Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Pull System Control For Job Shop Via A Holonic, Isoarchic & Multicriteria Approach

P. Pujo, F. Ounnar

Laboratoire des Sciences de l'Information et des Systèmes
Avenue Escadrille Normandie Niemen
13397 MARSEILLE cedex 20 France

patrick.pujo@lsis.org ; fouzia.ounnar@lsis.org

Abstract: Faced to international competition, the industrial production requires increasingly implementation conditions. In certain cases, that forces to seek new techniques of workshop control. It is the case when it is asked to establish a Just in Time management in a Job Shop having the characteristic of working in small series. We present here a new approach for the organization of the 'control' function in such a context. This approach rests on the use of the holonic paradigm, on an isoarchic architecture and on a decision-making capacity based on a multicriteria analysis. Initially, we approach the various concepts related to this approach. Then, we detail the used multicriteria decision mechanisms as well as the implementation and instrumentation phases. The first obtained results are presented.

1. INTRODUCTION

The evolution of the competition conditions in the industrial production world is done with the detriment of the enterprises having to support a high work cost. Some of them choose to outsource or to delocalize in countries having low cost of labour. Contrary, others choose to search new solutions to increase the productivity. This is particularly true for the companies no concerned by the mass production, and having problems with the Just in Time, Lean or 6 sigma approaches. In parallel, the scientific world proposed since a score of years many innovating ideas, mainly based on heterarchical architectures control. Unfortunately, the applications remained at the stage of elementary examples or canonical demonstrators. After having initially presented the evolution of the concepts related to the operation of the control systems for manufacturing systems, we briefly recall the most known solutions proposed by the scientific community working on the Holonic Manufacturing Systems. Then, we present our approach, developed within a holonic and isoarchic framework, allowing a multicriteria decision-making. We detail these decision mechanisms, by clarifying the motivations which brought to this proposal and the implementation structure. Lastly, we present the application of this approach to a real industrial situation, with the first obtained simulation results.

2. HOLONIC AND ISOARCHIC CONTROL

2.1 Evolution of the production systems control

The control systems are in perpetual evolution. We present here how, starting from the conventional control approaches, are currently developed new approaches and how our approach is different from these approaches. The production activities are generally organized by hierarchical decomposition and successive refinements of the tasks to be carried out (Mesarović *et al.*, 1980). At the lower decisional level of a workshop, operational control must indicate in a precise way the actions to be led in the short term. To be able to obtain an effective and efficient operation of the production system, this must be often carried out in real time. In other words, it is necessary to indicate WHICH does WHAT, WHEN, WHERE and HOW, by respecting on the one hand the constraints defined at the higher decisional levels and on the other hand those relating to the production system and to its environment. In the almost cases, the 'WHICH' is associated to the 'WHERE', and the 'HOW' is preset for each 'WHAT'. The organization of the tasks requires to define a subset of the cartesian product {WHAT} X {WHERE} X {WHEN} for the whole of the tasks to be realized. This organization activity is generated by a planning carried out off line and in a precise way, leading to a scheduling of the operation of the workshop: it is estimated control. At the effective implementation of the tasks in the workshop appear contingent events which disturb this initial plan. The role of the control is then to find on line a solution allowing to continue the operation of the workshop by preserving acceptable performances. This operational aspect of control is more and more often carried out by MES (Manufacturing Execution System), on the basis of re-scheduling of the tasks on the *ad hoc* resources. For some time a scientific community emerges around the systems controlled by the product. The interaction between the manufacturing process and the product must integrate, in the cybernetic loop, new technologies such as the WSN (Wireless Sensors Network) and the RFID (Radio Frequency IDentification). These technologies must allow the product to be equipped with storage capacities, calculation and communication: then, it becomes "active" within the production system which treats it. This "active" product can be equipped with means allowing to collect the variations of its environment, to take decisions and thus to fully interact with its environment (resources of the process, other products, operators…) (Petin *et al*, 2007). (Mathews, 1995) evokes the holonic paradigm which is not reduced, in the field of the HMS (Holonic Manufacturing System), to a vision only oriented products. We fully join this vision related to the evolution of the control systems. In our point of view, control by product of production systems is not sufficient. Indeed, the product doest not carry out all the operation constraints and all associated information which would allow taking optimal control decisions, or at least satisfactory. This position is largely consolidated by IMS (Intelligent Manufacturing System) community work, which allows the identification of the various entities types in interaction in a manufacturing production system. Each one of these entities brings its own data file and its own constraints, thus constituting a point of view. It is the taking into account of the whole of the data and the constraints, sometimes contradictory, which can generate the best possible solution, at a given time. This is why we propose a control integrating multiple points of view and resulting from various types of entities in interaction. The HMS results agree conceptually with this proposal.

