College admission problem for university dual education

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***Abstract*— Dual form of higher education training exists in Hungary since 2015. Students in a dual university programme complete their theoretical study at the university and participate in practical trainings at designated companies. In this paper we analyse the current recruitment process of the dual training, its relation to the classical and generalised stable matching problems. Possible alternatives for the current procedure are explored and a web application supporting the dual college admission procedure is presented.**

Keywords—college admission problem, stable matching, dual university training

I. INTRODUCTION

The dual form of higher education training was introduced in the following five fields in the Hungarian universities in September 2015: engineering, informatics, agrarian studies, natural sciences and economics. The essence of this type of education is that a dual student receives both theoretical and practical training during her university years. The former at the university and the latter at a company closely co-operating with the higher education institution. The training time proportion is roughly half-half for both practice and theory distributed throughout the course.

Students in dual training complete their theoretical study at the university together with traditional students and then participate in practical trainings at the company stage. On an annual basis, the student must spend 2 semesters (each lasts 14 weeks) with university studies, and 24 weeks at the companies (8 weeks in the winter and 16 weeks in the summer including 4 weeks of leave).

The company must sign a cooperation agreement with the university in order to participate in the dual training. The companies sign a student-contract with the students. The company is obliged to provide a grant to the student throughout the whole course of the training, including the institutional period. The grant is about 70% of the minimum wage per month. A dual student can opt for a transition to a traditional type of study during her university studies at any time, and the company can terminate the student's legal relationship at any time as well. Each company uses its own selection method to decide which candidate student can take part in its dual training system. It can be based for example on the students' CVs, on personal interviews or on admission tests.

The purpose of this paper is to analyse the recruitment process of the dual training, its relation to the stable matching problem and the presentation of the web application supporting the dual college admission procedure. To this end, the publication

a. describes the Hungarian college admission procedure and its connection to the stable matching problem,
b. reveals the current admission procedure for university dual training and its possible alternatives, describes their advantages and disadvantages,
c. introduces the basics of a web application supporting dual university admission that we have developed.

II. THE HUNGARIAN COLLEGE ADMISSION PROCEURE AND THE GALE SHAPLEY ALGORITHM

Admissions into Hungarian universities have been organised via a centralised matching scheme since 1996. The current algorithm implemented is based on the student-proposing algorithm of Gale and Shapley [10] with some heuristics included due to the special features present.

In the classical model of Gale and Shapley we have students on the one side of the market and colleges on the other side. Note that in the writing we will have university programmes instead of colleges, since in Hungary the students are applying to programmes in the central admission scheme. The students submit their strict preferences over the programmes and the universities rank the students strictly and set upper quotas for each programme. A solution is a *matching*, where every student is admitted to at most one programme and each programme receives at most as many students as its upper quota. A matching is *stable* if there is no so-called *blocking pair* consisting of a student S and a programme P such that S is matched to a least preferred programme in the matching (or remained unmatched) and P admitted another lower ranked student than S (or it has remained some empty seats). Gale and Shapley showed that their *deferred-acceptance* (DA) algorithm always produces a stable matching, and if the students make the proposals then this stable matching is the best possible for every student. Furthermore, this algorithm can be implemented in linear time in the number of applications [11], and no student has incentive to submit false preferences [16].

Due to the above desirable properties, the Gale-Shapley algorithm has been used worldwide in many applications [19], [3]. In particular, it has been already used since 1952 for the US resident allocation programme (NRMP) [17]. The topic of stable matching has been studied in multiple disciplines, such as mathematics, computer science [12], and economics V, [20], with a Nobel prize awarded to Gale and Roth in 2014 in the latter field.

However, it is enough just to have a special feature in the application, and the problem can turn computationally hard, and challenging to solve in practice. One such example is the presence of couples in the resident allocation scheme, who are looking for pairs of positions on the market. This feature made the redesign necessary in both the US [21] and later in

Scotland [6] as well. The corresponding stable matching problem was proved to be NP-hard [15] (in fact W[1]-hard [13], so the exponential running time effect of the couples cannot be separated). Therefore an engineering approach is needed for the solution [21]. This can be in a form of a Gale-Shapley type heuristic as in the US and Scotland, or some more robust optimisation technique, such as integer programming [8].

