International Conference on Industrial Engineering and Systems Management
IESM 2005, May 16 – 19, Marrakech (Morocco)

Multicriteria approach to rank scheduling strategies

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Abstract

This paper deals with multicriteria decision-making applied to discrete-continuous scheduling problems. The need for reusability and modularity leads us to build a "generic" optimization and simulation framework, while the need to quickly generate good compromises between conflicting objectives requires the implementation of multicriteria scheduling models. This paper describes the practical possibilities of two hybrid models within this framework, the first one uses a lexicographical sort and the second one a multicriteria method to rank scheduling strategies.

Keyword

Multicriteria decision-making, optimization, simulation, scheduling, performance improvement

1. Introduction

In the particular context of discrete or discrete-continuous production processes organized as generalized jobshops, we are developing a "generic" framework for the optimization and simulation of real-life multicriteria planning and scheduling problems [3]. When considering these problems, it clearly appears that exact methods are limited in the size of the problems they can handle because of their time/space requirements. The selected method must be able to overcome the "difficulty" of accurately simulating the details of the functioning of real-life problems in a reasonable amount of time. Consequently, our framework is based on several hybrid models combining a simulator with several optimizations tools. The scheduling unit comprises a set of widely used dispatching rules such as Shortest Processing Time [3], as well as dedicated dispatching rules. The simulation model is used to capture all the details of the functioning of real-life problems. Considering discrete-continuous processes, two approaches have been investigated in our framework. According to its complexity, the "continuous part" of the problem is either directly embedded in the simulation model using simple mathematical functions, or modeled using a hybridization of our simulator with an external solver dedicated to this continuous part. Concerning the optimization aspects of the problem, our work aims at assessing which solving tools are useful in the context of real-life problems [4,5,6,9]. In this paper, we will focus on dispatching rules as simple methods to be hybridized with our simulation model and a multicriteria method. In many applications it has been shown that even simple methods can improve the efficiency of the solution obtained from simple isolated algorithms. We are perfectly aware that, when it comes to assessing the solutions found by these methods, there are some limitations in the theoretical results. However, an argument for these hybrid methods is the need for reactivity. Indeed, in considering real-life problems, the speed of decision-making can be crucial in the context of present-day

competitiveness. An "effective" solution is not necessarily an optimal solution but rather a "*good*" solution obtained in a small amount of time.
In comparison with "*academic*" problems (see *flowshop*, *jobshop*, *openshop* instances available via the *OR-library* for example [11]), considering actual industrial problems needs to make additional efforts from the point of view of research and development which are capitalized in our framework. These efforts aim at balancing the need to adapt and customize the optimization method to the problem under consideration (so as to obtain *efficient* tools), and the need to cover a wide spectrum of problems (so as to obtain *generic* tools). Moreover, our framework provides us with an environment to be used as a test-bed for comparing the performance of different multicriteria scheduling strategies and select the most suitable strategy to the *context*. This context might notably take the economic context into account as well as the important/high demand variations. Each scheduling strategy is composed of two stages: a dispatching rule followed by a simulation. The first stage computes an initial solution. The second one converts this solution into a list of scheduled orders and a set of related performance measures.
When tackling real-life problems, the objective is rarely to optimize one criterion or to find a global optimum. In most cases the objective is to balance criteria so as to generate a good compromise between conflicting criteria. This leads us to embed a multicriteria method in our framework so as to rank the scheduling strategies.
This study synthesizes the results of this application of the framework to a real-life, highly constrained, discrete-continuous problem. A lot of additional constraints make this problem harder in terms of modeling, optimization and simulation. These include: the heterogeneity of the machines, the consideration of several kinds of setups and the inclusion of auxiliary resources management. Thus, in addition to the hybridization of several methods derived from different fields (modeling, optimization, simulation and performance), one of the original aspects of our work is that we take into account auxiliary resources. Another original aspect of our work is that we have developed an accurate simulation model as well as a diversified set of performance measures and a set of scheduling strategies available through our framework.
It should be mentioned that our framework is able to integrate various optimization tools such as meta-heuristics or exact methods in order to optimize the scheduling and/or the planning part of a real-life problem. However, we focus our description on the hybridization of a simulation model and the multicriteria method while comparing several scheduling strategies.
The rest of this paper is organized as follows. In Section 2 we present our framework. In Section 3, we describe the industrial problem. In Section 4, we set out the results of our analysis. Finally, in Section 5 we present our conclusions and discuss some issues arising from this work.