2.2 *Holonic architecture of the control*

The holonic paradigm was initially proposed by (Kostler, 1967) allowing the modelling of complex social systems. In such systems, an entity (a holon) is at the same time a whole and part of a whole (Janus effect). This approach marks a rupture with the former hierarchical models, where the behaviours are of the 'master-slave' type according to an arborescent and invariant topology of the decision-making centres, the whole reinforced by the respect of the orders by the decision-making centre slave. Indeed, the holon has a decisional intelligence which enables it to act on its own behaviour, but which also enables it to intervene on the behaviour of the system to which it belongs (Pujo and Ounnar, 2007). The hierarchical decomposition is replaced by the recursion of holons and the implementation of the Janus effect. This allows large latitude for the implementation of the control system, according to an heterarchical architecture (Trentesaux, 2002), i.e. being able to mix centralized and non centralized decision centres. Various holonic architectures are proposed in the scientific literature for the HMS control. The most known is PROSA (Product, Resource, Order, Staff Architecture) (Van Brussel *et al.*, 1998). The other architectures do not offer possibilities to describe completely decentralized architectures: ADACOR (Leitão *et al.*, 2006) positions without ambiguity as adding to the basic PROSA holons a supervisory holon in charge for coordination, optimization in a group of holons: it is a local and centralized decision-making centre; MetaMorph (Maturana *et al.*, 1999) is a holonic control architecture based on a control via a whole of mediators which are centralized decision-making centres. We used thus the heart of PROSA, constituted of 3 types of basic holons: Product Holon (PH), Resource Holon (RH) and Order Holon (OH).

2.3 *Isoarchical Architecture of the control*

We worked for a few years on the problem of designing control solutions disregarding concept of hierarchy and centralization (Pujo and Ounnar, 2007). The study of decentralization and self-organization led us to develop the concept of isoarchy and to revise the use of the proposed concepts by PROSA. The term 'isoarchy' is formed starting from two Greek radicals: *isos* (equal) and – *arkhes* (ruler), thus meaning the same authority and thus total absence of hierarchy. In a decision system composed of several decision-making centres, a decisional architecture can be described as isoarchic when each decision-making centre is equipped with the same capacity of decision. This property can be easily obtained when the decision mechanisms are duplicated on each decision-making centre and are parameterized according to the characteristics of each one. The isoarchy seems then as a particular specification of the heterarchy concept and the absolute opposite to the hierarchy concept (Mesarović *et al.*, 1980). Within the meaning of (Trentesaux, 2002), it can be classified in decentralized of type III without any nuance. Indeed, the scientific discussions about the architectural structures of control are situated in a linguistic space: 'centralized/hierarchically' to 'decentralized/self-organized'. This space of course includes all the intermediate solutions. This has collaterals damages, because there is not any more exclusive term contrary to 'centralization'. For example, the 'heterarchical' term, used during a time, is now applied to distributed architectures on several decision levels, with local hierarchical decisions. It thus seems to us that the concept of isoarchy should be only used on really and completely egalitarian architectures. In a complex system composed of entities having decisional capacities, the isoarchy is characterized when all the decisions are taken thanks to the autonomy of these entities. That requires a direct communication capacity between these entities, in order to be able to effectively solve the problems of synchronization, coordination and/or co-operation. The decentralization of the decision centres offers this possibility: the decentralized entities '*jointly ensure the decisions that concerned them, without instruction or order coming from higher level entities and thanks to functional primitives duplicated on each decision centre and in interactions via a common communication protocol*' (Pujo and Brun-Picard, 2002). This concept of isoarchy can be implemented via the holonic paradigm: we can also found in the concept of '*Flat Holonic Form*' (Bongaerts *et al.*, 2000), isoarchical particularization of a holonic architecture. In addition, the absence of a central decision system prohibits any preset or estimated organization of the system operation, which will be progressively organized by the entities. This self-organization implies a real time character which takes into account all information characterizing each entity contributing to the establishment of this operation. We speak then about self-organized control functions. These functions are integrated in the intelligence associated to each entity which we call holons. We define a Holon a conceptual entity based on the association of a given *Material Structure* with an *Information System*, providing the whole thing with a *Decisional Intelligence* giving the capability to operate in interaction with other holons (figure 1).

