS web-site (http://www.homucs.org), where both the documentation and source code files can be found.

5.1 The Architecture of A Holon

By definition a Holon is an autonomous and co-operative element of a manufacturing system. It is autonomous since it can derive its own plans and execute them. It is co-operative since it can interact with other manufacturing holons in the system to define mutual plans and contingencies. In fact it is very similar to a

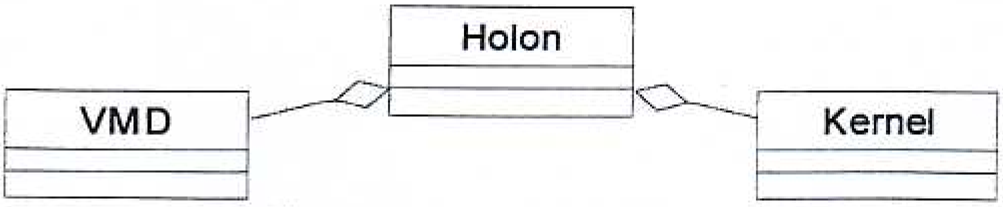


Figure 4. The Structure of the Holon

software agent, yet it has its differences. First, there is a strict structural definition regarding the different types of Holons and their functionality, secondly it consists of a physical part such as a manufacturing resource or product and has a special mechanism to interface with that physical part. A Holon does not have to be intelligent. In other words it is not part of the specification that it has to have built in intelligence such as an artificial intelligence engine, although this is practically unfeasible since it is essential in achieving autonomy and co-operativeness. In practice its autonomy can be achieved by simple logical tests, while its co-operativeness can be achieved by programmable interactions between objects (see Figure 4). However in order to obtain optimal performance in complex manufacturing environments there is a need for more complex autonomy and co-operation engines, which can be realised by such methods as Fuzzy Cognitive Maps (FCM) [see LAR, Section 4] and software agents.

A Holon has an VMD (Virtual Manufacturing Device) and a Kernel. The VMD allows for a vendor independent and easily configurable interface to manufacturing equipment and the kernel allows for system independent implementation of multi-agent systems. The VMD defines the interface to the physical manufacturing devices based on the MAP/MMS and ISO OSI layer model. The client-server relation between the holon and the VMD object represents the application layer in the ISO OSI model. The Kernel is an implementation of an agent that drives the Holon, thus making the HoMuCS a specialised Multi-agent System (MAS). The Kernel defines the interface to an agent and thus all the logic of the Holon is contained in the Kernel.

Internal interaction within a Holon is the interaction between the Holon, VMD and Kernel. The external interaction is the interaction between holons within the HoMuCS and external information systems like ERP, etc. The internal and external interactions are called intra- and inter-holon interaction respectively. The inter-holon interaction between Holons is performed at two levels. Between holons,

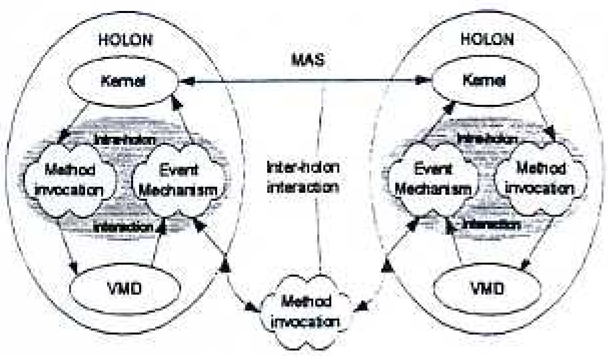


Figure 5. Intra- and Inter- Holon Interaction

implemented through the method invocation and exchange of holons (objects), and between kernels using the implemented MAS. The intra-holon interaction is performed using the event mechanism implemented in the HoMuCS architecture (Figure 5).

The Kernel contains the Holons decision logic, which is used to interact using both long and short-term interaction. Long-term interaction for a Holon can be a message about the future arrival of an Order Holon, enabling the Kernel logic to make advance decisions. Short-term interaction concerns real-time decisions about dispatching of orders or events. E.g. where should an order be put after processing, which encompasses the information flow between the Holon, VMD and Kernel as mentioned above. Information about the physical system is crucial in integrating the physical manufacturing system into the manufacturing control system. One method of providing this information is by continuously reading state information through the VMD.

The HoMuCS architecture supports this internal structure of a Holon by providing a set of classes and an event mechanism to support interaction between the kernel of the Holon and the Holon. The registration operation is encapsulated in the Holon class such that it is an attribute of all the Holons in an HoMuCS. The implementation of the Kernel class is done according to the actual enabling technology being used. This is also valid for the communication and interaction protocol between the kernels, e.g. a bidding mechanism.

5.2 Functionality of A Holon

In order to supplement the structural description of the Holon with an overview of the required functionality of the HoMuCS and its elements, the architecture includes a set of functional models using the IDEF0 technique. The specific generic functional definition of a Holon with respect to how it uses its kernel is given by modelling from the viewpoint of the Holon performance of production tasks. The context is the generic functionality of the Holon. Thus the functions described are common to all types of Holons in the HoMuCS architecture [19]. It describes the three central functions that a Holon has to include in the context of a shop floor control system.

