PROPOSAL FOR INTER-ENTERPRISES NEGOTIATION INFRA-STRUCTURES USING AN HOLONIC APPROACH

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Abstract: Manufacturing systems are changing its structure and organisation. Supply chain structure is evolving to more dynamic organisations such extended enterprise and virtual enterprises, enhancing single entity autonomy, adaptability and dynamism properties. Such organisations are very different from the established, which imply organisational and technological shift through distribution, decentralisation, reactivity, flexibility and agility. New organisational and technological paradigms are needed in order to reply to these challenges. This paper present a brief description of three organisational paradigms, and relating to its properties, proposes a holonic manufacturing system architecture. Developed complementary services are introduced and its advantages in overall system new requirements are justified.

Keywords: Co-operation, Co-ordination, Intelligent Manufacturing Systems, HMS.

1. INTRODUCTION

Economy globalisation, increased social demands, increased product diversity over time and increased technological complexity, are affecting manufacturing context and imposing technological shifts. Enterprises must change approaches to business, reducing costs, time-to-market and product lifetime, although increasing product quality and environmental care. Enterprise needs to modify manufacturing attitude. Distribution, Decentralisation, Co-operation, Negotiation and Co-ordination are concepts the enterprise must adhere to. Expansion of partnerships is a potential strategy. Adopting the Virtual Enterprise (VE) or other related paradigms (Silva, 1998), the traditionally centralised systems become distributed from the physical and from the logic point of view. Traditional enterprise comprises different sub-systems or divisions (e.g. Sales, Manufacturing, Forecasts, and Accounting). Applying the VE paradigm, traditional enterprise increases partnership to a complete new set of functions that were absolutely intra-enterprise responsibility until few years ago. From the logical point of view, it is also a distributed problem considering that most of the functions can be executed concurrently by different entities. In addition, the task/entity association is foremost unknown, which imply the system must be prepared to ill specification, thus dynamically fit on going constraints.

Section 2 discusses the need for new organisational structures and behaviours, analyses recent organisational paradigms and identifies related requirements. In section 3, the conceived manufacturing system structure is presented. Section

4, introduces and describes the services developed in order to reply to identified requirements.

2. ORGANISATIONAL CONCEPTS

Until few years ago, CIM concept was considered satisfactory enough treating manufacturing enterprise requirements. However, taking in to account a new set of organisational and economic concepts, it becomes clear that the centralised CIM approach is not the answer (Solberg and Kashyap, 1993). On the contrary, organisational concepts like Supply Chain, Extended Enterprise or Virtual Enterprise, suggests simultaneously the idea of Distribution, Decentralisation, Dynamism, Autonomy; Ill-specification, Agility (Sousa, *et al.* 1999). Consequently (Silva, 1998), traditional centralised approaches, like CIM, do not fulfil modern enterprises functional requirements. Hence new organisational concepts must be analysed and validated. Three of these are briefly presented focusing its roots and fundamental features.

2.1. Fractal Factory

Fractal Factory paradigm is based on mathematical fractal concept and its associated theory of chaos. The fractal is characterised by constant evolution related to its partners and environment (Tharumarajah, *et al.*, 1996). Warneck, the author, defends the factory of the future will be substantially different, specially concerning its dynamic organisational structure (Sihn, 1997). It suggests the enterprise will abandon the function-oriented organisation and adopt the project-oriented organisation. This approach implies the organisational structure will encapsulate the process and the technology, therefore forming a cybernetic structure. Thus, the factory will not have a predefined organisation, but a more or less static set of resources and a very dynamic set of projects (tasks). As a new project is introduced into the system, each resource starts negotiation (it can even compete) with remainder resources, the execution of each sub-project. Thus, each project initiates a very dynamic process, responsible for resource/sub-project binding, leading to constant changes in the enterprise structure and organisation. This process is more dynamic (and presumable successful) as the resource can (well) decide about its own behaviour and does not rely on a higher entity to do it. Thus, the fractal factory must be understood as a non-linear system (Sihn, 1997), structurally reactive and adaptive to the dynamic context. In addition, the concept easily models different enterprise dimension, like strategic, social, cultural, informational and technological (Zelm, *et al.*, 1995).

