Int J Flex Manuf Syst (2007) 19:107–121
DOI 10.1007/s10696-007-9022-8

Improvement of earliness and lateness by postponement on an automotive production line

Xavier Fournier · Bruno Agard

Published online: 25 November 2007

Abstract This article takes an interest in improving the performance of a subproblem of car sequencing: the resequencing problem. It extends a model of assembly line with the simulation of buffer stocks with drawers. Presequencing and resequencing are modeled with different types of stock management policy. Furthermore, postponement is introduced by two points of differentiation within the line. After choosing relevant variables and performance indicators a large-scale design of experiments finally enables to estimate average improvement brought by postponement to more than 39.7%, compared to the situation without postponement.

Keywords Resequencing · Presequencing · Mixed-model production line · Simulation · Postponement · Just-in-time production system

1 Introduction

The automotive industry is subject to high competition and in order to get a larger market share each company tries to provide the exact car each customer requires. This leads to an increasing final product diversity and its complex management (Womack et al. 1991). In the same time, customers want to receive the product as fast as possible while still getting the lowest price. This leads the companies to focus on just-in-time production policies. Consequently, to achieve this goals automotive companies introduced just-in-time production systems (Miltenburg 1989).

X. Fournier · B. Agard (✉)
Département de Mathématiques et Génie Industriel, École Polytechnique de Montréal,
C.P. 6079, succ. Centre-Ville, Montreal, QC, Canada H3C 3A7
e-mail: bruno.agard@polymtl.ca

X. Fournier
e-mail: xavier.fournier@polytechnique.org

Just-in-time production systems require the contractor and its suppliers to share some production information so that the suppliers are able to deliver the exact components at the exact moment for the exact product (car) directly on the contractor's production line. The contractor provides a car sequence that must be respected for all participants, otherwise the production line may stop!

The car sequencing problem has been largely studied in the past and it has first been introduced by Parrelo et al. (1986). Its objective is to find an initial production sequence for a car assembly line with three different workshops, see Fig. 1, with two types of constraints: grouping and spreading-out constraints.

The car sequencing problem is NP-hard because of these two antagonistic types of constraints (Kis 2004). The grouping constraints correspond to formation of batches, i.e. minimizing the number of tool changes in the body shop or tool changes and pipe purges in the paint shop (Lahmar et al. 2003). The spreading-out constraints occur in the assembly shop. They have been expressed in many different ways such as smoothing the workload on each workshop in the Product Rate Variation problem (Thomopoulos 1970; Kubiak 1993; Karabati and Sayin 2003), or keeping a constant rate of usage of products' parts in the Output Rate Variation problem (Miltenburg 1989; Kubiak 1993; Korkmazel and Meral 2001).

Bolat (1994) and Giard and Jeunet (2004) give a deeper view on possible approaches of the car sequencing problem. However, they all consider the sequence of products as a constant, whereas in several current assembly lines it can be modified along the line. Some disturbances can appear in workshops: a vehicle is put aside because of work defects, processes failures or parts shortage. It is subsequently reinserted in the line once the problem has been fixed.

Local sequencing is a response to such sequence's changes within the line. It introduces permutations in buffer stocks before each workshop (Guerre-Chaley et al. 1995). Instead of determining the production sequence before the entry in the line, local sequencing enables to improve the response to the constraints presented above. It has been largely developed by Baratou (1998) and Bernier (2000), see Fig. 2.

Fig. 1 The three workshops considered in the car sequencing problem

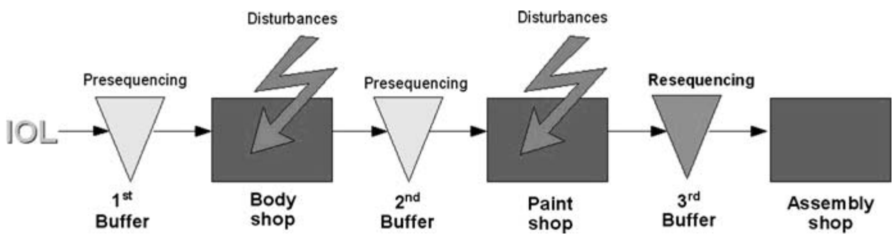

Fig. 2 The resequencing problem

An Initial Orders List (IOL), determined by satisfaction of the assembly shop's constraints, is initially sequenced by a first buffer stock in order to form batches of same bodyshell. This local sequencing is called *presequencing*. The second presequencing before the paint shop forms batches of same color. These two first buffers try to satisfy the grouping constraints presented above.

As the IOL is given to suppliers at the entry of the assembly line, the third buffer tries to regain it to satisfy the assembly shop's constraints and the synchronous transfer. It is called *resequencing*.

Baratou (1998) develops buffer management policies in this context so as to prioritize vehicles to be sent to the next workshop. While defining the resequencing objective in terms of respect of the IOL along the line (Bernier 2000) has also implanted his findings on a real production line and presented a well-chosen performance measurement system.

