Referee's report on the Ph.D. thesis

*Scheduling in Manufacturing Systems*

by Jan Kelbel

**Overall recommendation: Accept.**

**General remarks.** The thesis deals with three practical optimization problems — scheduling with earliness/tardiness penalty costs (Chapter 2), allocation of components (Chapter 3), permutation flow-shop with blocking (Chapter 4).

The thesis has a lot of positive features, but it also suffers from some negative ones. The **positive features** include:

- The problems are of practical nature and are useful in industrial management.
- The presentation of the problems is clear and well-written.
- The problems motivate interesting theoretical questions.
- References to the existing literature are very good.
- Some of the results have been published in a good journal (Journal of Intelligent Manufacturing).
- The author has achieved very good computational speed-up.

The **negative features** include:

- The three problems do not have much in common; the thesis is a 'concatenation' of three independent parts. It would have been more suitable to focus on a single problem.
- The basic solution method is constraint programming. A thesis of this kind should contain a single chapter on CP, with sufficient theory as well as information on solvers. In this thesis, the notion of CP is only briefly sketched in each chapter; for example, the text of pg. 2 is reproduced on pg. 55, even with the same mistakes. [This again shows that the thesis is a 'concatenation' of three independent parts.] In my opinion, presentation of CP is insufficient.
- The work heavily relies on properties of *particular* CP solvers (for example, pg. $12^{\downarrow 10}$, $14^{\downarrow 20}$, $37^{\uparrow 8}$ — formulation of the problem is dependent on the choice of the solver), but neither the solvers nor the properties are described in the thesis. Furthermore, it should be explained why the particular solver has been chosen (ILOG OPL Studio in Chapter 2, Gecode in Chapters 3 & 4; why does the author use different solvers?) and it should be justified that this is the best possible choice.

**Chapter 2. Overall assessment: very good.** The chapter is well-written, the problem is (except for some remarks, see below) stated clearly, the solution of the problem is clear as well, the computational results are convincing. The most interesting concept is the time-reversing transformation, which is of both theoretical and practical importance. I have only a few remarks.

- Pg. 6: I don't agree that "generic CP/MIP algorithm = naïve algorithm".
- If $\mathcal{J} = \{J_1, \ldots, J_n\}$, then in (2.2) the author must write $J_j \in \mathcal{J}$.
- There is a problem with the laboratory (pg. 10). The author writes (roughly): "when the mixing procedure is finished, the lacquer quality is checked in laboratory. The step is necessary *if the lacquer quality requirements are not satisfied.* (...) Then, the procedure is repeated. The quality is checked again." This shows that the production process has a stochastic (or: nondeterministic) nature — it might happen that after the mixing procedure the quality is good, or the quality is low and the procedure has to be repeated. If this is right, then the problem, involving probabilistic components, would have to be addressed using a completely different toolbox. The author should justify in his Ph.D. lecture that his approach is indeed correct.

- Symbol $r_j$ in Algo 2.2 is undefined.
- Pg $15^{\uparrow 8}$ : "(...) maximal allowed weighted tardiness cost $\overline{f}$, that is found experimentally during the solution". This is a highly unsatisfactory explanation of the strategy for the choice of $\overline{f}$. Algo 2.2 depends on the choice of $\overline{f}$ significantly.

**Chapter 3. Overall assessment: very good.** The chapter is well-written, the problem is stated clearly, the solution of the problem is clear as well, the computational results are convincing. Example 1 is good for understanding. Some remarks:

- The notation "$\{j,k\} \subset \mathcal{J}$" is confusing and nonstandard; when the author writes "$|r_j - r_k| \leq 1$, where $\{j,k\} \subset \mathcal{J}$", then everyone understands "$(\forall j \in \mathcal{J})(\forall k \in \mathcal{J})|r_j - r_k| \leq 1$".
- The formula for $\lceil a/b \rceil$ on p. $37^{\uparrow 5}$ is incorrect.
- The formulation (3.9) is interesting. Why is this formulation better than simply saying "we optimize with respect to the first criterion, then fix its value and optimize with respect to the second criterion, etc."?
- Why is the solver used here different from the solver used in Chapter 2?

**Chapter 4. Overall assessment: premature.** The idea of the chapter seems to be good and interesting (though sometimes it is not easy to decipher it from the text). In particular, the lower-bound approach seems promising. However, it is apparent that the chapter was written in a hurry and lacks the final "polish-up".

- There are many mistakes (pg. 51: "The start time $S_{j,i}$ of all task determine (...)"; "there exist a precedence relation" (pg. 52), "let $\pi$ denotes a permutation" (pg. 52) to state some).
- There are many formal flaws, for example: the symbol "$D$" is used in three meanings — as $D_{ji}$, as $D_i$ and as $D$; this is highly confusing; the definition $next_j = \pi^*_{h_j+1}$ (pg. $57^{\downarrow 7}$) is incorrect (take $h_j = n$; then $\pi^*_{h_j+1} = \pi^*_{n+1}$ which is undefined); the symbol $R$ (pg. $57^{\uparrow 15}$) is undefined; $\pi \cup \{j\}$ should be written instead of $\pi \cup j$; it is correct to write $J_j \in \mathcal{J}$ instead of $j \in \mathcal{J}$ (this occurs four times); "each variable $d_i = \{v_1, \ldots, v_k\}$" (pg. $55^{\downarrow 6}$) — $d_i$ is not a variable; moreover, $k$ is used incorrectly here, there is no reason for the requirement that all the domains have the same cardinality.
- The term "grid graph" should be defined if it is used in a proof. (The definition is quite trivial.)
- The section 4.3.3 is written poorly — the author must have been indeed in a hurry. Formulations such as "insert something in front of a permutation $\pi$" are not rigorous enough.
- $|OS| \in \{n-10, \ldots, n-5\}$ (pg. 53) — what is the reason for this choice?
- The constraint (4.3) is, in my opinion, incorrect. Take $\pi =$ *identity permutation*, $k = 1$, $i = 2$. Then (4.3) states that *the first task of the second job cannot start earlier than in the moment when the second task of the first job is done.*

**Summary of the recommendation.** Though there are some weaknesses, I recommend to accept the thesis in particular for the following reasons:

- chapters 2 and 3, which are well-written, would qualify for a Ph.D. thesis themselves;
- some of the results have been published in a good journal;
- the computational results are convincing;
- the work suggests interesting ideas worth to be subject of further research.

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