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A hybrid manufacturing control based on smart lots in a disrupted industrial context

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Abstract: In the context of high-quality products, some manufacturing companies suffer from a high reworks rate and, consequently, they have also problems with their production flow scheduling. This preliminary work deals with one of such companies. The aim, is to propose a solution based on a global schedule which will interact with the smart products or lots and with collaborative local schedules having their own specifics goals. In order to strengthen the reactivity faced to internal variations (reworks loops) or external variations (demands changes) and to ensure that the global schedule of the whole system will be realistic, the concept of smart products has been adopted.

Keywords: Hybrid Manufacturing Control smart products, lot-sizing, schedules synchronization, disrupted context, HMS, CPS

1. INTRODUCTION

Nowadays, huge efforts have been made on products quality in companies to face the increasing customers' requirements. It is a considerable challenge for them to improve their manufacturing processes by replacing or retrofitting their machines and tools. This is also the case of enterprises concerned by reworks rate.

ACTA-Mobilier, a high-quality product lacquering manufacturer, is faced to many challenges: Quality and high technological requirements lead this company to have a reworks rate upper than 30% and reaching 80% for some products. Many critical consequences, including production cost increasing, products flow perturbations and steady deterioration of deliveries rate, are implied by this fact. Penalty costs and brand image damage may also be at stake. A mass customisation business strategy has been adopted by the company, which leads to a significant diversified products panel and, at the same time, pushed to optimise its manufacturing processes. This paper exposes a way to take-up those challenges especially in the ACTA-Mobilier company context. The objective is to construct a product driven dynamic planning with various horizons and control modes. Different local schedules dedicated to specific workcenters and focused on their critical workstations have to be synchronized by the global scheduling plan. The proposed control architecture must be seen as a hybrid manufacturing control architecture. A VSM (Viable System Model) meta-model was used as conceptual model for this architecture. The following section describes the industrial problem and the related scientific purposes. Section 3 presents the proposed VSM for hybrid manufacturing control. The related state of the art and the different scientific

challenges which must be addressed are presented in Section 4. Then a conclusion and perspectives are set.

2. INDUSTRIAL PROBLEM

The ACTA mobilier company has 2 core business: front manufacturing for kitchen specialists (subcontracting) and the realization of shops and stand (layout). Both of them use the same human and material resources.

Subcontracting activity consists in the realization of periodic orders in short deadline. Despite a variation from 30 to 40% in the ordered quantity, the company has for policy to bring the best service to customers. From this standpoint, all customers' orders are accepted without taking into account actual or predicted load.

The mass customization approach leads to very customized products. Thus, each "product" has custom dimensions, thickness, colors and many other parameters like the handle dimensions and position for example. That implies a lot of different rooting sheets. However, the manufacturing process could still be considered as standard and must be optimized.

The layout activity produces special products, with low reusable components and with almost unique customer orders (specific volume and lead times). The layout production is planned using free slot times between the subcontracting orders. Order's delay is sometimes significantly impacted by this strategy.

Six different workcenters compose the manufacturing facility (Fig 1). They all have different optimization objectives but also many interactions.

Moreover, the high-quality requirement leads to very high reworks rate (able to go over 30%). This implies huge reworks loops. With such issues a global predictive schedule alone does not seem enough robust and adaptive to overcome every variation.

