

EXPLOITATION OF THE KNOWLEDGE OF THE FINAL DEMAND IN THE PILOTING OF A LOGISTICS CHAIN

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Abstract: The transition from synchronous supplies to synchronous production represent a possible alternative to the neighbourhood logistics configurations, especially in the automotive industry. It allows to gain, on certain conditions, efficiency and more manoeuvrability faced with a strong variability of the demand on the supply chain. The utilization of the Order Penetration Point (OPP) will introduce problems in piloting production between clients and suppliers processes. This article is based on several working assumptions which form an algorithm for the resolution of this problem resulting from an analysis of two industrial cases with stochastic models.

Key words: supply chain, anticipation, piloting of flows, order penetration point, kanban, synchronous production.

Over the last two decades, the evolution of the economic environment of the companies led to an increasing tension on flows, in particular for the companies specialized in the mass production of strongly diversified products. One will focus on those companies in the following article. This shortening of the interval time between the placing of an order and the moment when it must be met has cascading repercussions in the logistics chain. This is due to the pressure caused by increased costs. Delayed differentiation is not longer sufficient to face new challenges, the piloting of flows must be improved. The solution which consisted in improving quality of information in circulation throughout the logistics chain and increasing its circulation speed is not sufficient when certain processes mobilized by the production to order are not perfectly reliable: it is necessary to find new rules of piloting reconciling effectiveness and efficiency. One will examine here the few approaches available and the necessary adaptations to deal with these new challenges, before presenting a new approach for piloting the flows, tested successfully.

We will start by specifying concepts (§ 1) which once will make it possible to justify the plan selected to find a remedy to these problems. Then, one will on to presenting (§ 2) new rules allowing a synchronous production for the processes of a secondary logistics chain feeding a principal logistics chain when the reliability of the production of the latter is insufficient. The profits associated with this logic of synchronous production have been identified through an industrial case; the use of simulation made it possible to evaluate the sensibility of the results obtained with stochastic models (§3).

1 Concepts

In order to position the stake, we will start by defining what the logistics chain is (§ 1-1). The distinction between pull system and pushed system, with its implications on the methods of piloting of flows, requires to be specified when it is used in the analysis of operations of a logistics chain (§ 1-2). In this chain, the speed of information flow relating to the firm orders, from the process having to satisfy these demands with the direct or indirect process-suppliers, plays an important part on the organization of the production. The concept of order penetration point (OPP) clarifies the stakes of an anticipation of the demand to satisfy in the secondary logistics chains (§ 2). The remarks which result from it ground the structure of this analysis.

1-1 The logistics chain

Many problems arise in the definition of the logistics chain and in its use from an operational point of view (see Giard, 2003 and 2004). The authors will limit the analysis to some specific elements dependent on the use of information in the piloting of flows of a logistics chain, as a sequence of production process or of transport, bound by relations of the customer-supplier type and directed towards the satisfaction of a final demand. In this context, the logistics chain allowing the manufacturing of a given range of products is characterized, in general, by a network of processes converging towards a process of final assembly; the distribution and the sale of these products are often then carried out by a diverging type distribution network. This logistics chain can be described by the general diagram shown in flow chart of figure 1.

One will be interested in the logistics chains directed towards the manufacturing and assembly to satisfy the final customer orders or those of intermediaries of the distribution network formulated in response to know demands (supplying-to-order) or anticipated (supplying-to-stock). In this network, one

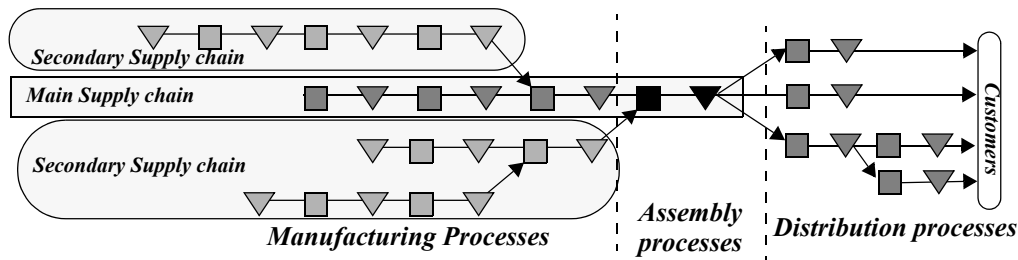


Figure 1: Graph of the logistics chain processes

will distinguish a principal logistics chain, made up of a sequence of process converging towards the process of assembly which delivers products satisfying the demands of customers, of the secondary logistics chains, which feed into components the processes of the principal logistics chain. Generally, the manufacturing system of the principal logistics chain belongs to the same legal entity which may or may not own whole or part of the manufacturing systems associated with the secondary logistics chains. In both cases, the problems of piloting the logistics chain arise in the same manner but it seems easier to reconcile the local points of view when all the processes are in the same legal perimeter. Let us add that this general diagram does not fit all, reality can sometimes be more complex¹ or more simple².

The traditional distinction between pull system and pushed system must be supplemented when it applies to the piloting of a logistics chain.

1-2 Piloting with pushed systems - piloting with pull systems

In general, one speaks about pull systems when the production of a process A is started by the ordering of a process-customer B, process-supplier A avoiding to produce in the absence of order. Two remarks must then be made:

- For economic reasons (arbitration between set-up costs and possession costs in the event of sufficiently regular demand), launching in production of process A can relate to a batch size higher than the order made by the process B. Surplus stock thus created will be used by further orders which will not generate production by process A as long as stock available is higher than the orders; in this case, the concepts of pull systems and the make-to-order are not completely substitutable.
- Nothing prevents the process-customer to manufacture on the basis of anticipation of orders and not on firm orders (make-to-stock). From the local point of view, the denomination of pull systems is worth only for the process-supplier whose production is started only by the ordering of the process-customers with which it is in direct relation. From the global point of view, which is that of the logistics chain, this denomination refers to the piloting of flows of a sequence of active process until that satisfying the demand of a finished product, regarded as the triggering event of the production in this logistics chain. In this case, the production of a process is not necessarily triggered by the ordering of the one of the process-customers with whom it is in direct relation. It is then necessary to specify whether it is the local point of view or the global point of view which one retains while speaking about pull systems.