The Hungarian college admission scheme have at least four special features. The ranking of the students by the universities may involve ties due to equal scores. This feature can be treated efficiently with an adjusted Gale-Shapley algorithm [7]. The second main feature is the presence of lower quotas, which are minimum target numbers set by the universities for each programme to make the education economical. The third feature is the set of common quotas, which are faculty upper quotas and nationwide upper quotas in field of studies. Each of the latter two features makes the problem NP-hard [5], so heuristics are implemented to deal with these features. Alternative solution may be integer programming that has been studied recently [1]. Finally, the last feature that became present again in the application since 2010 is the application to pairs of teachers' programmes (such as math-physics), which is similar to the feature of couples, and also makes the problem NP-hard.

Regarding the practical implementation of the Hungarian college admission procedure a detailed description can be found in [4]. All the relevant information about the programmes is available in a centrally published booklet prior the central admission procedure. The students apply for programmes, they receive scores based on entrance exams (possibly different scores at different programmes) and they are ranked by their scores. After getting know their scores they have the opportunity of changing their preferences. Then a central agency is responsible for computing the matching and the scores of the weakest candidates admitted are published as cutoff scores. The fairness of the matching is guaranteed, as every student is admitted to the best programme of her list, where she achieved the cutoff score. (Yet, it is possible that there remain some empty seats even at some popular programmes, so stability might not be satisfied.)

The stable matching model for dual programmes can be defined in the following way. We have a set of students $\mathbf{S}=\{S_1, S_2, \dots S_n\}$, a set of university programmes $\mathbf{P}=\{P_1, P_2, \dots, P_m\}$ and a set of companies $\mathbf{C}=\{C_1, C_2, \dots, C_t\}$. A dual programme D_{jk} consists of a pair (P_j, C_k), where P_j is a university programme and C_k is a company. Every university programme P_j has a quota q_j and every dual programme D_{jk} also has a quota q_{jk} that is fixed in a partner agreement between the university and the company. An *application* is by a student to either a university programme (simple application) or to a dual programme (dual application). The students have strict preferences over their applications. The university programmes has strict rankings over the students and the companies also have strict rankings over the students.

A matching M is an allocation of the students to university programmes and dual programmes, such that no quota is violated. A matching is stable if there is no *blocking application* that is an application preferred by all parties involved. A simple application by student S_i to programme P_j is blocking if S_i prefers this application and P_j did not filled its quota q_j with higher ranked students. A dual application by student S_i to dual programme D_{jk} is blocking if S_i prefers this application to the solution and neither P_j has filled its quota with higher ranked students nor D_{jk} has been filled with q_{jk} higher ranked students according to the ranking of C_k.

Finally, we note that there is a variant of the matching with couples problem, the so-called dual-markets [14] which is very close to our college admission problem with dual programmes. In this former problem one type of members in the couples (say men) apply to a separate market than the other type of members (women). McBride showed that stable matching may not exists in this case and the problem is NP-hard under severe restrictions [14]. However, our problem is different, as the companies have fixed quotas with each of the partner universities (rather than having an overall quota on the number of students admitted).

III. The Hungarian dual college admission and its alternatives

This section highlights the current procedure of admission to dual programmes and its possible alternatives that we propose for consideration.

A. Current procedure: centralised university admissions and decentralised company recruitment

The centrally published booklet described in the previous section contains for each university programme whether it runs in a dual form and the list of companies involved. Besides the dual form, the relevant university programme must be advertised in a traditional form as well.

According to the current procedure, the dual university admission occurs in two parallel phases. One phase is the normal university application described in the previous section, which is the same as applying for an ordinary university programme. The other phase is the recruitment process of the company.