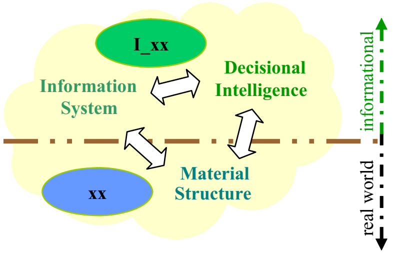

Fig. 1. Basic structure of XX Holon

This structuring allows a recursive decomposition of the production systems, in agreement with the holonic paradigm, while clearly revealing the duality and parallelism between real world (material) and informational (immaterial, where the decision-making is situated). We easily find the concepts of Product Holon, Resource Holon and Order Holon. Product Holon (PH) consists of a product and an I_product which contains the manufacturing process of the product, but also its state model and all information concerning its traceability. It thus exist as many PH as manufactured products or in WIP. This is a major difference with PROSA. This unit identification requires the deployment of ad hoc technologies, whose good example is the RFID. Order Holon (OH) represents a task in the production system: a work order concerns a whole of PH. It is thus closely related to the concepts of batch, of WIP and lead times. The I_order ensures, during the completion of the work, the respect of the lead times as well as the taking into account of economic factors (size of the batch, WIP quantities, minimization of the production changes, split batches…). Resource Holon (RH) remains conceptually similar to the definition of PROSA. Only, the allocation methods of the resources of the I_resource evolve, since the interactions with the other types of holons are different in our isoarchic context. In addition, an I_resource is used as a reception platform for the I_products and the I_orders which treats the corresponding resource. The problem of the decision-making in the control becomes then a problem requiring the participation of all the entities: resources, orders and products. For that, local and specific interactions will be established between I_xx of concerned holons. It clearly appears that these various entities do not seek all the same objective, and that the best possible compromise should be found to find a control solution which is in this context an optimal solution. Faced to this problem, we have used multicriteria decision-making aid methods. The necessary data to the implementation of the selected method will result from the interactions previously evoked between concerned holons.

3. MULTICRITERIA DECISION-MAKING FOR HOLONIC AND ISOARCHIC CONTROL

3.1 Analysis methods and multicriteria decision-making

We can distinguish three classes of multicriteria methods: multicriteria decision-making aid methods, elementary methods and optimization mathematical methods. The choice of one of the three methods classes can depend either on the data we have to treat the considered multicriteria problem, or on the way with which the decision maker models his preferences. In our case, the choice process of the product having to be treated by a resource supposes the knowledge of the various possible alternatives in order to carry out a sorting compared to a whole of criteria. So the use of the optimization mathematical methods is not possible. In addition, the objective being to carry out a classification, the elementary methods are not considered. The multicriteria decision-making aid methods make it possible to bring a help to the decision maker during the refinement of his decision-making process which relates to the choice of an alternative among a whole of potential alternatives. The whole of the products in the resource queue (WIP) constitutes the whole of the alternatives. The classification of the alternatives will be carried out by examining the logic, the coherence of the choices, then by aggregating the preferences, according to one of the three approaches complete, partial or local. In our case, the complete aggregation is applied to classify the whole of the products in the resource WIP. We chose the Analytic Hierarchy Process method (AHP) (Saaty, 1980), which allows to break up a complex decision problem into one or more levels of details where the evaluation of the values is provided by pair wise comparisons. Contrary to the other methods, AHP is the only one which allows on the one hand the measurement of the coherence of the decision maker preferences and on the other hand the taking into account at the same time of the independence and the interdependence of the considered evaluation criteria. The taking into account of the interdependence results in the construction of a hierarchical structure thus reflecting the various levels according to the interdependence between the criteria. The elements of the hierarchy (criteria, sub- criteria, alternatives) are not inevitably dependent between them; nevertheless they can be grouped in disjoined sets. Consequently, this method allows the use of complete lists of evaluation criteria without excluding any from it. Let us also note that AHP method allows the taking into account of qualitative and quantitative criteria. All these characteristics constitute the strong points of the AHP method (Ounnar, 1999). A multicriteria decision-making algorithm applying AHP is thus established in each RH and defines a classification of the PH taking into account the RH, PH and OH constraints. Only the product classified in first position is interesting: it is the next one product to be treated by the resource.

