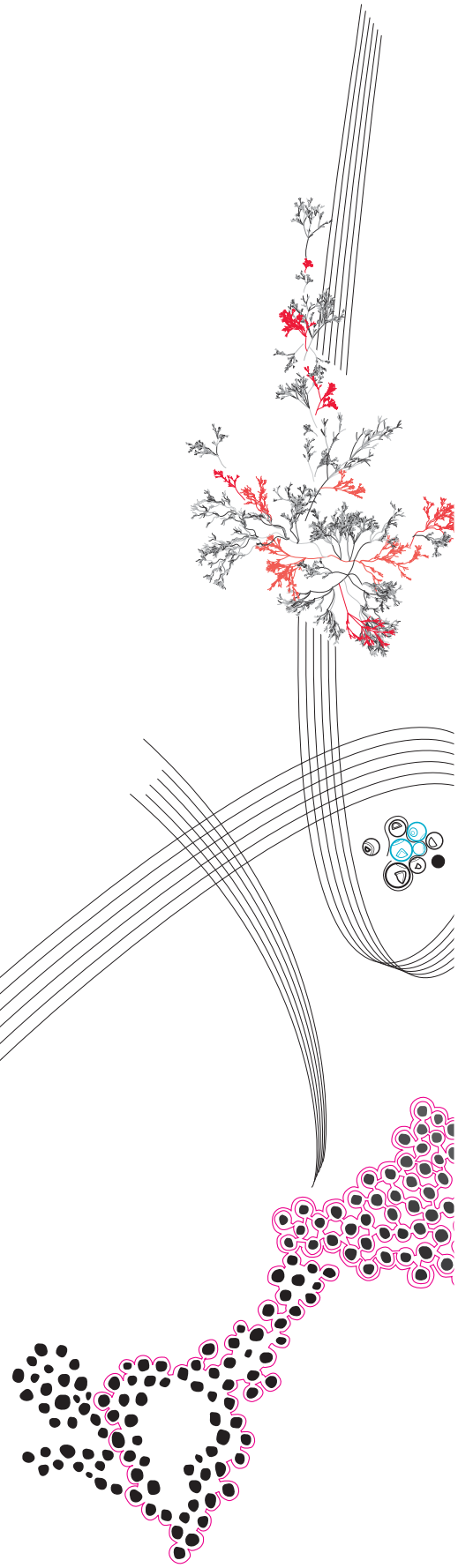

BSc Thesis Applied Mathematics

Optimal automated matching of students and universities in the 'study abroad' exchange programme

Nynke Luijten

Supervisor: R. Boucherie

June, 2024

Department of Applied Mathematics
Faculty of Electrical Engineering,
Mathematics and Computer Science

UNIVERSITY OF TWENTE.

Preface

This section is dedicated to the acknowledgement of help to the people who contributed to this thesis.

First and foremost, I want to thank my supervisor, Richard Boucherie, for his continuous guidance, expertise and enthusiasm throughout the project. Even as chair of SOR, Richard would always find the time to assist me with my questions and give feedback throughout the project. Richard insisted on efficiency from the very start, including agendas and summaries for meetings. This helped me a lot to keep an overview of the thesis.

Secondly, I want to thank Dorien van de Belt from the Scholarship Office & International Relations. She suggested this project to Richard, who turned it into a bachelor assignment. Dorien was very willing to meet and reform the data on request.

Moreover, many thanks to the ECOs, Jitse Rijken, Tahnee Smits, Sarah Kotter, Belinda Jaarsma - Knol, Brigitte Leurink, Gyöngyi Karácsony and Jaap Stout, who let Richard and I join a meeting to present the program and discuss the challenges. Special thanks to Sarah Kotter and Gyöngyi Karácsony, with whom a second meeting was held to follow up on some points.

Last but certainly not least, I want to thank my family and friends for their support and interest in my thesis. Special thanks to my mom and Tristan for proofreading, and to Tristan for being an inexhaustible source of support.

Optimal automated matching of students and universities in the 'study abroad' exchange programme

Nynke Luijten *

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Abstract

In this thesis, a model is created that represents the optimal matching of students and universities in the 'study abroad' exchange program. The matching has many constraints that should be considered when performing the matching. The problem is a minimisation Integer Linear Program, and by the Totally Unimodular property, can be simplified to a Linear Program. A computer implementation using the closed-source library Gurobipy is used for the automation process. The automated matching substantially outperforms the current manual matching.

Keywords: Matching, Linear Programming, Integer Linear Program, Minimization, Graph, Totally Unimodular, Gurobipy

*Email: n.luijten@student.utwente.nl

Contents

1 Introduction

Around 500 students apply to the Study Abroad program at the University of Twente every year via Mobility Online (see section A.1). They are interested in studying abroad for a semester at a partner university. The students enter a list of their preferences in the system, after which the Exchange Coordinators (ECOs) make a matching. The matching that arises from this data, is ideally such that as many students as possible are assigned to a university that is high on their preference list.

Not only the preferences of students should be taken into account. The universities have many constraints, such as a limited number of available total places for each semester. Moreover, there is a limited number of spots per study level (BSc and MSc) as well as the different faculties and programmes. Furthermore, the ECOs should be able to assign students to a specific spot if they so wish. All these factors should be taken into account when finding an optimal matching.

The matching of the students and the universities is currently done by hand by the ECOs. This is a very time-consuming process, and an optimal solution is hard to find. Therefore it would be beneficial for both the ECOs and the students if the matching could be automated.

This thesis will focus on the optimal automated matching problem that arises in the matching of students and universities. The research question is: *How can the matching of students and universities be modelled, optimized and automated?*

A small data set with three students and six universities can be displayed as in figure 1.

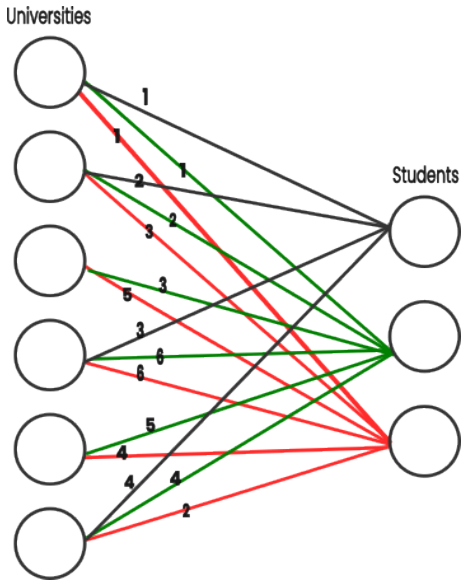

FIGURE 1: Graphical problem representation

This is a bipartite graph, as will be discussed in section 2.1. The edges but more specifically the numbers represent the preferences of the students. The goal is to give as many students as possible their highest preference, which can be written as a minimization

Integer Linear Program (ILP), as will be discussed in section 2.2. A solution to this specific problem that minimizes the sum of the chosen weights, could be to give every student their first choice. In practice, this is not possible due to the constraints of the problem, see section 3. A small problem as this one can be solved by hand, but with larger data sets, an automatic matching can be implemented, see section 4. The results that follow from this automated matching will be discussed in section 5.

2 Preliminaries

2.1 Graph Theory

2.1.1 Notation

A graph G is an ordered triple $(V(G), E(G), \psi(G))$, where $V(G)$ is a nonempty set of vertices, $E(G)$ a set of edges, disjoint from $V(G)$ and $\psi(G)$ an incidence function that associates each edge of G with an unordered pair of vertices of G. The size of $E(G)$ is denoted by ϵ and the size of $V(G)$ by μ. Edge e is a loop if the begin point and end point of the edge are the same, else the edge is called a link. Two edges e_1 and e_2 are adjacent if the begin or end point of edge e_1 is the same as the begin or end point of e_2. An edge e and a vertex v are incident if v is the begin and/or endpoint of e. The degree of a vertex is the amount of edges incident with the vertex. [3]

Figure 2 shows an example of a graph, with $V(G) = \{x_1, y_1, y_2, y_3, y_4, y_5\}$, $E(G) = \{x_1y_1, x_1y_2, x_1y_3, x_1y_4, x_1y_5\}$.

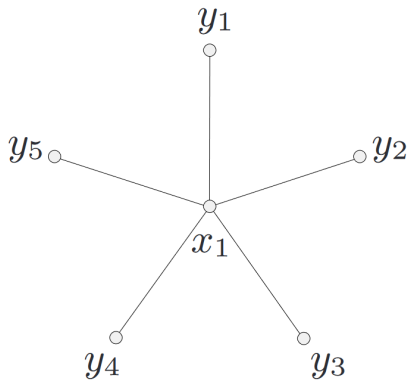

FIGURE 2: Example of a graph [2]

2.1.2 Incidence matrix

The incidence matrix of a graph is the matrix $A = [a_{ij}]$, where a_{ij} is 0, 1 or 2 and denotes the number of times that vertex v_i and edge e_j are incident. [3]
The graph of figure 2 has incidence matrix as follows:

$$\begin{array}{c} \\ x_1 \\ y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{array} \begin{array}{c} \begin{array}{ccccc} e_1 = x_1y_1 & e_2 = x_1y_2 & e_3 = x_1y_3 & e_4 = x_1y_4 & e_5 = x_1y_5 \end{array} \\ \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

It can be seen that the sum of every column is 2, as each edge has a begin and end point.

2.1.3 Bipartite graphs

A graph is bipartite if the vertex set can be partitioned into two disjoint subsets X and Y, such that each edge has one end in X and one in Y. (X, Y) is called the partition of

G. The edges going between the students and the universities satisfy the bipartite graph properties. Figure 3 shows an example of a bipartite graph, with $X = \{x_1, x_2, x_3\}$ and $Y = \{y_1, y_2, y_3\}$. [3]

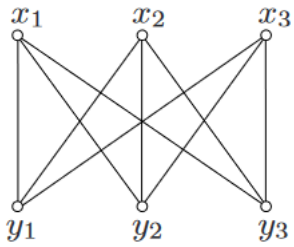

FIGURE 3: An example of a bipartite graph [3]

This particular graph is a complete bipartite graph, denoted by $K_{n,m}$, where $|X| = n$ and $|Y| = m$, meaning that there is an edge between each vertex of X and each vertex of Y.