2. The *PlanOrdo* framework

PlanOrdo is a "*generic*" framework for optimization and simulation of discrete or discrete-continuous planning and scheduling problems. In the project described here, the field of research is generalized jobshop planning and scheduling problems (as defined in Section 3). Using a divide-and-conquer paradigm, our framework is based on a model composed of several cooperating sub-models: at least one of them is dedicated to simulation and another one deals with the optimization aspects of the whole problem.

2.1 Description

Our framework uses several concepts derived from software engineering in order to build reusable modularized tools exchanging data via a common database. Thus, decision-makers are provided with a versatile application, which aims at taking advantage of combining complementary tools so as to obtain a multicriteria decision-making framework as comprehensive, accurate and robust/reliable as possible.

The graphical user interface of PlanOrdo controls several units. The main units that constitute our hybrid models are briefly described below. The scheduling unit comprises a set of widely used dispatching rules (such as Shortest Processing Time) and some dedicated rules. These rules are not only quick and easy to implement, to control and to run, but also easy to explain to workers. Another advantage is that these rules apply to a wide range of scheduling problems. Major drawbacks are that they do not always produce good results, and they are not stable when the variation of some parameters (such as the load of the simulated process) is considered [3,10]. To tackle this problem and increase the robustness of dispatching-rule-generated solutions, the optimization unit might be used to enhance the schedules. This unit might include several tools. It is reduced to a simple sorter (according to minimized/maximized criteria) when focusing our study on dispatching rules, but it might also be replaced by efficient optimization methods (meta-heuristics or exact-methods) when needed [4,5]. The performance measure unit is able to generate a lot of statistics such as reports and Gantt diagrams. Several links to external spreadsheets and data plotting programs exist in order to extend this unit. Thanks to its interface units, PlanOrdo is independent of the underlying tools (databases, …). The simulation model is based on the RAO simulator [1]. When considering the *complexity* of the functioning of industrial problems, the use of a simulation model is fully justified since there is no accurate and fast analytical function/model for this kind of real-life problems.

Acting as a toolbox, several units of PlanOrdo can be assembled so as to implement a wide range of hybrid methods based on various models.

2.2 Description of the hybrid models

This paper focuses on two hybrid models: the first one, *Hybrid 1*, is based on a lexicographical sort so as to simultaneously take into account several criteria; the second one, *Hybrid 2*, embeds a multicriteria method. These hybrid models are composed of a set of dispatching rules and a simulation model. These models are used to compare various dispatching rules according to a set of performance measures. These rules work by sorting orders/products according to predefined sorting keys (based on the processing time of orders for example). Starting from simple dispatching rules, such as SPT (Shortest Processing Time) and LPT (Longest Processing Time), these rules have been combined to obtain a set of accurate experimental dispatching rules. Each dispatching rule computes an initial solution to be sent to the simulation model. In our implementation, an initial solution is a permutation of integers representing the ranking of each shop-order to be produced by our simulation model. The simulation model generates a final solution composed of a list of scheduled orders and a set of related performance measures. To reduce the size of the detailed results, nine representative dispatching rules have been selected from the set of available rules.

In the remainder of this paper, a dispatching rule followed by a simulation is called a *scheduling strategy*. The results of several scheduling strategies are compared to decision-makers' choices. In most cases, PlanOrdo obtained better results than those generated by the human planner.