Inman and Schmeling (2003) propose to decouple orders from physical vehicles. An algorithm is also presented for scheduling and matching customer orders to vehicles. This method proves to reduce paint purges, spacing violations, material usage unlevelness, and worst-case lead-time via simulation. The same idea of decoupling is present in the presented research.

More recently, Gusikhim et al. (2007) proposed an heuristic to improve the number of in-sequence parts (called service level) for a fixed size of the resequencing buffer and to reduce the size of the resequencing buffer for a fixed service level. This heuristic is based on the frequency of occurrence of different parts to be assembled.

In order to improve the flexibility in the sequence along the line, the idea of inserting postponement in a simulated resequencing problem is introduced. Postponement is to delay as much as possible the moment when two different products have to be considered as different.

This principle has been first presented by Alderson (1950). van Hoek (2001) identified different types of postponement, but only form postponement is our concern here. It consists of delaying one or several stages of production until an order has been received and it can intervene in product design (Swaminathan and Tayur 1999; Ramdas and Randall 2004). Benefits of postponement as well as supplier relations are discussed in Krajewski et al. (2004). van Hoek (2001) and Yang and Burns (2001) also give a detailed classification of articles on the subject and suggest future research.

Assembly characteristics for each car are assigned at the beginning of the line. At this level only body and paint characteristics are necessary. At the exit of the paint shop, two cars with the same bodyshell and the same paint color are identical, even if some assembly characteristics may differ. The point of differentiation is implemented here by swapping orders of two vehicles whose order of precedence changed. This can happen when both have the same bodyshell and the same paint color but not necessarily the same assembly characteristics. Cars are not materially swapped; an order corresponding to an owner, it is as if the two vehicles have swapped their owners.

The method to proceed to this swap is presented here. It enables to consider the whole portion of the production list before the point of differentiation, see Fig. 3.

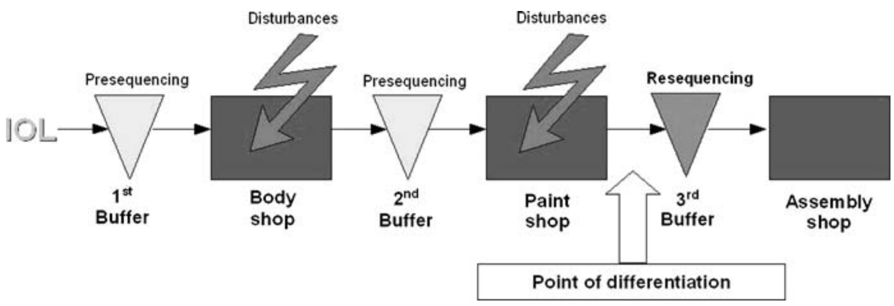

Fig. 3 Modeling of the production chain with a point of differentiation

Let us give an example, Fig. 4. When a vehicle exits the paint shop, the swap seeks every other vehicle that has not passed yet and has the same bodyshell, the same paint color and a lower initial position. This last quality means that the orders of precedence between the vehicle to be inserted have changed. In the example, the car number 8 (that should in the 8th position) overpassed the cars number 3, 4, 5, 6, and 7. The algorithm then swaps the car number 8 with the car that is the most late (number 3).

This idea of using the postponement principle in the resequencing problem gave rise to a first article (Fournier and Agard 2007). Considering direct access to the three buffer stocks of fixed capacity, improvement of resequencing by postponement was proven to be undeniable.

The goal of this article is to implement different stock management policies in the model and a second point of differentiation, in order to determine the relevant parameters and to quantify improvement brought by postponement for different values of those parameters.

The plan of this paper is as follows, in Sect. 2, the model on which this study is based is presented, the performance indicators are proposed and the relevant variables are determined. Section 3 refines postponement as well as stock structures and stock management policies. It finally presents a design of experiments and tries to obtain a deeper insight on improvement brought by postponement.

2 Problem modelling

This section aims at presenting a pertinent model and determining the influent parameters. It recalls the construction of the initial sequence, the performance

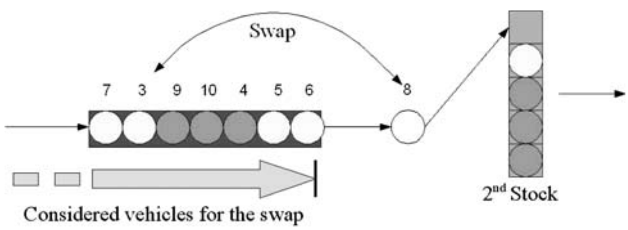

Fig. 4 Example of a swap of vehicle orders

Table 1 Example of the beginning of an Initial Orders List

Initial position	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bodyshell	6	3	7	1	5	8	9	2	10	4	3	8	1	5
Paint color	10	4	1	6	7	3	2	9	8	5	3	6	2	9

measurement system and the modelling of the disturbances in Sects. 2.1, 2.2, and 2.3, respectively. Stock structure, stock management policy and postponement are also presented in Sects. 2.4, 2.5, and 2.6, respectively.

