Holonic Dynamic Scheduling Architecture And Services

Nuno Silva, Carlos Ramos
Departamento de Engenharia Informática
Instituto Superior de Engenharia do Porto
Instituto Politécnico do Porto
Rua de S. Tomé, s/n
4200 Porto - Portugal
Tel.: +351 2 8340500 Fax: +351 2 821159
e-mail: {nsilva, csr}@dei.isep.ipp.pt
http:// www.dei.isep.ipp.pt/~{nsilva, csr}

Abstract: Manufacturing systems are changing its structure and organisation. Supply chain are evolving to more coupled organisations, like virtual enterprises, though maintaining the single entities autonomy, adaptability and dynamism properties. Such organisations are very different, which imply organisational and technological shift through agility, distribution, decentralisation, reactivity and flexibility. New organisational and technological paradigms are needed in order to reply to the modern manufacturing systems needs. This paper present a holonic manufacturing system architecture and complementary services supplied to assist overall Communication, Security, Reliability, Information Management, Co-operation and Co-ordination.

Keywords: HMS, MAS, Architecture and Services

1. INTRODUCTION

During the last years, enterprises felt the need to change approaches to market, reducing costs, time-to-market and product lifetime, at the same time increasing quality and environmental care. Hence, enterprise should be aware of concepts like concurrent engineering, lean production, core business, federation, extended and virtual enterprise. These new organisation concepts lead to new approaches in production and therefore in Manufacturing Systems. Distribution, Decentralisation, Co-operation, Co-ordination, Flexibility and Reactivity, are questions the manufacturing system should deal with more and more.

Operation in general and scheduling in particular, are systems domains that must change in order to meet future organisation challenges. Adoption of the Virtual Enterprise and other related concepts (Silva, 98), operation and scheduling manufacturing systems become a distributed problem from the physical and from the logic point of view. Physically, the Manufacturing System involves several entities or resources (different enterprises, CNC's, robots, AGV's, conveyors). From the logical point of view it is also a distributed problem, because several tasks (task is meant to be a set of operations) can be carried out at the same time and in different entities simultaneously. Due to these topics, organisational concepts like the Multi-Agent Systems (MAS), Holonic Manufacturing Systems (HMS) are pondered to adopted.

Section 2 discuss the new manufacturing systems requirements, describes the Multi-Agent and Holonic concepts and relating them clarify mutual relations and justify selection. In section 3 the system architecture and specially the Dynamic Scheduling sub-system are presented. In Section 4 some systems requirements are presented. Subsequently, three complementary services are introduced and described. In the last section, conclusions about already done work, and some remarks about questions not yet addressed are discussed.

2. SYSTEM REQUIREMENTS VS. PROPOSED 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, 93). On the contrary, organisational concepts like Supply Chain, Extended Enterprise or Virtual Enterprise suggest idea of:

- Distribution, which means different entities operating through a main goal;
- Decentralisation which mean multiple entities in the system executing the same activity;
- Dynamism refers to system modifications in composition and structure, and consequently different relations, responsibilities and competencies between entities;
- Non-determinism, that means it is not possible to specify the exactly situations and behaviours the system will exhibit during operation;
- Autonomy. Although distribution and decentralisation apparently imply autonomy, in fact, autonomy relates to the entity ability to specify and carry out their own objectives and plans. Consequently, it is possible to have a distributed and decentralised system without autonomy;
- Agility, which refers to adaptation to uncertain situations occurring in system life cycle. These situations are unpredictable during development, contrary to flexibility, which deals with reconfiguration under predefined situations.

Consequently, traditional approaches like CIM do not satisfy modern enterprises functional requirements. Consequently, new concepts must be analysed and validated.

2.1 Multi-Agent Systems

An agent is a rational entity sensing and acting on its environment in order to achieve its objectives. There are several properties presented in agents, among others Autonomy, Social Ability, Reactivity, Pro-activeness

(Bongaerts *et al.*, 96; Jennings and Wooldridge, 96). In addition to these properties, an agent can be grouped with other agents, thus forming a multi-agent. Not to be confused with Multi-Agent System (MAS) which refers to a set of agents grouped by some sort of interconnection mechanisms, in order to achieve a goal. Although Multi-Agent System paradigm satisfies the new manufacturing systems challenges, it is too vague to satisfy design and development requirements (Silva, 98). In fact, MAS potential is enormous, but issues like structure, organisation, behaviour or life cycle management are unspecified and too broad. For example, the co-operation mechanisms include but are not limited to self-reaction, master-slave command, restriction propagation, voting, negotiation, (predefined and fixed conversation), speech acts (non-fixed conversation) (Parunak, 98b; Silva, 98).