The lexicographical sort embedded in the Hybrid 1 needs to strictly rank the criteria to be optimized according to their relative importance. However this is neither easy nor realistic when considering underlying real-life problems. In reality, when comparing two scheduling strategies, a decision-maker often accepts a solution that is worse from the point of view of the main criterion if this solution leads to significant improvements in most of the other criteria. The classification of strategies by several criteria is not evident. Moreover, when generalizing the evaluation of the cost of the scheduling strategies, it might be interesting to consider – at least – two criteria which have the same importance. The best way to achieve this goal is to incorporate a multicriteria method into our second hybrid model, Hybrid 2. Consequently this hybrid is composed of a set of dispatching rules, a simulation model and a multicriteria method. This method is used to compare and rank solutions according to selected criteria (as expected by the decision-makers). A particular version of these multicriteria methods, Promethee II[1] is used to rank the nine presented scheduling strategies in decreasing order of preference. It provides a complete ranking based on pairwise comparisons of alternatives according to the decision-maker's preferences. These preferences are expressed in terms of a set of weights reflecting the relative importance of criteria. A preference function is also associated to each criterion. Obviously the Promethee ranking is influenced by the weights allocated to the criteria. Fortunately, Promethee II is robust towards the values of its parameters provided that the weights are in the interval of stability [2]. However, it is not the purpose of this paper to explain the Promethee methodology in detail [2,8].
Previous work on the integration of Promethee II into several tools has already been published, but to the best of our knowledge this is the first time that a hybrid model, including the simulation and the optimization of the scheduling of an actual highly constrained discrete-continuous problem and Promethee II, is presented.
Having now defined the scope and the structure of our framework, we will describe the industrial problem at Fontainunion below.

3. The industrial problem

The validation of our approach is performed on the Fontainunion plant (in Fontaine-Lévêque, Belgium). This plant produces high quality steel wires and strands that are used in pre-stressed concrete and major civil engineering projects (such as oilrigs, bridges, airports, stadiums and hotels) all over the world. This plant is organized as a *generalized jobshop* composed of seventeen machines (see Figure 1).

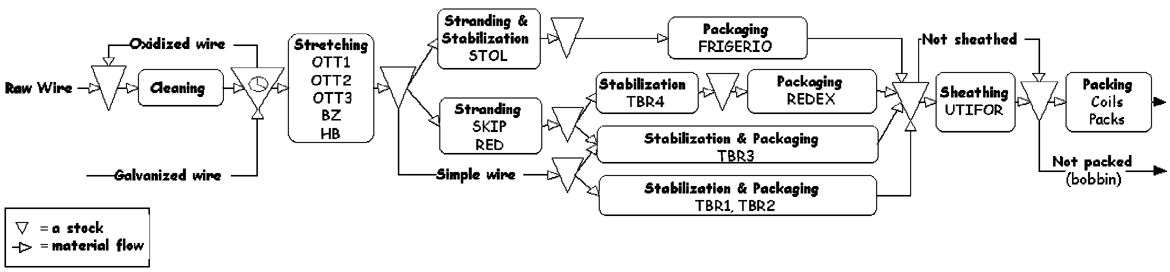

Figure 1. Description of the Fontainunion process.

In a *jobshop* organization, every job has its own predefined route (*i.e.* it is processed on machines in a specified order which may differ from that of other jobs). In a *simple jobshop* [3,7], each job has a single route and there is exactly one machine per stage. A *generalized jobshop* is a jobshop where at least one stage is composed of more than one

[1] There is a good URL dealing with Promethee: http://www.promethee-gaia.com.

machine and/or where at least one product may follow more than one route. At Fontainunion, the shop comprises seven stages (sets of machines): cleaning, stretching, stranding, stabilization, packaging, sheathing, and packing. In the process being studied, continuous and discrete operations are linked thanks to soldering and cutting operations in order to store semi-finished products on bobbins. Thus, stretching, stranding and stabilization are continuous operations. This continuous part of the problem is easily modeled by simple mathematical equations. Thus it is possible to formulate the whole problem (*i.e.* discrete and continuous parts) using our RAO discrete-event simulator.
Each product is composed of a sequence of operations that must be scheduled with respect to resource and precedence constraints. The resource constraints include input/output limitations, setups, and pre-emption (an operation cannot be stopped to start another one). The precedence constraints state that no operation can begin before the end of all the preceding operations. The duration of an operation depends on both the product and the chosen machine. The production of the shop is not cyclic, demand variations from one month to another are important. In this make-to-order process, several kinds of setup are considered (sequence-dependent, sequence-independent and weight-proportional setups). A lot of additional constraints make this problem harder. These include: the use of bobbins (supporting products); maximum/minimum input/output diameter and maximum input/output load; not all kinds of bobbins are compatible with all machines; not all lines are able to make all products or perform packaging; some orders cannot be late (due to severe external transportation constraints for instance). The simulation model must cope with ruptures of wire and other malfunctioning aspects. A scheduling strategy should avoid lack of bobbins; otherwise this might jeopardize the production plans. Moreover, when looking at the flexibility of lines, the strategy should keep empty bobbins – as far as possible – so as to be able to cope with uneven demand. Holding costs and internal transport problems are not included because they have no significant impact on the studied process. Workers are shared among three eight-hours shifts so as to produce 24 hours a day except during weekends (eleven workers are affected to each shift). It is noteworthy that the finalization of the simulation model including all the abovementioned constraints required more than one year. However, we have established an iterative enhance-and-optimize process in order to quickly compare the results of the simulation model to the actual production system, each cycle of this process provides us with more and more accurate simulation models. The current version of the simulation model comprises several optimizations at various levels (aggregation mechanisms, auxiliary resources handling…) that are out of the scope of this paper.
In the remainder of this paper, the results of nine scheduling strategies are presented. In order to compare and rank several scheduling strategies on the basis of a certain number of conflicting criteria, PlanOrdo uses the Promethee II multicriteria method.