2.1 Initial sequence

The resequencing problem is shown in Fig. 2. The Initial Orders List (IOL) is supposed to satisfy the assembly shop's constraints. It considers 20,000 vehicles with ten potential bodyshells and ten potential colors, randomly determined. It is represented by a list with 20,000 columns and 3 lines, Table 1. The three lines correspond to the initial position in the IOL, the bodyshell and the paint color. The latter two characteristics are assumed to be mutually independent and independent from the assembly characteristics. As the third stock does not presequence for the assembly shop but tries to regain the IOL, these latter characteristics don't interfere here.

2.2 Performance measurement

The performance measurement system consists of four indicators: the maximal lateness at 95% (ML), corresponding to the maximal lateness of the 95% of vehicles the less late, the maximal earliness at 95% (ME), the cumulative lateness at 95% (CL) and the cumulative earliness at 95% (CE), trivially understandable considering the first indicator. Earliness and lateness are computed by comparing initial position in the IOL and actual position of the car in the line. If a car whose actual position is 25 was initially in position 20 in the IOL, it is consider 5 places of lateness (25–20). Cars with negative lateness are then in advance.

The percentage 95% permits to avoid pathological cases that may occur in real cases. In practice it is to prevent bad values that come from special requirements such as police cars or ambulances. Those special products require special operations. In fact those cars are removed from the line for special requirements and go back in the line later. Those cars may have greater delay in the sequence and are not specifically considered in the resequencing.

2.3 Workshops modelling

The disturbances in workshops are modeled by column permutations whose distributions are similar to disturbances observed on a real production plan, Fig. 5. Each distribution is modeled as a weighted sum of two gaussian functions.

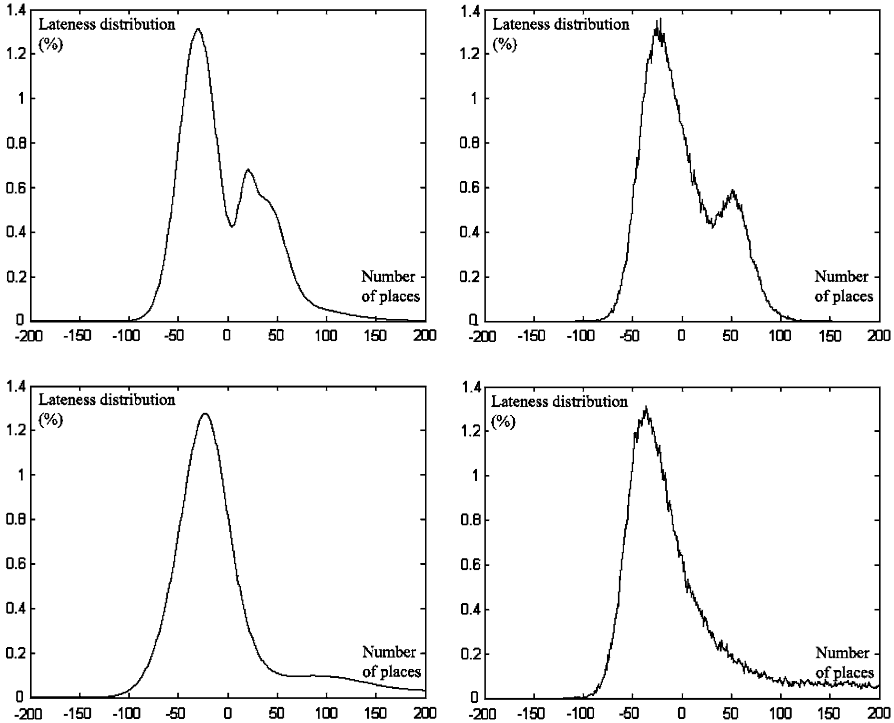

Fig. 5 Comparison of the distribution of lateness and earliness observed on a real production line (Bernier 2000, left figures) and the results of the modeling here (right figures) in the body shop (up figures) and the paint shop (down figures)

The distributions of perturbations presented in Fig. 5 do not allow any car to wait more than 90 cars in the body shop and 125 cars in the paint shop.

2.4 Stocks structure

Formerly, any vehicle from the stock could have been sent to the next workshop. The stock was then said to have a direct access. However, there exists another possibility where the stocks can be made of drawers. Each drawer's policy is first in first out. Only the first element of a drawer can be sent downstream, see Fig. 6.

If the number of drawers equals the capacity of the stock, its access is direct. So the structure is completely represented by the number of drawers. As a result, two interesting parameters are left for each stock: its global capacity and its number of drawers.

