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PULL PRODUCTION IN A JOB SHOP: PROPOSITION OF A SELF ORGANIZED CONTROL BY VIRTUAL FLOW SHOP AND MULTICRITERIA ANALYSES

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Abstract: *To increase the productivity of manufacturing systems with small renewable series, we propose to introduce into a new type of industrial management techniques and concepts resulting from the mass production. This must allow to considerably decrease production costs and to give a new profitability to industrial sectors strongly competed at the international level.*

Key words: *pull production, job shop, flow shop, self organized control, analytic hierarchy process.*

1. INTRODUCTION

The internationalisation of manufacturing production brings a great number of companies together to find themselves facing an increasingly keen competition with new foreign industrial actors. This trend is extending to those companies traditionally protected by very specific niche markets (high technology, very specialized know-how, reserved or protected domains...) and to small and average series high value-added products with job shop production system companies too. This is the case of the mechanical production at Eurocopter company. The various reactions usually observed in this case, such as delocalisation, externalisation or refocusing, only prove the insufficiency of productivity in comparison to the challengers. This phenomenon is largely amplified by the labour time cost in Western countries relative to those observed in the emergent countries and their technological development. These usual reactions are not however a forgone conclusion. New ways must be explored to find new margins of productivity. These include a strong questioning of traditional practices of production control, a reengineering at the various processes of the company, the development of new techniques of production management. Each one of these three points is detailed in this communication.

2. INSUFFICIENCY OF THE CLASSICAL MODES OF PRODUCTION CONTROL

The search for greater productivity results in solutions aiming on the one hand to eradicate production losses, or at least to strongly reduce them, and on the other hand to reduce the costs of obtaining the products, in order to better cover the financial commitments. The Yield Management approach, that we can see more and more in companies, constitutes a synthesis of the computer-integrated manufacturing and quality-focussed approaches. Various tools, often related to quality approaches, initially allow substantial and fast profits. Secondly, progress reasoning, implemented through methods of continuous improvement, allow in a more regular way to continue in this direction. Unfortunately, the progression of the results obtained by these methods becomes weak at the end of a certain time: one can say that the potential of these methods was reached and that the system of production operates as well as possible within the framework in which it was conceived. This situation is difficult to observe, because of the weakness of the evolution of results when the improvement reasoning is continued until its term and that the operation of the workshop is near to its optimum. In order to continue the progression of the workshop productivity, the production actors and the decision-makers do not know then any more what they must make. In fact, a productivity plateau is reached and is inherent to the organization mode and industrial management which under tightens its operation, which generally consists, in the case of the production systems in job shop, in a sectional organization (equipments are grouped by kind, or by operators' skills) and a maximum loading of the equipment (it is necessary to produce a maximum on each equipment to limit its un-utilization) inducing the creation of WIP (Work In Progress) stocks to control the flow of products (resulting from discretization and forecast approach). Generally, it is the MRP (Manufacturing Resources Planning) approach that prevails for this type of small production. The complexity of the workshop control problems is very difficult to approach, and MRP classically treats it by decomposing it into 3 dimensions, which generate a number of disadvantages. Concerning the quantitative aspect, it is necessary to decrease the number of references by working by batch as opposed to working by unit. Thus, the unit treatment become the batch, while at the same time in certain domains (microelectronics, aeronautics, agro-alimentary...), the traceability by product becomes a requirement. In order to simplify the problem concerning the temporal aspect, the organization is decomposed into several layers of analysis having each one a temporal horizon and a level of abstraction that are inversely proportional to the level of detail of the obtained solutions. Thus, we found in MRP the three decisional layers (planning, programming, scheduling and control). Each of these layers is independent from its neighbours, and it well operates in the up-down case. On the other hand, in the down-up case, it is rather difficult to start from the back-up of the events to understand the foreseen-realized differential according to the choices previously carried out. Concerning the space aspect, MRP allows the reduction of the complexity of the problem by segmenting it, bringing at the same time an optimal solution with respect to a point of view but sub optimal according to a global solution. Whereas the best solution involves a necessary compromise among these various problems. Thus, we often find equipments that are organized by section, or then grouped in functional cells (that need competences of only one operator).