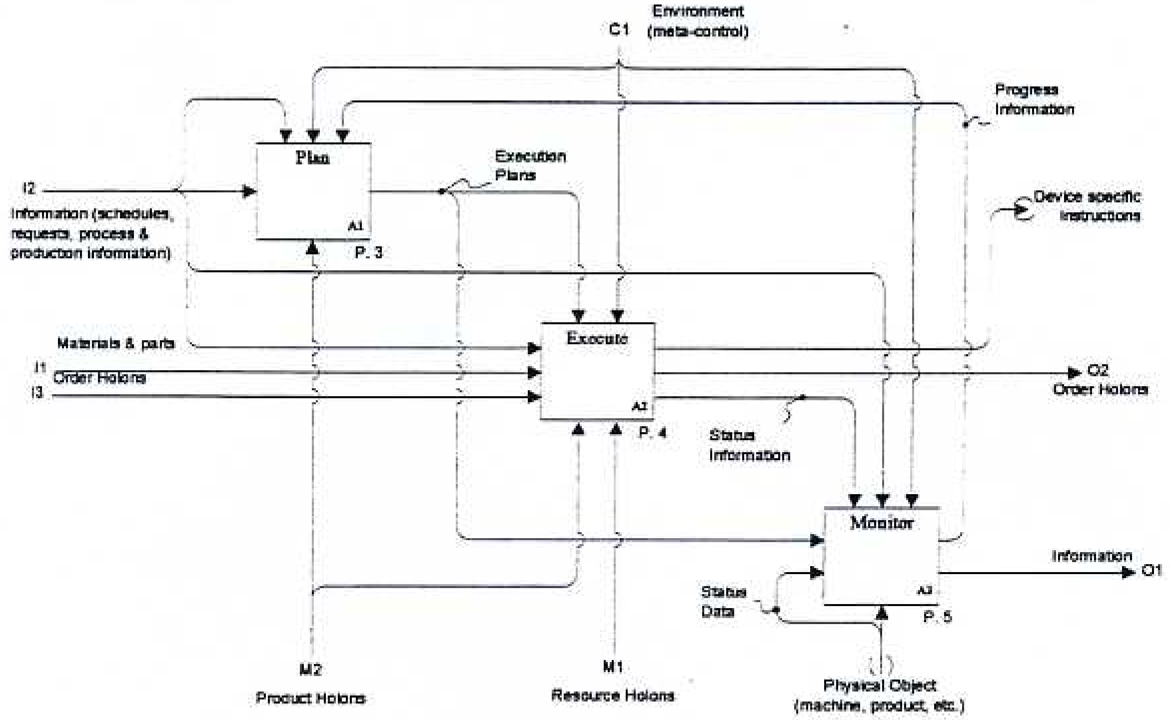


Figure 6. The Generic Functionality of A Holon – A0 IDEF0 Diagram

Figure 6 illustrates the three fundamental functions of a Holon. These are Planning, Execution and Monitoring. They have to be performed by all Holons in order to be able to act autonomously. Thus they have to be able to compile their own plans and execute them while monitoring their progress. This generic functionality model is in fact no different from the models used to describe traditional SFC systems and known from the integrated framework (Table 1) and the systemic approach of the Production Activity Control (PAC) functional architecture [20]. This is of course obvious since the SFC task is independent of SFC solution, traditional or holonic. The difference lies in that, in a HoMuCS, this generic functionality exits in the entire element of the SFC system and not only at the shop floor controller level. Furthermore the functionality is attributed to the Holons, which also consist of the physical shop floor equipment and materials. Thus Order holons also have this functionality, which allows the planning of the production flow to be performed in co-ordination by both material and resources in contrast to traditional systems where the control is exerted solely by what is considered to be resources in the HoMuCS.

6. From Integrated-Distributed Shop Floor Architecture Based on Interoperable Field Components, to Intelligent Shop Floor Architecture

In relation to Distribution-Integration issues, the first research performed at CRAN/GSIP contributed to the formalisation of the generic engineering process of integrated - distributed shop floor architecture. This work is justified by the recurring needs of industrial system engineering process and their reference models allowing the system structure to change and adapt as a dynamic organisation. The engineering process is not focused on the product definition ('the What' of the Enterprise) but on the definition of the operational system ('the How') at the shop floor level which supports the product manufacturing. The application of the reference models leads to building a physical shop floor architecture, which is composed of co-ordinated and co-operating interoperable and reusable hardware/software field components (devices). The resulting shop floor architecture is therefore constituted by a network of field components integrating a ' technical form of intelligence ' (local capacities) that offer a greater reactivity while interoperating among them to ensure the integration (co-ordination) of operational activities.

That means to add to the field components classical missions new services related to monitoring, validation, evaluation, decision-making, etc. [21], with regard to their own operations (an increased degree of autonomy) but also to their interoperability context for application (an increased degree of component interaction).

The interoperability, in accordance with the definition proposed by the SEMI organisation (Semiconductor Equipment and International Material)[1] can be described by :

- Interoperability of class A for the **communication**,
- Interoperability of class B for the application **services**,
- Interoperability of class C for the **interchangeability** ... towards **adaptability**.

The resulting shop floor architecture based on interoperable components is thus characterised by three keywords: Interoperability, Integration and Distribution. This architecture is complex due to, first, the interaction between its various field components, and second, the heterogeneous nature of the various techniques implemented in it. Its development implies definition of its components, the carrying out of the development itself and finally their assembly and checking that their interactions constitute correctly the functions expected from a distributed-integrated architecture. The engineering process of such architecture has to master the complexities of distribution and interactions, to provide better global performance and better reactivity at disturbances (a compromise between hierarchy and heterarchy [3]).

Early works in European ESPRIT Projects[2] on CMM concept (an integration view) have contributed to this engineering process but mainly from technological and normative points of view. They proposed pre-integration of the CMM activities through the implementation of Intelligent Actuation and Measurement systems (**IAM** concept: a distribution view) composed of smart devices and field-buses [22] developed as specific field components.