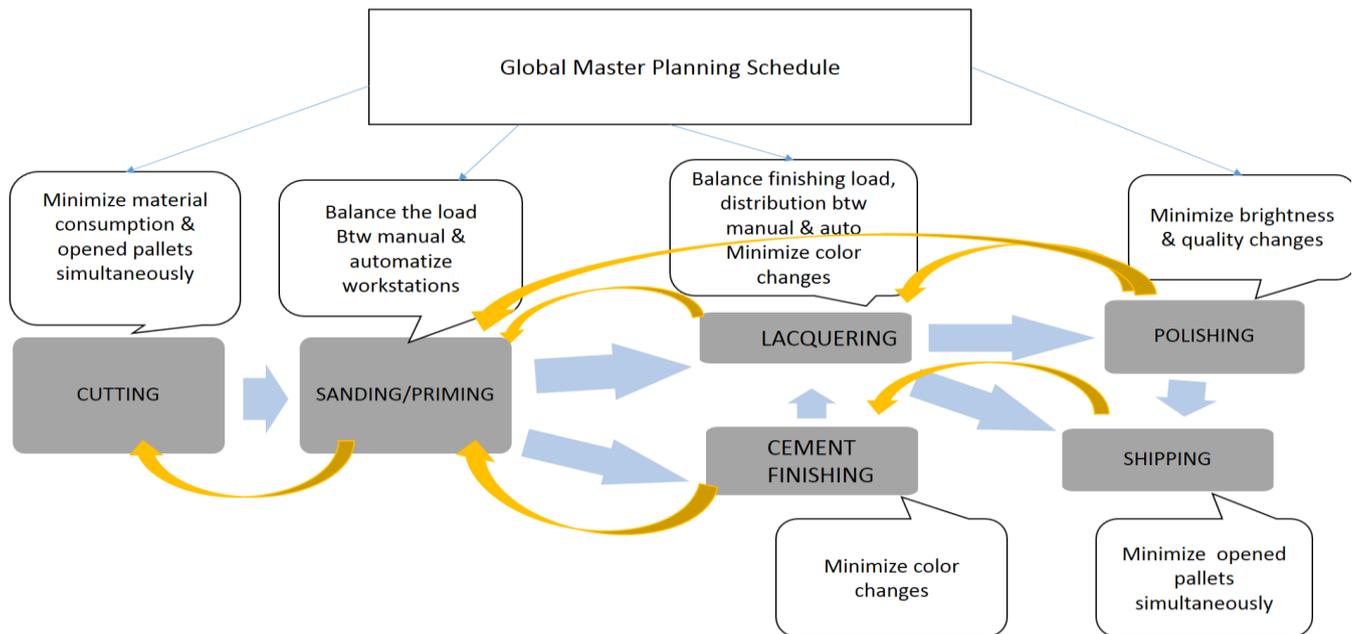


Fig 1. Acta Process Model and relative objectives

As consequence, the company Master Production Schedule (MPS) corresponds actually to an infinite capacity schedule of the customer orders scheduled according to their due-dates and without any optimization or load smoothing. The only available delay indicator is based on the field experience: if at the time t , the weekly order of customer C has not been processed on workstation W , then the production is delayed. Besides, all the products have not the same routing sheet: if no optimization are made some workstations could be in starvation while others will be overloaded. This phenomenon is enhanced by the reworks loops on certain key workstations. A better visibility of the products routing sheets and decisions taken locally by the operators became possible with the integration of a M.E.S. (Manufacturing Execution System) to the legacy manufacturing systems to follow and supervise the whole the production processes. Consequently, the reactivity faced to disturbances is facilitated.

The main objective of this study is to minimize delays in the context of highly disturbed environment. Moreover, as presented in Fig.1 each workcenters has its own objectives which have to be considered. In order to provide overall efficient production performance and ensure reactivity face to unpredicted events, the industrial experiences and research activities, for example El Haouzi et al. (2009) and Pach et al., (2014), have demonstrated the interest of a hybrid manufacturing control system. The aim was to couple a predictive centralised mode when the manufacturing schedules are generated based on optimization or heuristic algorithm (Implemented on ERP or SCM systems) with a distributed mode based on the reactivity of smart products. The design and control of such manufacturing capable to adapt their behaviour to the changing environment still a big challenge. Especially, Cardin et al. (2017) highlight the need of designing efficient synchronization mechanisms.

To deal with ACTA-Mobilier problem, we explore the use of a hybrid manufacturing control based on smart lots and local workcenter optimizers combined with predictive scheduling establishes by ERP and by the local optimisers. In order to formalize and to explain the synchronization mechanism, the VSM conceptual framework has been chosen.