One speaks about pushed systems when the production of a process is decided on the basis of anticipation, and not in response to definite order placed by the customer process. This anticipation can be the outcome of a forecast of not yet formulated demand (potential demands), in which case, we clearly refer to make-to-stock production. It can also result from a calculation of procurement in time of components to a process-customer, to make the delivery of products possible on a later date in accordance with an effective order already placed by a customer of the ultimate process of the logistics chain considered. This last process which cannot be the process-customer of the process considered here. Then we are in a local logic of pushed systems and, overall, in a logic of pull systems. These remarks make it possible to better characterize the piloting of the various processes of a logistics chain and to better determine the operational value of information relating to the final demand circulating in a logistics chain of production and

1. For example, the diversity of the production can be that certain processes of this graph are not systematically mobilized, generally because of the diversity of the products assembled, while others can be duplicated, including that of the final assembly which can extend upstream. Lastly, this process of final assembly is fed only by only one secondary logistics chain, however it could be fed by several ones.
2. The logistics chain of distribution is simplified when the number of customers is low and when the logistics chain is directed towards an order to manufacture than towards an order to assemble. The logistics chain of production and assembly can be limited to a simple sequence of process, if the components used are easily found in the trade (decoupling ensured by stocks).

assembly. Potential decoupling between these two modes of piloting (pushed system/pull system) is demonstrated by the description of the order penetration point.

1-3 Order Penetration Point (OPP)

The production of a complex product implies the combined use of the bill of material and the production route sheet of this product and its components. The route sheets make it possible to associate a process to the manufacturing of each component; the bill of material then makes it possible to thus establish the cartography of the flows implied in the production of the product and of the logistics chain concerned.

The knowledge of the interval of time separating acceptance from the order, of its delivery, can be reflected in cascade in the processes concerned being upstream process in the beginning of the order in the logistics chain. On a Gantt chart visualizing the sequence of the processes of the logistics chain, the length of the rectangles associated with the processes being proportional to their duration¹ one can locate on the axis of time, the point corresponding to the date on which the delivery date is known in a secondary logistics chain. This point, single if all the processes have this information at the same time, is described as Order Penetration Point (OPP). It makes it possible to trace a border in the cartography of the processes between those which can make-to-order and those which must make-to-stock, a similar border being able to be established in the bill of material. Figure 2 illustrates this determination of the OPP and the division which it operates in the whole of the processes and in that of the references.

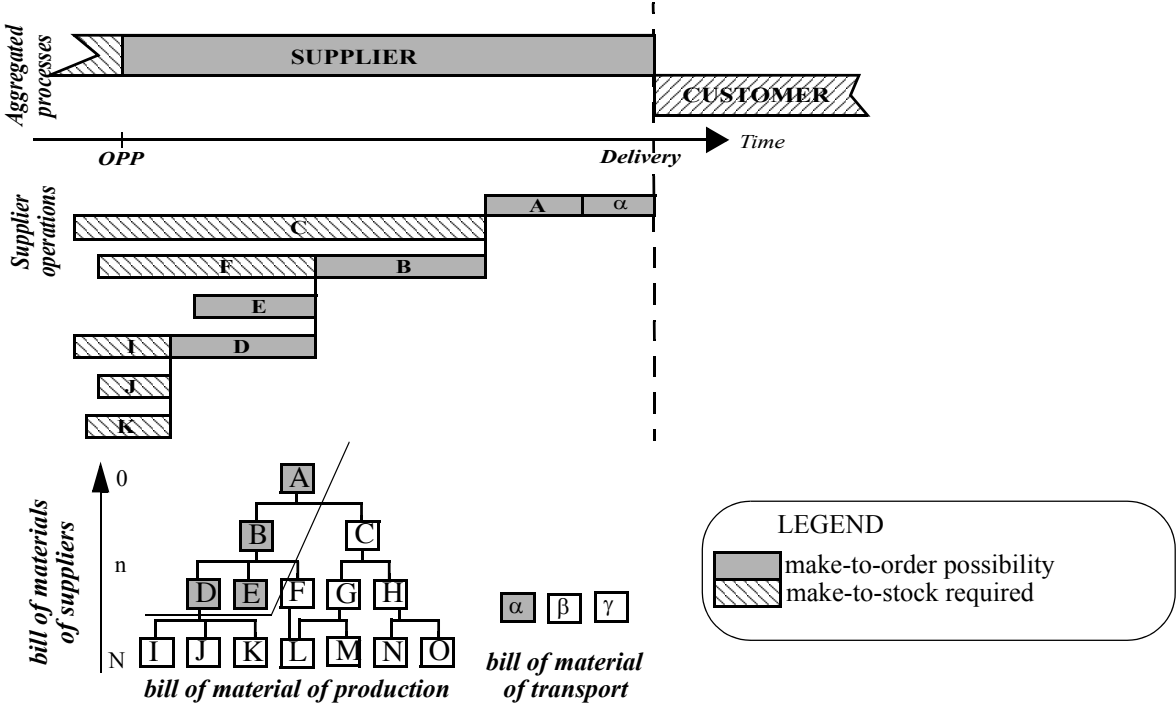


Figure 2: Principle of Order Penetration point (OPP)

Upstream to the OPP, the knowledge of the final demand comes in too late to be able to produce at the time of the order but it can be used by certain policies of make-to-stock production (policy of periodic replacement on a order-up-to-level). Downstream from the OPP, this information allow as well a make-to-stock strategy as a make-to-order one. One will locate the processes of a sequence of processes of a secondary logistics chain by indices marging from h or h' , for the first process located downstream to the OPP, index 0, for the process of the principal logistics chain which uses the components diversified manufactured by this secondary logistics chain. Two situations can be identified:

- Information go up immediately from level 0 to level h and, in certain cases, to all the intermediate levels (1 with). Its use is not the same if it relates to a demand immediately satisfied by taking away stock of finished products on level 0 or on a demand to satisfy by production and/or assembly.