All these European R&D projects have been supported by industrial users coming mainly from energy domain such as EDF (F), ENEL

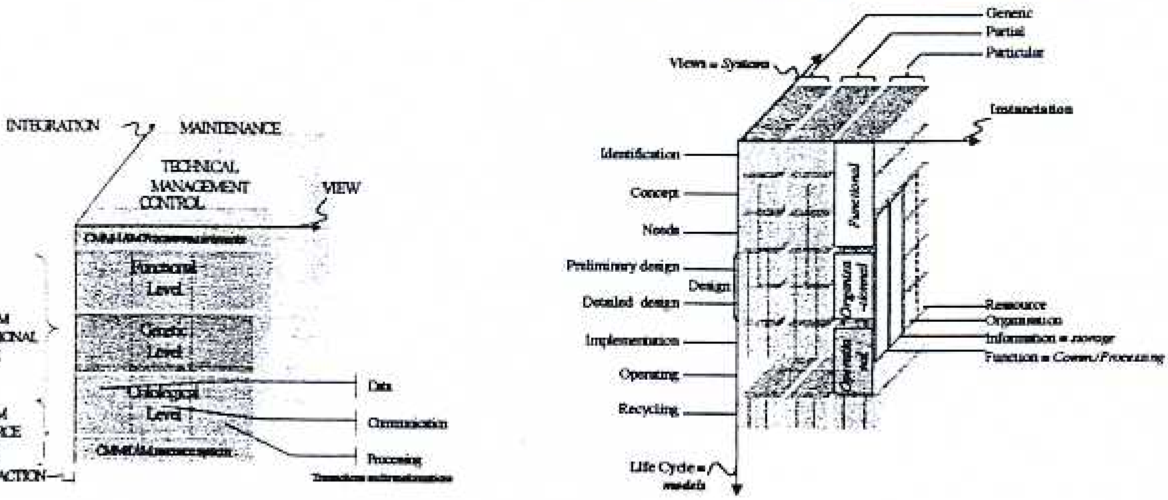


Figure 7. CMM/IAM Modelling Framework-GERAM Modelling Framework

1 Sematech (1995), '*Device Interoperability Guideline for Sensors, Actuators, and Controllers*', Technology Transfer 94102567A-STD, February. www.sematech.org

2 ESPRIT II-2172 DIAS "Distributed Intelligent Actuators and Sensors"; ESPRIT III-6188 PRIAM "Prenormative Requirements for Intelligent Actuation and Measurement"; ESPRIT III-6244 EIAMUG "European Intelligent Actuation and Measurement

(I), EDP (P), LABORELEC (B) and by industrial vendors such as SEMA GROUP (F and B), BERNARD (F), ABB (SW), ELSAG BAILEY (I) and BIFFI (I). Some of the partners are already involved in our current R&D.

This "technological" CMM/IAM integration is not sufficient to fulfil all the features of the engineering process and to ensure its consistency and reusability. Indeed, the behaviour of the whole CMM/IAM system cannot result only from assembling the required technology. It is necessary to move from a "Technology push" situation to a " Requirement pull situation".

So, to be compliant with both integration and distribution paradigms, we have promoted the formalisation of the CMM/IAM engineering process through a systemic framework and by means of reference models that can be applied in defining specific integrated-distributed shop floor architectures. The reference models are formalised inside the framework by using an extended entity/relationship formalism. The use of reference models has several advantages, such as their reusability for other applications of the same type, their steady improvement by collection and analysis of experience, the reduction of development costs, the upgrading of the quality of solutions, the dependability of the resulting architectures.

The framework allows to structure the development of the architecture in a more effective way by taking into account the systemic paradigm and considering the architecture through its functional, genetic and physical representations [5]. It can be synthesised along the three abstraction, view and integration axes in accordance with the GERAM framework [23] (Figure 7). In this framework, the engineering processes have to :

1. ensure that the operational architecture resulting from the reference models application will satisfy the integration and distribution requirements (to reach the levels 'Visible' and 'Interoperable' of Table 1),
2. support formal reference models guaranteeing the quality of the approach required to master the modelling process consistency, reusability and improvement (to reach the levels 'Defined' and 'Quantitatively Managed' of Table 2).

So, the role of the modelling agent is, viewed from the user needs, to deduce the functional model of CMM/IAM architecture and, from a real CMM/IAM resource system, to induce the operational ones knowing that these stages are guided by the framework previously defined, which implements the systemic modelling approach on two main planes:

- a "system/abstraction" plane which consists in modelling, in a separate way, the transformational processing of the shop floor activities, and their organisation on a distributed architecture in order to satisfy the user needs,
- an "integration/abstraction" plane which consists in integrating through transactional processing the previous transformational ones and in implementing them in an integrating infrastructure [9] in order to form a coherent whole.

6.1 From Closed[3] Distributed Operational Activities

The framework aims in the first instance at modelling each one of the three CMM operational activities (its transformational processing), with no considerations for the other ones (no integration). At this stage, the global 'How' of the process is designed in terms of mechanical field (device) components, which support elementary physical transformations required to elaborate the product (e.g. to store water by means of tank, to regulate the water flow by means of valve, ...). On these assumptions, the framework has to ensure the mapping between the requirements expressed by the users and represented by a functional model of the expected services, and the offered vendor's solution represented by an operational model. So, the modelling framework supports three abstraction levels:

- functional level, which expresses the user's requirements in terms of each operational activity of the shop floor architecture without considering any distribution criteria or technological constraints on the IT processing, storing or communication,
- organisational level, which introduces distribution criteria such as those linked to :
    - user's organisational requirements resulting from safety, dependability, redundancy and other constraints. These criteria are IT implementation independent,
    - vendors' organisational architecture which results from matching existing (or new) field components to the user requirements

User Group", ESPRIT IV-25525 IAM-PILOT "Intelligent Actuation and Measurement Pilot".