2.5 Stocks management policies

The structure is not a complete way to define a stock because it is also necessary to determine the best stock management policy. First of all, in each stock there is a

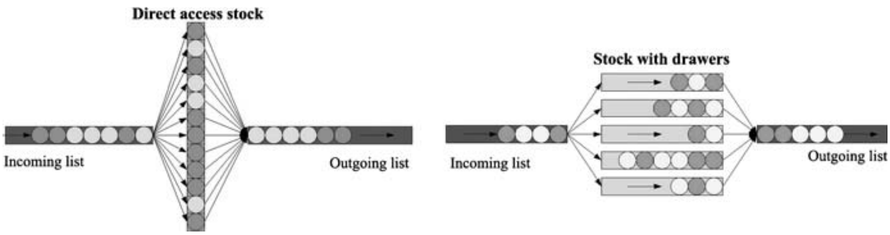

Fig. 6 The two kinds of management policies: direct access (left) and drawers (right)

warming-up period during which the stock is filled in (the vehicles are then inserted in the first less filled drawer).

The input rate is assumed constant, hence as a vehicle gets out of the stock, another one gets in (at the same place for direct access or in the same drawer in the other case). The stock remains full as long as the incoming list is not empty, as a result there is no need for insertion policies in the stock. Therefore an exit policy is still necessary as much for presequencing as for resequencing. It will be discussed in Sect. 3.1.

Finally, the stock is emptied during a cooling-down period. Considering the size of the list, the effects of the warming-up and cooling-down periods of the buffer modelling will be considered as negligible.

2.6 Postponement

In Fournier and Agard (2007), one point of differentiation is introduced between the paint shop and the third buffer stock. Cars with the same color and bodyshell can swap their orders if their precedence relation is not the initial one. So as to better reduce lateness and earliness of vehicles, it is possible to introduce a second point of differentiation between the body shop and the second stock. Cars with the same bodyshell can swap their orders if their precedence relation has changed. It is as if the paint colors were determined at this first point of differentiation and the assembly characteristics at the second point of differentiation formally introduced. See Fig. 7.

The introduction of each point of differentiation has an influence on the performance in the line, see Sect. 3.2. Consequently, each point of differentiation will be considered as a parameter of the model.

2.7 Parameters to investigate

The exposed model presents more flexibility. Different parameters show a noteworthy influence on the performance indicators:

- the size of the three stocks, respectively s_1, s_2, and s_3,
- their number of drawers, respectively d_1, d_2, and d_3, respectively divisors of s_1, s_2, and s_3,

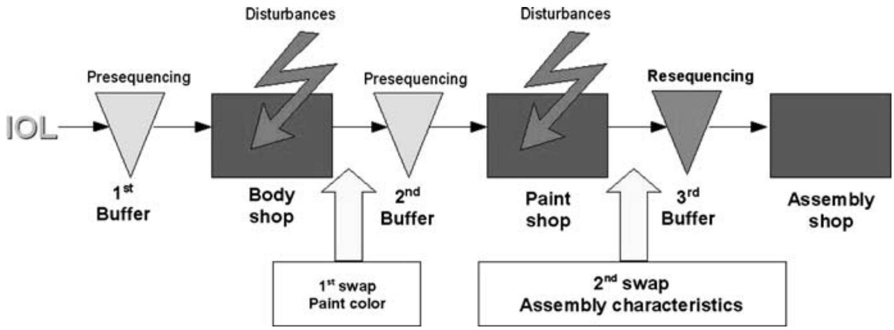

Fig. 7 Modeling of the production chain with two points of differentiation, relatively to the paint color and the assembly characteristics

- the stocks exit policies,
- the use of postponement at the first point of differentiation, p_1, or at the second, p_2.

With various values of these parameters, simulations can now be done, so as to define the best configuration for all the system. Section 3 is going to respond to this issue.

3 Simulations

This section aims at refining the presented model above and having a closer look at the influence of postponement. It will first evaluate the best stock exit policy to be used below, Sect. 3.1, followed by the influence of postponement which is proved in Sect. 3.2. A design of experiment is finally conducted for the remaining parameters to be examined, Sect. 3.3.

3.1 Stock management policies

3.1.1 Presequencing

The first buffer tries to form batches of same bodyshell. It must determine the best batch to be sent downstream. For direct access, Fournier (2006) showed that the best management policy was to select the batch with the biggest mean lateness. In the drawers case, the situation is more complex because a vehicle can be in a batch only if it is the first of his drawer or if the vehicles before him in the same drawer have the same bodyshell. Four sorting rules are compared here. R_1 and R_2 are defined by choosing the biggest batch that is found. If there are several, R_1 chooses any of them whereas R_2 chooses the one with the greatest sum of lateness. R_3 considers the biggest mean lateness and R_4 the biggest cumulative lateness. The flexibility of drawers being limited, it is not necessary to consider more restrictive sorting rules. Twenty production sequences are evaluated after the first buffer. The

Table 2 Comparison of different sorting rules of presequencing in the first buffer stock with ten drawers of five places. Mean results on twenty simulations (number of places and number of batches)

Rule	R_1	R_2	R_3	R_4
CL	145034	122244	13634	3074
CE	−179728	−148530	−10303	−765
ML	80.2	61.4	7.6	5.5
ME	−35.0	−32.3	−8.4	−2.3
Batches	6862	6777	17285	19382

mean values of the performance indicators are presented in Table 2 for ten drawers of five places.