1. The article of Giard & Mendy (2004) discusses the incidence of the organization of the manufacturing system intervening in the process (job shop, flow shop) over these durations as well as the impact of the organization of the design of the products to face the variety required by the market, on the interest of the anticipation of the OPP.

- Information go up gradually from level 0 to level h' , as a process-customer gets components produced by their process-supplier. In this case, the information available is known later than in the preceding case and the OPP approaches the process 0 ($h \geq h'$). This mode of piloting, which is that of the kanban system, functions without stock-out under drastic conditions.

The synchronous procurement and the synchronous production can effectively relate to these two approaches. The tension on flows, combined with an insufficient reliability of the productive processes of the secondary logistics chain, led to imagine new methods of piloting for the synchronous production to limit stocks and to avoid procurement disruption (§ 2).

The coordination of the production between the principal logistics chain and the secondary logistics chains can be based on the kanban system if the characteristics of the demand for volume and structure are sufficiently stable and the diversity of references assembled by the process of assembly towards which converges a secondary logistics chain is compatible with the space of storage available as well as the insufficiency of reliability of the processes of stake is correctly taken into account.

2 The synchronous piloting of flows of a secondary logistics chain insufficiently reliable

The problem of storage space closed the line of production due to a strong diversity in assembly led the automotive constructors to pass in synchronous supplying in a context characterized by a low anticipation of the demand (§ 2-1). In this case the only solution is to use the delayed differentiation carried out by one of the last processes of the secondary logistics chain starting from preexistent stocks of different components (the assembly of the automobile seats covers constitutes the classical example). An increase in this anticipation makes it possible to go from a synchronous supplying system to a synchronous production system where the components ensuring differentiation can be manufactured with the order instead of being stocked. If the reliability of the processes of the secondary logistics chain is good, one is brought back to the issue of scheduling evoked in § 2-1 with but in a logic of slipping programming on a range of a few tens of hours. The problem is definitely more complicated when the production process of the secondary logistics chain does not have sufficient reliability compared to the quality standards (whose severity tends to increase). New approaches of piloting must then be designed (§ 2-2).

2-1 The synchronous delivery

The synchronous delivery is based on the making of an order to the supplier who is in charge of supplying a workstation assembling substitutable components. The principle is to deliver a batch of components at a precise time in order to cover exactly the demand until the following delivery, these components being arranged in the order of their use (sequencing¹). The problem of overspace in the line stock does not arise any more, depending on the frequencies of deliveries. The sequence of the order, passed a few hours before the consumption, must respect exactly the sequence on the customer assembly line after delivery. This sequence can be the one observed in the production line or that observed at a collection point upstream the assembly station considered if this order can be disrupted. One is then on a piloting in pushed system on the basis of anticipation considered as reliable. The weak reaction time left to the suppliers obliges them to mobilize the principles of delayed differentiation in the design of their products and processes and to use closer structures making it possible to prepare the delivery of a sequenced batch (Advanced Store Supplier, ASTS) or to complete the differentiation required by the customers (Advanced Site Supplier, ASS).

2-2 The synchronous production

The synchronous production is basically characterized by a transmission of the requisition of components to the supplier, several tens of hours in advance instead of a few hours in advance as is the case with the synchronous supplying. This solution is somehow interesting because the upstream movement of the order penetration point makes it possible to decrease the share of production for stock to the profit of a production to order, making gravitational the use of closer structures, as MAF or SAF. However it encounters two difficulties.

- First of all, it is necessary that transmitted information is completely reliable. This reliability is not ensured if the order observed at the time of the sending of information to the supplier can then be

1. The sequencing takes into account all of the differences of the finished products due to options

disturbed for reasons already mentioned either line control of quality, or of stock-out of supplying upstream to the assembly station. The use of corrective mechanisms (Automated Storage and Retrieval System¹ allowing a partial rescheduling of flow, safety stock...) proves to be necessary.

- It is then necessary that the supplier benefits from transmitted information. If the usual approaches of piloting of flows are not adapted, it is appropriate to conceive new ones. One will examine some mobilizable principles successfully tested.

If the production process of the supplier guarantees a quality without any defect, the piloting of flows is relatively easy. One will only examine here only the case of a process allowing manufacturing of several references, the management of a mono-product process is obvious. The process of the supplier can carry out the sequence required in two ways illustrated by flow chart of figure 3.

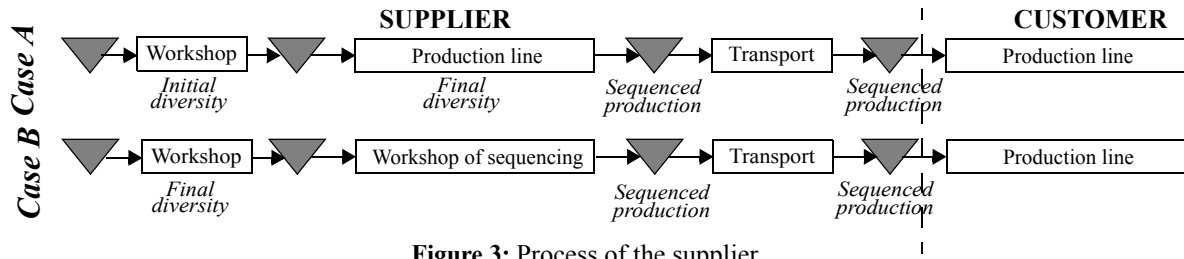


Figure 3: Process of the supplier

- In case A the supplier produces from the line of production or assembly which takes components varied and substitutable in a stock supplied by a workshop of production of the process-upstream, which ensures the final diversity of the finished products. Generalization with several processes converging towards the line of production and supplying stocks on the line of production is immediate, the problems of programming the productions of these processes being separate. The scheduling retained on this line is defined by the requisition of the customer (operation of batch sequencing).
- In case B, the line of the supplier is reduced to only one workstation whose role is to take components in the order defined by the requisition of the customer.

