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DISCUSSION

Rejoinder on: an overview of curriculum-based course timetabling

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We would like to thank our colleagues Roberto Asín, Edmund K. Burke, John H. Drake, Marco Lübbecke, Barry McCollum, Ender Özcan and Andrea Schaerf for their careful reading and their insightful comments, and Miguel A. Goberna for inviting us to contribute to TOP. Most of the discussants remarks (referring to a preliminary version of our paper) have been included in the new version, leading to an improved overview of the topic. In the following, we wish to make some considerations about their comments.

We wish to thank Roberto Asín for his classification of the methods according to the modelling language [direct representation, Mixed Integer Linear Programming (MILP), Constraint Satisfaction Problems (CSP) and Satisfiability problems (SAT)] and on solving the algorithms (branch-and-cut, metaheuristic methods, backtracking-based algorithms). We think that this is an interesting alternative way of classifying the methods proposed in the literature. The discussant emphasized, as a guideline

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for future research, investigating the reasons why an approach is strong in certain instances and weak in others. He also suggested the development of hybrid methods, that combine, for example, SAT-based techniques for finding starting feasible solutions and metaheuristic methods for improving the solutions found. We agree with him that a deep analysis of the problem structure would help derive more powerful methods. We added an observation on this to the paper.

We wish to thank Edmund K. Burke, John H. Drake, Barry McCollum and Ender Özcan for highlighting the area of parallel processing, which could improve the effectiveness of the exact methods. We have mentioned this in the paper. We agree with the discussants that introducing fairness in CB-CTT is a delicate, though increasingly important issue, and it is not trivial to find an appropriate definition. We added the reference suggested by the discussants concerning the field of multi-objective optimization. We especially liked the observations the discussants made on the practical applications of university timetabling and the importance of not losing the connection between academic problems and real-world ones. We have added a comment on this to the paper. We thank the discussants for bringing to our attention the recent survey on hyper-heuristic methods for educational timetabling problems, which is now in our list of references.

We wish to thank Marco Lübbecke for his deep analysis of our overview paper. We have added the references to the recent surveys he provided us. We agree that some characteristics of CB-CTT are specific and might be quite far from applications arising in other universities. However, we think that a precise definition of CB-CTT helped to stimulate research in this topic and allowed performing the comparison of several approaches. On the contrary, as also mentioned in the comments by Edmund K. Burke, John H. Drake, Barry McCollum and Ender Özcan, we must not forget the features appearing in real-world applications. The discussant underlines how multi-objective optimization is hard, and especially how it is difficult to present a set of Pareto optimal solutions to the practitioners. We agree with him and think that this could be an interesting topic of research. The discussant brings focus on the concept of robustness. Robustness has been deeply investigated in other optimization fields, such as "train scheduling", taking into account the construction of solutions that can reduce the effects of possible "disturbances", such as delay propagation, as much as possible. This concept cannot be directly extended to university timetabling, since usually a lecture is not delayed even if the previous one has been delayed. However, uncertainty also appears in this context. For example, the number of students attending a course is often not known in advance. This can affect the objective function as in CB-CTT and even the problem feasibility if these numbers vary considerably. In addition, it would be useful to construct a solution that is robust to room unavailability, i.e. to derive a solution that allows moving a lecture from a room to another one, possibly with a "similar" capacity. Another comment by the discussant is on the fairness of the comparisons between the different existing methods. We fully agree that it is very hard to make a really fair comparison. Even if the methods are applied to the same benchmark instances, they use different computers, different computing time limits and different general-purpose MILP solvers. We have emphasized this many times throughout our overview. Indeed, we have not identified a single "winner" method that outperforms the other ones on all the instances. Finally, we regret that it is very hard to

answer appropriately to the comment of the discussant on "what approaches are most promising for achieving which goals". As he also observed, "such advise can hardly be given without experimenting with all the models and approaches oneself". We have done our best to partially reply to his interesting request. We do not completely agree that the overview supports investigating a branch-and-price like approach to derive optimal solutions. Our observation on the column generation method was just related to deriving lower bounds to CB-CTT, and, by looking at the current state-of-the-art methods, we think that column generation has a good behaviour, but it is certainly not the single best method. We agree that new modelling techniques should be investigated and this remains a challenge for future research.

We wish to thank Andrea Schaerf for providing us an updated list of references on CB-CTT before the writing of this overview paper, which helped us in not missing relevant contributions to the field. We agree with the discussant that some features of the benchmark `comp` instances are actually typical of real-world problems in Italian universities. Indeed, they were derived from the CB-CTT arising in the university of Udine. Clearly, different universities can have different constraints/objectives, but the introduction of benchmark instances is to be appreciated. As observed by Edmund K. Burke, John H. Drake, Barry McCollum and Ender Özcan, and by Marco Lübbecke, having a close connection with real-world applications is very important. We liked the observations of the discussant on the instance generators and added a comment on this to our paper. We highlighted the differences between CB-CTT and PE-CTT, as suggested by the discussant. Finally, we agree with the discussant that the constraint satisfaction methods were wrongly placed in the overview paper and moved them to the section on the exact algorithms.