4. Comparisons of scheduling strategies

In accordance with the confidentiality agreements for this project, no direct or detailed comparisons between the simulations and reality are presented.
In this paper, the performances of two hybrids are compared on the same period. On this period, one simulation takes three to six seconds on a Pentium IV 1.5GHz, the exact time depending on the number of orders in the period and the kind of statistics computed during the simulation.
The objective of this section is twofold: the first step is to experimentally show that Hybrid 2, which embeds the Promethee II multicriteria method, is able to obtain – at least – same result as Hybrid 1, which embeds a lexicographical sort. The second step is to show the

adaptability of Hybrid 2, which is able to incorporate gradation, tinge and fuzziness into the judgment of decision-makers while ranking scheduling strategies.

The results of the use of the two hybrid models implemented in PlanOrdo where 134 orders are simulated in a period of one month are synthesized in several tables. Each table contains a ranking of the scheduling strategies, where the quality of a solution is measured in terms of five criteria[2]:

1. minimize N_T, the number of tardy jobs;
2. minimize T, the average tardiness;
3. minimize C_{max}, the makespan;
4. maximize E, the average earliness;
5. minimize B, the duration of lacks of bobbins.

The ranking is obtained by a lexicographical sort when using Hybrid1; it is also computed by Promethee II when using Hybrid 2.

According to the decision makers, the criteria 1 to 4 must be considered in this order (from the most important to the less important). The criterion 5 must be weighted so as to be less important than the criterion 2. These constraints are denoted by the following relations: $N_T > T > C_{max} > E$ and $T > B$.

Next paragraphs present the evaluation of the different feasible configurations of the weights assigned to criteria using either Hybrid 1 when criteria are strictly ranked, or Hybrid 2 otherwise. This leads to the notations:

- Hybrid 1.1 stands for configuration $N_T > T > C_{max} > E > B$ applied to Hybrid 1;
- Hybrid 1.2 stands for configuration $N_T > T > C_{max} > B > E$ applied to Hybrid 1;
- Hybrid 1.3 stands for configuration $N_T > T > B > C_{max} > E$ applied to Hybrid 1;
- Hybrid 2.1 stands for configuration $N_T > T > C_{max} > E = B$ applied to Hybrid 2;
- Hybrid 2.2 stands for configuration $N_T > T > C_{max} = B > E$ applied to Hybrid 2.

In this notation, $E = B$ means that the decision-maker attaches the same importance to criteria E and B. The values of criteria T, C_{max}, E and B are expressed in hours. It is noteworthy that there are no late orders (N_T and T are equal to zero) in best solutions given by our hybrids. Consequently, we will not come back to the values of these criteria when analyzing the different rankings of the scheduling strategies.

4.1 Results of Hybrid1

The results of our first hybrid are compared with the real-life situation. In most cases, Hybrid1 is able to obtain results identical to, or better than, those generated by the human planner (in terms of delays, makespan and lack of bobbins).