AHP is carried out in two great phases, the configuration and the exploitation, which we will detail now.
To be able to use the AHP algorithm in order to classify the products located in the queues, it is necessary as a preliminary to regulate the setting of the relative importance of the criteria and their indicators: it is the setup phase. This sets the pair wise comparison between the various criteria C_j compared to their importance in the choice of the PH decision. This 'static' phase of the algorithm must be validated by a mathematical checking of coherence. First of all, it is necessary to classify the criteria compared to a global objective. We build for that a matrix [C] where each element c_{ij} is a judgement or a comparison between a pair of criteria C_i and C_j, according to a scale 1-9, with $c_{ij} = 1/c_{ji}$ & $c_{ii} = 1$. This matrix makes it possible to determine the relative importance vector $[V_{COg}]$. Coherence checking allows detecting and correcting the affected weights. Then, with

respect to the whole of the criteria C_k, a classification of each indicator $I_{k,i}$ is established, compared to its C_k criterion. For this purpose, a matrix $[I_{Ck}]$ is built where each element $i_{k,ij}$ is a judgement or a comparison between a pair of indicators $I_{k,i}$, and $I_{k,j}$. For each matrix $[I_{Ck}]$, the relative importance vector $[V_{ICk}]$ is estimated according to the same principle, with validation of the matrix $[I_{Ck}]$ consistency. This initialization phase must be validated for each new configuration of parameters.

The dynamic exploitation phase of the AHP algorithm makes it then possible to classify the PH in the queue. Firstly, a classification of PH compared to each I_{kx} indicator of each criterion C_k is established. For each indicator, we compare pair to pair the indicator values between PH of the queue. The $[P_{kx}]$ matrix is thus built, with: $p_{kx;ij} = I_{kx,j}/ I_{kx,i}$ to minimize the criterion and $p_{kx;ij} = I_{kx,i}/I_{kx,j}$ to maximize the criterion, $p_{kx;ij} = 1/p_{kx;ji}$ and $p_{kx;ii} = 1$. The vector $[V_{PIk,X}]$ is the relative importance vector between PH which it is then possible to calculate. Then, it is necessary to go up in the relative choices hierarchy, because the goal is to determine the relative importance of PH compared to the global objective. The matrix $[PI_k]$ is built, where each column is a vector $[V_{PIk,X}]$. A vector giving the relative importance of the products compared to the criteria is built, and this, for each criterion: $[PC_k] = [PI_k] * [V_{ICk}]$; The vectors $[PC_k]$ make it possible to build a matrix $[PC] = [PC_1, PC_2,\ldots, PC_n]$. The product $[PC] * [V_{COg}]$ provides the priority vector $[V_{POg}]$ of the considered PH, of which the largest component v_{POg}) corresponds to the PH_y chosen.

3.2 Building the hierarchical decision process

We present below the hierarchical criteria system and the corresponding indicators by describing the various points of view to be jointly analyzed to respect the various interests of the holons in interaction.

At first, let us examine the interests from the 'Resource Holon' point of view. The first criterion (C1) relates to the product type. A resource must before all seek productivity, which minimizes the exploitation costs of the resource. This can be evaluated through an indicator such as the OOE (Overall Equipment Effectiveness), which must be maximized. A strategy consists in avoiding the resource downtimes. For this reason, the strategy consists to supplement the work load corresponding to the principal production by a secondary production, inevitably with less priority. C1, which binds each RH to PH, allows to determine priorities to certain types of production, according to their belonging to various classes:

- principal resource (resource dedicated to the product) or secondary (substitution resource in the case of unavailability of an equivalent resource),
- regular product (great and average quantities) or work load complement product (small quantities),
- product for new finished good assembly or product for spare part…

Each associated indicator (I11: Principal or Secondary Resource, I12: Principal Product or of Complement, I13: Produced for Assembly or Spare Part) are qualitative indicators, defined by values that are periodically actualized by the management of the workshop.

The criterion C2 relates to the resource work load. It is interesting to avoid working without effectiveness. The more the resource work load is raised, the more it becomes judicious to privilege the products with high priority. It is also not judicious to treat a product with weak or average priority on a resource if the following resource relating to this product is overloaded. The criterion C2 relates to the resource occupation rate and allows taking in consideration these constraints. In the other cases, this criterion will not influence the classification obtained by the AHP algorithm. The indicator I21 (Resource Work Load), associated to this criterion, quantifies the rollup of tasks that are on standby in the queue.