2.2 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 systems 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 and non-interactive elements. On the contrary, they are simultaneously a part and a whole, a container and a contained, a controller and a controlled. Also, each entity has no chances to define or control the entire system, it simply orients and represents a set of entities to an larger system. In order to designate these hybrid nature and behavioural entities, Koestler (1967) proposed the terms Holon[1] and Holarchy. “A holarchy is a hierarchy of self-regulating holons, in supra-ordination to their parts, in sub-ordination to the higher levels and in co-ordination with environment” (Koestler, 67).

Additionally, the IMS – HMS group defined a set of properties related to the manufacturing systems based on the holonic paradigm:

- 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.*, 96).

Thus, goals are partially defined in higher holon, and travelling down the holarchy tasks and plans are progressively refined. 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. In this sense, the Holonic paradigm is an organisational and architectural concept since it defines the entity structures and its conceptual behaviours.

The properties and behaviours defined for the holonic concept fits the structure and the dynamic behaviour of the modern manufacturing system. The result is a highly complex but reactive system with minimal concession to efficiency.

However, the properties previously mentioned require implementation technology, which can be supplied by the MAS concept. Consequently, MAS is seen as a technologic concept while HMS is seen as an organisational and architectural paradigm, thus compatible and mutually complementary. In this sense, the HMS was been selected as main organisational concept along with MAS as implementation technology.

3. MANUFACTURING SYSTEM ARCHITECTURE

A holonic manufacturing system is a holarchy composed by autonomous and co-operative entities, the holon. The proposed architecture, first proposed in (Sousa and Ramos, 96), follows this approach (Figure 1). It is a holarchy composed of multiple high-level holons (e.g. Process Planning, Scheduling, Stock Management) responsible for the co-ordination of its sub-entities. Lower, the product, the resource and the task holons (among others).

[1] *Holos* (whole in greek) + *on* (a particle, like in neutr*on*)

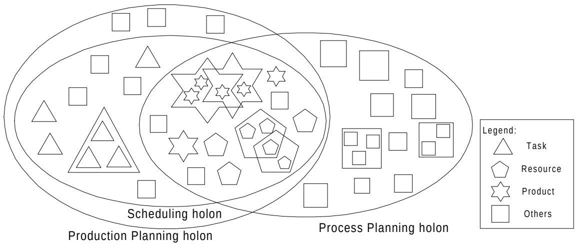

Figure 1 - Proposed architecture model (Silva, 98)

During the case study, the focus is putted in the scheduling process, which relates its functionality with Production Planning. Nevertheless, the scheduling process deals with specific tasks, resources and products. Consequently, the Scheduling holon both sub-ordinate to the Production Planning holon and supra-ordinate to Product, Resource and Task holons:

- **The Product holon** represents the type of product, not the product object itself. The complete set of Products represents the system production possibilities (the catalogue). The Product is responsible for product planning specification and production quality control (Van Brussel *et al.*, 97). The Product can be composed by sub-Products, each one belonging to or be composed by others;
- **The Task holon** models a production task received in the system, each one constrained by products, resources, quantity and quality parameters. The Task holon is responsible for scheduling, control, execution and conflict avoidance between entities performing the task (Van Brussel *et al.*, 97). The Task holon is potentially made of other Task holons, but contrary to Product, the Task can not belong to different Tasks;
- **The Resource holon** represents the production elements in the system Each Resource can be made of others (e.g. a working cell) and share it with other (e.g. a tool used by multiple machines). The Resource holon is responsible for the operation control and sub-resources co-ordination, and concurs to the scheduling process, defining agendas, capabilities and capacities.

However, these entities also concern with other activities like Process Planning. 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. For example, Product and Resource holons belong to both Production Planning and Process Planning:

- Resource holon simultaneously engages in product process definition and scheduling activities. First, supplying capacity and functionality information needed to process planning, second, supplying time agenda and activity control information fundamental to dynamic scheduling;
- Product holon, concurrently contribute to the product process re-planning together with the Process Planning holon, and responsible by the quality control together with Production Planning holon.