In both cases, if the order penetration point is placed upstream to the workshop, the difficulty is the piloting of the production of this workshop, by an exploitation of the information transmitted by the customer (presumably single for these products²). Several working hypotheses melt the reasoning at the base of an algorithm of resolution of this problem.

- The decisions of launching in production by the supplier are made at regular intervals of amplitude τ . This interval could not be lower than maximum unit operational time τ_0 of the process nor higher than a threshold τ_1 defined by the last requisitions known by the customer at the time of the decision-making. The definition of τ must take account of the periodicity of the rounds of removal but also, as it will be seen, of the possible existence of launching time. At the time of the decision, date t , one lays out for each reference i of a stock S_{it} and the demand to satisfy between t and $t + \tau$ is D_{it} . These demands are certain and defined at the movement of the stock located downstream from the supplier's production workshop, starting from the estimated dates of consumption of the components by the customer and of a shift defined by the whole of the production process or of transport located between this stock and the station of consumption of the process of the customer.
- No problem arises from the flows synchronization between the workshop and the line of production or the workshop of sequencing. The rejection of this hypothesis does not pose a problem but complicates the analysis without changing the bases.
- The production of this workshop is without defect. The rejection of this hypothesis will result in proposing new rules of production programming.

With these three hypotheses, the programme of production q_{it} for the period going from t to $t + \tau$ is such as $q_{it} \geq D_{it} - S_{it}$, reference i has to be necessarily launched in production if $D_{it} \geq S_{it}$. As one is in stochastic models, the existence of stock S_{it} is justified only for three reasons:

- The launching of reference i in production is preceded by a set-up time and the output of the workshop does not allow to satisfy the whole of the demands, to have too much time wasted in launching (point

1. An Automotive Storage and Retrieval System (ASRS) is a stock of vehicles where one can choose any vehicle without taking account of FIFO regulations in order to arrange the initial In Line Vehicule Sequencing list.
 2. If the studied process serves several customers, one is reduced to the preceding case by allocating to each customer a fraction of the capacity, which is acceptable if the total demands of each customer are stable. In the contrary case, it is advisable to adapt the step suggested, which one did not shoe here.

of view adopted for each programme of production in particular) but one can also justify these stocks by the decision to limit the set-up costs of the programme of production (angle agreed for the whole of the programmes of production).

- The existence of this stock can also rise owing to the fact that reference i is launched in production with a minimal size of batch higher than one, in which case, S_{it} corresponds to the surplus of the sum of the previous productions compared to the sum of the last demands.
- An alternative of preceding case can be observed when the process led to simultaneously treat several batches (heat or chemical treatment), each batch of fixed size relating to the same reference (what does not exclude the possibility of having several batches relating to the same reference), the number of batches which one can treat simultaneously being lower than the number of references, which does not make it possible to produce with each launching all the necessary variety.

Once the references determined to launch in production are ($D_{it} \geq S_{it}$), it is easy to determine the residual capacity as being the difference between the capacity available and the capacity used to avoid these out-of-stock conditions, by taking account of the minimal sizes of batch. This residual capacity can be used to increase the size of the batches of the references launched in production and/or for launching new references. The first solution keeps costs and time of launching constant contrary to the second but in both cases, it is necessary to have additional information on the «profile» of the demands beyond the horizon selected. If the production rate of the workshop is higher than the rate of consumption of the supplier, it is advisable to take care not to create stocks unnecessarily. This statement can easily be proved by an economic argument arbitrating between carrying costs and set-up costs.

The questioning of the hypothesis of a production without defect is essential for many production processes; those of painting, for example, generally know rate rejection p going from 5 to 15%. The solution consisting in considering that on $n =$ produced parts, n corresponding to the upper round-off of $q_{it}/(1-p)$, noted $\lceil q_{it}/(1-p) \rceil$, q_{it} will be good, cannot guarantee the absence of stock-out condition, the number X_{it} of good parts according to the binomial distribution $\mathcal{B}\{q_{it}/(1-p), (1-p)\}$. The risk incurred with this solution is illustrated in table 1.

p	$n = \lceil \frac{5}{(1-p)} \rceil$	$P(X < 5)$	$n = \lceil \frac{10}{(1-p)} \rceil$	$P(X < 10)$	$n = \lceil \frac{15}{(1-p)} \rceil$	$P(X < 15)$	$n = \lceil \frac{20}{(1-p)} \rceil$	$P(X < 20)$
5%	6	3,3%	11	10,2%	16	18,9%	22	9,5%
10%	6	11,4%	12	11,1%	17	23,8%	23	19,3%
15%	6	22,4%	12	26,4%	18	28,0%	24	28,7%

Table 1: Probabilities of stock-out of supplying for the customer $P(X < q_{it})$ for various rejection rates p and various productions demanded ($q_{it} = 5, 10, 15$ and 20) • Use of the law $\mathcal{L}(X) =$

$$\mathcal{B}\left\{\left\lceil \frac{q_{it}}{(1-p)} \right\rceil, (1-p)\right\}$$