3 The modelling of closed operational activity corresponds to the modelling of this activity of the shop floor architecture, with no considerations for the other shop floor activities.

- operational level taking into account the IT technological constraints and developments.

The objective of each operational shop floor activity is :

- for the control, to ensure the commandability and observability of the physical architecture, by means of actuation and measurement channels, defined from the needs of the functional step [24] [8],
- for a "Just in Time" Predictive Maintenance, to ensure the availability of architecture resources [25] [26] through Forecasting, Diagnosis and Monitoring processes based on the causal relationships between functioning and malfunctioning,
- for the technical Management, to optimise the operation phase by modifying control or maintenance procedures, tools and materials.

So, the reference models have to formalise (a) the functional requirement diagrams from the user needs and related to each CMM goal (definition of Functional Companion Standards); (b) the distribution of these requirements (Functional Companion) in co-operating organisational-units while respecting, on the one hand, the appropriate corporate and site policies on safety, hazard and operability studies, ... and, on the other hand, the application goal; (c) the mapping of these org-units onto physical field components from a processing, storing and communication point of view. The distribution is made on two levels linked by a fieldbus :

- *Internal functions*, which are directly supported by the field devices components : 'intelligent field devices', performing a mechanical or electrical transformation (actuators and sensors),
- *External functions*, which are not supported by the field devices and need to be implemented into another field component within the process systems , to satisfy the user's needs (e.g. control unit).

The communication interoperability (class A) is supported by the fieldbus and the processing interoperability (class B) is supported by the Functional Companion Standards. The features of the selected fieldbus ensure the co-operation of the Communication services and the Functional Companion Standards as well as the co-operation of the application services.

The resulting architecture, obtained by derivation of reference models, models each operational shop floor activity called 'interoperable', because it is based on interoperable and distributed components but closed because it is not integrated with the other activities.

6.2 ... To An Open Integrated Shop Floor Architecture ...

To open and enhance the closed operational shop floor activities to become a Control, Maintenance and Technical Management integrated system, the modelling framework has to support also the representation of information transaction between Control, Maintenance and Technical Management activities [27]. The engineering process has to take into account the communication of the transactional information, its processing and its storage to realise a horizontal integration (between all the operational activities) and a vertical one with the other Enterprise functions.

At this stage, the reference models formalise, first, the development of the technical information systems, to integrate the three shop floor islands, and second, the mechanisms to complete the operational architecture, that is to say the implementation of the control, maintenance, technical management and technical information systems in the integrating infrastructure. This integration is supported by the selected fieldbus and by technical Data Base Management Systems that ensure the co-ordination of the CMM islands in space and in time respectively.

All these shop floor reference models have been applied and validated during the design and implementation of the integrated - distributed shop floor architecture of the CRAN Laboratory platform (to reach the level 4 of Table 2). The goal of this laboratory platform is to carry out a water level regulation in a closed control loop. The loop keeps a constant level (volume) of water where an input water flow represents the disruption, and an output water flow is controlled to maintain the level. From a technological point of view, the CRAN Laboratory platform (Figure 8) is structured, on the one hand, on an IAM composed of two integrated valves, a level and a flow transmitter and, on the other hand, on a CMM composed of a control system, a maintenance system, a technical management system and a technical database. These two levels of the platform are connected through a FIP fieldbus. All these CMM/IAM components are realised as field components (devices) already available on the market and of which processing-storing parts have already been implemented or can be developed by means of standardised tools like IEC1131-3.

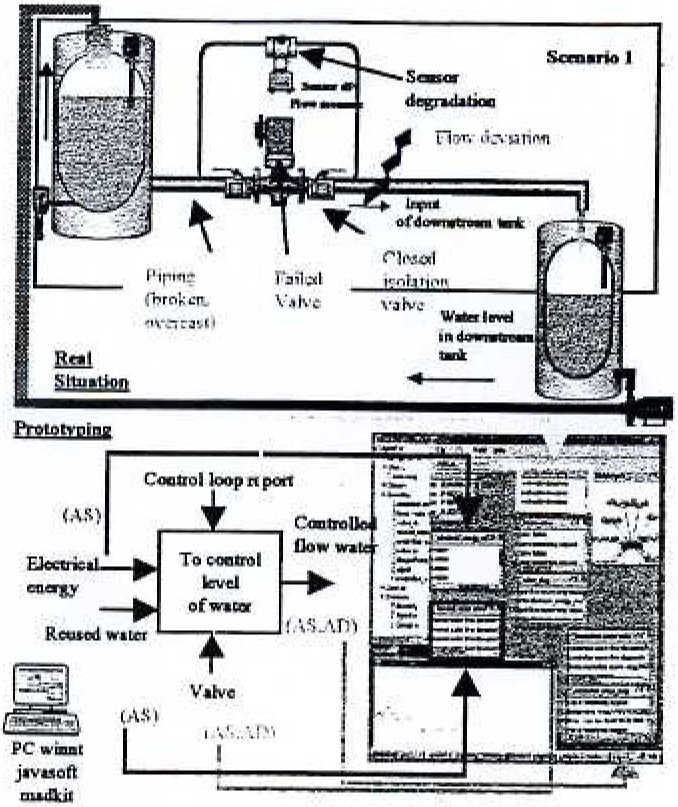


Figure 8. Validation Based On MADKIT Platform of Agent-oriented Maintenance Functional Architecture of the CRAN Laboratory Platform