Table 1. Ranking given by Hybrid 1.1 using configuration $N_T > T > C_{max} > E > B$

N°	N_T	T	C_{max}	E	B
1	***0***	***0***	***753,90***	***271,50***	***3,17***
2	0	0	757,71	277,40	1,11
6	0	0	757,71	277,15	1,09
3	0	0	760,17	256,84	3,14
7	0	0	760,17	256,83	3,15
4	2	17,65	749,77	287,42	0,52
8	3	23,09	750,80	288,62	0,40
9	4	17,08	754,08	259,82	2,93
5	6	10,55	756,68	266,57	3,33

[2] These criteria have been chosen according to decision makers, but PlanOrdo is not limited to them.

Table 1 compares the solutions provided by the Hybrid 1.1 for the selected period. The number of the dispatching rule that provided the initial solution for our simulation model identifies each solution. The best rule, according to the five predefined criteria, is highlighted.
For the selected period, configuration and criteria, the best scheduling strategy is the strategy 1. However, this strategy leads to a lack of bobbins during 3.17 hours, which causes a partial or total breakdown of the industrial process. In order to avoid this situation, we will assign an intermediate weight to *B*, between those related to C_{max} and *E*. Despite this, Hybrid 1.2 provides similar results as Hybrid 1.1. So we have increased the weight of *B* in Hybrid 1.3.
Table 2 compares the solutions provided by this Hybrid 1.3 for the selected period. The order of the columns of this table has been modified so as to reflect the ranking of the criteria related to the third configuration ($N_T > T > B > C_{max} > E$). When increasing the weight assigned to *B* again, so as to be greater than those assigned to C_{max} and *E*, the strategy 1 is now ranked fifth whereas the strategy 6 is the best one.

Table 2. Ranking given by Hybrid 1.3 using configuration $N_T > T > B > C_{max} > E$

N°	N_T	T	B	C_{max}	E
6	***0***	***0***	***1,09***	***757,71***	***277,15***
2	0	0	1,11	757,71	277,40
3	0	0	3,14	760,17	256,84
7	0	0	3,15	760,17	256,83
1	0	0	3,17	753,90	271,50
4	2	17,65	0,52	749,77	287,42
8	3	23,09	0,40	750,80	288,62
9	4	17,08	2,93	754,08	259,82
5	6	10,55	3,33	756,68	266,57

In comparison with the best strategy obtained by Hybrids 1.1 and 1.2, this configuration ($N_T > T > B > C_{max} > E$) has the following impact on criteria:

- 2.08 hours are gained in terms of duration of lacks of bobbins, *B*;
- 3.81 hours are lost in the working time, C_{max};
- 5.65 hours are gained in terms of average earliness of orders, *E*.

These results show that an improvement of the duration of lacks of bobbins *B* leads to a deterioration of the makespan C_{max}.

4.2 Results of Hybrid2

The results generated by Hybrid 1 perfectly illustrate the consequences of lexicographical sort: a small gain on a criterion may induce significant losses on other less weighted criteria. This problem results from the impossibility to introduce the gradations and fuzziness in the lexicographical sort. However this is neither easy nor realistic when considering underlying real-life problems. In reality, when comparing two scheduling strategies, a decision-maker often accepts a solution that is worse from the point of view of the main criterion if this solution leads to significant improvements in some (or all the) other criteria. Similarly, the simulator computes the schedules with a great accuracy whereas process times can vary by a significant factor when considering the production process (mainly due to workers' interactions). Consequently, it is more realistic to add a threshold on the criteria that are expressed in hours. In the Fontainunion process, this threshold is set to half an hour. Similarly, it is more realistic to add a "*pinch of fuzziness*" when comparing the values of several criteria in order to balance the impact of conflicting criteria. In the Fontainunion process, this *fuzziness* is set to two hours, except for the

average earliness, *E*, which was estimated to have significant impact when at least the difference is greater or equal to four hours between two compared strategies. A particular case must be considered when comparing two strategies on the makespan criterion: if the difference is greater or equal to eight hours, this means that at least one eight-hours shift is gained in the working time of a team of eleven workers, during the simulated month.
The Promethee multicriteria method is able to take all these "gradations" in account thanks to several preference functions associated to each criterion in accordance with the decision-maker (see Tables 3 and 4).