This kind of architecture is more flexible and reactive than the static and traditional CIM architecture (Bongaerts *et al.*, 96, Sousa and Ramos, 96, Silva *et al.*, 98). However, such properties impose multiple constraints in system operation and functionality.

4. COMPLEMENTARY SERVICES

In fact, Communication, Security, Reliability, Coherence and Information Management are fundamental elements in holonic systems. Apart from the fact each holon is responsible about these questions, special features can be supplied, in order to assist overall system operation. Therefore, three complementary services were combined into the system: Registration, Information and Pooling. Each of these services must concerns reliability, dynamism, security and coherence.

4.1 Registration 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 involve four phases:

- Identification phase, relate to the first contact, made by the requesting holon and HNS reply;
- Authentication phase refers to the mutual authentication between holon and HNS. Notice that, not only the generic holon must identify to the HNS, but also the HNS holon to the generic holon.
- Registration phase occurs when both HNS and requesting holon match authentication,

the HNS registers identification and location about the requesting holon. When the holon is registered, it is said the holon is accepted in the holarchy.
- Unregistration phase occurs when the registered holon is no longer valid, accessible or abandon the holarchy.

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 data base 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 HNS comprises three different services:

- HNS protocol (HNS) refers to the generic holons registration in the HNS;
- HNS Private protocol (HNSPRIV). This protocol refers to the holons registration in the service;
- HNS Auxiliary protocol (HNSAUX) provides mechanisms to help generic holons to validate direct connection with other generic holons.

4.1.1 HNS protocol

The process is quite simple. The requesting holon broadcasts a HNS request, informing 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 received password match the holon DB entry then the holon is authentic and the registration is established. Else, the registration is refused.

Once the registration is mutual accepted, a permanent connection is maintained open. This connection is useful to further test holon registration. Holon must unregister its self from the HNS, however, many questions origin fatal error in holons, disallowing unregistration process. Thus, using the permanent connection, as soon as the connection is closed both parts knows the occurrence, allowing to process such abandon. For example, if any holon abandons the HNS connection, the HNS holon will automatic unregister the holon form the HNS.

However, any non-HNS holon could perform the HNS holon tasks. Consequently, the requesting holon could be incorrectly attached. To prevent this situation, the HNS should authenticate it self to the holon. Yet, HNS password can not be spread all over the community.

The solution is to use the public key technique (Silva, 98). Figure 2 represents such method.

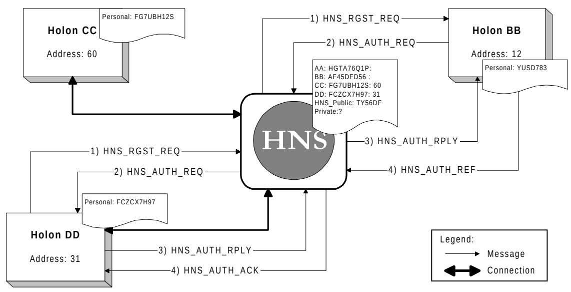

Figure 2 – HNS protocol summary.

The HNS holon provides the public key along with the HNS_AUTH_REQ message. Further, the requesting holon uses it to encrypt its own password, which is transmitted to the HNS holon, who decrypt the password with its private key. If the obtained password does not match the holon entry in the HNS DB, then the holon is untruthful and HNS holon refuses authentication. Else, HNS holon sends back the unencrypted password. If the holon receives its own password, then the HNS holon is truthful and registration can proceed. If password does not match, the holon refuses HNS holon connection.

4.1.2 HNS Private protocol

Multiple HNS holons must co-operate in order to co-ordinate requesting connections and its related information. As been proposed, each holon must have only one 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. If any other HNS holon owns the register, then new register must be refused.

Additionally, HNS DB is distributed by multiple holons, altogether forming a whole. Thus, individual holon DB might be incomplete. If identification do not exists in HNS holon DB, then, the HNS holon must check with its partners the holon identification (Figure 3).