6.3 ... and to An Intelligent Shop Floor Architecture

To confer interoperability of class C to this type of shop floor architecture, our objective is to evolve from 'visible-interoperable' to 'adaptable' (intelligent) architecture (to reach the level 5 of Table 1), that is more able to support changes of the structure. It means also an evolution towards the engineering processes related to Distributed Artificial Intelligence based on emerging trends. So the current CRAN/GSIP research is to apply the Multi-Agent System modelling technique for the development of the proactive maintenance intelligent system of the CRAN Laboratory platform [28]. The proactive maintenance strategy [26] is based on the prognosis of the degradation through a prognosis process enabling to propagate the degradation causes in order to anticipate the manufacturing system failure. The cause identification is realised through a diagnosis process determining the degradation origins from the symptom observation. The degradation identification highlights the system malfunctioning states from the material flows properties deviations through a monitoring process.

This agent -oriented maintenance architecture supports the Aalaadin model [10] composed of generic MAS concepts as agent (e.g. monitoring, diagnosis, prognosis, communicator), group (e.g. maintenance, communication), role (e.g. to diagnose...) and kernel which ensure the co-operation, the flexibility and the adaptability of the maintenance system (software or mechanical component modifying, adding, removing, redistributing, ...). The reactive agent identification is based on the functioning analysis knowing that each agent of monitoring, diagnosis and prognosis is associated with each flow, each activity and with each decomposition level of the analysis. This functioning formalisation can induce the malfunctioning by considering that the relationship between these two modes is directly linked to the relationship between the normal and abnormal states of the system (degradation of the flow and/or the activity).

The implementation of these MAS concepts in the case of the CRAN Laboratory platform, led first to an agent -oriented functional architecture, then to an organisational architecture, and finally to an operational one. The two first architectures which have not integrated yet mechanisms to resolve semantic and spatial diagnosis conflicts, have been prototyped on the generic case tool MADKIT[4] (Multi-Agent Development Kit) supporting JAVA code, the model of communication agents of the contractual network, and a graphical interface. They have been validated (Figure 8) by executing a set of test scenarios, which is a representation of real degradation vectors of the platform.

Finally, the implementation of the proactive maintenance intelligent system on the platform (operational architecture) is in progress by coding the agents, kernels, communicators and synchronisers (developed in JAVA) into the industrial components (PLC of the two valves, of the flow sensor, of the maintenance workstation...) supporting IEC1131-3 and into the FIP fieldbus.

This research is a first real step towards the modelling and implementation of Intelligent Manufacturing Systems.

7. Development of An Object-oriented Data Model As A Gateway Between Shop Floor and Business Levels

The WZL research focused on the connection between shop floor and business level in the manufacturing system. The drawbacks of the current interface between two levels were analysed and a new data interface proper for the intelligent manufacturing system was introduced.

7.1 Autonomous Production Cell and Machining Holon

Following the recent trend toward small lot production and a large number of product variations, an autonomous production cell (APC) is being developed at the Aachen University of Technology [29]. The objective of this research is to implement a new manufacturing system emphasising autonomy and co-operation (adaptable level of Table 1). The idea underlying this project reflects the reality that the conventional automated systems of the 80's, designed to be coherent with the integration paradigm (the visible level of Table 1), have not met the new demands of manufacturing systems, which should be more adaptable, intelligent and co-operative. This objective also coincides with that of the Holonic Manufacturing System researches, which is one of the major projects of Intelligent Manufacturing Systems, especially regarding the realisation of the Machining Holon.

In the old style of machining cell embodied in the hierarchical framework, the manufacturing commands are delivered from CAD/CAM system in the design department. The machine operator should optimise the machining and operational parameters manually at the test phase. He should also monitor the whole machining process and solve the problems which occur dynamically. This situation leads to high complexity and low efficiency of the machining process.