Table 3. Ranking given by Hybrid 2.1 using configuration $N_T > T > C_{max} > E = B$

N°	N_T	T	C_{max}	B	E
2	***0***	***0***	***757,71***	***1,11***	***277,40***
6	0	0	757,71	1,09	277,15
1	0	0	753,90	3,17	271,50
7	0	0	760,17	3,15	256,83
3	0	0	760,17	3,14	256,84
4	2	17,65	749,77	0,52	287,42
8	3	23,09	750,80	0,40	288,62
9	4	17,08	754,08	2,93	259,82
5	6	10,55	756,68	3,33	266,57

The comparison of the best strategies obtained by Hybrid 1.1 and Hybrid 1.2 to those generated by Hybrid 2.1, shows the following impact on criteria:

- 3.81 hours are lost in the working time, C_{max};
- 5.90 hours are gained in terms of average earliness of orders, *E*;
- 2.06 hours are gained in terms of duration of lacks of bobbins, *B*.

For the selected period, without introducing any tardiness (N_T and *T* are equal to zero when considering best solutions), increasing the working time by four hours (C_{max}) leads to a better load balancing of the production lines. This, in turn, leads to a gain of almost six hours on average earliness of orders (*E*), and also to a gain of a little bit more than two hours on the duration of lacks of bobbins (*B*).
The comparison of the best strategy obtained by Hybrid 1.3 to the best strategy obtained by Hybrid 2.1, shows the following impact on criteria:

- no change in the working time, C_{max};
- 0.25 hours (15 minutes) are lost in terms of average earliness of orders, *E*;
- 0.02 hours (a little bit more than one minute) are gained in terms of duration of lacks of bobbins, *B*.

In other words, a gain of a little bit more than one minute on *B* leads to loose fifteen minutes on *E*. This might have a significant impact on production costs.

Table 4. Ranking given by Hybrid 2.2 using configuration $N_T > T > C_{max} = B > E$

N°	N_T	T	B	C_{max}	E
6	***0***	***0***	***1,09***	***757,71***	***277,15***
2	0	0	1,11	757,71	277,40
1	0	0	3,17	753,90	271,50
7	0	0	3,15	760,17	256,83
3	0	0	3,14	760,17	256,84
4	2	17,65	0,52	749,77	287,42
8	3	23,09	0,40	750,80	288,62
9	4	17,08	2,93	754,08	259,82
5	6	10,55	3,33	756,68	266,57

Table 4 gives the ranking obtained when *B* and C_{max} are equally weighted. The strategy 6 appears to be the best one, as when considering Hybrid 1.3, so we do not detail any more the results of Hybrid 2.2.

4.3 Results synthesis

The relations between the best solutions given by our hybrids are the following:

- concerning C_{max} the strategy 1 dominates strategies 2 and 6, equivalent on this criterion;
- concerning *B* the strategy 6 dominates strategies 2, which dominates strategy 1;
- concerning *E* the strategy 2 dominates strategies 6, which dominates strategy 1.

Detailed analysis of these results shows that the ranking of scheduling strategies according to several – often conflicting– criteria is not so obvious. Thanks to the embedded multicriteria method, our Hybrid 2 provides the decision-makers with a multicriteria decision-making tool, which is able to integrate a lot of criteria and to consider the balance between the solutions generated and the up-to-date economical context.
It should be pointed out that these rankings, related to the selected period, cannot necessarily be generalized to another period due to the influence of the parameters on the performance of dispatching rules (as mentioned in Section 2.1). These results also depend on the weights associated with the considered criteria. It appears that Hybrid2 is as efficient as, and much more versatile than, Hybrid1 thanks to the Promethee II multicriteria method, but it needs several additional parameters to be tuned so as to capture the gradations and fuzziness in the judgment of decision-makers. Fortunately, several tools are available to guide decision-makers when they are tuning our multicriteria hybrid. For example, it is possible to perform a sensitivity analysis on the results so as to compute the weight intervals stability [2].