A certain number of principles can be retained to ensure a robust piloting of the synchronization of the production by the supplier. The general algorithm describes hereafter was tested successfully in the resolution of two industrial problems¹. It carries out an estimated simulation of the process as from the moment of the decision-making, by holding account the demands to satisfy in their order of arrival starting from this date and launchings in production decided during simulation to avoid any stock-out of supplying. This simulation stops when the output defined on the window of time τ is completely used or that there is no more demand to satisfy (what occurs if the production rate of the workshop is higher than the rate of consumption of the supplier). Conventions selected to describe this algorithm are as follows:

- j is the row of the component to be delivered to the customer ($j = 1, \dots, J$);
- i is a reference number, $i(j)$ is then the reference number of the component of row j to be delivered to the customer;
- the launched production of the reference i which will be launched between t and $t+\tau$ is q_{it} ; the first decision of launching of this reference will relate to a quantity $q_i^{min} \geq 1$ and each following decision of increase in q_i will relate to a quantity $q_i^{\Delta} \geq 1$ (possibly equal to q_i^{min}); one will note $K(q_i)$ the capacity consumed by q_{it} , knowing that the total capacity available for this period τ is noted K and that one will note KC the capacity consumed overall by the program of production;

1. One of these problems implied the taking into account of additional constraints to respect at the time of the decision-making but not modifying on the bottom the step described here.

- S_{it} represent the stock available to the moment of the placing of order (the index t of this date of catch will be omitted in the description of the algorithm); it is then treated in the algorithm like an estimated stock;
- x_i the strongest quantity such as $P(X_i < x_i) < \alpha$, where α is a risk of stock-out of accepted maximum supplying and follows the law $\mathcal{B}\{q_i, (1-p)\}$. this quantity is used in the update of estimated stock at the time of decision of launching of this reference by the algorithm in order to control the risks; table 2 illustrates this determination for a probability of non-acceptance of a part from an unspecified batch, equalizes to 10%; if one launched in production a batch of 16 units, one would enter only 10 in stock entry, which amounts to a probability of 0,33% of stock-out of supplying for the customer.

q_i	6	8	10	12	14	16	18	20
x_i	2	4	5	7	9	10	12	13
$P(X_i < x_i)$	0,13%	0,50%	0,16%	0,43%	0,92%	0,33%	0,64%	0,24%

Table 2: Good production x_i having more than 99% of chances to be exceeded on a batch of size q_i knowing that each part of the batch has a probability $p = 10\%$ of being defective

In the algorithm in table 3, one will preferably use notation $i(j)$ with i retained in the last three subparagraphs. In addition, the reference to the date t of decision-making will be omitted there in the indices used, which is without ambiguity, since it is a question of establishing a program of production to be implemented at this date until the next decision, to take at the date $t + \tau$.

-	<i>Initialisation:</i> $j = 1; q_i \leftarrow 0, \forall i; KC = 0$
-	<i>Step 1:</i> $S_{i(j)} \leftarrow S_{i(j)} - 1$; if $S_{i(j)} < 0$ then go to the step 3, else go to the step 2
-	<i>Step 2:</i> $j \rightarrow j + 1$; if $j \leq J$ then go to the step 1; else go to the step 4
-	<i>Step 3 (forecast stock-out):</i>
-	If $q_{i(j)} = 0$ then $q_{i(j)} \leftarrow q_{i(j)}^{min}$ then
-	If $KC + K(q_{i(j)}) < K$ then $S_{i(j)} \leftarrow S_{i(j)} + x_{i(j)}$ and $KC \leftarrow KC + K(q_{i(j)})$
-	If $KC + K(q_{i(j)}) > K$ then go to the step 4
-	If $q_{i(j)} > 0$ then $z_1 \leftarrow x_{i(j)}$; $z_2 = K(q_{i(j)})$ then
-	If $KC + K(q_{i(j)}) > K$ then go to the step 4
-	If $KC + K(q_{i(j)}) < K$ then $q_{i(j)} \leftarrow q_{i(j)} + q_{i(j)}^\Delta$; $S_{i(j)} \leftarrow S_{i(j)} + x_{i(j)} - z_1$ $KC = KC + K(q_{i(j)}) - z_2$
-	<i>Step 4: End</i>
1	The horizon of customer demand is insufficient to make it possible to saturate the period capacity (possibly because of the excessive importance of stocks available at the time of the decision-making, in which case we are talking about levelling).

Table 3: Algorithm of programming of the production for the period to come

Let us illustrate this algorithm supposing that, for the reference $i = 5$, one has $S_5 = 3$ (opening inventory at the time of the decision-making), $q_5^{min} = 6$ and $q_5^\Delta = 4$, the risk selected is $\alpha = 1\%$ and that one does not have to be worry about problem of available capacity. Let us suppose that the 27th required component corresponds to the 4th required unit of this reference $i = 5$ ($j = 27 \rightarrow i(27) = 5$); the stock S_5 (estimated) passes from 0 to -1 (stage 1), then at stage 3 we have: $q_5 = q_5^{min} = 6$ and $x_5 = 2$ (see table 3) and the stock S_5 (estimated) passes from -1 to $-1 + 2 = 1$.

Let us suppose that to the required components 45th and 56th correspond this same reference $i = 5$ and that they are the only ones between the 28th and 56th rows; when $j = 56$, the stock (estimated) S_5 passes from 0 to -1 (stage 1); stage 3 one has $z_1 = 2$, then $q_5 = 6 + q_5^\Delta = 10$, then $x_5 = 5$, then S_5 passes from -1 to $-1 + 5 - 2 = 2$.

Four complementary remarks must be made.

- By precaution, calculations of estimated position of stock undervalue the quantities in stock. With the following decision-making in $t + \tau$, whole or part of the production q_{it} decided in t will be completed;

this new decision will be made on the basis of stock observed $S_{i, t + \tau}$, calculated from S_{it} and of the part of q_{it} delivered good between t and $t + \tau$.