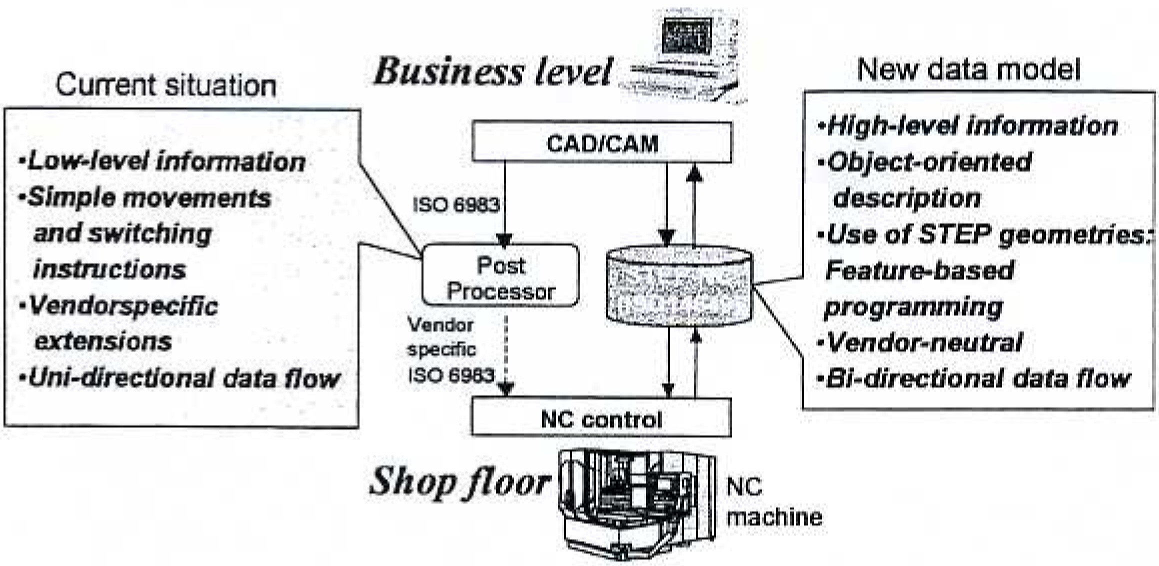


Figure 9. The Current and New Schema of the Interface Between CAD/CAM and CNC

4 Copyright © O.Gutknecht & J.Ferber - LIRMM - 1997.

In order that the old style of machining cells progresses toward the Machining Holon, it should be able to carry out its own machining plan independently and to support an effective co-operation with other Holons. Considering these requirements, WZL studied on the data interface between shop floor and business for the new manufacturing system (see Figure 9).

7.2 Current Situation of the Data Interface

The exchange of the part program in the manufacturing industry is currently done using the ISO 6983 standard [30]. The standard, however, dates back to the time of primitive NC controllers and is designed to be consistent with separated manufacturing cells (the fragmented islands level of Table 1). Therefore, it is considered to be technologically outdated and improper for the new autonomous-co-operative manufacturing system.

Additionally, this standard presents many drawbacks: (1) It describes only a low level of data such as axis movement (like G1, G2, G3) and switching instructions (like M3, M8); (2) It is poorly suited for high-level machining; (3) It is impossible to exchange part programs between various controllers; (4) It is impossible to change complex NC programs at shop floor level; (5) It is impossible to feedback the modified part programs to planning department. Due to these disadvantages, controller and machine -tool manufacturers have introduced their own extensions, which can be coded only by vendor-specific post-processors. This severely prevents the manufacturing system from realising an open architecture. The low level of data that it describes also prohibits the manufacturing system from being equipped with intelligent functions.

In the meantime, the Standard for the Exchange of Product Model Data (STEP) [31] was proposed in order to provide a neutral mechanism capable of describing product data throughout the life -cycle of a product independent of any particular system. The STEP is extending its application areas to such a case as the contribution to the concurrent engineering through the implementation of Engineering Data Management system at the business level [32]. The integration into the shop floor level, however, is still to be achieved.

This mismatch of the data model between CAD/CAM and CNC has also caused much difficulty in verification of the machined part compared to the designed part. Many researches on the NC code verification using reverse engineering technology have been done as the case of Roy's [33].

7.3 The New Data Interface, STEP-NC

Regarding the aforementioned situation, WZL has developed a new programming interface with many industrial partners within several projects such as MATRAS and OPTIMAL. The new interface, today called STEP-NC (STEP-compliant data interface for Numerical Controls), aims not only to replace ISO 6983

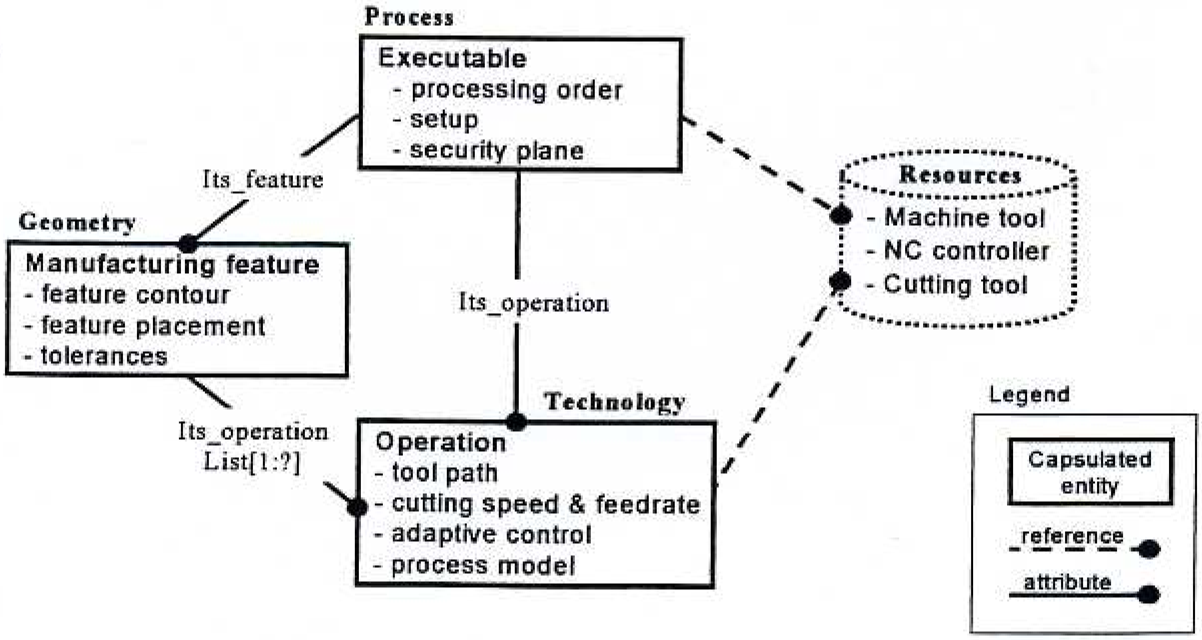


Figure 10. Capsulated Structure of Manufacturing Information

but also to support much improved functionality. Figure 9 shows the characteristics of the current interface and of the new one.