3. CROSS ANALYSIS OF OPTIMISATION CONSTRAINTS OF A PRODUCTION SYSTEM

One cannot properly control a production system unless its organization allows it: the organization of the operational, informational and decisional systems must present a total homogeneity, a homogeneity which must be measured using a representative criterion of whished optimisation [3]. However, there is a whole range of independent and contradictory criteria of this optimality, and there is little chance of finding solutions where several criteria are simultaneously optimum in their respective spaces of resolution. In the case of job shop, the setting in product line of the equipment allows a better productivity in a flow shop. However, the diversity of the products and the heterogeneity of the routings make it complicated: a solution should be found allowing a linearization of flows, by minimizing on the one hand the number of returns in against flow, and on the other hand the number of lines so created. In addition, it is necessary to take into account the balancing of the stations composing the product lines, to maximize their utilization rate (unless wanting to privilege the use of certain equipment of which the depreciation would be more sensitive) while taking into account the problems of equipment reconfiguration among each transformation operation, and the allocation of human resources, with proximity constraints among the equipments controlled by the same operator. Another significant criterion lies in the synchronization of the production with the downstream: in an ideal situation, a transformation operation would finish on a product at the same moment as the following operation could start, which is seldom the case. We can observe such a situation on the mono product transfer lines, which are synchronous lines without possibility of flexibility. As we previously said, WIP stocks are used to control the flow of products, and this reality is amplified in terms of quantity by a production by batches, which translates the unreliability of the control operations. Stock is used to take into account operation conditions that have not been sufficiently considered. The more the stock is important, the less the appearance of risks will have consequences. The consequence is to increase the queue times of a value equal to the latency of the products in WIP stocks. In a job shop, the EPR (Efficiency Process Ratio, equal to the sum of the transformation effective times divided by the production time) is usually ranges between 10 and 20%: the latencies account for 80 to 90% of the time spent by the products in the workshop and have a considerable cost dependent on the possession cost of WIP stocks. A WIP is a part having already a certain value, related to the raw material cost and to the sum of that of the transformation operations already carried out. Conversely, decreasing the WIP volumes reduced the operation margins and forces to a greater rigour in the control: a too great reduction can involve risks of shortage, procurement interruption of the downstream and thus an increase in the number of disturbances. However, the reduction of WIP volumes must be regarded as a fundamental criterion, because it involves a reduction of the queue times and, in fine, a reduction of production costs. It is thus necessary to seek on this level the conditions of a good compromise. Each mentioned problem can be modelled in order to reach "good" solutions. In order to implement methods of optimisation allowing to find optimal solutions, we have 3 types of resolution. If the problem can be modelled in a mathematical form, an exact solution can be calculated if it exists. If this mathematical form does not exist, it is possible to try to model the problem using the constraints which underlie it. The whole of the solutions, if it exists, can be obtained using operational research techniques, using a solver for example. The third and last approach consists in seeking a 'good solution' using heuristics. The idea consists here in testing in a random way various solutions and to determine, using a criterion representative of the obtained performance, among the tested solutions, the best solution that respects this criterion. The choice of the tested solutions can be more or less directed in order to obtain an acceptable solution more quickly. These approaches of optimisation can be separately implemented for each previously evoked constraint. Any solution that only optimises one constraint is sub optimal from the point of view of the complete problem. Any solution that simultaneously implements several of these constraints is sub optimal too, but is also the subject of a compromise which is better. This does not mean that the control will be efficient, since certain aspects will not be taken into account. However, the complexity of the resolution strongly increases as soon as we seek to optimise several criteria simultaneously. The previously evoked single criterion optimisation techniques cannot be directly applied. To reduce the complexity of the resolution, a technical work of homogenisation of the practices is needed, in order to decrease the complexity of the problem. That involves the identification of the real families of parts to put into product lines; the reconfiguration of the routing to insert them as far as possible in a production line and the forecasted dimensioning of the necessary load capacities... Once these prerequisites have been carried out, it is possible to carry out a multi-view optimisation of the whole organization of the workshop, via CSP (Constraint Satisfaction Problem) techniques. The idea is to propose solutions based on algorithmic and complexity concepts related with the CSP. The principal theoretical bases to exploit here relate to isomorphism and to the concept of Treelike decomposition, which allows to provide theoretical terminals of complexity for the resolution of many NP-complete problems. The expected result consist in obtaining the 'least bad' solution for an organization of the workshop operational system representing the best possible compromise among the various criteria of optimisation previously evoked. On this basis of this best possible workshop, we can study some innovative ideas to allow a more fluid control of the products.