3. VSM CONCEPTUAL FRAMEWORK FOR HYBRID MANUFACTURING CONTROL

This concept has been introduced by Stafford Beer (Beer, 1984) which explains that an organization must not be seen like a pyramidal entity. The organization is a collaborative being, split in 3 parts: control unit, operating system and environment (Fig 2). Inside the operating unit, the same scheme exists and will take, at its own level, some decisions. That gives to the system a recursive property. The proposed system was thought this way because, like in a basic VSM, on each level the cybernetic entities have the same structure. The differences between them are the data they embedded and the decisions they are allowed to take. VSM model adaptation are already numerous in literature (Stich et al, 2009; Laws et al, 2005). In particular, The VSM-SCP metamodel proposed by Herrera et al. (2011) has been adopted for the studied case: the intelligence given to the entities is the one of the MRP2 system and the centralized decision has been distributed to them. Fig. 3 represents the Herrera's VSM model re-adapted to answer the problem induced by Acta-Mobilier case. Like a living being composed of organs themselves composed of cells. The kernels are the cells composing the production lots themselves composing the whole system. Each of them are cybernetic entities which react to their own environment and data they are able to deal with.

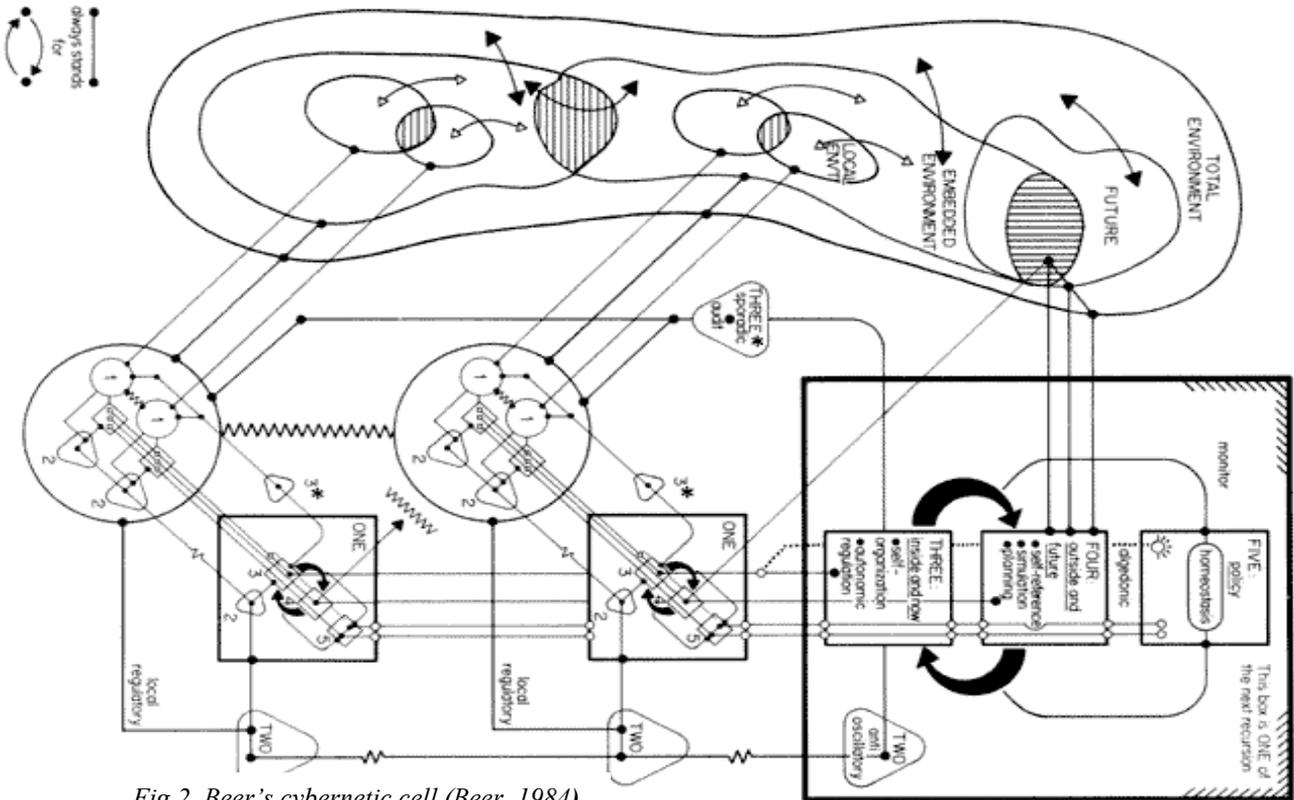


Fig 2 Beer's cybernetic cell (Beer, 1984)

4. STATE OF THE ART

The main goal of the VSM hybrid manufacturing control is to perform a dynamic scheduling (§4.3) in order to adapt the production to perturbation. A primary way to implement this dynamic scheduling is to modify the lot or batch size to deal with the changing objectives. That corresponds to a dynamic batching and scheduling problem (§ 4.2).