The applicant is involved in the company's recruitment process independently from the university admission. Companies individually design the process of selection with their own methodology. They set up a ranking on the students and the companies do not share these rankings with each other. Companies participating in dual training must notify applicants about the results of the selection no later than the deadline for admission preference list modification (usually this is in July). According to the feedback from the companies the student can modify her preference list in the application. If the student is admitted to more than one company, then she can decide which one to choose. The applicant may, on the basis of the results of the recruitment procedure, modify the order of application of the higher education recruitment procedure one time.

If the student successfully completes the normal university and the company admission procedures, she must indicate at the university enrolment that she wishes to begin her studies in a dual form of training. Such a student is then classified as a dual university student. In other words, successful admission to a company is not obligatory for the student, and at the time of enrolment, she may decide to start her studies in a traditional form. In the same way, the

company does not issue any binding agreement towards the student, as the contract is signed only after enrolment.

We found that the low level of trust in this type of admission procedure could cause several problems. Disadvantages of this type of admission procedure are the following:

- At the time of the recruitment period the company does not know which students will be admitted to the university programme, so they might interview students unnecessarily, bringing unnecessary costs to the recruitment process, therefore resulting in an expensive admission procedure for the company.
- A student can be admitted to more than one company, a company may not be able to receive the students it chooses, dual student positions may remain vacant at the company.
- It is difficult to inform the potential participants (i.e. students) about the possibilities of the dual training, its application procedure and about the list of the participating companies (organisational difficulty only!).
- No real commitments are established at the end of the company recruitment period from either party towards the other, the contract between the student and the company will be signed only after the student university enrolment.
- There is no guarantee that the recruitment and admission processes will result in a stable matching. It can happen that a company-student pair would prefer to match each other compared to the final solution. Example: Companies: C_1, C_2, C_3, Students: S_1, S_2. Preference lists: C_1: (S_1, S_2,…), C_2: (S_1,…), C_3: (S_2), S_1: (C_2, C_1), S_2:(C_1, C_3) and each company accepts one student. (C_2, S_1) and (C_3, S_2) pairs are formed in the process, as both C_1 and C_2 offer position to S_1 only, and S_1 chooses C_2, so the seat remains unfilled at C_2. Here (C_1, S_2) is a blocking pair. Note that this issue is arising by the decentralised nature of the recruitment process.

Advantages of the process are the following:

- Students can modify their preference list in the university application form according to the result of the company admission process.

- Flexible recruitment process at the companies, they can work on its own methodology.

B. Two-stage central recruitment procedure

After the general admission run in Hungary there is another extra run for the remaining seats for both regular university programmes and for dual programmes as well. So, the universities may try to organise the admission to their dual programmes by facilitating coordinated admission to their partner companies for those students who are already admitted to their university programmes. This two-stage procedure is summarised below.

Students first apply for the university programmes. The centrally published university admission booklet contains whether a programme runs in dual form as well. After the announcement of the score limits, the coordinator of the given university programme notifies the students about the opportunity to participate in the dual training, including the list of companies, and the deadlines. The students must contact the companies and arrange their interviews with them. The students and the companies submit their order of preference to the university coordinator after the recruitment process. A matching can be run to determine the actual pairing according to the Gale-Shapley algorithm.

Advantages:

- The calculation of the pairs can be automated.
- It is a cheaper and more transparent procedure, since only those students appear at the company admission, who have been admitted to the university.

Disadvantages:

- Students cannot validate the result achieved at the company recruitment process in their order of preference between universities.
- The solution may not be stable, even if the rankings of the programmes and companies are aligned. Take the following example with three students S_1, S_2, S_3, two university programme P_1 and P_2, ad one company C_1. The students are ranked everywhere according to their indices. P_1 has quota 2 and the dual programme (P_1,C_1) has quota 1. S_1 applies to (P_1,C_1) only, S_3 applies to P_1 only and S_2 has the following applications in the order of her preference: (P_1,C_1); P_2; P_1. In the first round of the admission procedure S_1 and S_2 are admitted to P_1, S_3 is rejected. In the second round company C_1 selects S_1 only, so S_2 is not admitted to the dual programme, only to simply P_1. Student S_2 forms a blocking pair with P_2 (and if she is admitted to P_2 then S_3 could also be admitted to P_1).

