Review Report on the PhD Thesis of Zdenek Baumelt– "Advanced Methods and Models for Employee Timetabling Problems" by Broos Maenhout (05-28-2015)

Employee Timetabling embodies a very diverse research domain with many practical applications that is widely studied in the academic literature for several decades now. Employee timetabling problems arise in different forms and have different formulations leading to a enormous number of solution methodologies. Despite the overwhelming amount of papers, the candidate has succeeded to provide a general and accurate overview of the used terminology and categorization in the operations research literature on timetabling. Moreover, the student was able to give a suitable introduction on the socio-economic context of timetabling in general. Especially, figure 1.1 deserves plaudits, which gives insight in the different facets of timetabling for both the employer and the employee.

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, which may lead to unreasonable long running times. The underlying thesis tries to tackle these problems by proposing an adequate solution methodology for a real-life and complex timetabling problem with a very large number of shifts and by exploiting a GPU parallel solution methodology to speed-up the running time of an established algorithm in the employee timetabling.

Chapter 3 of the thesis provides a contribution to the academic community as the employee timetabling problem with a high diversity of shifts is investigated. In the literature, most papers consider only a limited number of shifts (in most cases 3 shifts, in some cases up to 7 shifts). An increase in the number of shifts, i.e. more than three shifts, is widely recognised to lead to an enormous rise of the complexity. The research in this chapter comes towards this lacuna in academic research and even more gives the opportunity to integrate two well-known scheduling problems, i.e. the tour scheduling problem and the personnel rostering problem. This is highly relevant for some application areas (e.g. call centers) and for services with a highly volatile demand in general. Hence, the research provides primarily academic value as a stage-wise optimisation approach is proposed that has been demonstrated to tackle the increased complexity due to the high diversity in shifts. Given the problem definition, the candidate was able to construct a well-performing algorithm that first simplifies the problem by reducing the number of possible assignments and that thrives on (meta-)heuristic optimisation principles. The latter is shown by the extensive computational experiments and the comparison of the proposed approach with different existing approaches that show the contribution of the multi-stage approach (MSA) versus a single stage approach (CMPA1) and

other existing algorithms from literature. Further, the research in this chapter also provides some societal and practical value as the research helps to reduce the gap between closed between academic research and practice. Capturing real-life data and solving these data instances have proved the practical relevance of the research.

Parallel computing for combinatorial optimisation problems is a topic that has been studied already for quite some decades but this topic is not widely established in the operations research community. The underlying chapter provides a first contribution to the academic community on the use of parallel computing for employee timetabling. Most algorithms in the literature are described and implemented on a CPU processing unit. With the rise of GPU parallel computing during the last decade, it is the general belief in the academic community that efficient implementations of algorithms for combinatorial optimisation problems will become significantly important. The PhD thesis represents a very important step in this direction, as a relevant comparison is made for a CPU model with two GPU models, i.e. a homogeneous and a heterogeneous model. This chapter gives a very good idea – I complement especially section 4.5 – on the relevant steps that are necessary to design a parallel computing algorithm. In his research the candidate has proven in the computational results that the employed approach leads to high-quality solutions and a significant speed-up in running time.

Topics for discussion at the thesis defence

- In general, the decomposition of the employee timetabling problem makes the problem not easier to solve due to the many different constraints imposed on the days on and the working shifts. The first stage problem is NP-hard, the second stage is NP-complete and the third stage problem is NP hard. I would like to see some more discussion on the second and third stage. What is the performance/impact of the second stage? What happens with the feasibility of the solutions in the second phase (look to the number of understaffed shifts, the time-related horizontal constraints) as the number of possible assignments explode?
- Similar stage-wise approaches are described in Valouxis et al. (2012) and in Tassopoulos et al. (Algorithms, 2013). The PhD student should compare conceptually both types of approaches.
  The papers of Valouxis et al. (2012) and in Tassopoulos et al. (2013) use an employee-day representation (gene length $l = 1$) whereas the proposed approach mixes an employee-day representation with an employee-pattern representation (with a gene length $l > 1$). A computational experiment could further strengthen this comparison by setting the gene length $l = 1$.
- In the model formulation of stage 1 (3.9)-(3.16) not all constraints are clearly formulated. Is constraint 3.11 a relevant constraint in this stage given the problem transformation? Constraints 3.14 and 3.15 are ambiguous as the meaning of indexes t and d are not perfectly clear.

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- As the encoding seems to play a major role, the authors should discuss the impact of the gene length l (certainly in relationship to the block constraints).
- The authors spend a lot of attention to the generation of the initial population in their reported computational experiments, but less attention goes to the other elements of the evolutionary approach, the proposed strategy and their parameter values. E.g. in the selection step, comparison could be made with random selection, the roulette wheel selection.
- A detailed description of the problem instances and parameter values is required in Chapter 3 (number of shifts, workers, days, workload pattern, etc).
- Chapter 4 provides an indication of the potential contribution of parallel computing for combinatorial optimization problems and for employee timetabling in particular. However, the implications of this particular implementation on the generality of the approach are not clear:
    - Why is the Nurse Rerostering Problem has been chosen?
    - What can be said about employee timetabling problems in general?
    - A sequential algorithm is now implemented, but what with other types of algorithms? Will the gain in CPU always be that large?
    - Are the achieved computational benefits in line with the literature on parallel computing for combinatorial optimisation problems?
- The backtrack mechanism is used to improve the convergence to feasible solutions. However, this mechanism is based on swapping, whereas a single shift-day neighbourhood seems to be more appropriate. Computational insight is necessary in this backtracking mechanism and its success rate to improve the solutions towards feasible solutions.
- The local search method embodies only a random swapping mechanism whereas other local search mechanisms discussed in literature have a better performance and/or are complementary with the employed local search mechanism.

Summary

It is clear that the student has done a large amount of high quality work. Based on a rigorous literature study and categorization, the student is able to identify significant lacunas in the research domain of employee timetabling. The candidate has demonstrated creativity to master the challenging optimisation problems. He has proven to come up with different innovative ideas concerning large-scale optimization problems based on operations research and how to improve the computational performance using new architectures inspired by parallel computing. Overall the methodology and test design is worked out very well as both practical and academic relevance are demonstrated throughout the computational experiments. Overall the candidate has made a number of significant contributions to the domain of employee timetabling. These contributions are not only related to operations research but also to computer science and these will facilitate the further development of new research directions in the domain of employee timetabling.

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 the Degree of PhD.

Yours sincerely,

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