2.2. Bionic Manufacturing System

Bionic Manufacturing System is based on structures and behaviours observed in biology. Okino, presented the Bionic Manufacturing Systems and the associated term *Biological-oriented*, which intends to apply to manufacturing systems the structure and organisation behaviour of the living beings. In his analyses, Okino mention the fact that from the simplest through the most complex living form, inside of certain hierarchically ordered relations, all manifest autonomy, spontaneous behaviour and social harmony. In biological systems, autonomy and spontaneous behaviour means each entity is responsible for its activities and self-division according to a genetic code named DNA[1]. Furthermore, consistency and goal orientation are conceptually supported by the genetic inheritance, in which the genetic code of the entity (be a cell or a complete living being) is inherited. BMS tries to define a parallelism between biological systems and manufacturing systems, traducing the DNA inheritance in biology to characteristics, states, behaviour and domain knowledge in manufacturing. Moreover, the surrounding environment supplies both system memory and "small" entities influencing inter-entities relations, the enzymes in biology.

2.3. Holonic Manufacturing System

The Holonic paradigm arises from Herbert Simon and Arthur Koestler studies about biological society evolution and organisation. Simon observed that complex systems are hierarchical and formed by intermediate stable forms. These forms allow system to be stable, reliable and evolutionary, while maintaining a goal oriented functionality due to its hierarchical structure. Later, analysing Simon theory and comparing it with its own observations, Koestler perceived that each system and its intermediate forms do not exist as auto-sufficient, non-interactive elements. On the contrary, they are simultaneously a part and a whole, a container and a contained, a controller and a controlled. In addition, each entity has no chances to define or control the entire system, it simply orients and represents a set of entities to a larger system. In order to designate these hybrid nature and behavioural entities, (Koestler, 1967) proposed the term Holon as the combination of the Greek word *Holos* (whole), and the *on* suffix (particle, like in neutr*on*). Also, "Holarchy is a hierarchy of self-regulating holons, in supra-ordination to their parts, in sub-ordination to

[1] The DNA is contained in chromosomes, *stores the genetic information about the individual to further transmission to its descendants, during the cell division. Each species has its own DNA composition and even each individual has its own DNA composition that makes it unique.*

Table 1 - Structural aspects of Fractal Factory, BMS and HMS

	Fractal Factory	BMS	HMS
Unit	Fractal	Modelon	Holon
Unit Creation	Predefined	Genesis & Dynamic	Predefined
Unit Modulation	Multi-dimension	Multi-functional	Functional & Physical
Group	Fractal	Modelon	Holon
Group Creation	Predefined & Dynamic	Predefined & Dynamic	Predefined & Dynamic
Group Creation Process	Regroup	Unit division	Regroup
Group Goals	Projects & Optimisation	Functional	Functional

the higher levels and in co-ordination with environment" (Koestler, 1967). Additionally, the IMS-HMS group defined a set of properties related to the manufacturing systems based on Koestler work:

- The holonic manufacturing system entities are autonomous and co-operative;
- Holon has information about itself and the environment;
- Each holon is composed by other holons and thus each holon is a also a holarchy;
- Each holon can dynamically belong to multiple holarchies;
- The holarchy has fixed rules and directives (the *canon* (Tharumarajah, *et al.*, 1996).

Each holon combines its set of competencies with its lateral partners, with whom co-operate in order to achieve both individual and system goals. This suggests the holon is an autonomous entity, including operational features, individual goals and ability to define its own tasks and execution plans. Goals are partially defined in higher holon, and travelling down the holarchy, tasks and plans are progressively refined. The result is a highly complex but reactive system with minimal concession to efficiency.

2.4. FF Vs. BMS Vs. HMS

Fractal Factory, Bionic Manufacturing Systems and Holonic Manufacturing systems are three examples of organisational manufacturing paradigms comprehended in the broad term Open Hierarchical Systems introduced by (Koestler, 1967). These paradigms suggest the idea that manufacturing systems will continue to need a hierarchical structure besides the increased autonomy assigned to individual entities. Also, they advise the hierarchy is needed in order to maintain the overall system coherence and objectivity, guarantee the inter-entities conflict resolution arising from the individual and autonomous attitude of the entities.