C. Nationally centralised recruitment procedure

A nationally centralised college admission procedure for university dual education might be also possible. In this case we propose the following alternative:

Universities publish in the centrally published booklet the list of companies participating in their dual training for each university programme. Students submit their university application by giving a preference list, whose elements are (P, C) pairs, where P: university programme, C: company, In the case of a programme running in non-dual form, C will be a special value, e.g. zero. Each university programme has a quota q(P) and each dual programme a quota q(P, C). It holds, that q(P, C) smaller then q(P) for each C and P.

After the application the companies and the universities must rank the students by scoring them. The university scores would be based on the existing centralised scoring system [4]. Let s(S,P) denote S's university score for P. A student's score at a company s(S,P,C) would be 0 or 1 depending on whether the student is accepted or not by the company. Remark: if a student applies to the same company through more university programmes, she must be treated separately. So theoretically it can happen that the same student receives 0 through P and receives 1 through P' from the same company.

The admission process is based on the university scores and uses a variant of the student-proposing Gale-Shapley algorithm.

At the first iteration, students submit their applications (P,C) of their first choice. Each university programme P goes through all submitted applications in decreasing order of the university scores s(S,P) of the applicants. P decides to accept

an application (S,P,C) if q(P,C) and q(P) are not reached yet with better applications and s(S,P,C) is 1. Otherwise the application is rejected. In the following iteration the students' best choice of applications are considered that have not been rejected before. P decides to accept or reject an application as in the previous step. The procedure terminates when no rejection takes place in an iteration. This procedure terminates in a stable matching and the proof is similar as in [5].

Advantages of the centralised mechanism:

- The procedure always results in a stable matching, so we can avoid the main issue of the current system (A) and the two-stage admissions (B).
- Students can better express their preferences, as they designate company-university programme pairs at the time of application. It can happen that a company C_1 has dual partnership with more programmes e.g. (P_1, C_1) and (P_2, C_1) exist and P_1 and P_2 run in a non-dual form as well. In the suggested procedure a student can express her preference of a company over a programme with the order of her preference: (P_1,C_1); (P_2,C_1); P_1; P_2.
- Computing the matching result for the applications can be implemented in a centralised automated way with clear deadlines, so no ad-hoc decentralised and strategic decision making is needed.
- The fairness of the solution can be easily demonstrated by publishing the cutoff scores of the programmes, as usual in the current practice.

Disadvantages of the process:

- The companies can express only an accepted-rejected type of preference over the students.
- The suggested procedure would imply some basic changes to the current system. For example the number of free applications should be increased.

IV. Web application for supporting dual university admission

A web-application framework has been developed for educational institutions to allocate members of different groups (e.g. students) under various special conditions to projects that has been used for internship allocation to CEMS Business Projects [2]. This framework can be expanded by submodules to solve various matching problems for concrete applications. In this section we describe a submodule developed by the authors for supporting university dual education admission conducted by the university programme as described previously in subsection B.

The framework provides students and company representatives with the ability to sign in and to add their own preference lists. When the matching process runs by the submodule, the framework provides the above data to the submodule. We use the following terms:

- Campaign: a specific matching task to be implemented between the cooperating companies and the students who apply for dual training.
- Preferences: the participants' custom ranking in the campaign. The students have strict preferences over the companies and the companies have strict rankings over the students.
- Quota of the company: the maximum number of students that a particular company wants to employ through the campaign. Setting the quotas to the campaign is the task of the company representative.
- Company representative: a person who represents the company involved in the campaign and is charge of handling the student's recruitment.
- Coordinator: the person who is responsible for the campaign from the side of the university programme. At the end of the campaign he can run the matching between the participants and then share the results with them. He can also set the deadlines for specifying the preference lists by the participants in the campaign.

The framework provides the authentication and authorization operations, and the necessary user roles for the submodule. Participants after authentication can use the framework in the campaign to set their personal information and preferences. A user (student or company representative) can participate in multiple campaigns. Participants' preference lists in the campaign can be exported from the framework to an Excel file for later use.