The results show that there is a large difference in the number of batches formed with the different sorting rules. Sorting rules R_3 and R_4 are excluded because the number of batches is important and it may require much more settings in order to operate on the production line. It can also be seen that R_2 gives better results than R_1 on every performance indicator. The results are similar with five drawers of ten places. The sorting rule R_2 will then be used in the case of stock with drawers.

Bodyshell and paint color characteristics have been assumed independent. The situation in the second buffer stock is then exactly the same as that in the first buffer (the paint color is considered instead of the bodyshell). In case of direct access, the sorting rule is to choose the batch of same color with the biggest mean lateness. In case of drawers, it is the biggest batch that will be selected. If there are several batches the one with the maximum sum of lateness will be concerned.

3.1.2 Resequencing

In case of direct access, resequencing is very simple. The latest vehicle in the stock is to be sent to the assembly shop. In case of drawers it is a more complicated process and a criterion of selection must be assessed. It consists of affecting a penalty to each drawer and the first vehicle of the drawer with the highest penalty will be chosen. There are two possibilities, on the one hand, the penalty P_1 is the lateness of the first vehicle of the drawer, and on the other hand, P_2 is the mean lateness in the drawer. Twenty production sequences are simulated before the third buffer. They are then resequenced with the two penalties and the mean values of the performance indicators on the final sequences are shown in Table 3.

The second penalty brings great improvement in cumulative indicators and in maximal lateness at 95%. But the results are not better for maximal earliness at

Table 3 Comparison of the two different penalties of resequencing in the third buffer stock with ten drawers of five places. Mean results on twenty simulations (number of places)

Penalty	P_1	P_2	Improvement (%)
CL	610631	527071	13.7
CE	−673618	−553050	17.9
ML	239.6	197.6	17.6
ME	−110	−142.0	−28.2

95%. The situation is similar with five drawers of ten places. We will assume here that improvement on cumulative indicators is more relevant than on maximal earliness at 95%. Therefore the second type of penalty prevails. P_2 is retained for the below simulations.

3.2 Postponement

At a first glance of the influence of postponement, the lateness distribution before the assembly shop is represented in Fig. 8 for direct access to stocks. Lateness distribution represents the percentage of cars that move a certain number of places from their expected position. Because lateness distributions are presented, negative values are for vehicles in advance. The capacity is 150 places for the two first stocks and 100 for the resequencing stock. Four cases are considered: without swap (a), with only the first swap (b), with only the second swap (c) and with both swaps (d).

It appears that each individual swap (Fig. 8b, c) improves both earliness and lateness. Besides the influence of the first swap is slight but quite visible (Fig. 8b) on earliness (as negative lateness). The second point of differentiation itself generates higher improvement (Fig. 8c). The reason why this second point of differentiation is much more efficient is because it is closer to the assembly shop where the lateness is evaluated. It allows to consider the perturbations that come

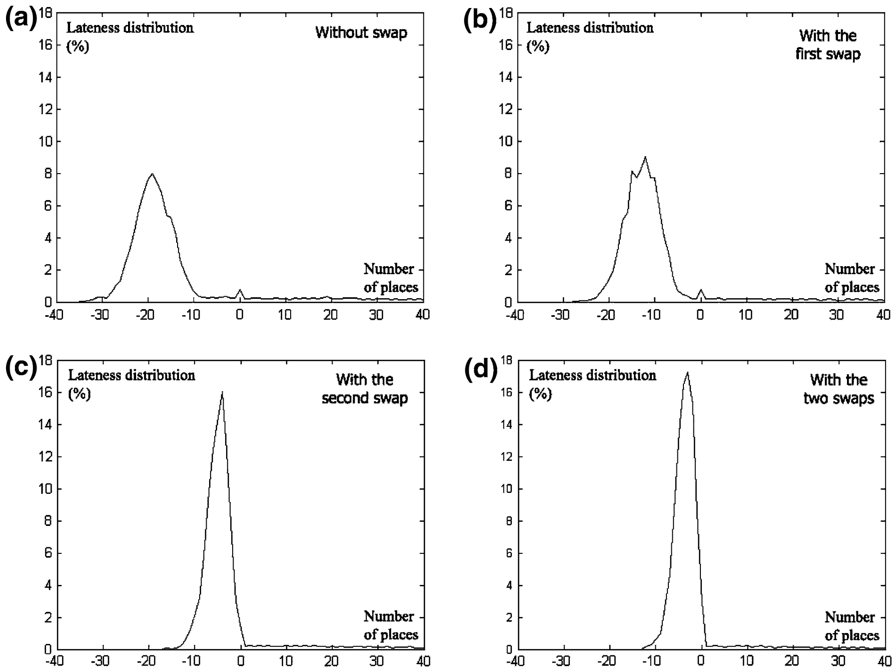

Fig. 8 Distribution (%) of lateness (positives) and earliness (negatives) in number of places along the line with or without postponement. Direct access to the stocks

from the bodyshop and the paintshop in the same time. The improvement of only the first swap is diminished with the perturbations that come from the paintshop.