In the meantime, Pritschow [34] presented the benefits of using object-oriented modelling in machining technology. Gibson [35] used the EXPRESS language, which is capable of describing object-oriented modelling, in order to exchange capsulated feature information between CAD and CAM. Tönshoff [36] presented the way how the geometrical, technological and functional parameters can be combined and capsulated. Based on this research trend, the new data model uses entities, which capsulate all attributes of manufacturing information such as geometrical, technological, process model, and resource information. Therefore, the modularity and the reusability of information are being improved.

Figure 10 shows the capsulated structure of manufacturing information: all the information of the machining processes including the manufacturing sequence is capsulated in Entity "executable". In like manner, does all information of the product design data in Entity "manufacturing_feature" and all information of the machining technology in Entity "operation". The execution of manufacturing task can be interpreted as an execution of an "executable" which machines a part of "manufacturing_feature" through an "operation".

The new interface is designed (1) **to improve the exchange of information between manufacturing cell and its environments,** and (2) **to describe high-level information in order to improve autonomy**. These design criteria are also conformant with the research purpose of Holonic Manufacturing System, which aims at the stability and the flexibility of manufacturing process and an efficient use of available resources.

Concerning (1), the bi-directional exchange of information between NC controller in shop floor and CAD/CAM system at business level is promoted by means of the geometry representation of STEP. As the interface is vendor-neutral, it also improves the exchange of information inside the shop floor where usually many different types of controllers are equipped. This aspect significantly contributes to improving flexibility and co-operability of manufacturing systems. In other words, the part program can be modified at the shop floor in order to adapt the technological data to the dynamically changing situation and this modified program can easily be fed back to the planning department. The example data, which need be input or modified at shop floor, are set-up data, security plane, cutting parameters (cutting speed and feed rate), and machine functions.

If small change of product design occurs, modifications are needed for only some part of the data and other parts being possible to reuse. This also provides a clue for sharing know-how of the operator at the shop floor among the departments in the enterprise. Figure 11 shows the data model for a round hole and a drilling type operation. A feature "round_hole" is manufactured through a list of drilling type

