EDUCATION FOR CHEMICAL ENGINEERS XXX (2017) XXX–XXX

Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

Mathematical programming approach for optimally allocating students' projects to academics in large cohorts

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ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form 9 May 2017
Accepted 6 June 2017
Available online xxx

Keywords:
Allocation
Mathematical programming
Large cohorts

ABSTRACT

Many university degree programs (including chemical engineering ones) require final year students and Masters' students to do an extended research project under the supervision of an academic staff member. However, obtaining a satisfying allocation for both students and supervisors is often a challenging task, especially when the amount of available supervisors is particularly tight and their popularities are highly diverse.

In this article we propose a novel method based on a ranked list of supervisors and categories provided by each student, where a category corresponds to a general research area, incorporating this information into the allocation process. A student's satisfaction may therefore correspond to getting a project either with a highly ranked supervisor and/or in a highly ranked category. With this information, we propose here a systematic approach that relies on a novel mixed-integer linear programming (MILP) model based on a flexible definition of students' satisfaction. Our MILP overcomes the limitations of manual allocation approaches, which when applied to large cohorts are highly time consuming and may produce suboptimal solutions leading to poor satisfaction levels. This MILP has been applied successfully in the School of Chemical Engineering and Analytical Science of The University of Manchester with increased levels of student satisfaction.

1. Introduction

In many universities, final year undergraduates and Masters students do an extended research project. This generally makes a big contribution to the final degree classification or the final mark. Not surprisingly, students are keen to do well in their project work and thus it is important to them that they be given projects that they enjoy and which match their skills and their interests.

While in many disciplines, like humanities, the student is responsible of devising the project, in physical sciences (e.g. chemical engineering) it is much more common for an academic supervisor only to run projects closely allied to his or her own research area. In this case, it is required that academic supervisors provide a list of possible projects, which the students can then select.

In the case that the number of students requiring projects is not too large compared to the number of available supervisors,

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http://dx.doi.org/10.1016/j.ece.2017.06.002
1749-7728/

Please cite this article in press as: Calvo-Serrano, R., et al., Mathematical programming approach for optimally allocating students' projects to academics in large cohorts. Education for Chemical Engineers (2017), http://dx.doi.org/10.1016/j.ece.2017.06.002

it may be possible for all students to choose their favourite supervisors. If an academic staff member happens to be popular and ends up with a larger work-load than other staff, then fairness can be restored by reducing this person's teaching duties elsewhere. This process, however, runs into problems for larger cohorts of students. As will be seen later, commonly some supervisors are more popular than others, and the former would end up supervising a disproportionate amount of students. One thus needs an allocation scheme that matches students to supervisors in such a way that overall student satisfaction is maintained but no staff member supervises more than a set maximum number of students.

A very small survey of various UK Universities and their Schools/Departments revealed a number of strategies in operation for managing project allocation. In all cases there was a cap on the number of students given to an individual supervisor. One method, used to allocate final year undergraduate students, was to make use of their academic performances of the previous year. As well, all students would submit a ranked list of supervisors. The student with the top marks would get his/her first choice supervisor. One then would simply work down the list, allocating according to the first choices, until one came to a student who had chosen a supervisor whose quota had been filled. This student would then receive his/her second choice. This procedure would carry down the entire list, though, by the time you get near the bottom, there is a big risk that a student will be allocated to a supervisor either very far down the ranking or, possibly, not even on the student's list at all. This of course, is a very easy algorithm to use and it does ensure that students with high marks get a very satisfactory allocation. The method cannot be used, however, for a one year MSc programme, where there would be no ranked mark list from the previous year. Also this runs counter to the more prevalently held belief, within the small survey, that this is an unfair process, because of the potential high degree of dissatisfaction experienced by students with less good examination results. Another approach that came up in the survey was the "first come, first served" method. Here students would need to meet prospective supervisors in person and, if the student wished to work with that supervisor and the supervisor was agreeable, then that student would be allocated to him/her. This would carry on until the supervisor has filled his/her quota. Once this had happened, a student would have to look elsewhere for a project. Again, any student who failed to fix up a supervisor in good time, ran the risk of ending up with a supervisor not in his/her ranked list.

This procedure is easy to administer and it does have the virtue of requiring students to discuss projects with supervisors and thus be in a more informed situation. Drawbacks are firstly that the supervisor does his/her own selection, so there is a danger that this can be based, maybe unconsciously, on overly subjective factors. Secondly the time element can create stress for students. Indeed, the motivation is to sign up one's supervisor as quickly as possible, rather than spending the time to consider a range of possible projects. And finally, this scheme is not designed to provide an overall optimisation of student satisfaction. Those who cannot find a supervisor quickly can end up with highly unsuitable projects.

The most common approach in order to solve these deficiencies is to try to match up students and supervisors so as to optimise student satisfaction while still retaining a cap on the number of students allocated to any given supervisor. In order to do so, usually students are required to provide a ranked list of supervisors. Frequently this is done by hand, but again, this procedure does not guarantee an optimal allocation in terms of student satisfaction. Also, unexpected changes during the allocation process (like agreed allocation of one student to one supervisor) may force to re-allocate all the students again. In addition to these disadvantages, the differences on supervisors' popularity imply that some students may have to be allocated with supervisors who do not appear on their ranked lists (also being allocated to unappropriated projects). Q3

Another classical approach for student allocation is to consider the preferences of students over specific projects. If this was applied together with the approaches presented above, it would be necessary to rank the preference of supervisors to specific projects (assuming that projects and supervisors are completely unrelated). In any case, this would only worsen even more the overall satisfaction as the allocation becomes more constrained and complex. Therefore, the use of a less restrictive satisfaction metric like the preference towards project categories (instead of specific projects) should improve the overall satisfaction. Here, project categories are general research areas (such as process modelling or bioprocesses in chemical engineering), represented by several supervisors. Generally, once an academic has a set of students to supervise, discussion can take place, taking into account the students' specific preferences, to arrive at satisfactory project allocations. Additionally, in most cases all the projects proposed by each supervisor share category (research area) and nature (approach followed, for example experimental or computational). If the projects proposed by a supervisor are very different in nature, it could be possible to add these project characteristics as categories, since both are project descriptors.

Again, as for the supervisor preference, it would be required that the students provide information about their preferred project categories (ideally together with information on preferred supervisors), so at least supervisor or category satisfaction can be achieved for each student. While this facilitates the generation of good allocations, it does not ensure that the allocation is optimal, particularly if students are to be allocated via manual procedures. Furthermore, the methodology is still very sensitive to unexpected changes in supervisors and/or students availability.

Automating the allocation process can greatly reduce the time needed to obtain a satisfactory allocation, allowing to recalculate it in reasonable time even if new unexpected changes occur. In addition, automated methods may be the only reasonable and sensible procedure in today's academic environment, which has experienced a pronounced increase in university students (for example from 2009 to 2014, the number of chemical engineering students in the UK increased by 97%) ("UCAS (Universities and Colleges Admissions Service) Database" 2016). This automation, however, requires of specifically designed algorithms (depending on the particular criteria followed when allocating), usually based on mathematical principles so to find an optimal allocation.

Several allocation methodologies can be found in the literature, some using the principles mentioned above. The allocation (or matching) problem has been widely considered in the operations engineering (Arora and Puri, 1998; Wu and Sun, 2006) and chemical engineering (Cecconet al., 2016; Kang and Liu, 2014) research literature, especially for scheduling of processes (Kondili et al., 1993; Méndez et al., 2006), where certain tasks have to be allocated in time periods in order to optimise the overall production time. In these

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