Figure 8d shows improvement on earliness when both swaps are introduced simultaneously. Highest improvement seems to be brought by the introduction of two points of differentiation at the same time. However the difference in improvement from the second swap is not that big. Thanks to this example it is possible to see that the introduction of postponement interferes in the performance of the line.

As a conclusion from these first simulations, eight pertinent parameters are retained:

- the size of the three stocks, s_1, s_2, and s_3,
- their number of drawers, d_1, d_2, and d_3,
- the use of postponement, p_1 and p_2.

Section 3.3 considers all of them in the simulations.

3.3 Design of experiments

Because of the cost in computing time and the number of parameters, it is not possible to be exhaustive and to give many different values to the parameters. In addition, it is paramount to minimize the number of simulations to search for more pertinent results on the influence of postponement. For that matter, this section develops a design of experiments.

With so many parameters with three different numbers of modes, designs are searched empirically. Three modes are chosen for three numbers of drawers: $(d_i \in \{5,10,s_i\})_{i\in\{1,2,3\}}$ (there will have 5 drawers, 10 drawers and a direct access stock—when $d_i = s_i$), and two modes for postponement $(p_i \in \{0,1\})_{i \in \{1,2\}}$ (p_i equals 1 if postponement is used at the ith point of differentiation, and 0 otherwise). For the three capacities, a multiple of the other numbers of modes, two and three, would make it easier to find a little number of experiments to conduct. Hence, the best design is found by choosing nine modes for the three capacities $(s_i \in \{20,30,40,50,70,90,110,130,150\})_{i\in\{1,2,3\}}$. It reduces the number of simulations and enables to evaluate more modes than choosing six modes.

The selected design is made of 324 experiments (instead of 78732) for an exhaustive experimentation and will be repeated ten times so as to obtain a better precision on the simulations. The total computing time reaches about 2 weeks with a Intel Pentium M Centring 1,500 MHZ, 512Mo Ram with Matlab 7.0.

For each selected variable, experiments with each mode are isolated. The average values with the same mode are then calculated. Every indicator's evolution in function of every parameters can not be represented here. The most pertinent figures will be shown.

Firstly, the cumulative indicators are represented in function of the parameters of the third stock, Figs. 9 and 10.

As it makes more sense, the cumulative indicators have a tendency to be decreasing with the third stock capacity (Fig. 9) and flexibility (Fig. 10) (lateness

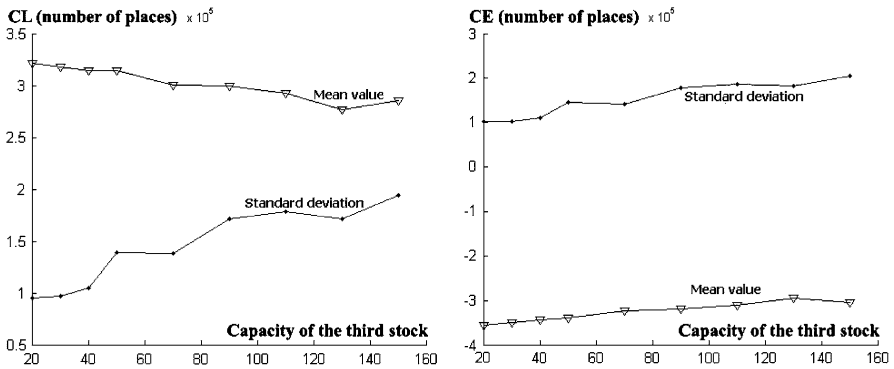

Fig. 9 Evolution of cumulative indicators in function of size of the third stock's capacity

are evaluated with positive values and earliness with negative values). They are improved by more than 54.93% in the direct access case compared to the cases with drawers, Fig. 10. It is similar with the two first stocks: the cumulative indicators are increasing with their capacity and flexibility. The behavior of maximal indicators is therefore indeterminable: their tendencies seem to be coherent with the above remarks but the uncertainty prevents to make a statement. In all cases standard deviation increases with the third stock flexibility. If a car lateness (or earliness) is above the capacity of improvement of the stock flexibility then it is corrected, otherwise the improvement is limited to the stock flexibility. With a higher flexibility, there is a more important deviation with the cars that are corrected and those that are not.

Secondly, the mean values for the two variables p_1 and p_2 are represented in Fig. 11 for each performance indicator with the respective standard deviation. This shows the influence of postponement from a general point of view in this model.

