Review Report on the PhD Thesis of Ondřej Benedikt – "Energy-aware scheduling with resource state considerations: Modeling and optimization" by Broos Maenhout (01-23-2023)

Energy-aware scheduling embodies a very diverse research domain with many practical applications, which has been increasingly studied in the academic literature in recent years because of its contemporary relevance. Energy-aware scheduling problems arise in different forms and have different formulations requiring dedicated solution methodologies to support short-term scheduling decisions. However, despite the research efforts of the OR community, academic state-of-the-art solution methodologies are rarely implemented in practice because of a gap between theory and practice. Real-world problems are often too complex in terms of problem size and/or problem characteristics. The underlying thesis tries to tackle these problems by proposing an adequate solution methodology for different real-life and complex energy-aware scheduling problems and by exploiting problem-specific properties to speed-up the running time and devise competitive algorithms that are readily implementable for real-life practices.

Chapter 2 of the thesis provides an interesting contribution to the academic community as a new scheduling algorithm has been proposed to minimise idle energy consumption. The authors show that their approach is better suited to model machine dynamics and finds optimal schedules following a polynomial-time algorithm exhibiting a smaller complexity. Research has been validated in a real-life case study, showing the potential and relevance of this approach. Hence, the research provides not only academic value but also practical results. Chapter 3 studies an extension of the idle energy function with time-varying energy costs. A clever pre-processing technique is proposed pre-computing the optimal switching behaviour in time with respect to the energy costs. The proposed problem decomposition leads to significant savings in run time, allowing the solving of real-life instances in acceptable time spans. Chapter 4 studies the problem of thermally efficient task allocation under temporal isolation constraints on heterogeneous multi-processor systems. With the rise of the energy-awareness in society, this chapter also presents an important step in the use of (generic) combinatorial optimisation demonstrating the real-life applicability and benefits of scheduling algorithms.

Topics for discussion at the thesis defence

Chapter 2

- The real-life relevance of the research done in chapter 2 is proven via a case study. However, it seems that the case-specific character of the research is rather prevalent and the generality of the research can be questioned as a lot of assumptions have been taken, e.g.,
    - The objective considers solely the minimisation of the idle times when the machine is on and does not optimise energy consumption (as temperature could be lowered to save energy).
    - All tasks are operated at the same temperature. I can imagine that in some environments, tasks are sensitive to temperature and require different temperatures to be operated, such that adequate periods should be inserted for further heating or cooling.

- The bilinear model approximation of furnaces is motivated by the existing literature but is questionable. The proposed model attains a mean absolute percentage error of 4.49%. It would be more reasonable to apply a second-order regression model with interaction effects to model the furnace dynamics. If the coefficients of the second-order terms are not significant, a simplification to a linear model with interaction effects can be done.

It is not clear what the implications are for the research done if assumptions would be omitted or different than the ones indicated. In other words, the boundaries of the research should be investigated, and limitations more clearly described. Correspondingly, the applicability of the research done to energy-aware scheduling questions should be indicated in a more detailed manner. The student indicates, however, that the objective can be conceived differently by minimising the number of times the heating power is idle (independent from the interval length) but little is done with this later when drawing conclusions. My question is initiated by the fact that a literature synthesis (preferably using a table) indicating relevant problem characteristics studied in previous literature is missing. How does this research come forward to the gaps in the literature?

- Associated with the previous question, the test design is constructed based on the different parameter values related to the number of tasks, and values for δ and γ. I can concur with the choice for the number of tasks but why are the other parameters chosen? Because they impact utilisation? Other research studies consider the utilisation directly as a parameter for the generation of instances, so it is not clear what these parameters really indicate for the problem. I think that there should be at least a motivation given for the use of these parameters. Would it not be more relevant to widen up the test design to other settings with industrial relevance or rely on important properties of single-machine scheduling problems?

Chapter 3

- In the literature, different model ILP formulations have been proposed to solve single-machine scheduling problems such as the ones with completion time variables, time index variables, linear ordering variables and positional & assignment variables (see Keha et al., Computers & Industrial Engineering, 2009). You have selected the one based on time index variables whereas in literature the formulations with linear ordering variables and positional & assignment variables perform best. Can you motivate your choice (with the performance measure in mind)?
- Comment on the wider applicability of the instance pre-processing step and list the relevant conditions for using the polynomial algorithm. Connection should be made to related energy-aware scheduling problems.

Chapter 4

- Is a linear regression model sufficient to predict the average power consumption of a whole isolation window? Typically, there is started from a more general model, like the second-order regression model and when the regression coefficients of the quadratic terms are insignificant, you can reduce it to a first-order linear regression model. Have you further investigated the sensitivity of the assumption of the linear regression model?
- Can you motivate why you rely on black-box optimisation methods (Section 3.7.2.2) and not develop a dedicated procedure to make the solution approach more efficient? Although the research and problem analysis are based on deep insight with respect to the application domain and run times seem to be important (only 60s), developed optimisation approaches are quite generic and little effort has been done to improve those approaches.

- The downside of using an experimental approach for evaluation (Section 3.3.3) is that you are able to replicate the experiment only a limited number of times. How do you know that generated solutions are quite representative and how do other researchers compare their results to yours?
- Is there a particular method serving as a benchmark? Can you make comparison with real-life solutions? What are the real-life benefits?

Summary

It is clear that the student has done a large amount of high-quality work. Based on rigorous analysis of the literature and problem properties, the student is able to develop efficient algorithms for different energy-aware scheduling applications. The candidate has demonstrated creativity to master challenging optimisation problems. He has proven to come up with different innovative ideas based on operations research to improve computational performance. Overall, the methodology and test design are worked out very well as both practical and academic relevance are demonstrated throughout the computational experiments. The candidate has made a number of significant contributions to the domain of energy-aware scheduling, facilitating the further development of new research directions in the domain.

The author of the thesis proved to have an ability to perform research and to achieve scientific results. I do recommend the thesis for presentation with the aim of receiving a Ph.D. degree.

Yours sincerely,

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