The submodule supporting the university dual education admission is responsible for the matching process and for the visualisation of the results. To calculate the result of the matching the submodule uses the list of the participants (i.e. students and company representatives) and their personal preference lists as an input. This information is provided by the framework. The campaign coordinator initiates the pairing process.

Four different user roles exist in the software: student, company representative, coordinator and administrator. Only the coordinators and the administrators have access to the submodule's functions. Students and company representatives only have access to their own data and preferences, as well as certain details of those in the opposite group, which are required to determine their preferences. The coordinators can inform the students and the company representatives about the obtained results regarding only the individual student and company representative.

The web application was developed in Microsoft Visual Studio 2017, using Visual Studio Team Service (VSTS) version management options. The database is stored using Microsoft SQL Server. The availability of the web application is provided by the Microsoft Azure cloud service, which ensures proper load distribution, thereby increasing availability. It also provides fast access under high loads.

The submodule was created and the stable matching algorithm was implemented in C# programming language, using LINQ instructions. The web presentation was developed with the ASP.NET (.NET Framework 4.6.2) programming language complemented by the jQuery JavaScript library. The latter is responsible for providing convenience functions. Such as manually changing the displayed order of the student and company listing or AJAX function calls for faster operation.

The following NuGet function packages were required: Entity Framework, Microsoft MVC Framework, Moq, Nunit 3, GemBox Spreadsheet. The used programs and

programming languages for the submodule are consistent with the framework's.

The submodule is based on five database tables:

- Student
- Company
- StudentPreference
- CompanyPreference
- Matching

Functions

- Import: The submodule as input parameter looks for a list of students and companies, their preference lists and the companies' quota. The input parameters can be transferred in two different ways: directly from the framework's database or from an Excel file which is exported from the framework in the right format and layout.
- Matching: It automatically performs the stable matching process based on the input data after the import. It uses the Gale-Shapley algorithm to ensure the finite number of steps and the stability of the result.
- Stability check: Checks whether the result is actually stable. If for some reason it is not stable, the application lists the student and company pairs for whom the end result is not optimal and for whom the stability of the result is compromised.
- Print results: The result of the matching can be printed in the visual display's simplified black and white layout.
- Export results: The result of the matching can be exported to Excel spreadsheets for storage or for a possible later processing.

Visual Display

The submodule provides a visual display enabling the coordinators to review the result and its details of the matching run (as shown in Fig. 1). The visual display allows the user to select a student, a company representative, or a student-company representative pair; to display the detailed result of the matching. Then it is possible to check list-like how exactly the end result is generated for the chosen participant or their pairs.

Evaluation of the results and simulations

The proper operation was tested by running simulations on sample data from previous years and on generated data as well (even with extremely selected values).

The average running time of the algorithm for participants up to a few hundred is close to $O(n)$, so the run-time is directly proportional to the number of participants.

V. CONCLUSION AND FUTURE WORK

In this paper we present the admission process to dual programmes in Hungary, where the students are seeking admission to both a university programme and an associated company training. Currently the university part of the admission is centrally coordinated, but the companies' recruitment is decentralised. In the paper the stable matching model for dual university programme is defined as a special case for the college admission problem. Furthermore a nationally centralised college admission procedure is described and analysed as an alternative solution for the currently used method.

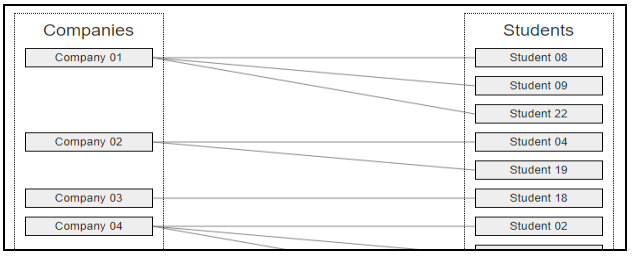

Fig. 1 - Visual display of the matching process

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