2.1.4 Matching

A subset E' of E is a matching of G if the elements of E' are links and no two elements are adjacent in G. In terms of the student matching problem, this means that a student cannot be matched to two universities. A matching E' saturates a vertex v of G if some edge in E' is incident with v, in which case the vertex is called E'-saturated. A matching E' is perfect if every vertex of G is E'-saturated. The bold lines form a perfect matching of the graph in figure 4. [3]

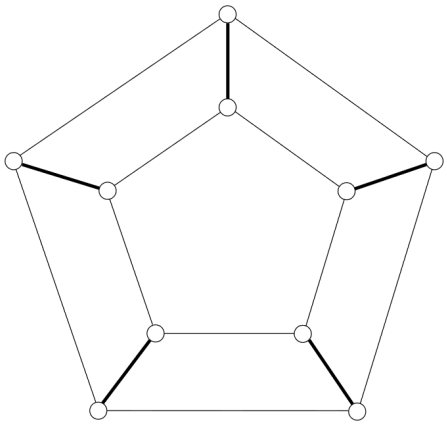

FIGURE 4: Perfect matching [2]

2.2 Linear Programming

2.2.1 Notation

This section is adapted from the book Introduction to Linear Optimization by D. Bertsimas and J.N. Tsitsiklis [1]. For readability, further citations will be omitted.

A general linear programming (LP) problem has a cost vector $\mathbf{c} = (c_1, \ldots, c_n)$. The goal is to minimize a linear cost function $\mathbf{c'x} = \sum_{i=1}^{n} c_i x_i$. This function is called the *objective function*. The decision variables $x_1, \ldots, x_n$ are subject to a set of linear equality and inequality constraints. A vector $\mathbf{x}$ that satisfies all constraints is called a *feasible solution*.

An LP can have more than one feasible solution, so the set of all feasible solutions is called the *feasible set* or *feasible region*. A feasible solution $\mathbf{x}^*$ that minimizes the objective function is called an *optimal feasible solution*. The value of $\mathbf{cx}^*$ is the *optimal cost*. There can be more than one optimal feasible solution if all these solutions have the same optimal cost, from which a random solution can be chosen. If for every solution $\mathbf{x}^*$, a better solution can be found, then the problem is said to be unbounded below (or just unbounded) and $\mathbf{cx} = -\infty$.

Define D_1, D_2, D_3 to be some finite index sets, and suppose there is a scalar b_i and an n-dimensional vector $\mathbf{a_i}$. Define N_1 and N_2 as subsets of $\{1, \ldots, n\}$, which will be used to indicate the non-negativity or non-positivity of the decision factors. If $j \notin N_1$ or N_2, then x_j is called a *free or unrestricted variable*. This all boils down to the following notation.

$$\begin{array}{rll} \text{minimize} & \mathbf{c}'\mathbf{x} & \\ \text{subject to} & \mathbf{a}_i'\mathbf{x} \geq b_i, & i \in D_1, \\ & \mathbf{a}_i'\mathbf{x} \leq b_i, & i \in D_2, \\ & \mathbf{a}_i'\mathbf{x} = b_i, & i \in D_3, \\ & x_j \geq 0, & j \in N_1, \\ & x_j \leq 0, & j \in N_2. \end{array}$$

This can be denoted more concisely, by introducing the $m \times n$ matrix A as follows:

$$\mathbf{A} = \begin{bmatrix} - & \mathbf{a}_1' & - \\ & \vdots & \\ - & \mathbf{a}_m' & - \end{bmatrix}$$

Then the general form of the LP becomes

$$\begin{array}{l} \text{minimize } \mathbf{c}'\mathbf{x} \\ \text{subject to } \mathbf{Ax} \geq \mathbf{b} \end{array} \tag{1}$$

The following example illustrates the use of the A, $\mathbf{b}$ and $\mathbf{c}$.

Example 1

$$\begin{array}{lll} \text{minimize } x_1 - x_2 + 4x_3 & & \\ \textit{subject to } x_1 + x_2 + x_4 & \leq 2 \\ 3x_2 - x_3 & = 0 \\ x_3 + x_4 & \geq 3 \\ x_1 & \geq 0 \\ x_3 & \leq 0 \end{array}$$

Then

$$\mathbf{A} = \begin{bmatrix} 1 & 1 & 0 & 1 \\ 0 & 3 & -1 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

The cost vector $\boldsymbol{c} = (1, -1, 4, 0)$ *and* $\boldsymbol{b} = (2, 0, 3, 0, 0)$.

The standard form (2) is equivalent to the general form (1) and is denoted as follows:

$$\begin{aligned} &\text{minimize } \mathbf{c}'\mathbf{x} \\ &\text{subject to } \mathbf{A}\mathbf{x} = \mathbf{b} \\ &\qquad\quad \mathbf{x} \geq \mathbf{0} \end{aligned} \tag{2}$$

The notion of a basic solution and a basic feasible solution is defined below and will be referred to later.

Definition 1 *Consider a polyhedron P defined by linear equality and inequality constraints, and let $\mathbf{x}^*$ be an element of $\Re^n$.*
(a) The vector $\mathbf{x}^*$ is a basic solution if:
(i) All equality constraints are active;
(ii) Out of the constraints that are active at $\mathbf{x}^*$, there are n of them that are linearly independent.
(b) If $\mathbf{x}^*$ is a basic solution that satisfies all of the constraints, we say that it is a basic feasible solution.

The following theorem clarifies the definition.

Theorem 1 *Let P be a nonempty polyhedron and let $\mathbf{x}^* \in P$. Then, the following are equivalent:*
(a) $\mathbf{x}^*$ is a vertex;
(b) $\mathbf{x}^*$ is an extreme point;
(c) $\mathbf{x}^*$ is a basic feasible solution.

Figure 5 shows an example of a feasible region P with its basic feasible solutions.

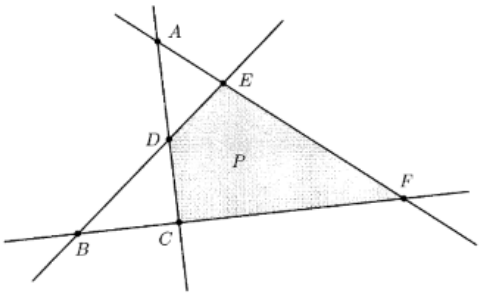

FIGURE 5: The feasible region is P, and C, D, E, and F are basic feasible solutions [1]

2.2.2 Total unimodularity

Before we begin with the notion of unimodularity, we must first define the notion of a determinant of a matrix.

Definition 2 (Determinant of a 2×2 matrix) *If*

$$A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$$

is a 2×2 matrix with entries from a field F, then we define the determinant of A, denoted $\det(A)$ or $|A|$, to be the scalar $ad - bc$ [5].

This definition is used recursively in the calculation of the determinant of a $n \times n$ matrix.

Definition 3 (Determinant of a $n \times n$ matrix) *Let $A \in \mathrm{M}_{n\times n}(F)$. If $n = 1$, so that $A = (A_{11})$, we define $\det(A) = A_{11}$. For $n \geq 2$, we* define $\det(A)$ *recursively as*

$$\det(A) = \sum_{j=1}^{n} (-1)^{1+j} A_{1j} \cdot \det\left(\tilde{A}_{1j}\right)$$

where $\tilde{A}_{ij}$ is obtained from A by deleting row i and column j. [5]

Now that the notion of determinant is clear, we can move on to unimodularity.

Definition 4 (Unimodular) *A square matrix whose determinant is 0, 1 or -1 is called unimodular [4].*

This is a stepping stone to the definition of total unimodularity.

Definition 5 (Totally unimodular) *A matrix is totally unimodular (TU) if the determinant of each square submatrix is 0, 1 or -1 [4, 6, 8].*

The TU property is very useful in Linear Programming. The next result from [8] is used in the proof of a later theorem that concerns the TU property.

Theorem 2 *Let A be a matrix with entries 0, +1 or -1. Then the following are equivalent.*
(i) A is TU
(ii) Each collection of columns of A can be split into two parts so that the sum of the columns in one part minus the sum of the columns in the other part is a vector with entries only 0, +1, -1.

The incident matrix of a bipartite graph is TU, as is formalized in the following theorem.

Theorem 3 *Let $G = (V, E)$ be an undirected graph, and let A be the $V \times E$-incidence matrix of G. Then A is TU $\iff$ G is bipartite. [8]*

Sketch proof Theorem 3
The rows of A can be split such that each column contains a 1, since there must be two 1's in each column. Therefore each collection of columns of A can be split into two parts so that the sum of the columns in one part minus the sum of the columns in the other part is a vector with entries only 0, +1, -1. Then by the result from theorem 2, we can conclude that A is TU. [8]

In an integer linear program as in equation 2, if A is TU, then the ILP can be solved as an LP and still an integer solution will be found. This is formalized in the following theorem.

Theorem 4 (Hoffman-Kruskal) *Let A be a TU matrix and let b be an integral vector. Then the polyhedron $P := \{x|Ax \leq b\}$ is integral. [8]*

Therefore, for example the simplex method could be used to find the solution. This method goes from vertex to vertex in the feasible region until an optimal vertex is reached.

3 Model

Now that the mathematical foundation has been made, the model that applies to this problem can be defined.

3.1 Problem description

In the introduction, a general problem description was given. This section will discuss the detailed problem description and the challenges that come with this problem.

The university has contracts with the exchange universities that specify the total places the university has, and if applicable, the places per programme, faculty and study level. Those last three options might not be specified.

There are several types of contracts. The UT has so-called Exchange-I contracts. These are mostly non-EU universities in special places such as Australia. As can be expected, these places are popular among the students, and these places are distributed first. After that, the other contracts will be dealt with.

The students can be master (MSc) or bachelor (BSc) students. They can go on exchange in semester 1, semester 2, or the full academic year. Students who want to go the entire academic year, would in theory participate in the semester 1 draw, and stay at the university for semester 2. For the second semester, there would be a place less, since the full academic year student has already taken up a place. In practice, the exchange universities are very flexible on this regard, and therefore full academic year students may be considered as first semester students.