From the 'Product Holon' point of view, the interests are distinct. The criterion C3 relates to the progression of the product. The minimal obtaining cost is a fundamental objective that must be reached for a PH: the flow time has to be reduced. As the treatment technological times are generally optimized by the *ad hoc* process setups, we can act effectively only by minimizing the queue times of the product. If this is systematically carried out in all the WIP crossed by the products, we obtain the obtaining average cycle the shortest as possible, and thus the weakest production costs. To meet this aim, we developed a strategy aiming at creating artificially a pull system effect. The criterion C3 allows supporting the PH that has a progress state close to the final state. Let us note n, the number of data processing runs to be carried out on a PH and k the current data processing run of the PH. The closer the PH is close to its completion (k/n near to 1), the more the priority of this PH will have to be important. The indicator I31, corresponding to the global progression of the product ($I31=k/n$), allows to accelerate flows throughout the 'virtual production line' associated to its routing. This downstream call is caused by the PH itself. In other words, PH firstly contributes to empty the production system, which releases capacity that RH use. In order to minimize the queue times, an indicator I32 (Local Progression) supports the PH flow if the next RH related to this PH will treat it immediately after. The criterion C4 is composed of the queue time in front of the resource. Different products with various priorities circulate simultaneously in the production system. An important risk would be to forget a product with weak priority in a queue and to have not the possibility to leave it from the queue. The indicator I41 (Queue time) associated to the C4 criterion, composed of the PH queue time in front of a RH, aims at leaving the PH from the queue if it remains there since a long time, while increasing for that, its relative importance.

Lastly, from the 'Order Holon' point of view, the fundamental objective is the respect of the delivery lead times. The criterion C5 examines the remaining slack for each PH: if the number of remaining operations on a PH is important and if the delivery lead time of the OH to which it is attached is close, it becomes urgent to give it a high priority with respect to the other PH. This criterion thus allows respecting the delivery lead time of an OH. For an OH composed of several PH, we can consider that most of the PH will be treated in times, but it will remain some late PH: this criterion aims at accelerating the treatment of these latter.

The associated indicator I51 (Remaining Slack) is given by the formula:

I51 = remaining_duration – remaining_phases_duration. (1)

The smaller I51 is, the more the PH concerned will be affected with high priority. Other indicators could be of course used such as for example a balanced remaining slack (I51/remaining_phases_number), which would increase the consideration of this criterion.

The whole of choices concerning the criteria and associated indicators stated above makes it possible to set up the hierarchical decision structure illustrated by figure 2. Other criteria and indicators could be added.

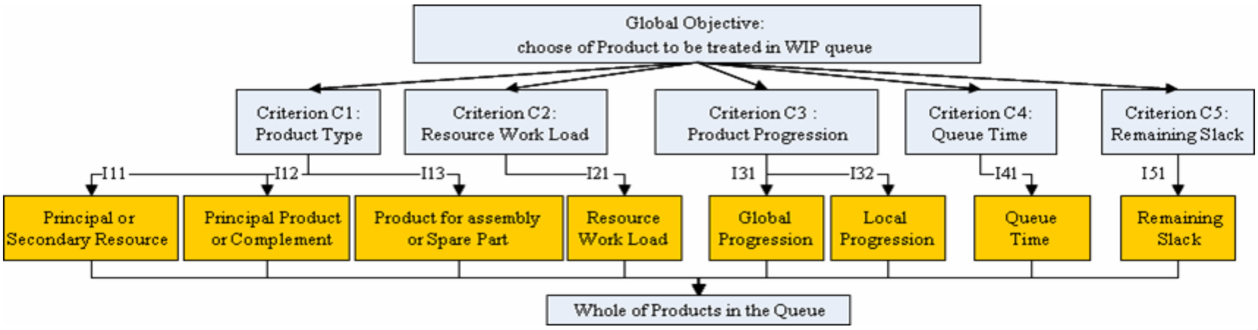

Fig. 2. Hierarchical structure of multicriteria decision-making: detail of the corresponding indicators

4. APPLICATION TO AN INDUSTRIAL CASE STUDY

4.1 Description of the production system and configuration of a simulation prototype

The production system test, the Unit 4-5, is a mechanical production workshop that manufacture in a recurring way a score of different parts types, mainly 'shafts' and 'sleeves' of big sizes, having close tolerances and complex routings. These parts are in the heart of the kinematics diagram of the aircraft mechanical engineering manufactured by the company. This workshop comprises about fifteen CNC machining centre. This tool machines are versatile, of high precision, with great capacities and equipped with all the *ad hoc* peripheral equipments and tools. The batches size seldom exceeds about fifteen parts, each part representing a value of many hundreds of thousands euros. The throughput time can reach for the most complex productions 6 months.