3. PROPOSITION OF AN ORGANIZATION BY VIRTUAL FLOW SHOP

The production organization that we propose is based on the following points. First, identification of families' parts having common routing characteristics and whose the manufacture is strategic. Thus, constitution of a set of production lines corresponding to these families parts, some of these lines sharing certain machines. Last, elaboration of control rules to support the flow of stocks.

3.1. Organization of the production in the workshop

The first task to be carried out is to revise the routing of parts manufactured internally by Eurocopter. At present, two thirds of the business codes in mechanical manufacture are subcontracted. In term of part references number or in term of manufactured quantities, the ratios are very sharply more important. In fact, all the low-size parts or parts concerning common technologies are potentially outsourced. Only, the parts with high technologies, concerned with a specific knowledge and/or having to be protected, must be considered as the production target. The workshop having evolved in the past several times, the successive reconfigurations limited the legibility of this objective, which must to be clarified. Indeed, to the parts set normally assigned to this workshop had appointed parts allowing to complete the loads of certain machines under loaded. To this, was added during time new parts which could have been included in the set of the produced parts, but which for lack of availabilities, were directly outsourced. Fig. 1 presents the methodology of constitution of production lines according to the identification of the families' parts. Initially, the principal parts were classified according to an analysis of production flows. This has allowed to define two great groups of parts, spindles and sleeves, which are divided into a limited families number. For each family, we have analyzed the routing of the concerned parts and we have determined a standard flow corresponding to the majority of the family parts. Then, we have examined the remaining parts, and we have tried by reindustrializing their routing to complete the strength of each family.

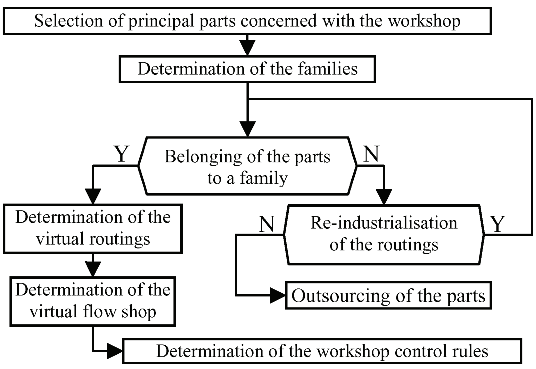

Fig. 1. Re engineering method of the workshop organization.

Finally, we have also examined the parts currently subcontracted in order to possibly reinstate them in the internal production. Each family having its complete strength, we have determined the corresponding virtual flow shop by using the fictitious routing method.

3.2. Reorganisation of the workshop control

There are then so much of virtual flow shop than families parts, that is approximately a half dozen. These production lines support the production of parts rather different. They share certain resources, but must function as mass production lines, to reduce the cycle time and to decrease the WIP. This means specializing the throughput flow in the initial job shop, in order to profit an increase in treated volumes in a similar way, to allow the overlapping of the operations and to simplify the management of the workshop. In fine, that gives a throughput diagram of flows which remains relatively complex, but which has the advantage to be stable and repetitive. If the operation of each production line could be envisaged in an independent way, we could model the organization of each line according to an alternation of buffer stocks and workstations. In fact, that is more complicated, because the different virtual flow shops crosses on certain resources. These last must then share production constraints resulting from various production lines. These constraints are not necessarily compatible. Thus it is necessary to set up a control system which organizes, on the level of each workstation, the passage order of the parts coming from the various lines.