The students are obligated to give at least three preferences and at most six. Students that want to go to an Exchange-I university, can only choose three of those and are advised to place them in their top 3. Students who only give three options should not be favoured.

3.2 Model set-up

In this problem, there is a set of students for each semester S_1 and S_2 respectively, and a set of universities $U = \{u_1, u_2, \ldots, u_m\}, m \in \mathbb{N}$. This section will define the model for semester 1, since both semesters have the same model. Take $S_1 = S = \{s_1, s_2, \ldots, s_n\}$, $n \in \mathbb{N}$. Each $s_i \in S$ is a quadruple with the programme, level, faculty, and the identification number of that student, so $s_i = (p_i, l_i, f_i, i)$.

We can model the students and universities as a graph G, with vertices $V(G) = U \cup S$. The graph is bipartite, since there are only edges going from the students to the universities. The edges, or more precisely the edge weights, represent the preferences of the students. The edge weights can be 1, 2, 3, 4, 5 or 6. An edge weight of $k \in \{1, \ldots, 6\}$ of edge $s_i u_j$ means that the university u_j is the k-th place on student s_i's preference list. If there is not an edge between student s_i and university u_i, that means that u_i is not on the preference list of the student s_i.

Let E be the set of all edges of the graph, $E = \{e_1, e_2, \ldots, e_\epsilon\}$, $\epsilon = |E|$. Let W be the matrix representing the value of all edge weights, $W = \{(s, u) : e \text{ for } (s, u) \in E\}$. W has

the students on the vertical axis and the universities on the horizontal axis, with elements 1, 2, 3, 4, 5, or 6. The placement of these values will be determined from the data files of the ECOs.

Let O be the set that contains tuples of students with universities, $O = \{(s, u)|s \in S, u \in U\}$. These are the tuples that should be assigned. Let T be the set of the total capacity of the universities, $T = \{t_{u_i} \mid t_{u_i} \in \mathbb{N} \; \forall \; u_i \in U\}$. Let B be the set of the BSc capacity of the universities, $B = \{b_{u_i}| \; b_{u_i} \in \mathbb{N} \; \forall \; u_i \in U\}$. Let M be the set of the MSc capacity of the universities, $M = \{m_{u_i}| \; m_{u_i} \in \mathbb{N} \; \forall \; u_i \in U\}$. Let P be the set of all study programmes, $P = \{p_1, p_2, \ldots, p_{|P|}\}$, and F the set of all faculties, $F = \{$BMS, EEMCS, ET, ITC, ST, UCT$\}$.

Let L be the matrix of faculty capacities of the universities:

$$L = \begin{bmatrix} L_{u_1,BMS} & L_{u_1,EEMCS} & \ldots & L_{u_1,UCT} \\ L_{u_2,BMS} & L_{u_2,EEMCS} & \ldots & L_{u_2,UCT} \\ \vdots & \vdots & & \vdots \\ L_{u_n,BMS} & L_{u_n,EEMCS} & \ldots & L_{s_n,UCT} \end{bmatrix} \tag{3}$$

Let R be the set of study programme capacities of the universities:

$$R = \begin{bmatrix} R_{u_1,p_1} & R_{u_1,p_2} & \ldots & R_{u_1,p_{|P|}} \\ R_{u_2,p_1} & R_{u_2,p_2} & \ldots & R_{u_2,p_{|P|}} \\ \ldots & \ldots & \ldots & \ldots \\ R_{u_n,p_1} & R_{u_n,p_2} & \ldots & R_{s_n,p_{|P|}} \end{bmatrix} \tag{4}$$

Let A be the incidence matrix of G (see section 2.1.2):

$$A = \begin{bmatrix} A_{s_1,e_1} & A_{s_1,e_2} & \ldots & A_{s_1,e_\epsilon} \\ A_{s_2,e_1} & A_{s_2,e_2} & \ldots & A_{s_2,e_\epsilon} \\ \ldots & \ldots & \ldots & \ldots \\ A_{s_n,e_1} & A_{s_n,e_2} & \ldots & A_{s_n,e_\epsilon} \\ A_{u_1,e_1} & A_{u_1,e_2} & \ldots & A_{u_1,e_\epsilon} \\ A_{u_2,e_1} & A_{u_2,e_2} & \ldots & A_{u_2,e_\epsilon} \\ \ldots & \ldots & \ldots & \ldots \\ A_{u_m,e_1} & A_{u_m,e_2} & \ldots & A_{u_m,e_\epsilon} \end{bmatrix} \tag{5}$$

Lastly, define the decision variable x.

$$x(e) = x(s, u) = \begin{cases} 0 & \text{if } s \text{ and } u \text{ are not matched} \\ 1 & \text{if } s \text{ and } u \text{ are matched} \end{cases}$$

The students should now be matched to the universities. The goal is to give as many students as possible their highest choice. Therefore, we want to choose the edges such that the sum of all selected edges is as small as possible. This implies that the problem is a minimization ILP:

$$\min \sum_{i=1}^{\epsilon} W[e_i] \times x[e_i]$$

Subject To

$$\forall\ u \in U: \quad \sum_{i=1}^{n}(A[u,(s_i,u)] \times x[s_i,u]) \leq T[u] \tag{6}$$

$$\forall\ s \in S: \quad \sum_{j=1}^{m} A[s,(s,u_j)] \times x[s,u_j] = 1 \tag{7}$$

$$\forall\ u \in U: \quad (\sum_{i=1}^{n}(A[u,(s_i,u)] \times x[s_i,u]) \text{ if } l_i = \text{BSc}) \leq B[u] \tag{8}$$

$$\forall\ u \in U: \quad (\sum_{i=1}^{n}(A[u,(s_i,u)] \times x[s_i,u]) \text{ if } l_i = \text{MSc}) \leq M[u] \tag{9}$$

$$\forall\ u \in U, \forall\ p \in SP: \quad (\sum_{i=1}^{n}(A[u,(s_i,u)] \times x[s_i,u]) \text{ if } p_i = \text{p}) \leq R[u,p] \tag{10}$$

$$\forall\ u \in U, \forall\ f \in F: \quad (\sum_{i=1}^{n}(A[u,(s_i,u)] \times x[s_i,u]) \text{ if } f_i = \text{f}) \leq L[u,f] \tag{11}$$

$$\forall\ (s,u) \in O: \quad x[s,u] = 1 \tag{12}$$

$$\forall\ (s,u) \in E: \quad x[s,u] = \{0,1\} \tag{13}$$

The following table explains what each constraint represents.

Constraint	Explanation
6	Every university has a total capacity of students per semester
7	Every student is assigned to a university
8	Every university accepts a max number of BSc students
9	Every university accepts a max number of MSc students
10	Every university accepts a mac number of students from each study program
11	Every university accepts a number of students from each faculty
12	The exchange planners can allocate a certain student s onto a university u
13	The decision variables are binary, so must be either 0 or 1

TABLE 1: Explanation of constraints

The numbers necessary for all these constraints can be read from the input data, see figure 10 and 11.

Since A is TU (see theorem 3), theorem 4 can be applied, and this ILP can be solved as an LP with for example the simplex method.

3.3 Model refinement

The model needs some refinement before it can be implemented.

3.3.1 Preventing an infeasible model

It is possible that matching all students to one of their options is not feasible. However to get a feasible matching, we cannot simply relieve constraint 7. Setting the constraint to less or equal to 1, the optimal solution will be choosing no edges at all. Therefore, another solution had to be constructed.

The solution is to add an additional degree of freedom by introducing a dummy university as a 7-th choice to each student with a high edge weight of 1000. If all other choices are not possible, this university will be chosen for that student. This represents a student not being matched, while still having a feasible solution.

3.3.2 Preventing tactical preference input

Another issue that arises due to constraint 7, is that students who only select a top three preferences and leave the other three open, will be sure of a university that is in their top three. This is extremely unfair to the students who select six universities.

The solution for this issue is very similar to the previous section. Three so-called Fictional universities have been added as a preference to all students who did not enter a preference for options 4, 5 or 6. These universities are fictional-4, fictional-5 and fictional-6 respectively. The edges between students and these universities will have the same edge weights as actual fourth, fifth or sixth choices, which solves the tactical input problem.

3.3.3 Exchange-I universities

As mentioned before, the UT has several contracts that are so-called Exchange-I (EI) universities. The ECOs prefer these places distributed first, before moving on to the other universities. This can be done by changing the edge weights of the lines going to EI universities.

Consider a line between student s and university u, which is the k-th choice of the student. If u is not an EI university, the weight of the line is set to $G * k$. If u is an EI university, the weight of the line is just k. The value of G can be any value equal to or larger than 1. If G is 1, the line weights are 1 to 6 as before. If G is a number larger than 1, the weights of the lines to EI universities are lower than the other weights, giving these lines more priority. This is in principle the same as distributing the EI places first.

The weight of the lines going to the fictional universities and dummy universities should always be more than the weights produced by the $G * k$ factor.

4 Implementation

Now that the mathematical model has been finalised, the implementation can be started.

4.1 Flowchart implementation

The following figure shows the steps that are taken in the implementation. The library Gurobipy is used for the optimisation.

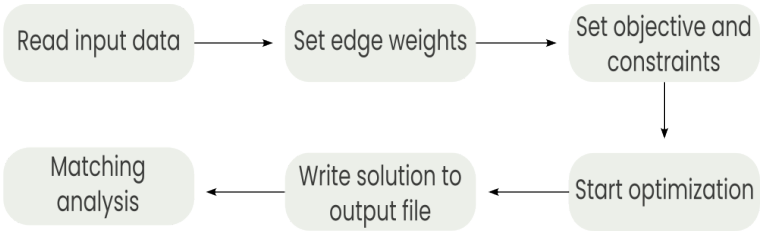

FIGURE 6: Flowchart of implementation

The pseudocode as well as the entire source code can be found in section A.2.

4.2 Branch-and-Bound algorithm

Gurobipy makes use of the Branch-and-Bound (BB) algorithm to solve ILPs. The BB is a tree search method, that starts with a (not necessarily integer) feasible solution guess.