Various problems are observed in the Unit 4-5. The workshop control results from a traditional MRP calculation, associated to batch sizes obtained via optimization economic calculations. We note too long cycle times. This generates chronic delivery delays. In addition, due to a lack of synchronization, the resources remain without occupation part of time, and the OEE is weak (< to 50%).

To develop a simulation model of the workshop which is most realistic as possible, we chose to use an industrial simulation tool: Arena 8.01. This model comprises the general flows organization between the resources. The model of each RH allows, starting from a Boolean variable defines at the beginning of simulation, either to use a FIFO discipline in the queue, or to use the discipline resulting from the AHP algorithm. Below is regulated the criteria and indicators hierarchical system describes higher, then is shown how the Arena data are used. It is necessary to start with the setup of the AHP algorithm. Each resource has its own weighting. The relative importance matrix of the criteria [C] (table 1) is constant on all the RH.

Table 1. Relative importance matrix between criteria

	C1	C2	C3	C4	C5
C1	1	1/3	1/3	3	1
C2	3	1	1	9	3
C3	3	1	1	9	3
C4	1/3	1/9	1/9	1	1/3
C5	1	1/3	1/3	3	1

It is the same principle for the relative importance matrices $[I_{Ck}]$ between indicators, I_{C1} et I_{C2}. On the other hand, the relative importance matrices $[P_{kx}]$ between alternatives, for an indicator have variable dimension according to the number of PH in WIP. This dimension already depends on the number of the types of different products having to use the resource. The elements $p_{kx;ij}$ are directly calculated from the indicators values. These values are either preset values or computed from the attributes of certain components of the simulation model. Arena simulation is coupled with a calculation module developed under Excel. The various necessary data (PH, OH), concerning the products on standby in WIP, are collected in the Arena model, then exported in a specific Excel sheet to each RH. To each cell corresponds attributes for the calculation. The AHP algorithm of the RH is programmed in the same Excel file. The actualization of calculations is done by the introduction of new data in the sheet. The result of the multicriteria classification is then imported again in the Arena model, and is used to select the good PH in the queue, to then continue the simulation. The corresponding product is then treated by the simulation model of the resource.

4.2 Experiments and obtained results

The experiments used a data file corresponding to 18 months of the Unit 4-5 real production. This pilot period is sufficiently large to put in evidence the diversity of the production situations. In addition, the period being already completed the real performance of the Unit 4-5 was known in term of productivity. Only, the products and the resources names were made anonymous. We thus used the same release dates as those used in the real production. One modification was done and corresponds to the transformation of batches *i* of size n_i to n_i batches of unit size. This corresponds to support part/part production approach, which is more fluid than the economic batches traditional approach which generates synchronization tasks problems which degrade the OEE.

The experiments were carried out under the conditions described in the section 4.1 with systematic comparison between the two disciplines. In the case of experiments carried out in FIFO discipline, the products are treated sequentially by the resource, according to the arrival order in the WIP stock. The only use of a strategy 'batches of unit size' gives a better productivity than the best one heuristic of scheduling by batches used in the Unit 4-5. In the case of multicriteria experiments discipline, the choices of the Product Holon to be treated by each Resource Holon are done in real time, i.e. during the simulation. When the resource finishes the preceding product, it thus necessary to choice the following product, using the AHP algorithm.

The figure 3 presents the average results over the 18 months period: a comparison of the two disciplines results is presented. Are only indicated the 'shaft' products type assigned to the Unit 4-5. The 'sleeve' parts type give similar results and the additional parts are not concerned with productivity criteria. These results show progress concerning the reduction of the delivery lead time of the whole products. Only one anomaly appears on the product 14. After a checking, this product corresponds to a marginal production, in small quantity, for aircraft maintainability.