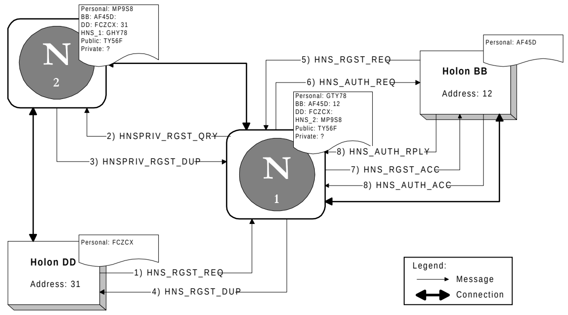

Figure 3 - HNS - HNSPRIV interconnection

If the holon identification is not known, then authentication must be refused, else, protocol must follow. Due to DB distribution, only after this proceeding authentication accuracy is assured. Figure 4 represents the described HNS-HNSPRIV integration. Each message name has a prefix: HNS prefix between holon (H) and HNS (N), HNSPRIV prefix between HNS (N) and other HNS (NN).

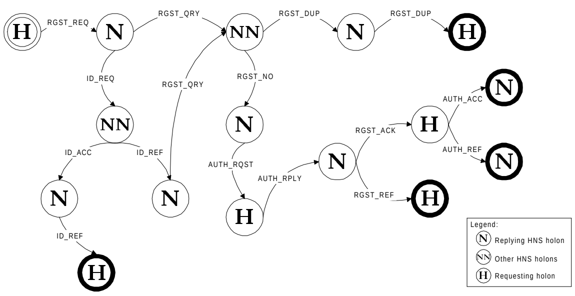

Figure 4 – HNS - HNSPRIV messages transfers (Silva, 98)

4.1.3 HNS Auxiliary protocol

HNS Auxiliary protocol (HNSAUX) provides mechanisms to help generic holons to validate holons that request direct connection. If an holon wants to communicate directly with another, it has to resolve its location and check its authenticity. Holon authenticity and location is HNS competence. In that sense, HNS must supplies mechanisms to help generic holons to accomplish these questions.

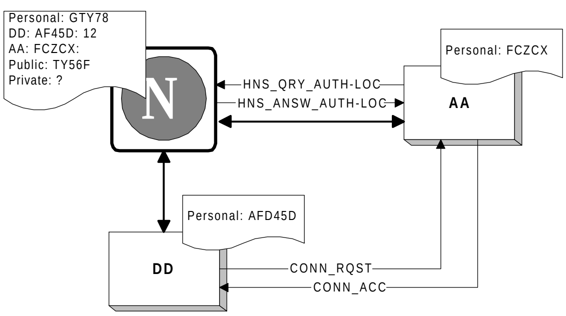

Figure 5 – HNSAUX protocol summary

It consists of query HNS about holon location and authenticity. Figure 5 summarise the explanation. Case holon location is unknown or authentication failed, HNS replies with a HNS_REF_AUTH-LOC instead of HNS_ANSW_AUTH-LOC.

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. Like the Registration Service, the Information Service concerns with reliability, dynamism, security and coherence.

To address reliability, multiples HIS holons are proposed. However, incoherence easily occurs with multiple and dynamic information sources, unless redundancy is prevented. 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 holon provides the published information;
- HIS holons when queried about unfamiliar information, query its HIS partners, supplying replied information;
- Information can not be updated until last supplied part looses validity;
- Information is valid during owner HNS registration.

So, any holon publish its information in the HIS holon, who provide it to the requesting holons.

Nevertheless, these rules are not satisfactory enough, since the holon can publish information in different HIS holons, and coherence and system security become precarious. The proposed solution suggests aggregating both HNS and HIS in a single holon. Both owner authenticity and information coherence is consequently easier to control.

Figure 6 summarises described process. HNS and HIS are aggregated in a single holon, providing and integrating both services. Holon XX uses its permanent connection to HNS-HIS(2) to publish some information about itself. Elsewhere, holon AA connected to HNS-HIS(1), requires information about holon

XX, but HNS-HIS(1) DB do not contain information about it.

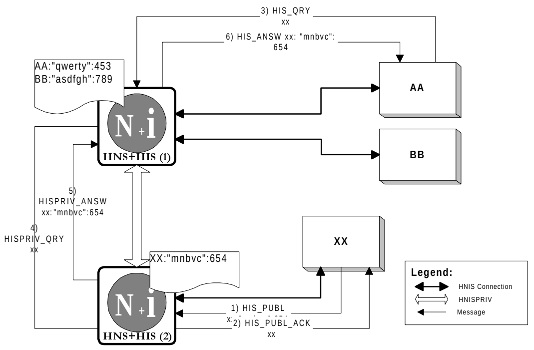

Figure 6 - HNS + HIS interconnection

However, it does not mean information is not available in system. Consequently, HNS-HIS(1) requires information to all the HIS holons it is connected to, querying such information using HISPRIV protocol. Since the information exists in a sole HIS, just one will reply. After response, HNS-HIS(1) will provide received information to the requesting holon.