Let X be the search space of valid solutions of the BB algorithm. A feasible solution $x \in X$ is called the incumbent solution and is stored. A subset S of X is created at each iteration, which is called a branch. If $x^* \in S$ gives a better objective value, then x^* becomes the new incumbent solution. If x^* gives a worse solution, then that entire branch will not be investigated further. Once all branches are investigated, the current incumbent solution is the optimal feasible solution. [7]

4.3 Assigning students to a specific university

Assigning a student to a specific university works as follows. In the current matching seen in figure 14, student 14 is assigned to its second preference, university 3. The first preference of student 14 is university 2. Student 14 can be assigned to university 2 by adding 14 in the column of *Students assigned* in the data file of the universities, see figure 7.

ID	Host cour	Partner in	Academic	ISCED 20	Abbr. of s	Study field	Agreemen	Total #	Max # BS	Max # MS	Nr of agre	Nr of agre	Students
1	Netherlan	UT-1	2024/2025	1111	B-TG	Technical medicine	Exchange-	2	1	1	0	0	
1	Netherlan	UT-1	2024/2025	1111	B-TCS	Technical Computer S	Exchange-	2	1	1	0	0	
1	Netherlan	UT-1	2024/2025	1111	B-AM	Applied Mathematics	Exchange-	2	1	1	0	0	
2	Netherlan	UT-2	2024/2025	2222	B-TG	Technical medicine	Exchange-	1	1	1	0	0	14
2	Netherlan	UT-2	2024/2025	2222	B-TCS	Technical Computer S	Exchange-	1	1	1	0	0	
2	Netherlan	UT-2	2024/2025	2222	B-AM	Applied Mathematics	Exchange-	1	1	1	0	0	

FIGURE 7: Assign student 14 to university 2 in the data file of the universities in column *Students assigned*

It is also possible to assign more than one student to a university, in that case the input in column *Students assigned* should be the students separated by comma and a space, see figure 8.

ID	Host cour	Partner in	Academic	ISCED 20	Abbr. of s	Study field	Agreemen	Total #	Max # BS	Max # MS	Nr of agre	Nr of agre	Students
1	Netherlan	UT-1	2024/2025	1111	B-TG	Technical medicine	Exchange-	2	1	1	0	0	30, 31

FIGURE 8: Two students assigned

4.4 Multiple feasible solutions

The program may give multiple feasible solutions, as can bee seen in figure 9.

```
Solution count 4: 3483 3493 3503 4.01e+07

Optimal solution found (tolerance 1.00e-04)
Best objective 3.483000000000e+03, best bound 3.483000000000e+03, gap 0.0000%
```

FIGURE 9: Multiple solutions found

In this case, there were four feasible solutions found, with objective value 3483, 3493, 3504, and $4.01 * 10^7$. The optimal solution is therefore the solution with objective value 3483. The other solutions can in principle also be chosen, see section A.2.4.

5 Results

5.1 Input data

The following section describes the input data. The data was received while the matching was in process. The data system of the ECOs works such that the assigned university is shifted to the first preference of the student. To clarify, when student 10 is matched to his third choice university u, u will be moved to his first choice and his first choice to place 3.

5.1.1 Universities

Figure 10 shows a subset of the input data for the universities for the academic year 2024/2025.

ID	Host country	Partner institutio	Academic ye	ISCE	Abbr. of stud	Study field	Agreement t	Total #	Max # BSc	Max # MSc
323241	South Korea	Hanyang University	2024/2025	9999	M-GEO-WO	Geo-information Science and Earth O	Exchange-I	8	8	8
323241	South Korea	Hanyang University	2024/2025	9999	M-ES	European Studies	Exchange-I	8	8	8
323241	South Korea	Hanyang University	2024/2025	9999	M-ITECH	Interaction Technology	Exchange-I	8	8	8
323241	South Korea	Hanyang University	2024/2025	9999	M-HS	Health Sciences	Exchange-I	8	8	8

Nr of agreed spots in 1st sem	Nr of agreed spots in 2nd sem	Students assigned	Partner department or consortium	Comments on spot	Comments regarding the agreement (in portal)
0	0				- Undergraduate programme only. - CGPA of minimum of 60% rec
0	0				- Undergraduate programme only. - CGPA of minimum of 60% rec
0	0				- Undergraduate programme only. - CGPA of minimum of 60% rec
0	0				- Undergraduate programme only. - CGPA of minimum of 60% rec

FIGURE 10: Input data universities

All universities have entries for each study that they accept. These inputs have the same ID, so they are differentiated from each other by the created tag *ID with study field*. For example, *323241_M-GEO-WO* is the tag of the first university.
The agreement type specifies the type of agreement that the UT has with this university. The data file contains many different types, but the most important one is *Exchange-I*. These are the partner universities outside the EU and are very popular with the UT students.

Some universities have a different number of spots in the 1st and 2nd semester. This is reflected by a nonzero value in the columns "Nr of agreed spots in semester" columns. If the value in these columns is 0, the number of spots in both semesters is the same and should be read from the "total places" column.

5.1.2 Students

Figure 11 shows a subset of the input data of the students for the academic year 2024/2025.

ID of application	Abbreviation	Study field	Study level	Academic ye	Semester	Agreement-ID	Agreement-ID	Agreement-ID	Agreement-ID	Agreement-ID	Agreement-ID	6th choice
1147093	M-BME	Biomedical Engineering	MSc	2024/2025	1st semester	666189	665339	665310	665150	665819	0	
1147111	B-CSE	Chemical Science & Engineering	BSc	2024/2025	1st semester	665835	665819	323530	665991	0	0	
1147170	B-IBA	International Business Administration	BSc	2024/2025	1st semester	666091	665234	665817	665140	0	0	
1147438	B-GZW	Health Sciences	BSc	2024/2025	1st semester	665819	665339	665880	665482	0	0	
1147541	B-ATLAS	Technology and Liberal Arts & Sciences	BSc	2024/2025	1st semester	665240	665912	665153	0	0	0	
1146899	B-EE	Electrical Engineering	BSc	2024/2025	1st semester	367666	323402	323241	367669	665753	665578	
1146928	B-TCS	Computer Science	BSc	2024/2025	1st semester	665317	666039	323402	371342	665819	665753	
1146932	B-IBA	International Business Administration	BSc	2024/2025	1st semester	323241	666039	323546	479344	665995	665873	

FIGURE 11: Input data students

For the implementation, the ID, study abbreviation the study field, the study level and the preferences are used. All students have to enter at least three universities. An input of 0 means that the student has not selected a university for this i-th preference ($i \in \{4, 5, 6\}$).

5.2 Output data

The output of the program is an Excel file, of which a subset is shown in figure 12. It shows several columns, with the most important the student, and the university it is matched to. The cells in the file can be sorted (see section A.3) on agreement type, then faculty, then agreement ID, and then semester.

Student	University	Agreemen	Semester	Preferenc	Programme	Study leve	Faculty	Agreement-ty
1146932	Hanyang University	323241	1	1	International Business Administration	BSc	BMS	Exchange-I
1147033	Hanyang University	323241	1	1	International Business Administration	BSc	BMS	Exchange-I
1147455	Hanyang University	323241	1	2	International Business Administration	BSc	BMS	Exchange-I
1147762	Hanyang University	323241	1	2	Industrial Engineering and Management	MSc	BMS	Exchange-I
1147600	Saitama University	323339	1	1	Psychology	BSc	BMS	Exchange-I
1147531	University of New South Wales (UNSW)	323533	1	2	Communication Science	BSc	BMS	Exchange-I
1147314	University of South Australia (UniSA)	323546	1	6	Communication Science	BSc	BMS	Exchange-I
1147556	University of South Australia (UniSA)	323546	1	2	Psychology	BSc	BMS	Exchange-I
1147687	University of South Australia (UniSA)	323546	1	2	International Business Administration	BSc	BMS	Exchange-I
1147333	National Yang Ming Chiao Tung University	367666	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147334	National Yang Ming Chiao Tung University	367666	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147718	National Yang Ming Chiao Tung University	367666	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147378	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	2	International Business Administration	BSc	BMS	Exchange-I
1147620	National Autonomous University of Mexico (UNAM)	426870	1	1	Psychology	BSc	BMS	Exchange-I
1147632	National Autonomous University of Mexico (UNAM)	426870	1	2	Management, Society & Technology	BSc	BMS	Exchange-I
1147664	National Autonomous University of Mexico (UNAM)	426870	1	1	Psychology	BSc	BMS	Exchange-I
1147717	National Autonomous University of Mexico (UNAM)	426870	1	1	Psychology	BSc	BMS	Exchange-I
1147255	Monterrey Institute of Technology and Higher Educa	432980	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147295	Monterrey Institute of Technology and Higher Educa	432980	1	2	Psychology	BSc	BMS	Exchange-I
1147488	Monterrey Institute of Technology and Higher Educa	432980	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147501	Monterrey Institute of Technology and Higher Educa	432980	1	1	International Business Administration	BSc	BMS	Exchange-I
1147532	Monterrey Institute of Technology and Higher Educa	432980	1	1	Management, Society & Technology	BSc	BMS	Exchange-I
1147560	Monterrey Institute of Technology and Higher Educa	432980	1	1	Communication Science	BSc	BMS	Exchange-I

FIGURE 12: Subset of output data

The entire results can be found in section A.4. It is clear if a student is matched to a dummy university or a fictional university, see figure 13 and 14.

Student	University	Agreemen	Semester	Preference
10	UT-1	1	1	1
11	UT-3	3	1	1
13	dummy-partner_name	dummy	1	-1
14	UT-2	2	1	1
16	dummy-partner_name	dummy	1	-1
18	dummy-partner_name	dummy	1	-1
19	dummy-partner_name	dummy	1	-1
21	UT-5	5	1	1
23	UT-6	6	1	4

FIGURE 13: Students assigned to dummy university

Student	University	Agreemen	Semester	Preferenc	Programm	Study level
10	fictional	0	1	-1	Applied M	BSc
11	fictional	0	1	-1	Applied M	BSc
13	fictional	0	1	-1	Technical	BSc
14	UT-3	3	1	2	Technical	BSc

FIGURE 14: Students assigned to fictional university

5.3 Matching analysis

The quality of the matching is shown in figure 15.

```
Optimal solution found (tolerance 1.00e-04)
Best objective 4.660000000000e+02, best bound 4.660000000000e+02, gap 0.0000%
First preference: 345, 85.8% of the students
Second preference: 52, 12.9% of the students
Third preference: 5, 1.2% of the students
Fourth preference: 0, 0.0% of the students
Fifth preference: 0, 0.0% of the students
Sixth preference: 0, 0.0% of the students
Students that are not matched: 0, 0.0% of the students

Execution time: 223 seconds,  4 minutes
```

FIGURE 15: Matching analysis

The percentage of students that get their first choice is very high, but for this data set that is to be expected. The matching that the ECOs make should be feasible, hence giving many students their first choice will be feasible and optimal. The program takes around 4 to 5 minutes to complete.