- The risk of stock-out of supplying of a reference i consecutively with a decision of programming taken in t can be null only if the initial inventory meets the needs S_{it} between t and $t + \tau$. That being, if because of the rules of batch process (q_i^{min} and q_i^{Δ}) the launched quantity is such as, the incurred risk is weaker. To take again our example ($i = 5$, $S_5^i = 3$ and $q_5 = 10$), if the demand to satisfy between t and $t + \tau$ is only 5 (the launching complementary to 4 units resulting from a out-of-stock posterior at the estimated date t and $t + \tau$), probability of out-of-stock before the next launching decided in t and $t + \tau$ such as $P(X < 5 - 3)$ for the binomial distribution $\mathcal{B}(10; 10\%)$, negligible risk (about 10^{-9}).
- At the time of the decision-making, components can be in the course of being produced in the workshop. It is the case, for example, if the workshop corresponds to a whole of poles assembled on a conveyor functioning in loop, of the components to be painted being hung on these poles, all the components of a pole being painted same colour, colour being able to vary from one pole to another¹. In this context, it is necessary to hold account in simulation not only taking away related sequence of demands but also the arrivals in stock. This taking into account is done simply in this example by calculating the estimated positions of stock, by taking account of the work in progress and of that projected which arrives in stock after the work in progress. This work in progress is treated in the same way as the new production programmed in the update of the positions of stock.
- The final advantage of this approach is its capacity of immediate adaptation to the variations in structure of the demand, which an approach kanban does not allow the price of important safety stocks.

Compared to the piloting based on the kanban system or that of the periodic stocks replenishment, the application of this algorithm to two industrial problems in which a difficulty of production quality arose, allows to clearly present the associated profits; the use of stochastic models made it possible to evaluate the sensibility of the results.

3 Illustration by two industrial cases in the automotive environment

The analysis of two industrial cases in the automotive sector takes place in a logic of drastic search for reduction of storage surfaces in a supplier's facility in case A and in an advanced site supplier (ASS) in case B. The modelling of the processes of suppliers of row 1 (§ 3-1) clarifies their rules of operations. From the introduction of the final demand of the customer, the position of the OPP makes possible to identify the operating modes able to work in command. The assumption of the implementation of the synchronous production rests on rules of operation retained during simulation which we present in detail. The analysis of the results will give more information about the sensitivity of the profits associated with stochastic models (§ 3-2).

3-1 Modelling supplier processes in the automotive sector

In partnership with an automotive manufacturer, the authors could carry out two case studies in two suppliers of row 1. The two cases have in common the fact that the production processes are not completely reliable but they differ by the mode of piloting currently in use, a kanban system in case A and a replenishment cycle system in case B; it is this difference which makes the presentation of these two situations interesting and the performance of a new form of piloting, quite general. The flow chart of figure 4 specifies description elements for cases A and B. It describes by Gantt the sequence of the production processes of the two suppliers. Case A is organised with different workshops and case B has a line organisation. In both cases, the production decision taken at time t uses the information of the position of stock P_{it} of each part i . This position is based on the position used in the last decision (taken at time $t - \tau$), the output O_{it} entered in stock after the quality test (each parts having the probability p to be rejected for painting problem), since the last decision, and the consumption C_{it} , since the last decision: $P_{it} = P_{i, t-\tau} + O_{it} - C_{it}$.

- In case A, in the initial situation, upstream to OPP, the supplier introduces the diversity by his painting shop. He has dimensioned an initial stock at its exit, for each colored reference which corresponds to a number of kanbans resulting from an analytical result. The calibration of stock is founded on the upper limit which one considers that the stock-out is not very probable (2 racks/color); we are not in a calculation of a maximum of kanbans which is equal to the maximum quantity required between two deliveries in order to cancel the risks of a stock-out. For a diversity of 14 colors, the supplier can

1. If one is in the case of several batches of references to launching simultaneously in production, with one common duration of treatment, one interest has to fix τ over this duration.

launch 3 batches in painting (one colour for each batch) of 18 parts and the cycle time is about 90 minutes. The decision-making for launching in painting is carried out every 90 minutes ($\tau = 1,5$) and adheres to a traditional kanban system.

- In case B, in the initial situation, upstream to OPP, the supplier realises the operations of manufacturing of semi-products on the basis of forecasted demand, in his facility located at 15 kilometres from his final customer. Case B has 16 colors and 20 different references. His production does not take into account at that level the sequencing order of the customer. The diversity is introduced with the painting operation. Its launching in production is based on the principle of replenishment cycle system (monitored on information periodically given by SAP) and its logic of scheduling takes into account the order-up-to level of its stocks for each reference (product semi-finished). On a period of each two hours ($\tau = 2$), the outputs realised in the assembly line located in the ASS are recorded in his systems. The order-up level S_i is fixed at 2 days in proportion of the average of consumption for each reference (estimated consumption) in order to avoid stock-out.

The logic of the replenishment cycle system is based on the launching of production for the reference which has the highest value of the difference $S_i - P_{it}$. With a loading capacity of 110 poles/hour, one gradually exhausts with this rule the capacity available to launching. Case B is more complex than case A because one can launch several sequences of painting in a number higher than 3, the importance of these sequences being limited technically; there is a continuous line of equidistant poles where pieces to paint are hung on with a decision-making every two hours and implies a partial update of stock. To continue his process, the supplier B has to organise the transport of all the references (for all diversity) from his own facility to the ASS in customer's facility where he carries out final operations of assemblies on the basis of firm requisition coming from the customer assembly line (consumption). At that time, the supplier introduce the sequencing order and can send in a final internal transport finished products to the customer's assembly line.