To strengthen the accuracy and the reactivity of the schedule, the lot have to exchange information about themselves with the information system, the environment, the schedules and the workstations. To be efficient and reactive it seems probably better to allow the kernels (or sub-lot that correspond to minimal unbreakable product lots) to decide with each other's which one should go first on each workstation. This implies the notion of smart product and the question of knowing what type of data should be used by and stored on the kernels and shared with the global system. This is a problem of data aggregation (§4.1). To be even more accurate a remaining challenge is to synchronize all the schedules. (Fig 3) summarizes the explanation gave before.

4.1 Data aggregation (knowledge characterization)

This problem corresponds to the study of the data aggregation, defined as the capacity to summarize the information, in a mathematical way, as a function going from a sub-space of dimension n towards a sub-space of dimension m (with $m < n$). Numerous algorithms exist and some of them deal in particular with the application of this principle to the distributed systems. Jesus et al. (2015) review a part of the algorithms which were developed: the first ones about the communication topic with the structured, unstructured and

hybrid communication classes. Then the computation classes are described (decomposable, complex and counting functions). A big part of the works turn around the wireless network communication which is constantly evolving and requires always more important performances (Xiang et al., 2013). The objective is to collect and exploit raw data to obtain meaningful information. For example, Noyel et al. (2013) used a neural network to analyse data and then forecast the quality of a lacquering robot. The main problem to deal with, on this subject, is to determine how smartness could be given to the products. Bring them smartness will allow them to decide which one has to be worked first. In the proposed system, data which have to be collect are for example the machine breakdowns. This way, the system will be able to take into account this failure and re-construct the schedule. The hidden problems to answer are: what kind of data must be stored in which entity to be relevant? How could data be stored and redistributed?

4.2 Product aggregation (lot sizing)

The lot-sizing problem in scheduling is widely studied (Glock et al, 2014). It corresponds to the separation of the production in lots of manufacturing to optimize the objective function by taking into account the times of setup, the operating time and/or the transfer time, etc... It was demonstrated that, to a certain extent, this principle improves largely the smoothness of the workcenter.

In the particular case of the Workload Control (WLC), defined for the needs of companies working in Make-to-order, numerous simulations (cited in Fernandes et al., 2016) were made to prove the efficiency of this model, but they supposed that lots never change their sizes during the process. Fernandes considered dynamic lot sizing in the WLC