5.4 Exchange-I universities

In section 3.3.3, the factor G was explained. The following table shows the results of the matching for different values of G.

	G = 1	G = 5	G = 10
% First choice	85.8	84.1	83.8
% Second choice	12.9	12.9	13.4
% Third choice	1.2	2.5	2.2
% Fourth choice	0	0.2	0.2
% Fifth choice	0	0	0
% Sixth choice	0	0.2	0.2
% Students who were not matched	0	0	0

TABLE 2: Results for G = 1, 5, and 10

It can be seen that increasing G decreases the quality of the matching. Less students get their first choice, and more their third, fourth and even sixth choice.

These results are not unexpected. By increasing G, a subset of the universities is forcefully matched. That can never result in a better matching.

5.5 Validation study

It can be checked if the program works as expected with the following validation case.

The program was tested with the final data from 2024/2025 where the total matching was already performed. Therefore, an outcome is expected where each student receives their first choice, since this is feasible and will result in the lowest possible objective. Figure 16 shows the result of this matching.

```
First preference: 332, 84.3% of the students
Second preference: 50, 12.7% of the students
Third preference: 9, 2.3% of the students
Fourth preference: 3, 0.8% of the students
Fifth preference: 0, 0.0% of the students
Sixth preference: 0, 0.0% of the students
Students that are not matched: 0, 0.0% of the students
```

FIGURE 16: Unexpected result

As can be seen, this is not the result as expected. Upon inspection of the data file of the agreements, from which the constraints are constructed, it was found that the solution created by the ECOs was not a feasible one according to those constraints. There were four universities missing from the list, as well as some total places and BSc or MSc places at several universities. The ECOs can sometimes negotiate more places at a university, or for a different level student to be sent than intended. The suspicion is that these negotiations have taken place, but the data was not updated. It is not clear why a university would be missing from the master data.

In order to still perform the validation check, the agreement data was changed by hand to ensure that the matching made by the ECOs was feasible. Figure 17 shows the matching analysis with the changed data.

```
First preference: 385, 97.7% of the students
Second preference: 9, 2.3% of the students
Third preference: 0, 0.0% of the students
Fourth preference: 0, 0.0% of the students
Fifth preference: 0, 0.0% of the students
Sixth preference: 0, 0.0% of the students
Students that are not matched: 0, 0.0% of the students
```

FIGURE 17: Validation case

Checking all the contracts was prone to mistakes and some conditions might have been missed. That would explain the 9 students who are not at their first choice. Therefore, it can be said that this validation case has proven the correctness of the method.

5.6 Comparison study

The original preferences of the students for the year 2024/2025 cannot be retrieved due to the way that the matching is stored in the system of the ECOs. However, the original preferences and the matching of the ECOs has been found for the faculty ET for 2021. Therefore a comparison can be made between the matching done by hand and the automated matching. Table 3 shows the number of students for each preference, as well as the number of students who were not matched.

	ECOs	Automated matching
# First choice	49	57
# Second choice	12	12
# Third choice	7	6
# Fourth choice	4	1
# Fifth choice	3	0
# Sixth choice	0	1
# Students who were not matched	2	0
Objective value	125	109

TABLE 3: Comparison of matching made by the ECOs and the automated matching

It can be seen that this automated matching has a lower objective value. More students are matched to their first choice, and also there are no students that are not assigned.

The automated matching has one student who is assigned their sixth choice. If desired, the program can be changed such that giving students their 6th choice is discouraged, by increasing the edge weights of those edges.

It can be concluded that the automated matching is substantially better for the students than the matching done by hand.

6 Concluding remarks

The research question of this thesis was: *How can the matching of students and universities be modelled, optimized and automized?*

It was found that the matching can be modelled as an Integer Linear Program. This Integer Linear Program can be solved as a Linear Program because the A matrix is a TU matrix. The optimization is the minimization of the sum of the edge weights of the chosen edges. This implementation used the library Gurobipy to automatise the solving of the ILP.

The automated process reduces the matching process to a task of 4 to 5 minutes. This is significantly faster than the current matching by hand, as six people are working on this for two weeks. It has been shown that the (validated) automated matching results in a significantly better matching for the students.

The main recommendation for further research is to continue with the implementation, until ready for use by the ECOs. The first suggested improvement of the implementation is using an open-source LP solver. The advantage is that no academic license has to be requested, which makes it more easily accessible.

The second suggestion is adding the capability to save data in a file format which can be loaded more quickly than the CSV files that are currently used. This can be done using for example the Python library Pickle.

Furthermore, the suggestion is to make the implementation more user-friendly. The recommendation is to build a website or computer application, in which the user can select the input files, and with one button can run the program. After some time, the application automatically opens the output file. In this way, the back end is hidden from the user.

If these suggestions are implemented, the program could be tested on the students from the second semester of 2024/2025. The completeness of the constraints could be investigated in that pilot.

Lastly, the data files need to be correct in order for the automated program to return useful data. Therefore, all contracts should be correctly in Mobility Online. However, this a task that only the ECOs can do, so if the program is used in the future, the data in Mobility Online needs to be checked thoroughly.

To conclude, it has been shown that the matching can be automated while taking all the specifications into account. The automated matching substantially outperforms the current matching by hand.

References

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A Appendix

A.1 Application via Mobility Online

When a student wants to go to an exchange university, they need to apply via Mobility Online. First, the student is asked for their application details, as can be seen in figure 18.

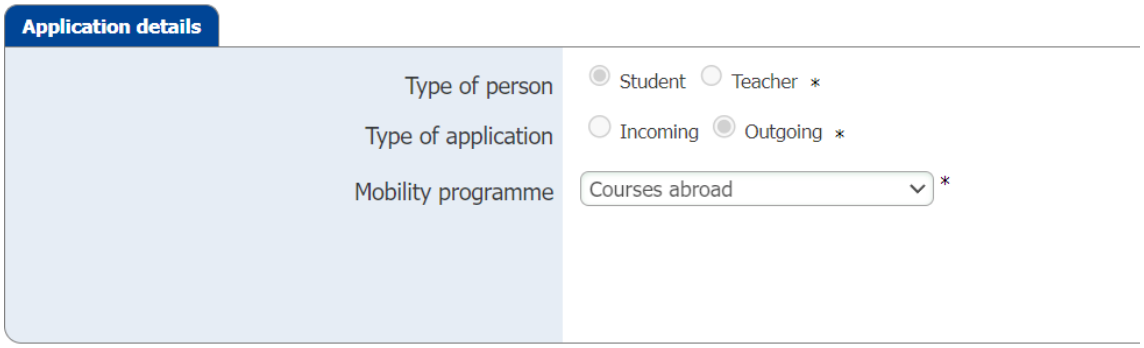

FIGURE 18: Application details

Then the student should enter their personal information such as student number and date of birth, see figure 19.

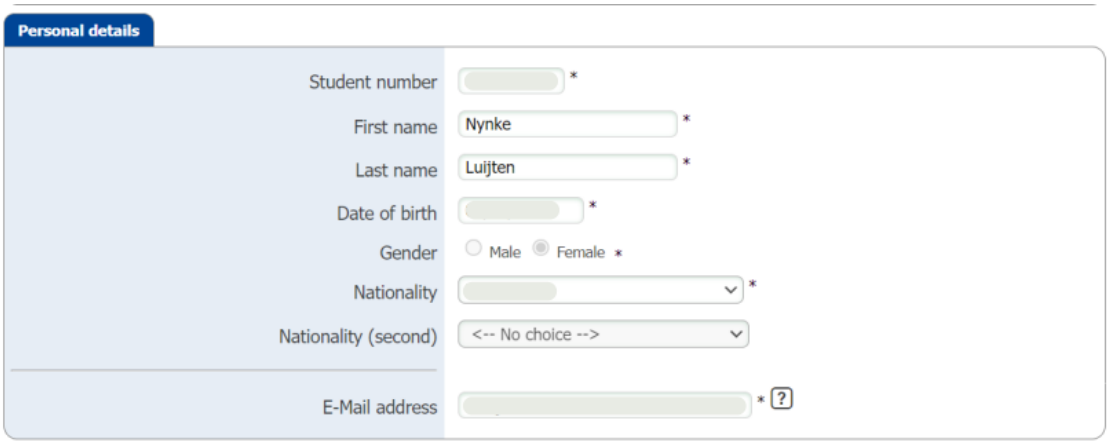

FIGURE 19: Personal details

Thirdly, the student is asked about their current study, see figure 20.

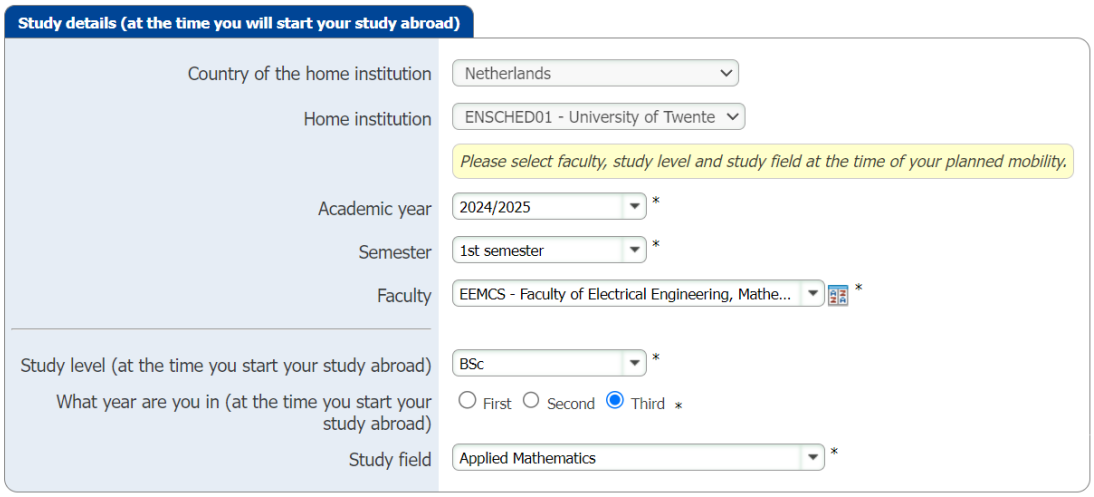

FIGURE 20: Study details

Lastly, the student can must enter at least three and at most six exchange universities in order of preference, see figure 21.