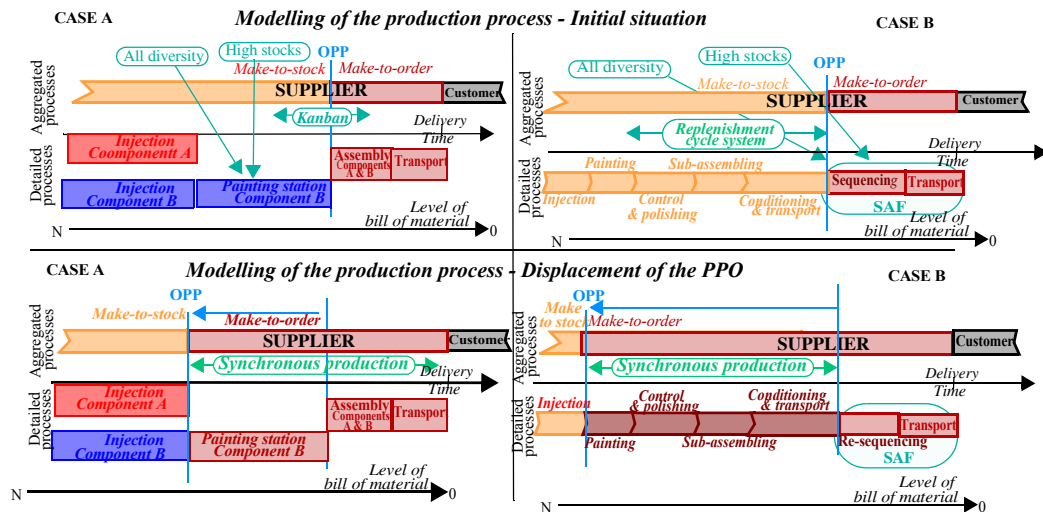


Figure 4: Modelling of the production processes of case A (left) and case B (right)

	Case A: kanban system	Case B: replenishment cycle system
Initialisation of stock	Kanban max for each reference	2 days of production for each reference (+ stock of desynchronisation)
Decision making time of launching	Each 90 minutes	Each 2 hours
Batch size	3 Batches of 18 parts	Continuous loading (capacity of 110 poles/hour)

Table 4: Characteristics of Case A and Case B

For both cases the displacement of the OPP towards the process-upstream of the suppliers brings a degree of freedom: uncertainty on the volume and the structure of the subsets disappears and makes it possible to the supplier to remove the safety stocks of these references and then reduce the carrying costs of immobilization mechanically; the sequence of consumption of the parts over the day is taken into account in launching in production of the references in painting. Upstream of the OPP its operations of scheduling can take into account its constraints of launching in production and also its rules of sequencing

can correspond to final consumption of the customer. This reasoning spreads without difficulty for several references whose activities of productions cross the border of the OPP. The displacement of OPP can involve a handing-over of cause in our example of the functions of the advanced site supplier who can have a role of Re-sequencing the references caused by modifications of the order on the line of production of the final customer (see Danjou and *al.*, 2000).

3-2 Principles and results of simulation

The identification of the profits of a displacement of the OPP upstream the introduction of diversity in the supplier goes through the analysis of a stochastic problem of scheduling production in painting for which simulation using the Monte Carlo methods (see Giard, 2003) is very well adapted.

In order to get the results obtained during simulation it is advisable to retain here two scenarios which we tested with stochastic models with a rejection rate in painting of 10%.

- Scenario 1 represents the current operation of the supplier, rests on the principle of the kanban for case A and on the replenishment cycle system for case B. For case B, a problem of desynchronisation of flows is introduced. This problem is related to a problem of production capacity of the supplier which is inferior to the production capacity of the customer. This implies for the supplier to catch up with this desynchronization over the night and over the week-end. This desynchronization problem mentioned here is independent of our algorithm and will not be presented in detail. Moreover it is important to note that the scenario of reference is a scenario with the maintenance of current rules but with an increase in the rate of customer consumption what explains why the stock-out conditions observed are higher than the current stock-out observed on the ground.
- Scenario 2, new rules of piloting of the synchronous production rests on the algorithm mentioned in § 2-2.

The simulation has been carried out starting from a film generated over 4 weeks of production (around 25624 production orders) in order to ensure a steady state. In case A as well as in case B, the out-of-stock is observed at the end of the week. This occurrence is explained by the fact of oversizing at the beginning of week stocks to mitigate the problems of quality and capacity.

The figures 5 and 6 clearly show the results of the simulation with an introduction of a rejected rate in painting of 10%:

- In case A, with a kanban system the oversizing of stocks (in a number of parts) does not make possible to cover the risks of stock-out. On the other side, the application of our algorithm in a synchronous approach of production allows an opening inventory reduced to 50% to cover the whole of the needs and to preserve risks of being out of stock.