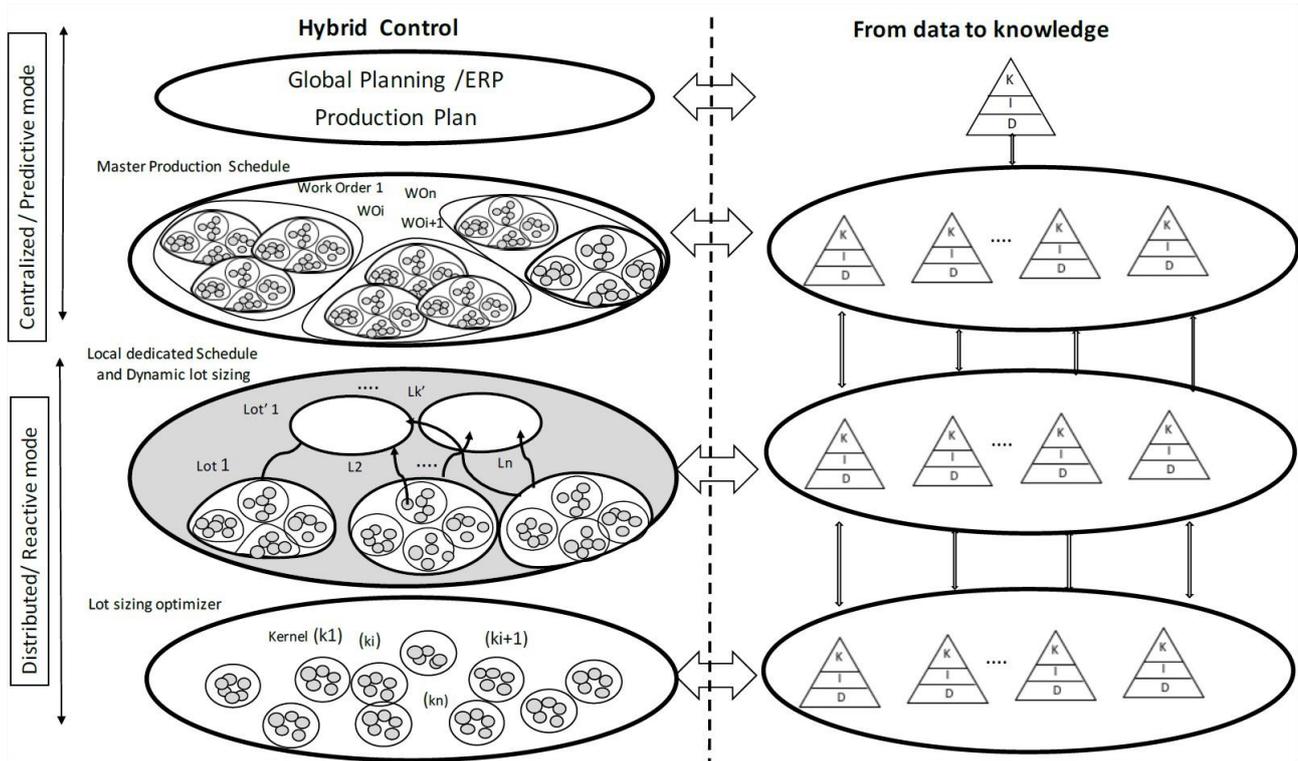


Fig 3. Herrera's re-adapted VSM model

and the results seem interesting. The principle of lot streaming, a subcategory of the lot sizing, could also be interesting in particular in their application for problem of sequencing of the NPFS (Not permutation Flow Shop) (Rossit et al., 2016). In this VSM metamodel, the lot-sizing, and especially the dynamic one, will permit to reach the objectives of the distinct workcenters and optimize the product flow.

4.3 Dynamic scheduling

There are, according to the literature, two types of dynamic sequencing who take into account the disruptive elements such as the appearance of new jobs after the planning establishment or the reworks flow (Tanimizu et al., 2006). The sequencing named "real time". Its specificity is to have no pre-established schedule. Its main advantage is to be effective and fast to be changed in front of unforeseen events but it suffers however from problems of optimization because its objective is to supply a satisfactory answer as soon as possible. And the sequencing named "reactive" which mostly uses genetic algorithms or ant colonies optimization heuristics for re-optimize the initial schedule as soon as it is necessary. The performances of the reactive sequencing also depend on the chosen model to realize the initial schedule and the way of developing it by using a reactive model of prediction (Zhao et al., 2013). To get as close as possible to the industrial reality (dynamic environments, multi workstations with disturbances and complex products), works

will lead on the EJSSP (Extended Job Shop Scheduling Problem) by using genetic algorithms (Madureira et al., 2003). Studies on scheduling distributed with vote process problems, as the MASP (Multi Agent Scheduling Problems) (Perez-Gonzalez and Framinan, 2014) were led and seem to correspond to a part of the problem described in this paper. Thus, the results they obtained are promising and could be re-exploited. It's a requirement to have a reactive and dynamic schedule because the workshop situation is in constant evolution and, to stay useable and pertinent, the schedules have to refresh themselves as often as needed.

5. CONCLUSION AND OUTLOOKS

A VSM meta-model was proposed to design a Hybrid Manufacturing Control dealing with Acta-mobilier issues. This architecture covers several decision levels, with various modes of control (centralized/ distributed). The smart lots and sub-lots (kernel) were used to enhance the reactivity for the system. Thus, the ongoing works are focused on developing all of the dedicated schedules based on operational research methods. Secondly, the Phd will have as objective to propose coordination mechanisms to develop the global optimizer (using the simulation method as support for decision for example) and finally, implement the smart objects (technologies, data storage, processing issues).

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