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Subject Evaluation of the PhD thesis by Antonín Novák

Dear prof. Milan Polívka, dear members of the PhD Committee.

With pleasure I follow the invitation to review the dissertation of Mr. Antonín Novák with the title "**Scheduling with uncertain processing times given by empirical distributions**". I have been working in the area discrete optimization and specifically scheduling myself since more than 20 years, and act as an editor for several scientific journal for corresponding areas. Therefore the evaluation of this PhD thesis fits my area of expertise quite well.

The thesis is presented in 6 chapters, four of which are containing genuinely new results about different models and algorithms to solve scheduling problems with uncertain processing times. The overall approach to these problems is motivated by practical considerations, because one of the difficulties in solving scheduling problems in practice is the uncertainty about the actual processing times of the jobs to be processed. For four different types of scheduling problems the author develops new models, new theoretical results, new algorithmic approaches as well as practical implementations and extensive computational results for these algorithms. In summary, the thesis is an excellent example of a choice of practically relevant and challenging research questions, combining theoretical foundations and algorithm engineering on a very high scientific level, and with extensive computational experiments that show practical validity and also improvements of the state of the art. The high quality is also testified by the fact that the corresponding research results have been published in highly ranked, international scientific journals such as the *European Journal of Operational Research* (three times) and the *Annals of Operations Research*.

Let me briefly comment on the specific questions.

To what extent is the subject of the thesis relevant to the current needs of the scientific community? Scheduling problems arise in a large amount of practical applications. And even though it is common sense that in almost all practical situations there is uncertainty about the precise duration of tasks, many questions for concrete models are still open, and it is often the case that standard or known techniques only have theoretical value, for example because they do not scale. In Chapters 2-5, the thesis addresses four different, concrete and interesting models for dealing with uncertainty. All problems are well put into context, both from a practical viewpoint ("why should we care?") and from a theoretical viewpoint ("what has been done and what is known?"). In each of the four chapters, the thesis enhances our understanding by theoretical analysis and significantly extends the algorithmic toolbox to solve such problems. The computational results

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that go along with the developed theory are extensive and convincing. I consider this a highly relevant and scientifically valuable contribution.

To what extent have the main objectives of the work been fulfilled? The main objectives are identification of relevant research questions for practically motivated scheduling problems under uncertainty, formalisation and modelling of these questions in scientific context, development of new algorithms both approximative and exact, and benchmarking these algorithms in computational experiments. All these objectives have been fulfilled with remarkable results. Chapeau.


To what extent are the methods used in the thesis appropriate? The algorithm engineering and analysis as done in this thesis builds on deep knowledge in discrete, linear and nonlinear optimization, linking to machine learning, statistics and probability theory. The overall arsenal of methods and techniques from different areas that need to be tackled in order to obtain the desired results is quite impressive for a PhD thesis.

What are the main results and contributions of the work? One of the highlights of the thesis is in my view Chapter 2. Starting out with an interesting non-standard formulation of the flow-time machine scheduling problem based on positional values, it is shown that certain distributionally robust versions of the problem can be efficiently solved by showing they can -eventually- be reduced to deterministic counterparts (Proposition 3). In that context, also the (re-)interpretation of the problem through the lens of regularization in machine learning is very enlightening. The subsequent computational results show the high practical relevance of the theoretical insights, and the practical value of the idea to replace the ℓ_2 regularization by the simpler ℓ_1 regularization, both in terms of solution quality and computation time. The amount of new results, their quality and depth are impressive. Chapters 3 and 4 address two different and interesting questions in mixed-criticality scheduling. First, Chapter 3 makes an interesting link between uncertain processing times and so-called F-shaped jobs, subsequently developing several algorithms for different versions of that problem, both approximative and exact. The mix of modelling complexity, theoretical insights and practical results is again impressive. Next, Chapter 4 addresses a different question in the same context, namely the computation of the execution probability of mixed-criticality tasks when these can appear not only once but with replications in a given schedule. Next to #P hardness of that problem, the chapter establishes an interesting connection to Bayesian networks that paves the way to efficient implementations, and it gives efficiently solvable special cases. The final research chapter (5) deals with the parallel machine scheduling problem with normally distributed processing times, and asks to maximize the probability that all jobs are finished by a given deadline. The chapter builds on earlier work on that challenging and relevant problem by Ranjar et al. Here, the thesis improves upon the state of the art by -among other things- new and better lower and upper bounds (Proposition 13 is a nice example of the latter), by designing a novel branch-and-price algorithm, and again by extensive and convincing computational results.

To what extent is the work important for the further development of science? The thesis has introduced several novel and highly nontrivial ideas for tackling scheduling problems with uncertain processing times, provides theoretical justification and computational proof that these ideas have practical value, too. It also introduces new models, like the ones for mixed-criticality scheduling, which will certainly lead to subsequent work by other researchers. Specifically the clever idea to re-interpret distributionally robust optimization problems through the lens of regularisation in machine learning, and playing with the regularization terms to obtain faster and better algorithms (Chapter 2) might prove to be applicable also elsewhere. Altogether there is plenty of new and interesting ideas which will be picked up also by others, both by practitioners and researchers with theoretical interest.



Does the thesis satisfy the conditions of a creative scientific work? The thesis shows a remarkable level of breadth and depth in methodology, is theoretically deep as well as computationally very convincing, and has a very high level of creativity in modelling, establishing sometimes surprising connections to adjacent areas. It definitely deserves to be labeled as creative scientific work.



In conclusion, I can clearly state that the author of the thesis proved to have an ability to perform research and to achieve scientific results. Without hesitation I do recommend the thesis for presentation with the aim of receiving a Ph.D. degree.

With kind regards,
Prof. Dr. Marc Uetz

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