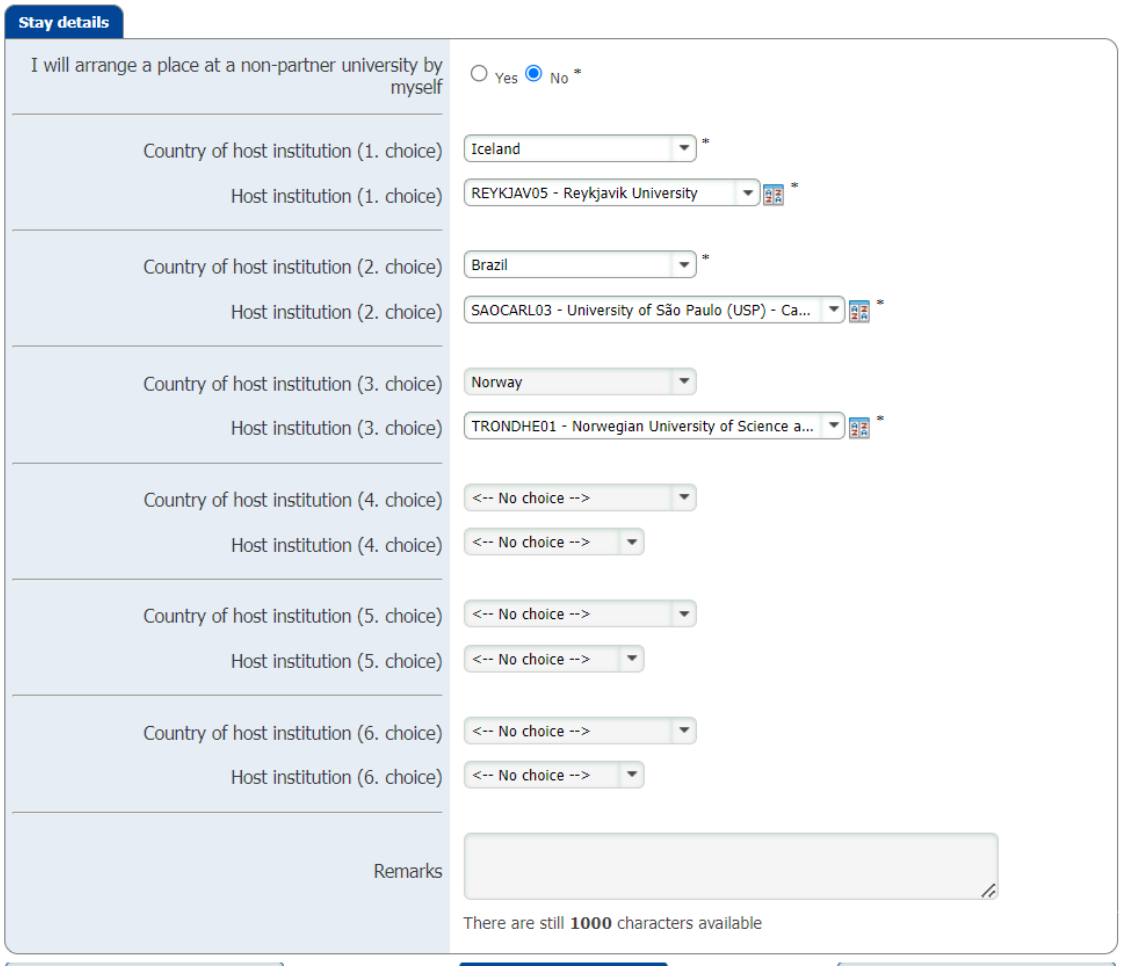

FIGURE 21: Stay details

A.2 Pseudo-code

The following section describes the code that has been written for the implementation. The entire source code can be found by scanning the following QR code:

FIGURE 22: QR code for accessing the source code

A.2.1 Classes

The implementation uses two classes, one for the students and one for the universities. The fields of the classes are filled with the information read from the input files.

A.2.2 Reading the data

The data can now be read, and all fields can be assigned to the university and student objects.

Algorithm 1 Load the universities

for each row (= university) **do**
    Read all the columns
    Determine if there are students assigned to this university
    Set the spots per semester correctly according to the input of nr of agreed spots
    Set the ID_with_study_level (=study abbreviation)
    Assign all values to a university object
    Add to the allUniversities list
    Add to the dictionary id_to_uni_object with the ID with study level as a key and the university object as a value
    Add the university to the dictionary agreement_id_to_all_universities with as key the agreement ID and as value all university objects with that ID
end for
Add a dummy university to the allUniversities list and the dictionary id_to_uni_object

Algorithm 2 Load the students

for each row (= student) **do**
    Read all the columns
    Set the preferences to the ID + _ + study abbreviation
    Set a list of all preferences
    Assign all values to the student object
    Add to the correct list, either to semester or semester 2
end for

A.2.3 Defining the model

The data has been read, so now we can define the model. For the model, the library Gurobipy has been used. This is not an open-source library since an academic license has to be requested.

Algorithm 3 Define the model

Set all possible arcs for the first and second semester (all students to all universities)
Initialize all edge weights to infinity
Change the edge weights to accord for the preferences of the students
Set model to minimize
Set model objective function
Set all constraints
Optimize the model
Select all chosen edges
Write the solution to an Excel file
Perform a matching analysis

A.2.4 Chose different solution

Algorithm 4 Chose different solution

solution_count = model.SolCount
for i in range(solution_count **do**
    model.setParam(GRB.Param.SolutionNumber, i)
    Find the active arcs as before
end for

A.3 Sort output data

The following figures show how to sort the output file.