The three paradigms have different origins, which imply different technical approaches. Based in (Tharumarajah, *et al.*, 1996), Table 1 briefly resumes the most important structural concepts, while Table 2 resumes the dynamic properties related to the paradigms. The BMS paradigm suggests some properties intimately similar to modern enterprises, specially relating to the environment, full of information and chances to improve business. However, so much information may have negative consequences due to stabilisation and productivity. On the other hand, the Fractal Factory paradigm is the most modern approach since it relies on individual entity autonomy and vitality to overcome responsiveness and performance. Further, it is based on mathematical formalisms that makes it the preferred approach to design and specification. However, its application tends to be complex especially respecting to implementing navigation and co-ordination mechanisms. Finally, the HMS paradigm, being the most traditional, due to its

Table 2 - Dynamic properties of Fractal Factory, BMS and HMS

	Fractal Factory	BMS	HMS
Autonomy	Individual goals & Vitality	Answer to changes in the environment and operators	Limited by hierarchical rules
Individual Planning	Continuous search for goals and optimisation	Minimal, most based on reaction to environment	Some defined hierarchically, most dynamically
Individual Control	Continuous control by state comparison	Reactive to changes in environment	Reactive and based in intermediate stable forms
Hierarchical Control	Between adjacent levels, through co-operation. Reactive conflict resolution	Hierarchical tasks, and results injected into the environment	Hierarchical plans with top-down refinement and bottom-up results
Lateral Co-ordination	Communication & Co-operation	Based on environment contents and Operators orders	Communication & Co-operation

structure and organisation, it is easily adaptable to the Object Oriented paradigm, thus sub-specification and specialisation. Also, is the most stable due to the hierarchical rules statically defined, the *canon*. Apart some minor points related to it, HMS paradigm has been adopted though it is possible and advised to combine properties related to others paradigms, namely the dynamic re-structuring process triggered by a new project arrival suggested by Fractal Factory.

3. ENTERPRISE STRUCTURE

Besides the fact the previous described paradigms are sufficient generic in order to be applied to different kinds of enterprises and business, during this project, the holonic manufacturing system focus in manufacturing enterprises, specially in the Scheduling system. The suggested architecture is based on holonic concept, thus composed by autonomous and co-operative entities modulated as holarchies and holons. The proposed architecture, first proposed in (Sousa and Ramos, 1996), is represented in Figure 1.

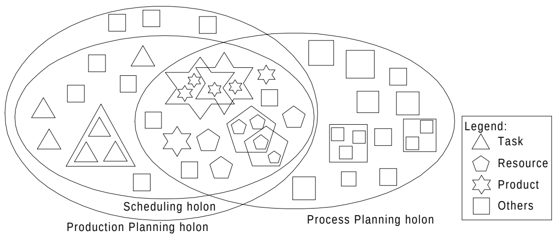

Figure 1 - Proposed architecture model

It is an holarchy composed of multiple high-level holarchies (e.g. Process Planning, Scheduling, Stocks, Forecasts, Sales) responsible for the co-ordination of its sub-entities. Lower, among other, resources, human entities, tasks, products, customers and suppliers; modulated as holons or holarchies. Meanwhile, each of these entities can simultaneously respect with multiple activities. For example, the Product holon simultaneously engage in Process Planning (defining design policies, inter-product constraints, etc.) and Production Planning (specifying operations, sub-products and raw materials). Consequently, some entities are simultaneously part of two holarchies, and thus, must contain and co-ordinate the functionality of the different processes they belong to. This kind of architecture is more flexible and reactive than the static and traditional CIM architecture (Bongaerts et al., 1996; Sousa and Ramos, 1996; Silva, *et al.*, 1998), but requires different characteristics comparing to traditional ones.

4. COMPLEMENTARY SERVICES

In fact, Communication, Security, Information Management and Coherence, Reliability and Dynamic Organisation are fundamental elements in holonic systems. Apart each holon is responsible about these questions, special mechanisms can be globally supplied in order to assist overall system operation. Therefore, four complementary services were combined into the system: Identification, Information, Pooling and Domain services. Each of these must concerns reliability, dynamism, security and coherence in order to accomplish conceptual holonic behaviours.

4.1. Identification Service

This service, internally named Holonic Name Service (HNS), is responsible for inclusion and exclusion of any holon in the holarchy. To adhere to the holarchy, each holon must request this service. When connecting to a holon, first off all, it must query to HNS the requesting holon location and authenticity.