It is clear that each swap improves the mean maximum and cumulative lateness and earliness at 95% and the standard deviations associated. As previously mentioned, it is also possible to observe that relative improvement brought by the

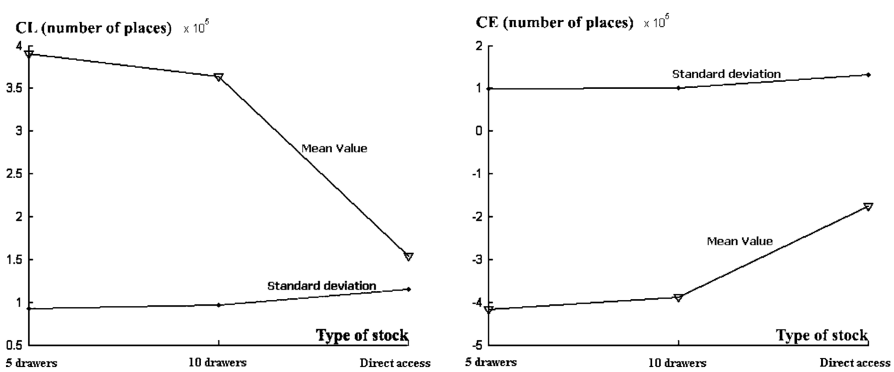

Fig. 10 Evolution of cumulative indicators in function of the third stock's type

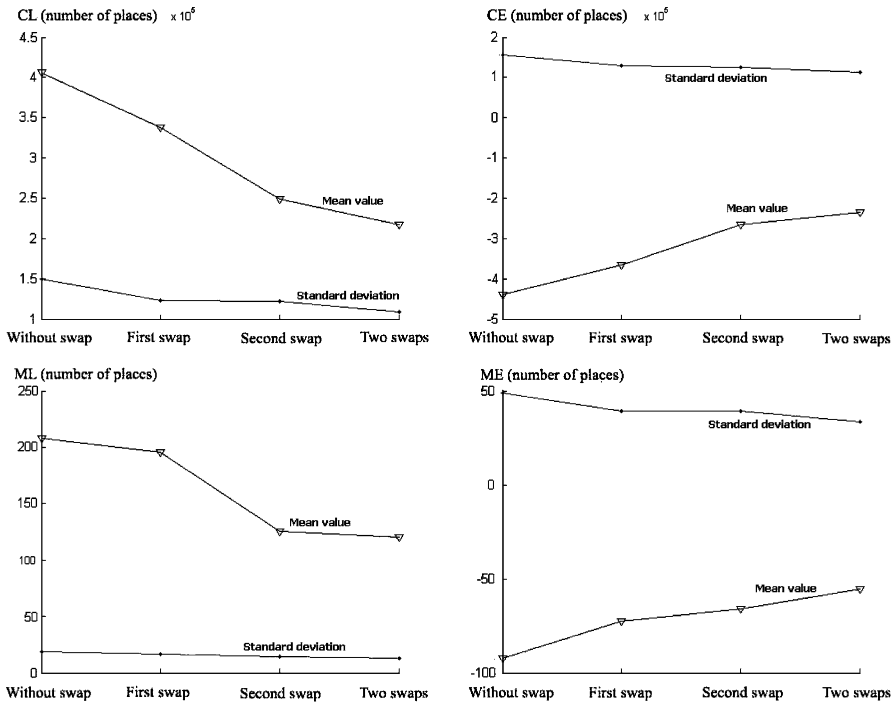

Fig. 11 Evolution of performance indicators in function of the use of postponement

second swap is much greater than by the first swap only. With the simultaneous use of both, the gain is situated between 39.70 and 46.55% on these mean values. It is indeed situated between 19.22 and 89.57% for every simulation. On top of that, it appears not to have any influence on the number of batches formed in the two first stocks, which is coherent with the assumption of independent characteristics.

Postponement is able to improve considerably the mean values of performance indicators as long as their standard deviation without disturbing the presequencing possibilities.

4 Conclusion

The paper addressed vehicle resequencing in automotive production. The production line consists of three main stages: bodyshop, paintshop, and assembly line. There is a buffer before each segment. Resequencing is implemented before each department, and achieved by a mechanism called postponement. The idea of postponement is to delay as much as possible points of differentiation. Points of differentiation are implemented here by swapping orders on partially completed assemblies. It is shown by simulation that the best results with respect to average and maximum lateness, respectively, are obtained when cars before the shops can be reordered to a greater extent.

In this research, a brief review of literature was presented followed by the introduction of the model and some developments made on stock structure and management policies. Two points of differentiation were inserted within the line. A design of experiments finally enabled to value average improvement brought by postponement to up to 39.70% on the chosen performance measurement system.

It is all the more interesting that it increases the flexibility of the production line and costs less than increasing the stock capacity or type of access. For example, if the third stock has drawers, given the improvement brought by postponement, it is highly profitable to minimize the number of drawers and introduce postponement. It might also be possible to find that replacing direct access by drawers in the third stock and introducing postponement does not decrease the performance of the assembly line. Consequently, postponement is indispensable in the resequencing problem for performance improvement.