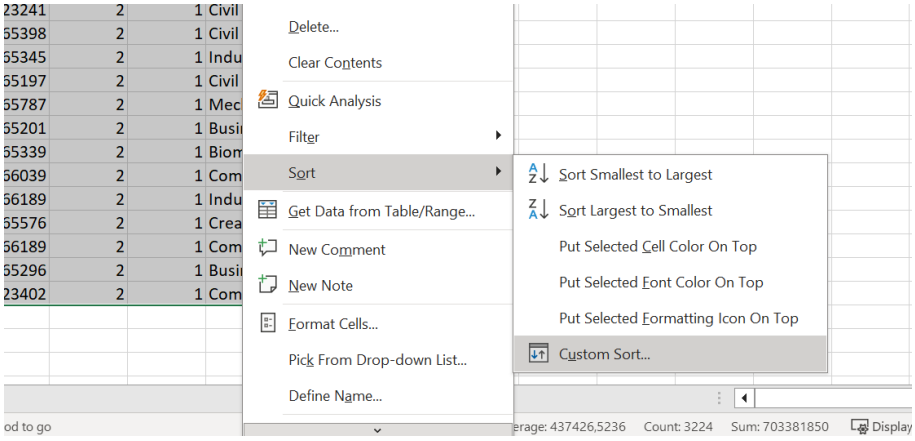

FIGURE 23: Select custom sort

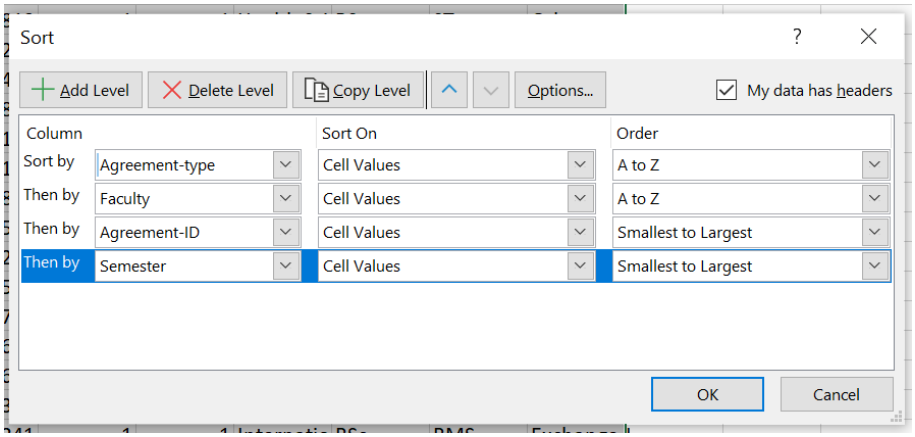

FIGURE 24: Select first faculty, then agreement ID, then semester

A.4 Full results

Student	University	Agreement-ID	Semester	Preference	Programme	Study level	Faculty	Type
1146932	Hanyang University	323241	1	1	International Business Administration	BSc	BMS	Exchange-I
1147033	Hanyang University	323241	1	1	International Business Administration	BSc	BMS	Exchange-I
1147455	Hanyang University	323241	1	2	International Business Administration	BSc	BMS	Exchange-I
1147762	Hanyang University	323241	1	2	Industrial Engineering and Management	MSc	BMS	Exchange-I
1147334	Saitama University	323339	1	2	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147600	Saitama University	323339	1	1	Psychology	BSc	BMS	Exchange-I
1147687	University of New South Wales (UNSW)	323533	1	1	International Business Administration	BSc	BMS	Exchange-I
1147314	University of South Australia (UniSA)	323546	1	6	Communication Science	BSc	BMS	Exchange-I
1147531	University of South Australia (UniSA)	323546	1	1	Communication Science	BSc	BMS	Exchange-I
1147556	University of South Australia (UniSA)	323546	1	2	Psychology	BSc	BMS	Exchange-I
1147333	National Yang Ming Chiao Tung University	367666	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147718	National Yang Ming Chiao Tung University	367666	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147378	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	2	International Business Administration	BSc	BMS	Exchange-I
1147295	National Autonomous University of Mexico (UNAM)	426870	1	1	Psychology	BSc	BMS	Exchange-I
1147620	National Autonomous University of Mexico (UNAM)	426870	1	1	Psychology	BSc	BMS	Exchange-I
1147632	National Autonomous University of Mexico (UNAM)	426870	1	2	Management, Society & Technology	BSc	BMS	Exchange-I
1147717	National Autonomous University of Mexico (UNAM)	426870	1	1	Psychology	BSc	BMS	Exchange-I
1147255	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147488	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147501	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	International Business Administration	BSc	BMS	Exchange-I
1147532	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Management, Society & Technology	BSc	BMS	Exchange-I
1147560	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Communication Science	BSc	BMS	Exchange-I
1147629	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Psychology	BSc	BMS	Exchange-I
1147664	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	2	Psychology	BSc	BMS	Exchange-I
1147668	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Psychology	BSc	BMS	Exchange-I
1147679	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	International Business Administration	BSc	BMS	Exchange-I
1147681	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147685	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Management, Society & Technology	BSc	BMS	Exchange-I
1147699	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	2	Psychology	BSc	BMS	Exchange-I
1147744	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Psychology	BSc	BMS	Exchange-I
1147745	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Psychology	BSc	BMS	Exchange-I
1147781	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	International Business Administration	BSc	BMS	Exchange-I
1147476	Institute of Technology Bandung (ITB)	665995	1	1	International Business Administration	BSc	BMS	Exchange-I
1147520	Institute of Technology Bandung (ITB)	665995	1	1	International Business Administration	BSc	BMS	Exchange-I
1147662	Institute of Technology Bandung (ITB)	665995	1	1	International Business Administration	BSc	BMS	Exchange-I
1147758	Institute of Technology Bandung (ITB)	665995	1	3	International Business Administration	BSc	BMS	Exchange-I
1147778	Institute of Technology Bandung (ITB)	665995	1	1	International Business Administration	BSc	BMS	Exchange-I
1147779	Institute of Technology Bandung (ITB)	665995	1	1	International Business Administration	BSc	BMS	Exchange-I
1147112	Nagoya University	666039	1	3	International Business Administration	BSc	BMS	Exchange-I
1147202	Nagoya University	666039	1	4	Industrial Engineering and Management	BSc	BMS	Exchange-I
1147674	Nagoya University	666039	1	2	International Business Administration	BSc	BMS	Exchange-I
1147576	Amrita University	666380	1	1	Industrial Engineering and Management	MSc	BMS	Exchange-I
1147113	Hanyang University	323241	1	1	Business & IT	BSc	EEMCS	Exchange-I
1147737	Hanyang University	323241	1	1	Electrical Engineering	BSc	EEMCS	Exchange-I

1147816	Hanyang University	323241	1	2	Creative Technology	BSc	EEMCS	Exchange-I
1147471	Saitama University	323339	1	1	Computer Science	BSc	EEMCS	Exchange-I
1146979	Tohoku University	323402	1	1	Computer Science	BSc	EEMCS	Exchange-I
1149979	Tohoku University	323402	2	1	Computer Science	BSc	EEMCS	Exchange-I
1147826	University of Melbourne	323530	1	2	Computer Science	BSc	EEMCS	Exchange-I
1147274	University of Melbourne	323530	1	2	Interaction Technology	MSc	EEMCS	Exchange-I
1147484	University of New South Wales (UNSW)	323533	1	2	Creative Technology	BSc	EEMCS	Exchange-I
1147829	University of South Australia (UniSA)	323546	1	2	Creative Technology	BSc	EEMCS	Exchange-I
1146873	National Yang Ming Chiao Tung University	367666	1	1	Computer Science	MSc	EEMCS	Exchange-I
1146899	National Yang Ming Chiao Tung University	367666	1	1	Electrical Engineering	BSc	EEMCS	Exchange-I
1147110	National Yang Ming Chiao Tung University	367666	1	1	Computer Science	BSc	EEMCS	Exchange-I
1147200	National Yang Ming Chiao Tung University	367666	1	1	Electrical Engineering	BSc	EEMCS	Exchange-I
1147376	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	1	Electrical Engineering	BSc	EEMCS	Exchange-I
1147470	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	2	Electrical Engineering	BSc	EEMCS	Exchange-I
1147177	Korean Advanced Institute of Science and Technology (KAIST)	367669	1	1	Interaction Technology	MSc	EEMCS	Exchange-I
1147757	Korean Advanced Institute of Science and Technology (KAIST)	367669	1	1	Computer Science	MSc	EEMCS	Exchange-I
1148523	National Autonomous University of Mexico (UNAM)	426870	1	3	Interaction Technology	MSc	EEMCS	Exchange-I
1147415	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	2	Electrical Engineering	BSc	EEMCS	Exchange-I
1147487	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Computer Science	BSc	EEMCS	Exchange-I
1147721	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Electrical Engineering	BSc	EEMCS	Exchange-I
1147830	New Jersey Institute of Technology (NJIT)	544234	1	2	Creative Technology	BSc	EEMCS	Exchange-I
1146928	Pohang University of Science and Technology (POSTECH)	665317	1	1	Computer Science	BSc	EEMCS	Exchange-I
1147899	Pohang University of Science and Technology (POSTECH)	665317	1	1	Creative Technology	BSc	EEMCS	Exchange-I
1146982	Institute of Technology Bandung (ITB)	665995	1	3	Creative Technology	BSc	EEMCS	Exchange-I
1147740	Institute of Technology Bandung (ITB)	665995	1	3	Creative Technology	BSc	EEMCS	Exchange-I
1146986	Nagoya University	666039	1	1	Computer Science	BSc	EEMCS	Exchange-I
1147503	Nagoya University	666039	1	2	Creative Technology	BSc	EEMCS	Exchange-I
1147821	Nagoya University	666039	1	2	Business & IT	BSc	EEMCS	Exchange-I
1147716	Nagoya University	666039	2	1	Computer Science	BSc	EEMCS	Exchange-I
1147482	Hanyang University	323241	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147461	Hanyang University	323241	2	1	Civil Engineering	BSc	ET	Exchange-I
1147582	University of South Australia (UniSA)	323546	2	3	Civil Engineering and Management	MSc	ET	Exchange-I
1147588	National Yang Ming Chiao Tung University	367666	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1146951	National Yang Ming Chiao Tung University	367666	2	1	Civil Engineering	BSc	ET	Exchange-I
1147338	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147440	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147240	Korean Advanced Institute of Science and Technology (KAIST)	367669	1	1	Mechanical Engineering	MSc	ET	Exchange-I
1147433	Korean Advanced Institute of Science and Technology (KAIST)	367669	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147268	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147270	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147344	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Mechanical Engineering	BSc	ET	Exchange-I
1147444	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Mechanical Engineering	BSc	ET	Exchange-I
1147465	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147479	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Mechanical Engineering	BSc	ET	Exchange-I
1147555	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Mechanical Engineering - Amsterdam (VU-UT)	BSc	ET	Exchange-I

1147563	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	2	Mechanical Engineering	BSc	ET	Exchange-I
1147573	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Mechanical Engineering	BSc	ET	Exchange-I
1147143	Pohang University of Science and Technology (POSTECH)	665317	1	1	Mechanical Engineering	MSc	ET	Exchange-I
1147480	Institute of Technology Bandung (ITB)	665995	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147719	Institute of Technology Bandung (ITB)	665995	1	1	Industrial Design Engineering	BSc	ET	Exchange-I
1147475	University of Melbourne	323530	1	1	Nanotechnology	MSc	ST	Exchange-I
1147330	University of Melbourne	323530	1	2	Technical Medicine	BSc	ST	Exchange-I
1147230	Hong Kong Polytechnic University (PolyU / PolyTech)	367667	1	1	Biomedical Engineering	BSc	ST	Exchange-I
1147786	Korean Advanced Institute of Science and Technology (KAIST)	367669	1	1	Biomedical Engineering	BSc	ST	Exchange-I
1147734	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	2	Chemical Science & Engineering	BSc	ST	Exchange-I
1147457	Pohang University of Science and Technology (POSTECH)	665317	1	3	Biomedical Engineering	BSc	ST	Exchange-I
1147550	Tohoku University	323402	1	2	Technology and Liberal Arts & Sciences (ATLAS)	BSc	UCT	Exchange-I
1147095	Tohoku University	323402	1	1	Technology and Liberal Arts & Sciences (ATLAS)	BSc	UCT	Exchange-I
1147097	Tohoku University	323402	1	1	Technology and Liberal Arts & Sciences (ATLAS)	BSc	UCT	Exchange-I
1147509	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Technology and Liberal Arts & Sciences (ATLAS)	BSc	UCT	Exchange-I
1147759	Monterrey Institute of Technology and Higher Education (ITESM)	432980	1	1	Technology and Liberal Arts & Sciences (ATLAS)	BSc	UCT	Exchange-I
1147345	Pusan National University (PNU)	323328	1	1	International Business Administration	BSc	BMS	Other
1147605	Pusan National University (PNU)	323328	1	1	International Business Administration	BSc	BMS	Other
1147609	Pusan National University (PNU)	323328	1	1	Psychology	BSc	BMS	Other
1147736	Pusan National University (PNU)	323328	1	1	Psychology	BSc	BMS	Other
1147690	Singapore University of Technology and Design (SUTD)	323346	1	1	International Business Administration	BSc	BMS	Other
1147539	Seoul National University (SNU)	479344	1	2	Communication Science	BSc	BMS	Other
1147594	Seoul National University (SNU)	479344	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147598	Seoul National University (SNU)	479344	1	2	Industrial Engineering and Management	BSc	BMS	Other
1147614	Seoul National University (SNU)	479344	1	2	Psychology	BSc	BMS	Other
1147649	Seoul National University (SNU)	479344	1	1	International Business Administration	BSc	BMS	Other
1147783	Seoul National University (SNU)	479344	1	1	Communication Science	MSc	BMS	Other
1147657	Sogang University	549535	1	1	Management, Society & Technology	BSc	BMS	Other
1147692	Sogang University	549535	1	1	International Business Administration	BSc	BMS	Other
1147752	Pontifical Catholic University of Rio de Janeiro (PUC-Rio)	585407	1	1	International Business Administration	BSc	BMS	Other
1147319	University of Agder	631009	1	2	Management, Society & Technology	BSc	BMS	Other
1147412	National Taipei University of Technology	665091	1	1	Management, Society & Technology	BSc	BMS	Other
1147615	National Taipei University of Technology	665091	1	1	Psychology	BSc	BMS	Other
1147123	Ruhr University Bochum (RUB)	665092	1	1	Psychology	BSc	BMS	Other
1147732	University of Barcelona	665095	1	1	Psychology	BSc	BMS	Other
1147619	University of Porto	665115	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147625	University of Porto	665115	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147409	Charles University Prague	665121	1	2	Psychology	BSc	BMS	Other
1147634	Charles University Prague	665121	1	1	Management, Society & Technology	BSc	BMS	Other
1147656	Charles University Prague	665121	1	1	Management, Society & Technology	BSc	BMS	Other
1147725	Charles University Prague	665121	1	1	Psychology	BSc	BMS	Other
1147595	Mälardalen University	665140	1	1	Psychology	BSc	BMS	Other
1147673	Aalto University	665148	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147700	Aalto University	665148	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147321	University of Lisbon	665160	1	1	Industrial Engineering and Management	MSc	BMS	Other