The service involves four phases (i) Identification, (ii) Authentication, (iii) Registration and (iv) Unregistration. In order to guaranty system Reliability, Security and Coherence, four rules are applied:

- The HNS is provided not by a single holon, but a set of holons;
- Each of the HNS holons owns a database table (DB) relating holons identification and passwords;
- Each holon is registered in one single HNS holon;
- HNS holons must co-operate and co-ordinate information to guaranty unique holon connection.

The requesting holon starts the process, broadcasting an HNS request, referring its identification and location. One of the HNS holons replies, requesting the holon authentication. The requesting holon uses its password to authenticate it self to the HNS. The HNS holon checks the received password. If the password matches the holon DB entry then the registration is established, else, the registration is refused. Once the registration is mutual accepted, a permanent connection is maintained open. As soon as the connection is closed, the unregistration process begins. In order to improve security, namely respecting authentication phase, a mutual authentication process has been adopted, based in the well-known public key method. Multiple HNS holons must co-operate in order to co-ordinate requesting connections and its related information.

As been proposed, each holon must have a single HNS connection, in order to guaranty coherence. Each time a holon requests registration, the replying HNS holon must query all the other about the holon password. Also, HNS DB is distributed by multiple holons, altogether forming a whole. Thus if identification/password does not exists in HNS holon DB, the HNS holon must assure it with its partners. If the holon identification is not known, then authentication must be refused, else, protocol must follow. Figure 2, represents the complete described process, using a finite state machine. The message exchanges inside the doted line correspond to the HNS private protocol between HNS holon, thus completely transparent to the requesting holon.

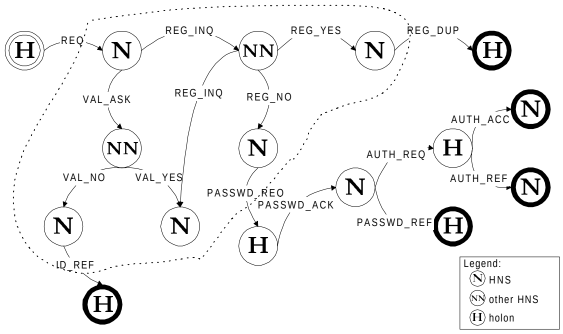

Figure 2 - HNS protocol representation.

4.2. *Information Service*

Information Service (HIS) is responsible for the information management in the holarchy. Each holon has some properties that needs to publish in order to be requested, e.g. performing operations, reliability, costs. This service intends to publish such information. To address reliability, multiples HIS holons are proposed, though incoherence easily occurs in such conditions. Subsequently, HIS co-operation and publishing rules are essential:

- Information has a single owner;
- The owner is responsible for information management (publish, update and unpublish);
- Owner limits information time validity;
- Only HIS provides published information;
- HIS holons when queried about unfamiliar information, query its HIS partners for it;
- Information can not be updated until last supplied part information releases it;
- Information is valid exclusively during owner HNS registration.

Therefore, any holon publish its information in the HIS holon, who provide it to the requesting holons, acting as a broker. However, any holon can publish information in different HIS holons. Coherence and system security potentially becomes unreliable.

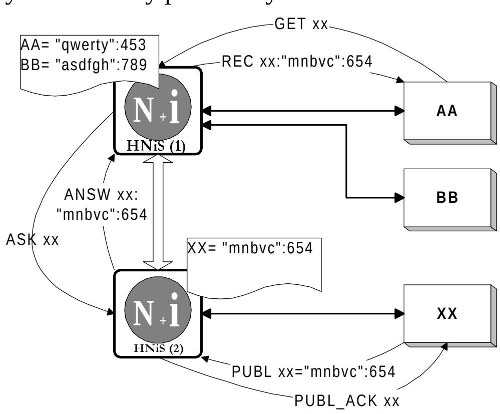

Figure 3 - HNS-HIS integrated service

Once HNS provides operational features respecting coherence and security, the proposed solution suggests the combination of HNS and HIS in a single holon/holarchy (HNiS), which provides and integrates both services with no negotiation overhead (Figure 3). However, if the requested information does not exists locally it does not mean it does not exits published. Consequently, HNiS requires information to its partners, querying such information using HISPRIV protocol. Since the information exists in a sole HIS, just one will reply. After response, HNiS will provide received information to the requesting holon, thus maintaining coherence.