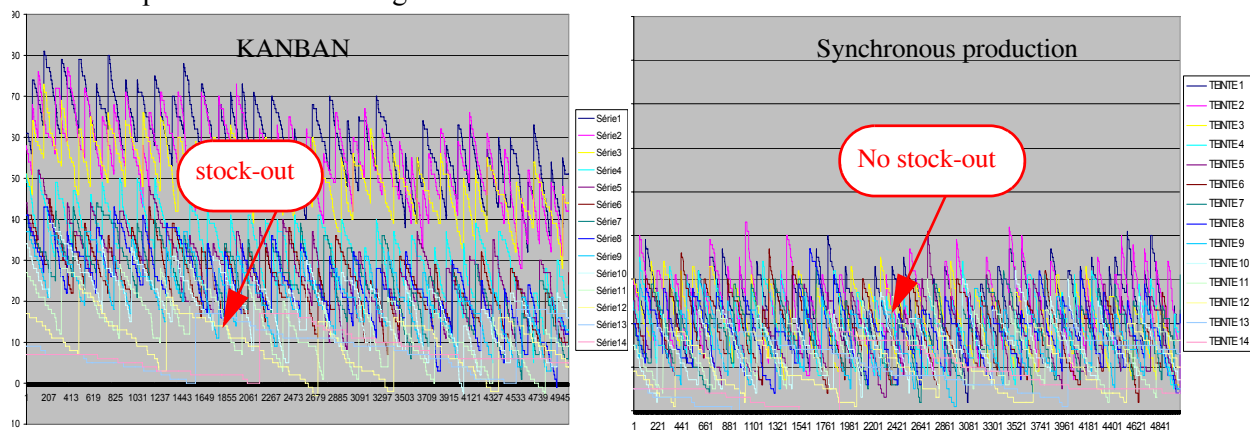


Figure 5: The effect of stocks and decrease of stock-out risks in case A

- The figure 6 shows the stock effect between a new approach and a replenishment cycle system. For a level of stock of 60% lower than the stock of reference in case B, this result highlights that the oversizing of stocks does not cover automatically the risks of stock-out in a total myopia of the demand to come. Within the framework of the new approach, the first estimated date of stock-out is estimated at 25 hours. With a slipping planning an additional information of demand does not have an added value.

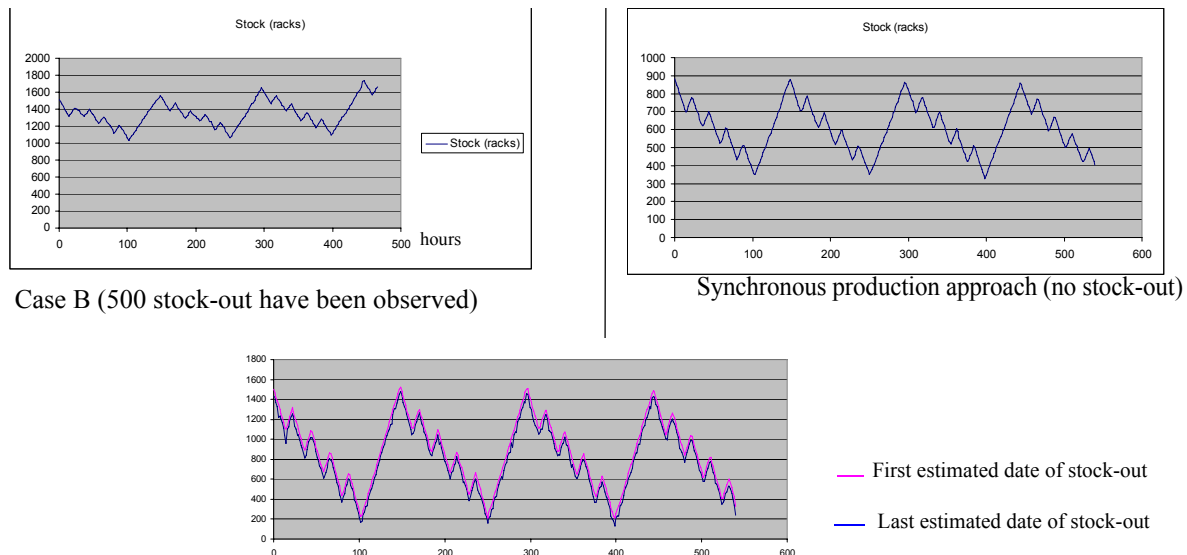


Figure 6: The effect stock and the limit value of knowledge

4 Conclusion

Compared to the piloting based on the kanban system or on the replenishment cycle system with periodic order set-up level, the application of this algorithm to two industrial problems in which a difficulty of a production quality arose, showed that it was possible to notably reduce the safety stocks while improving the security of supply of the customer. Moreover, these studies showed the limits of the value of the information transmitted by the customer: in the application of this algorithm, as soon as the output available for the period to come is saturated, information relating to the further demands which triggered the final decision of production is not of interest for the piloting of the workshop. This assertion has not to be discussed further if one also intends to control the process located upstream but this analysis is much more complex because of uncertainty on the production quality.

More generally one can say that by freezing what can be produced in advance it will make it possible to introduce a new degree of freedom within management decisions at strategic, tactical and operational levels, to take again the typology introduced by Anthony (1965) :

- *Among the strategic decisions*, the supplier has the possibility of considering an alternative solution with the ASS and Advanced Supplier store by a physical delocalization of the productive tool. It is a question in this case of considering, for example, the delocalization of the production of components of parts in more attractive countries economically. In our industrial case, the suppliers have to think about new organization in their production operations because they can not use anymore the ASS on the customer's site for economic and social reasons.
- *The tactical decisions* can be modified on certain aspects. The production planning can be adapted to take account of the displacement of the border production for stock/production with the order. The definition and preparation of the *Transport plan* with stochastic models are also modified by the displacement of the OPP with a local localization and rules which are now dissimilar. It was previously seen that the displacement of the OPP is characterized by a certain degree of freedom in the localization of the operations of production, which has an incidence not only on the frequency of the deliveries (possible reduction of the number of deliveries) but also on the volume to be conveyed (better optimization of the rates of filling) and on the optimal capacity of means of transport (knowing that in the car industry large efforts were already realized). This aspect has not been yet considered in simulation.
- *The operational decisions* relate to the piloting of flows first of all. It is a question as well as possibility of exploiting the information transmitted earlier by the customer to produce with the order. The displacement of the OPP upstream the diversity operation makes it possible to the supplier to produce with the order but the currently available methods of scheduling of the production are not adapted to an environment implying a slipping horizon of a few tens of hours, the relevant definition of a periodicity of decision-making, the utilization of constraints of allotment and the existence of rejections. The work which we undertook in partnership with this supplier, highlighted the superiority of new rules (see § 2-2) of piloting synchronous production, ensuring the synchronization of the production and leading

to a major reduction in stocks without causing out-of-stock condition. That being, it is illusory to think that the information transmitted to the supplier, in particular those relating to the sequencing, is always of an absolute reliability. The decisions making it possible to face the risks must be approached.

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6 Biography

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