A problem remains. What kind of information can be published? New manufacturing systems information characterises essentially by diversity and dynamism (Silva, 98; Parunak, 98a). Different kinds of information, relating different technologies and production steps, changing dramatically over a short period, is a resumed vision of the problem. How information is requested, what kind off queries relates to each information, are some questions remaining. Although distributed object technology (CORBA, RMI or DCOM) are strongly encouraged, case study implementation still does not use it.

The proposed solution suggests the use of a class database. This database is dynamically modifiable and provides information classes and its related procedures.

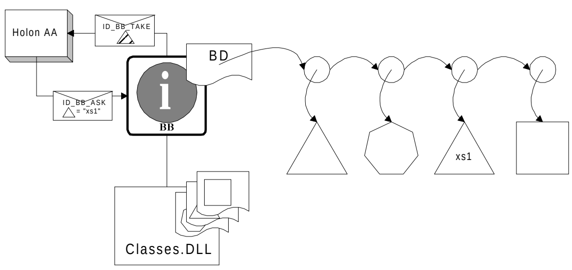

Figure 7 – Generic DB schema.

Figure 7 represents the solution. HIS holon understand several kinds of information, but that knowledge is exterior to the HIS holon, so, classes are replaced without any holon modification.

Using distributed object technology will enhance dynamism and correct information manipulation, while maintaining coherence and system security.

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 to other. 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 and co-operation is required.

Any message is stored in HPS holon DB without any processing. Hence, any message can be stored and pooled even HPS holon do not understand its contents or meaning. All it has to do is deliver message to the right holon as soon as possible. In order to accomplish that, HPS holon periodically query its associated HNS holon for the destination holons. The query, as the reply, is done in only one message for all the destinations required.

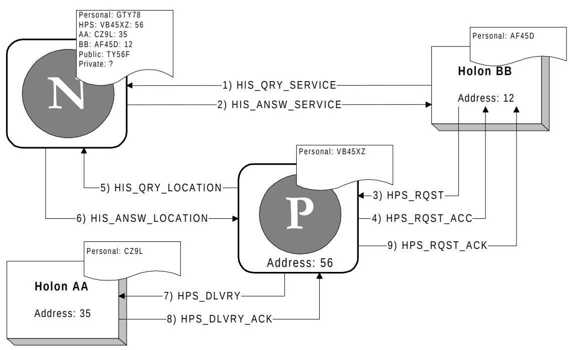

Figure 8 - HPS - HIS interconnection

Normally, Pooling is a service added to the Registration/Information holons, but its not necessarily that way. If the HPS is in the HNS/HIS, the query period can be larger, since it is possible to the HPS to know when a registration occurs, and only ate that moment, query its partners.

In order to guaranty security and coherence, HPS holon create a new message, comprising delivery message, HPS requesting holon and time.

5. CONCLUSIONS

This paper discusses the use of holonic approach to implement new generation of manufacturing systems. The holonic and multi-agent paradigms are briefly described and compared. Additional considerations advocate MAS and HNS are not contradictory or redundant. On the contrary, analysis refers that both are mutually compatible and complementary.

Due to distribution, decentralisation, dynamism, non-deterministic structure and unpredictable behaviour, modern manufacturing systems need new organisation and technology approaches. System architecture, organisation and theirs entities functionality were presented, while stressing scheduling sub-system description.

However, this paper emphasises three (essential) complementary services: Registration, Information and Pooling. Combining these three services it is possible to improve Dynamism, Reliability, Security, Coherence, Information management and general performance enhancement.

Although preliminary tests are optimistic, some changes might occur in order to employ distributed object technology in the information service.

Additionally, holarchy communications will impose some improvements. Is being analysed a conceivable Domain concept, associated with the further Routing service. The routing service will concerns with inter-domains (inter-holarchies) communication. Consequently, some changes must occur in Registration service, that must comprise domain authentication instead of system authentication.

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