1147287	University of Lisbon	665160	2	1	Industrial Engineering and Management	MSc	BMS	Other
1147774	Rīga Stradiņš University (RSU)	665176	1	2	Communication Science	BSc	BMS	Other
1147672	University of Sassari	665179	1	1	Psychology	BSc	BMS	Other
1147686	University of Sassari	665179	1	1	Psychology	BSc	BMS	Other
1147300	ESSCA School of Management	665183	1	2	International Business Administration	BSc	BMS	Other
1147498	ESSCA School of Management	665183	1	1	International Business Administration	BSc	BMS	Other
1147593	ESSCA School of Management	665183	1	1	International Business Administration	BSc	BMS	Other
1147630	ESSCA School of Management	665183	1	1	International Business Administration	BSc	BMS	Other
1147733	ESSCA School of Management	665183	1	1	Management, Society & Technology	BSc	BMS	Other
1147636	Tampere University	665195	1	1	International Business Administration	BSc	BMS	Other
1147675	Tampere University	665195	1	1	Industrial Engineering and Management	BSc	BMS	Other
1147784	University of Duisburg-Essen	665200	1	2	Psychology	BSc	BMS	Other
1147587	University of Trento	665205	1	2	International Business Administration	BSc	BMS	Other
1147667	University of Trento	665205	1	1	International Business Administration	BSc	BMS	Other
1147316	University of Trento	665206	1	1	Psychology	BSc	BMS	Other
1147528	University of Trento	665206	1	1	Psychology	BSc	BMS	Other
1147765	Norwegian University of Science and Technology (NTNU)	665220	1	1	Psychology	BSc	BMS	Other
1147768	Lappeenranta University of Technology (LUT)	665226	1	1	International Business Administration	BSc	BMS	Other
1147533	Luleå University of Technology	665234	1	1	International Business Administration	BSc	BMS	Other
1147618	Autonomous University of Barcelona (UAB)	665269	1	1	International Business Administration	BSc	BMS	Other
1147747	Autonomous University of Barcelona (UAB)	665269	1	1	International Business Administration	BSc	BMS	Other
1147500	Comillas Pontifical University	665273	1	1	International Business Administration	BSc	BMS	Other
1147547	Comillas Pontifical University	665273	1	1	Management, Society & Technology	BSc	BMS	Other
1147566	Comillas Pontifical University	665273	1	1	Management, Society & Technology	BSc	BMS	Other
1147575	Comillas Pontifical University	665273	1	1	International Business Administration	BSc	BMS	Other
1147469	Autonomous University of Madrid (UAM)	665275	1	1	Psychology	MSc	BMS	Other
1147680	Autonomous University of Madrid (UAM)	665276	1	1	International Business Administration	BSc	BMS	Other
1147490	University of the Balearic Islands	665278	1	1	Management, Society & Technology	BSc	BMS	Other
1147644	University of the Balearic Islands	665278	1	1	Psychology	BSc	BMS	Other
1147559	University of Valencia	665307	1	1	Psychology	BSc	BMS	Other
1147585	University of Valencia	665307	1	1	Psychology	BSc	BMS	Other
1147645	University of Valencia	665307	1	1	Psychology	BSc	BMS	Other
1147712	University of Valencia	665307	1	1	Psychology	BSc	BMS	Other
1147688	University of Münster	665312	1	1	Psychology	BSc	BMS	Other
1147703	University of Münster	665312	1	1	Psychology	BSc	BMS	Other
1147677	University of Fribourg	665315	1	1	Management, Society & Technology	BSc	BMS	Other
1147548	University of Münster	665330	1	1	International Business Administration	BSc	BMS	Other
1148808	University of Münster	665330	1	1	International Business Administration	BSc	BMS	Other
1147332	Athens University of Economics and Business	665332	1	1	International Business Administration	BSc	BMS	Other
1147557	Athens University of Economics and Business	665332	1	1	International Business Administration	BSc	BMS	Other
1147569	Athens University of Economics and Business	665332	1	1	International Business Administration	BSc	BMS	Other
1147683	Athens University of Economics and Business	665332	1	1	International Business Administration	BSc	BMS	Other
1147356	Istanbul University	665334	1	1	International Business Administration	BSc	BMS	Other
1147578	Linköping University	665338	1	1	Industrial Engineering and Management	BSc	BMS	Other
1147502	Karl-Franzens University of Graz	665345	1	2	International Business Administration	BSc	BMS	Other

1147562	Karl-Franzens University of Graz	665345	1	1	International Business Administration	BSc	BMS	Other
1147546	Karl-Franzens University of Graz	665345	2	1	Industrial Engineering and Management	MSc	BMS	Other
1147477	University of Macedonia	665390	1	1	International Business Administration	BSc	BMS	Other
1147481	University of Macedonia	665390	1	1	Management, Society & Technology	BSc	BMS	Other
1147497	University of Macedonia	665390	1	1	Management, Society & Technology	BSc	BMS	Other
1147568	University of Macedonia	665390	1	1	Management, Society & Technology	BSc	BMS	Other
1147616	Eötvös Loránd University (Elte)	665394	1	1	Psychology	BSc	BMS	Other
1147617	Eötvös Loránd University (Elte)	665394	1	2	Psychology	BSc	BMS	Other
1147772	Eötvös Loránd University (Elte)	665394	1	1	Psychology	BSc	BMS	Other
1147506	Polytechnic University of Turin	665399	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147269	University of Rome 'La Sapienza'	665421	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147499	University of Rome 'La Sapienza'	665421	1	1	Industrial Engineering and Management	MSc	BMS	Other
1147641	Pablo de Olavide University (UPO)	665510	1	1	Management, Society & Technology	BSc	BMS	Other
1147695	Pablo de Olavide University (UPO)	665510	1	1	International Business Administration	BSc	BMS	Other
1148187	Rey Juan Carlos University (URJC)	665511	1	1	Management, Society & Technology	BSc	BMS	Other
1147710	Rey Juan Carlos University (URJC)	665512	1	1	Communication Science	BSc	BMS	Other
1147653	Rey Juan Carlos University (URJC)	665513	1	1	International Business Administration	BSc	BMS	Other
1147666	Rey Juan Carlos University (URJC)	665513	1	3	International Business Administration	BSc	BMS	Other
1147696	Rey Juan Carlos University (URJC)	665513	1	1	International Business Administration	BSc	BMS	Other
1147729	Rey Juan Carlos University (URJC)	665513	1	1	International Business Administration	BSc	BMS	Other
1147491	Technical University München (TUM)	665563	1	1	Industrial Engineering and Management	BSc	BMS	Other
1147540	Dublin City University	665581	1	2	Communication Science	BSc	BMS	Other
1147554	Kyushu University	665606	1	1	Communication Science	BSc	BMS	Other
1147613	Kyushu University	665606	1	1	International Business Administration	BSc	BMS	Other
1147697	Kyushu University	665606	1	1	International Business Administration	BSc	BMS	Other
1147543	Washington State University (WSU)	665630	1	1	International Business Administration	BSc	BMS	Other
1147769	Washington State University (WSU)	665630	1	1	International Business Administration	BSc	BMS	Other
1147493	University of Tübingen	665672	1	1	Psychology	BSc	BMS	Other
1147375	Rennes School of Business	665758	1	1	International Business Administration	BSc	BMS	Other
1147313	Tallinn University of Technology (TalTech)	665779	1	1	International Business Administration	BSc	BMS	Other
1147682	Tallinn University of Technology (TalTech)	665779	1	1	International Business Administration	BSc	BMS	Other
1147767	Tallinn University of Technology (TalTech)	665779	1	1	International Business Administration	BSc	BMS	Other
1147776	Reykjavik University	665799	1	2	International Business Administration	BSc	BMS	Other
1147693	Reykjavik University	665801	1	1	Psychology	BSc	BMS	Other
1147724	Reykjavik University	665801	1	1	Psychology	BSc	BMS	Other
1147468	University of Stavanger	665817	1	2	Psychology	BSc	BMS	Other
1147545	University of Stavanger	665817	1	1	International Business Administration	BSc	BMS	Other
1147646	University of Stavanger	665817	1	1	Psychology	BSc	BMS	Other
1147698	University of Stavanger	665817	1	2	International Business Administration	BSc	BMS	Other
1147705	University of Stavanger	665817	1	2	Psychology	BSc	BMS	Other
1147714	University of Stavanger	665817	1	1	Psychology	BSc	BMS	Other
1147723	University of Stavanger	665817	1	1	Psychology	BSc	BMS	Other
1147760	University of Stavanger	665817	1	1	International Business Administration	BSc	BMS	Other
1147199	University of Navarra (TECNUN)	665833	1	1	Industrial Engineering and Management	BSc	BMS	Other
1147486	University of Navarra (TECNUN)	665833	1	2	Industrial Engineering and Management	BSc	BMS	Other