The manufacturing of automotive was the motivation of the work. We may obtain similar results in any three stages of production with perturbations. However, evaluation of real improvements may be difficult to evaluate in a general case. Considering a real automotive production permitted to better evaluate real possible improvements.

Further research could be conducted on insertion policies in the stocks with different number of characteristics or without the latter's independence. Also, all characteristics do not have the same frequency of occurrence, this property could be included in the model for further improvements. It would also be a challenge to implement postponement on a real car assembly line.

References

Alderson W (1950) Marketing efficiency and the principle of postponement. Cost Profit Outlook 3

Baratou P (1998) Gestion réactive des stocks intermédiaires d'un flux de production automobile. Thèse de doctorat, Université des Sciences et Technologies de Lille. Laboratoire d'Automatique et Informatique Industrielle

Bernier V (2000) Sur une nouvelle politique de gestion des flux, le cadencement reséquentable. Thèse de doctorat, Institut National Polytechnique de Grenoble

Bolat A (1994) Sequencing jobs on an automobile assembly line: objectives and procedures. Int J Prod Res 32(5):1219–1236

Fournier X (2006) Cadencement reséquentable et différenciation retardée: analyse par simulation pour une chaene de production multi-produits. Master thesis, École Polytechnique de Montréal

Fournier X, Agard B (2007) Analyse par simulation d'une chaene de production automobile multi-produit avec différenciation retardée. 7e Congrès international de génie industriel, 5–8 juin 2007, Trois-Rivières, Québec, Canada

Giard V, Jeunet J (2004) Modélisation du problème général d'ordonnancement de véhicules sur une ligne de production et d'assemblage. Annales du LAMSADE 2:235–256

Guerre-Chaley F, Frein Y, Bouffard-Vercelli R (1995) An efficient procedure for solving a car sequencing problem. Proceedings of Emerging Technologies and Factory Automation 1995—ETFA'95, vol 2, pp 385–394

Gusikhim O, Caprihan R, Stecke K (To appear 2007) Least in-sequence probability heuristic for mixed-volume production lines. Int J Prod Res

Inman R, Schmeling DM (2003) Algorithm for agile assembling-to-order in the automotive industry. Int J Prod Res 41(16):3831–3848

Karabati S, Sayin S (2003) Assembly line balancing in a mixed-model sequencing environment with synchronous transfers. Eur J Oper Res 149:417–429

Kis T (2004) On the complexity of the car sequencing problem. Oper Res Lett 32:331–335
Korkmazel T, Meral S (2001) Bicriteria sequencing methods for the mixed-model assembly line in just-in-time production systems. Eur J Oper Res 131:188–207
Krajewski L, Wei J, Tang L-L (2004) Responding to schedule changes in build-to-order supply chains. J Oper Manage 23:452–469
Kubiak W (1993) Minimizing variation of production rate in just-in-time systems: a survey. Eur J Oper Res 66:259–271
Lahmar M, Ergan H, Benjaafar S (2003) Resequencing and feature assignement on an automated assemblyline. IEEE Trans Robotics Autom 19(1):89–102
Miltenburg J (1989) Level schedules for mixed-model assembly lines in just-in-time production systems. Manage Sci 35:192–207
Parrelo B, Kabat W, Wos L (1986) Jop-shop scheduling using automated reasoning: a case study of the car-sequencing problem. J Autom Reason 2:1–42
Ramdas K, Randall T (2004) The impact of component sharing on product quality: an empirical study in the automotive industry. Darden, University of Virginia
Swaminathan J, Tayur S (1999) Managing design of assembly sequences for product lines that delay product differentiation. IIE Trans 31:1015–1026
Thomopoulos N (1970) Mixed-model balancing with smoothed station assignments. Manage Sci 14B: 59–75
van Hoek R (2001) The rediscovery of postponement a literature review and directions for research. J Oper Manage 19:161–184
Womack J, Jones D, Roos D (1991) The machine that changed the World: the story of lean production. Harper Perennial, New York, NY
Yang B, Burns N (2001) A conceptual framework of postponed manufacturing and its impact on global performance. Global integration (the symposium proceedings), pp 177–185

Xavier Fournier was student in a Master of Applied Science in Industrial Engineering—productics—in Ecole Polytechnique de Montréal, Québec, Canada. He graduated from Ecole Polytechnique, France (2004). He is now working in Supply Chain Transformation in the Manufacturing, Distribution & Retail branch of Capgemini Consulting, Paris, France.

Bruno Agard is Assistant Professor in Industrial Engineering at the École Polytechnique de Montréal, Québec, Canada. He graduated in Manufacturing from École Normale Supérieure de Cachan (1998). He received his Ph.D. in Industrial Engineering (2002) from the Institut National Polytechnique de Grenoble, France. He is interested in design of products, processes, and logistics and in applications of data mining in engineering.