4. SELF ORGANIZED CONTROL OF VIRTUAL FLOW SHOP BY MULTI-CRITERIA ANALYSIS

To cross the plateau which we already evoked, we propose to study the use of certain techniques of mass production, that allow to considerably lower production costs, applied to the production in small series. It is not at all necessary to use the new techniques of mass customization, which are in fact based on the delayed differentiation of a finished number of alternatives, initially chosen in an interactive way by the customer: the mass customization is in fact only a specific configuration of a standard mass production. For that, the basic idea is to configure the production system in product lines. There are many examples of implementations: production in synchronous production lines, production in just in time lines, automated lines. Among these various modes of production line control, it is interesting to underline that the most flexible mode is the just in time, with the example of the kanban method implementation. This mode allows to adjust slight variations in quantities and to easily change production. In the case of a large variety of products with high added-value manufactured in small series, the application of the kanban method would thus create a very great number of WIP stocks the instantaneous value of which would be of the same order of magnitude as that of the end products. The total value of WIP stocks would be enormous, and would go against the expected objective, therefore this method is not directly transposable. However, the kanban method is interesting because it rests on the call of production created by the downstream and the corresponding request. It is this concept of pull systems which we want to transpose to a production in small and very small series, supported by an organization based upon very easily reconfigurable product lines. This last remark is largely covered by the fact that the modern machines have generally numerical control, and thus easily reprogrammable. Thus we propose an approach where the parts progress in the workshop along production lines optimised for the principal productions or with a generalized job shop manner for the secondary productions. The manner of arranging the throughput parts in the queue in front of each machine will allow to support a better flow: thus, it is necessary to find conditions creating a call towards the downstream. This approach could be applied in an estimated way, to create optimized scheduling according to these same criteria. The results would be already interesting, but would lose part of their interest: the capacity to quickly react to the incidents and unforeseen which constitute the daily of the workshop. This reactivity must be favoured to the maximum, and it is for that we commend an organization of the control system based on the online development of this passage order in the micro queues existing in front of each machine. For that, we need an automatic method allowing to obtain an order of passage over each machine, machine by machine, by taking into account a number of criteria. We propose the use of the Analytic Hierarchy Process (AHP) method [4, 1]. The AHP is a method for complex multi-criteria problems involving multiple quantitative and qualitative criteria. It is based on the determination of classification of the alternatives (various parts which can pass on the machine). The central 'ingredient' of the AHP method is comparisons. The pair-wise comparison assesses the relative importance of two elements on the same level in contributing to reaching the objective of the adjacent higher level. This process involves four phases:

- building a hierarchical process for the decision-making problem.
- pair wise comparison of the elements of each built hierarchical level.
- calculation of the relative weight between the elements of each two adjacent levels which develops priorities for the alternatives.
- aggregation of the relative weights of the different hierarchical levels to provide classifications of the decision alternatives.

A multi-criteria decision algorithm based on the AHP method will be applied to define a classification of the parts according to their priorities of passage over the machine. The objective is to select the highest priority part. The hierarchy of the decision-making process for the classification of the parts is defined (Fig. 2) by a triplet < L1, L2, L3 > where L1 = Objective Level; L2 = Criteria Level; L3 = Alternatives (Parts) Level.

We clarify below the various criteria (L2 level) for the choice of the best part.

C1: Type of Part: The main parts must have priority over the secondary parts. **C2:** Progress: Let (n) be the number of phases to be carried out and (k) the phase of progress. The closer the part will be to the end of the range (k/n nearer to 1), the more the priority will have to be significant. It is this criterion which must mainly generate the flow of products. **C3:** Remaining Margin: If the

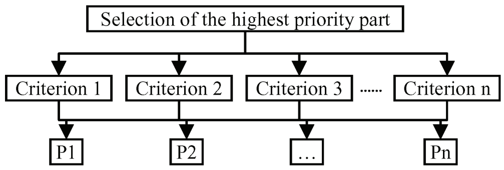

Fig. 2. Choice of the part to be manufactured via AHP.

number of remaining phases on a part is significant and that its delivery date approaches, thus it becomes increasingly urgent to make pass the part on the corresponding machines, while increasing by as much its level of priority. **C4:** Load of the Machine: The more loaded a machine is, the more significant its upstream queue is, and the more necessary it is that the high priority parts overtake other parts. **C5:** Waiting time of the part: A part which is in a queue for a long time must leave there at some time. For that, it is necessary that its priority increases according to the waiting time.

5. CONCLUSION

This work constitutes a first stage in the establishment of a self organized control system for job shop production. In this communication, we have explored new ways to find new margins of productivity. To increase the productivity of manufacturing systems with small renewable series, the idea consists in introducing Just In Time management techniques and concepts in job shop control. For that, we have created virtual flow shop lines in order to apply the mass production management techniques. After having analyzing the actual production system of Eutocopter, we have organized the different family parts. Each family having its complete strength, we have determined the corresponding virtual flow shop by using the fictitious routing method. Thus, we have obtained a complete throughput diagram of flows.

This work is related to the Lean Production concept [5] and still needs to be extended in order to propose a complete self organized control system [2]. All this will lead to the creation of a HMES (Holonic Manufacturing Execution System).

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