Report on the PhD thesis presented

By Ondrej Benedikt
" Energy-aware scheduling with resource state considerations: Modeling and optimization "

Mr. Ondřej Benedikt wrote a thesis entitled "Energy -aware scheduling with resource state considerations: Modeling and optimization", presenting the thesis work carried out under the supervision of Doc. Eng . Premysl Sucha , Ph.D at Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Control Engineering. The document is written in English and has 128 pages. It is composed of a general introduction (preface), 3 chapters presenting the contributions of the thesis and a general conclusion.

In the general introduction, Mr. Ondřej Benedikt introduces the context in which the contributions of his thesis work take place: the resources optimization use in production plant, by considering energy related constraints. A general overview of the work developed is given, emphasizing the links between the different parts, which are based on the problem of tasks (jobs) planning over time (scheduling), considering the optimization of energy and the resources state. Mr. Ondřej Benedikt illustrates with concrete application cases the importance of these questions in the industrial world of today and tomorrow. A quick general overview of the literature is discussed and highlights the main contributions of the thesis.

The first chapter is devoted to the scheduling of tasks in a unitary machine, for the energy consumption minimization, in presence of release dates and due dates, with a fixed sequence. These working hypotheses are illustrated by the case of an industrial oven encountered at Skoda Auto. A complex aspect in the ovens management is that they are unnecessarily heated to high temperatures, even when they do not process any task, heating and cooling requiring a lot of time and cannot be neglected. The objective of the work developed is to provide a decision support tool to better control the temperature of the ovens over the entire sequence and thus reduce their energy consumption. A quick synthesis of the state of the art shows that the majority of works in the literature consider a set of ON/OFF/IDLE states and the transitions between these states. These transitions are characterized by durations and associated energy consumption. This approach can be too simplistic and does not allow to correctly describe the problem as encountered in concrete cases. Mr. Ondřej Benedikt proposes to describe the relationship between the duration of the idle period and the energy consumption by an inactivity function, which will then be used to evaluate the energy consumption of a given schedule in a more realistic way. He proves that when this function is concave (which is the case in the example of the oven), the scheduling problem (decision of the states of the machine, for a given sequence) can be solved in polynomial time. The approach proposed in this chapter therefore makes it possible to deal with more varied problems than those approached and modeled in the literature with a finite number of modes and seems less impacted by the length of the decision horizon in terms of complexity.

The second chapter of the thesis is devoted to the study of the total energy cost (TEC) minimization problem when the price of energy varies over the decision horizon (TOU). This involves determining the order of the tasks if they are all available at the start of the decision horizon. Mr. Ondřej Benedikt proposes to improve the existing work in the literature by proposing a technique for preprocessing instances in order to improve the performance of solving this problem by reducing the search space for the optimal solution. Several models are proposed and compared with each other and with the reference works of the literature, on different instance types. The approach thus proposed

makes it possible to optimally solve many more instances than the work of Aghelinejad *et al* . to which Mr. Ondřej Benedikt compares his results.

The last chapter of the thesis is devoted to task scheduling in the case of a multiprocessor chip. The goal is to determine the timing to reduce the chip temperature while running a given workload. Among the tasks to be scheduled, a distinction is made between the critical tasks which are essential to the safety and functioning of the system and the tasks which can be ignored in the event of a thermal emergency. The objective is therefore to determine a thermally efficient offline scheduling. After an overview of the literature on this problem, Mr. Ondřej Benedikt concludes on the originality of the problem addressed here. In order to evaluate the quality of the solutions approaches, the choice is made to carry out experimental evaluations (thanks to 3 platforms). The platforms used are thus presented, then the thermal modeling is approached: transition from thermal modeling to energy modeling and specific power models (Sum-Max, Linear Regression). Several optimization approaches are then developed and compared: ILP, AG, greedy heuristic. After many experiments, it appears that the SM model is more efficient for optimization while the LR model was the most accurate. The GA makes it possible to resolve large instances when the ILP does not provide a solution in a reasonable time.

The manuscript ends with a general conclusion reminding the objectives of the thesis and highlighting the responses provided in all the work presented to these different objectives. Some future works are also discussed.

The work carried out by Mr. Ondřej Benedikt is very well illustrated, all the working hypotheses are justified by concrete cases of application, the demonstrations are rigorous, and the conclusions presented are based on a large number of experiments. The work has been the subject of 2 articles published in journals with a strong impact factor (*Computers & Operations Research* and *Constraints*) and 6 presentations at international conferences or workshops. The subject of the thesis concerns a topical issue related to the challenges of reducing the environmental impact of industry and better controlling energy consumption. The work allows to improve the results of the literature on two problems and to initiate an original problem. The methods used in the thesis are correctly justified and appropriate to the problems addressed and the approaches implemented are of great scientific rigor, opening up many perspectives. The objectives of the thesis are therefore achieved, even exceeded.

Mr. Ondrej Benedikt has therefore proven 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.

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