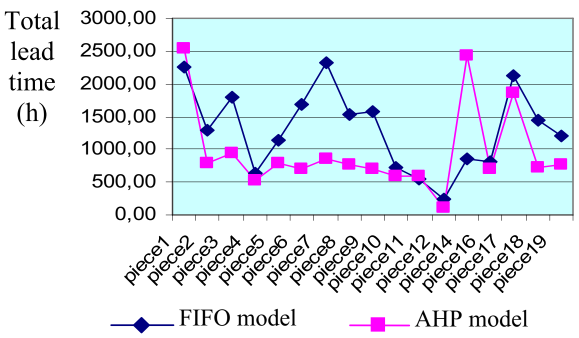

Fig. 3. Comparison results according to the 2 WIP management disciplines.

In the case of experiments carried out in FIFO discipline, we obtain an average total time of 1304.53h, an average queue time of 697.93h and an OEE of 46.49%. In the case of multicriteria discipline experiments, the same indicators are respectively 961.35h, 354,32h and 63.14%. On the whole of the production, we observe a reduction higher than 25% of average production time, for all products and by taking into account the quantities. This improvement is completely due to the very strong reduction of the queue times, about 50% on average. That results in an OEE progression of 35%.

5. CONCLUSION

We proposed a control system based on a holonic and isoarchic approach. The multicriteria decision mode via AHP will allow, on each Resource Holon, to choose in real time among the standby Product Holons that whose treatment supports the flows, therefore the reduction of the production durations, of the WIP volumes and of the associated costs to the Order Holons. We quickly presented the AHP algorithm implemented by each Resource Holon. The first obtained results on a complex industrial case are promising: even if they can be certainly improved, they show unambiguous the interest of a holonic, isoarchic and multicriteria control compared to the traditional approaches. In addition, we wish to test new criteria. The presented Work represents the premises of a new control orientation research. Many improvements will be made, as well on the functional level, with the taking into account of new criteria relating to the PH, RH and OH, as on the technological level, with the implementation of a demonstrator using distributed simulation. We would then work on the analysis of the results variability as well as on the sensitivity of the parameters setup of the AHP algorithm.

REFERENCES

Bongaerts L., L. Monostori, D. McFarlane, B. Kadar, 2000. Hierarchy in distributed shop floor control, *Computers In Industry*, 43, p. 123-137.

Koestler A., 1967. *The Ghost in the Machine*, Hutchinson, London.

Leitao P., F. Restivo, 2006. ADACOR: A holonic architecture for agile and adaptive manufacturing control, *Computers in Industry* 57, p. 121-130.

Maturana F., W.Shen, D.H. Norrie, 1999. 'MetaMorph : An adaptive agent-based architecture for intelligent manufacturing' *International Journal of Production Research*. Volume 37, Number 10.

Mathews J. 1995. Organizational foundations of intelligent manufacturing systems - the holonic viewpoint. *Computer Integrated Manufacturing Systems*, 8(4), p. 237-243.

Mesarović M. D., D. Macko, Y. Takahara, 1980. Théorie des systèmes hiérarchiques à niveaux multiples, Economica, Paris, 1980.

Ounnar F., 1999. Prise en compte des aspects décision dans la modélisation par réseaux de Petri des systèmes flexibles de production. PhD, INPG - Grenoble.

Pétin J-F., D. Gouyon, G. Morel, 2007. Supervisory synthesis for product-driven automation and its application to a flexible assembly cell, *Control Engineering Practice* , 15 (5), p. 595-614.

Pujo P., D. Brun-Picard, 2002. Pilotage sans plan prévisionnel, ni ordonnancement préalable. Dans : *Méthodes du pilotage des systèmes de production*, Traité IC2 Productique, p. 129-162, Hermès, Paris.

Pujo P., F. Ounnar, 2007. Vers une approche holonique des systèmes mécatroniques complexes - Proposition d'un système de pilotage auto-organisé et isoarchique, *JESA*, 41 (6), p. 673-706.

Saaty T., 1980. The Analytic Hierarchy Process, Mc Hill.

Trentesaux D., 2002. *Pilotage hétérarchique des systèmes de production*, Habilitation à Diriger des Recherches, Université de Valenciennes et du Hainaut Cambrésis.

Van Brussel H., J. Wyns, P. Valkenaers, L. Bongaerts, P. Peeters, 1998. Reference architecture for holonic manufacturing systems: PROSA, *Computers in Industry*, 37, p. 255-274.