5. Conclusion

In this paper we have presented a multicriteria optimization-and-simulation approach to a real-life industrial scheduling problem. The use of a multicriteria function is motivated by the underlying real-life problem. Thus, when comparing two scheduling strategies, a decision-maker often accepts a solution that is worse than another one on one of the criteria if this solution leads to significant improvements in some of the other criteria.
Thanks to the integration of PlanOrdo in the decision process, a lot of data have been gathered so as to implement, finalize and evaluate our framework. The undeniable advantage of PlanOrdo is to quickly provide decision-makers with a ranking of several scheduling strategies so as to select the most suitable strategy to the context. It is also easy to evaluate the impact of new criteria while comparing strategies. The selection of criteria as well as the associate weights is within the competence of the decision-makers. However, several tools are available to guide decision-makers when they are tuning our multicriteria hybrid. Its is also possible to evaluate several strategies on longer periods since the size of the simulated period is only limited by the available data in the information system of the target plant and by the duration of the execution of the simulation model.
We have studied the behavior of our hybrids over several periods; the results remain consistent with those generated by the human planner (in terms of delays, makespan and lack of bobbins). The results show the robustness of the generic multicriteria optimization-and-simulation model that was developed. As well as the automation of the tedious scheduling task, our framework provides decision-makers with a set of solutions, resulting from a panel of scheduling strategies. In this paper, we have also experimentally

demonstrated the efficiency and the versatility of the hybrid models presented. Thus the proposed approach is not restricted to the Fontainunion problem.
We have also implemented several variants of our hybrids including efficient meta-heuristics (such as taboo search). However, this paper focuses on another aspect of our study, the introduction of multicriteria aspects into our schedule builder. In this context, it is preferable to consider simple dispatching rules (with fewer parameters to tune) before generalizing this approach to meta-heuristics. However, when considering efficiency aspects it is clear that these simple dispatching rules must be followed by efficient meta-heuristics. The next step of our study will use efficient meta-heuristics such as simulated annealing or taboo search. The next version of PlanOrdo will be completed soon and will include a powerful multicriteria performance unit. Its aim is to synthesize pertinent measures into scorecards. This version will include financial criteria as well as other aspects (such as maintenance optimization). The new version of PlanOrdo will provide decision makers with an effective high-speed multicriteria decision-making framework, ready to face the context of present-day competitiveness.

Acknowledgments

This work is subsidized by the Walloon Region of Belgium and the European Social Fund. The authors would like to thank the staff at Fontainunion who contributed to this work.

References

[1] Artiba A., Emelyanov V., and Iassinovski S.: Introduction to Intelligent Simulation: The RAO Language. Kluwer Academic Publishers, ISBN 0792381769 (1998)

[2] Brans, J.P. and Mareschal, B.: PROMCALC & GAIA: A new decision support system for multicriteria decision aid. Decision Support Systems, 12, 297-310 (1994)

[3] Carlier J. and Chrétienne P. : Problèmes d'ordonnancement, modélisation, complexité, algorithmes. Masson, ISBN 2225812756 (1988)

[4] Dhaevers V., Duvivier D., Roux O. and Artiba A. : Intégration de l'Optimisation et de la Simulation en Industrie Semi-Continue. In Proc. of MOSIM'04, 2, 601-608, ISBN 2743007311 (2004)

[5] Duvivier D., Dhaevers V., Bachelet B. and Artiba A.: Integrating simulation and optimization of Manufacturing systems. IEEESMC, part C: Applications and reviews, 33(2), 186-192, ISSN 10946977 (2003)

[6] Iassinovski S., Artiba A., Bachelet V. and Riane F.: Integration of simulation and optimization for solving complex decision making problems. IJPE, 85(1), 3-10 (2003)

[7] Jain A. and Meeran S.: Deterministic job-shop scheduling: past, present and future. EJOR, 113:390-434 (1999)

[8] Pomerol, J-C. and Barba-Romero, S.: Multicriterion decision making in management: Principles and practice. Kluwer, New York (2000)

[9] Riane F., Artiba A. and Iassinovski S.: An integrated production planning and scheduling system for hybrid flowshop organizations. IJPE, 74, 33-48 (2001)

[10] Waikar A. M., Sarker B. R. and Lal A. M.: A comparative study of some priority dispatching rules under different shop loads. Production Planning Control, 6(4), 301-310, ISSN 09537287 (1995)

[11] J.E. Beasley. OR-Library: Distributing test problems by electronic mail. Journal of the Operational Research Society, 41, 1069-1072, (1990). This library is available via http://www.brunel.ac.uk/depts/ma/research/jeb/info.html