4.3. *Pooling Service*

Pooling Service (HPS) concerns with message delivery to holons temporarily unreachable or unregistered in the HNS. The service is requested by the holon that needs to send messages. Pooling service holon stores and deliver the message as soon as the destination holon is reachable. Each holon supplying the service should publish it in the HIS as any other holon property. In order to achieve reliability, multiple HPS holons can exist in the system, but no co-ordination or co-operation is required. Any message is stored in HPS holon DB without any processing. All it has to do is deliver message to the right holon as soon as possible. HPS holon periodically query its associated HNS holon for the destination holons. Although the pooling service is normally combined into the HNiS service, it can be separated or even ignored if the system communication and stability is sufficiently trustworthy. Although, if the HPS is combined into HNiS, the query process is not necessary since both services run in the same entity.

4.4. *Domain Service*

Fractal and Holonic paradigms suggest the regrouping property based on different perspectives and reasons, during the system operation. Dynamic grouping impose several constraints in system management, namely in inter-holarchy relation and information management. Some points should be remarked:

- Each holon might concerns to multiple holarchies. However, it does not mean it continually maintain participation;
- Each holarchy is a hierarchical system composed by holons; each of these can also be an holarchy. That means each holarchy have a top holon who represents it;
- Information related to each holarchy should not be spread all over the system, but maintain context restrictions;
- The holarchy has dynamic creation and destruction.

The proposed solution suggests the pertinence of an additional service, responsible for holarchy boundaries and inter-holarchy relations. This service should be responsible for logically group multiple holons and interface this set with its lateral partners. The service should filter and route conversations messages received from and sent to holarchy exterior. As suggested to the Information Service, again it is proposed to attach this service to the existent HNiS.

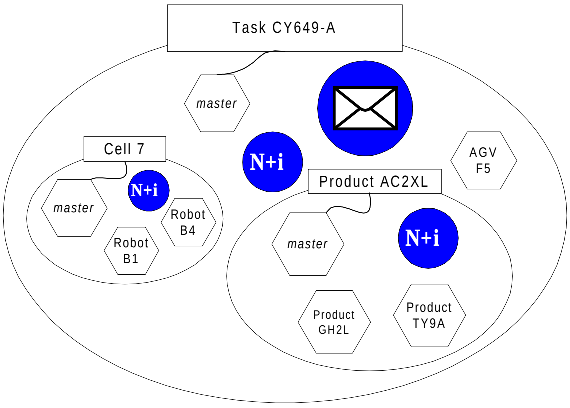

Figure 4 - Holonic Domain Service representation

As conceived, Holonic Domain Service (HDS) allows developers to construct composed entities that behave globally as hierarchical systems. Each of these entities is represented by a *master* holon that represents the entity global capabilities, behaviours and plans, but no other processing features are considered in it (Figure 4). The composed holon provided by HDS represents an autonomous, self-regulated holon, with ordinary constraints and features. Hence, each of these elements forms a completely independent information context, imposing publishing restrictions. The Information Service respects to a specific context and only with its internal partner it is allowed to share information. Since holon can belongs to multiple holarchies, it is holon responsibility to publish its specific information in contexts it belongs to. For example, a specific holon representing a production resource are logically grouped in the shop-floor holarchy, where it must publish its competencies, reliability, viability, costs, etc. However, as soon a new task is launched and it is group it into the task holarchy, that published information is not relevant though other type can be, and thus only such information should be published in the task holarchy.

5. CONCLUSIONS

This paper discusses the use of holonic approach to implement new generation of manufacturing systems. The holonic, bionic and fractal approaches were briefly described and compared. Additional considerations advocate these paradigms are not always contradictory and can even be combined into specific systems. Due to distribution, decentralisation, dynamism, non-deterministic structure, modern manufacturing systems need new organisation and technology approaches. A generic system composition, architecture and organisation were briefly presented. Also, this paper presents four complementary services: Identification, Information, Pooling and Domain services. Combining these four services, it is possible to improve Holonic conceptual characteristics like Dynamism, Reliability, Security, Information management and general performance. Although preliminary tests were optimistic, real case tests must be done to have accurate results in operation. Further tests will focus on open electric market negotiations.

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