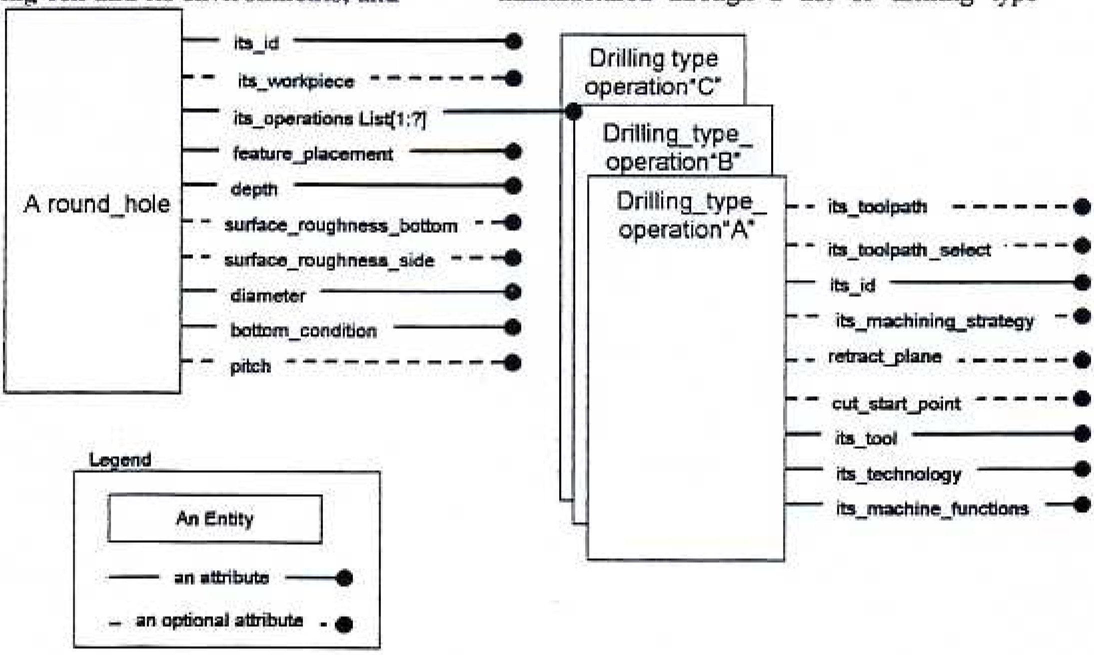


Figure 11. The Data Structure for A Round Hole and A Driling Type Operation

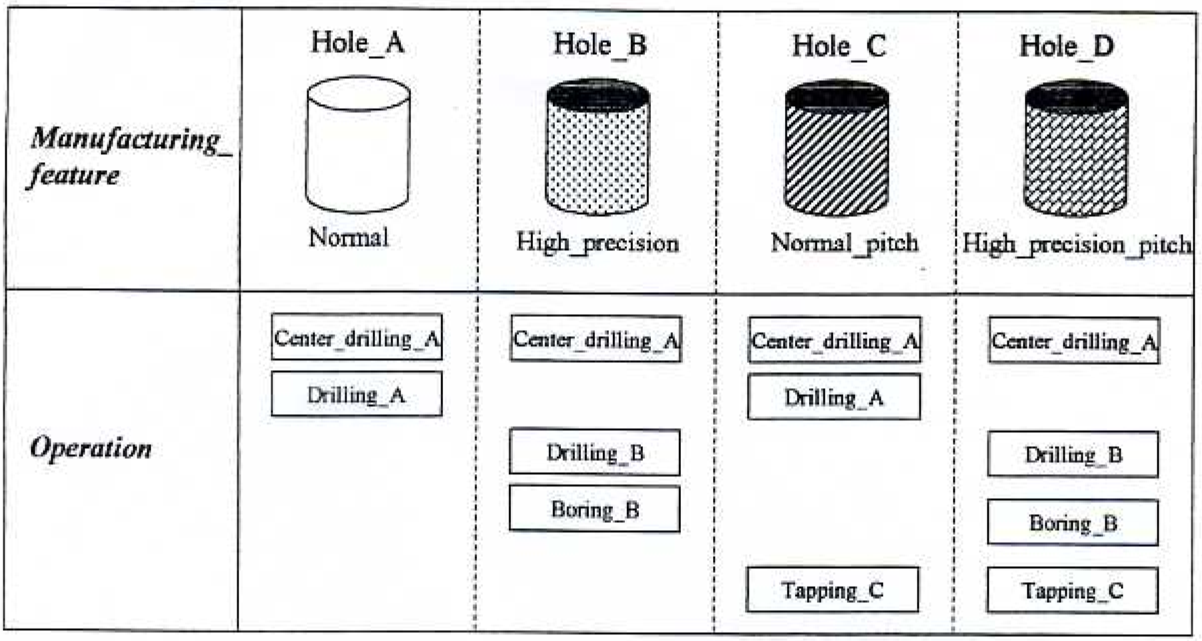


Figure 12. The Combinations of Particular Operation for the Machining of 4 Similar Holes

operations. As all technological data are captured in an operation, it plays a role of the building block for the machining of a hole. For example, let us consider the 4 holes (see Figure 12) which are made of the same material and have the same dimension but different surface quality: "Hole_A" has a normal surface quality, "Hole_B" has a higher surface quality, "Hole_C" has a normal surface quality with threads, and "Hole_D" has a higher surface quality with threads. A combination of particular operations can be used for the machining of each hole. The operation "Center_drilling_A" can be used for all 4 holes. The operation "Drilling_A" can be used for "Hole_A" and "Hole_C". After this manner, "Boring_B" is for "Hole_B" and "Hole_D" and "Tapping_C" is for "Hole_C" and "Hole_D". This illustrates the benefits of an object-oriented description of the machining information.

Not only are the operations handled as a building block but also are all geometrical and technological Entities. Therefore, if a database containing these building blocks of Entities is implemented, the know-how of the previous operations can be effectively saved and retrieved as well as the NC part program can be generated much more easily. Additionally, thanks to the common data model between shop floor and design department, it is also feasible to build an integrated database, which enables the agile exchange of information in the manufacturing industries.

Concerning (2), the new interface covers manufacturing tasks such as roughing or finishing of a pocket in contrast to the low level commands of ISO 6983. These tasks contain all operational and technological information necessary to produce the finished part from the raw piece. With this high-level of information, additional intelligent functions may be realised in the controller. Regarding stability, as the interface is provided with the entity for process models, the machining process should be self-reliant through the effective process monitoring and treatment of disturbances such as chatter, tool breakage, tool wear, tool collision, and machine faults. The intelligent functions like automatic selection of cutting tool and technological data can be implemented using much higher information about resources like raw -material and cutting tool. Additionally, an effective Man -Machine Interface program like a shop floor programming system can maximise the utilisation of the machine operator's know-how, which is also considered to be a very important resource.

7.4 Standardisation and Validation of the STEP-NC

The new data interface has been introduced into the ISO working group (ISO/ TC184/SC1/WG7) and the standard ISO 14649 [37] is now under final deliberation for the Draft International Standard version. A prototype implementation of a controller that is able to execute a part program according to the new interface has been done in the OSACA-based NC developed by WZL. OSACA [38] is the European open control architecture standard.

STEP-NC project is now running as a research and validation project in Europe. In this project, the new data interface will be verified through a number of implementations by industrial partners and could be extended to other technologies like turning, grinding, EDM, contour cutting, and rapid prototyping under the international co-operative works.

The new interface developed and verified through these research activities will give a solution to eliminate the bottleneck between the shop floor and business level and create a complete gateway between two levels. Through this gateway, the communication network systems for information processes can be realised and thus autonomy and co-operation will be significantly increased in the Intelligent Manufacturing System.

The described results are joint efforts of the ISO TC184/SC1/WG7. The authors would like to thank all partners for their contributions and efforts.

8. Conclusions

In this paper, discipline research approaches for the architecture and modelling of enterprise were presented. All these approaches have the same objective: to create and develop the framework for an IMS environment. They are different but complementary approaches, they work within the same scope and there is an overlapping among them, which encourages us to further investigate the integration of these approaches in order to follow the IMS perspective.

The IMS-WG gave us the opportunity to understand each other's research interest and find out that our collaboration can lend to more integrated approaches and thus to the development of sophisticated autonomous and co-operative systems. Our future common research approach will investigate the possibility of developing a Fuzzy Cognitive Map that will consist of concepts, some of which are holons, an area in which LAR and DTU will continue to work. Moreover LAR will continue their research collaboration with CRAN in the development of a supervisor over the CRAN architecture. DTU approach and CRAN are complementary /supplementary architectures and both teams have to work to this. On the other hand Aachen WZL research approach will help all other teams solve the communication problems that they face with in transmitting information between different parts of the enterprise and mainly in understanding subsystems constructed with different architectures and approaches. Within this framework all partners are going to present their results in European industries and moreover they are going to submit a proposal to continue their research collaboration.

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