IMPROVING THE ACADEMIC ENVIRONMENT THROUGH COMPUTERIZEDOPTIMIZATION TOOLS: A SUCCESS STORY AT THE LARGEST GULF UNIVERSITY

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Abstract

Enhancing the quality of the academic environment is considered as one of the major strategic goals of the College of Engineering (CoE) Deanship at King Saud University (KSU). For that aim, a series of projects have been carried out in order to design computerized optimization tools that are customized to the CoE needs.This paper briefly discusses the details of one application field that has been emphasized during these projects. The positive impact of implementing an optimization tool on the real ground has been quickly levied by all of the students, academic staff, and CoE managers. Moreover, this cost-effective management initiative is intended to be generalized to all KSU colleges in the near future.

Keywords—*Computerized optimization tools, Student registration.*

INTRODUCTION

This paper is a result of one of a series of improvement projects that are carried out at College of Engineering (CoE) at King Saud University (KSU) to enhance the quality of the academic environment. More specifically, this paper addresses the course selection problem that most of worldwide university students face during the registration period of each semester. Duringthe registration process, students face numerous issues in finding suitable schedules that account for their load requirements, prerequisite/co-requisite conditions, conflicts in exam/lecture periods, sections' capacities, idle periods, etc. Solving registration problems is a very tedious task that often requires more than the few dedicated days of the beginning of each semester. The student, along with the registrar, has to deal with thousands of possibilities to find a feasible schedule or to resorttoexceptional actions from higher-level decision makers. The issue becomes even more serious when dealing with some critical cases such as graduating students.

Actually, KSU owns a web-based registration system that enables the students to build their own schedules by providing them with all necessary information regarding course schedules, open/closed sections, instructors, room assignment, etc. It even suggests preliminary student schedules that mostly turn out to be deficientand require numerous manual adjustments before satisfying the student needs.If the student fails to build an adequate schedule, he (CoE is a college for male students only) can submit his requests via an electronic form which will be validated/rejected after being analyzed by the department registrar. The problem is that the student has to spend a lot of time and efforts in dealing with the huge database before either

accepting the first feasible schedule he may build (usually far from being the best possible schedule), or -worse- concluding, often by error, that he needs some exceptional actions from the registration committee. On the other hand, the registrar needs to thoroughly examine the students' requests before making any decisions. However, due to the heavy load and excessive stress during the registration period, the registrar often settles for validating any student's request if it turns out to be feasible, without seeking better alternatives. Also, it sometimes happens that the registrar accepts doing exceptional actions for some students, passing by potentially feasible schedules. Moreover, when opting for such decisions, the registrar must accurately know which action fits best the situation. Alas, it often occurs that the registrar does not choose the right action to do.

Having on hand an electronic registration system undoubtedly constitutes a considerable progress compared to the old-fashioned paper-based process. It indeed helps students and registrars easily detect inconsistencies in any suggested schedule. However, as far as we know,no existing course registration system does include an optimization tool that provides the best actions to do. As a matter of fact, students and registrars are restrained to proceed in a trial-and-error fashion.

To the best of our knowledge, the course selection problemhas never been addressed from mathematical modeling point of view. The two only exceptions that we are aware of are the application of the theory of constraints to the elective course registration (Üstün, 2010), and the network-flow formulation of student-to-tutorial distribution (Jeschke et al., 2007). Nevertheless, numerous investigators contributed in assessing/devising computerized course registration systems. The reader is referred to Al-Bastaki andAl-Ajeeli(2005), Al-Qatan (2009), Athineos et al. (2005), Gunawardana et al. (2008), Higaki et al, (2006), Little et al. (2000), Peng et al. (2012), Takeshita and Maeda (1999), Tchouakeu et al. (2012).These advanced information systems focus on various informaticsfeaturesincluding scripting language, open source technology, security protocols, database infrastructure, storage management, interfacing, etc. Over the years, a high level of expertise has been accumulated in these fields, resulting in course registration systems with excellent interactive communication with database, good capability of handling extreme heavy loads during the peak registration period, efficient request management techniques(in terms of issuing, receiving, processing, and replying), and successful utilization of smart phones/tablets technology.

This paper does not pretend to compete with such well-established softwarewith respect to any of the aforementioned aspects. Rather, it aligns to them by suggestingan optimized decision support tool that could be easily embedded as a complimentary module in any existing course registration system. The proposed tool provides an optimized schedule within few seconds, accounting for registration policies, sections' status, and student requests. A goal programming model has been designed in order to minimize registration problems in terms of efficient use of section capacities, fulfillment of prerequisite/co-requisite conditions, and avoidance of conflicts in lecture/lab/tutorial/exam periods.A successful implementation on all CoE

departments during the registration period of Fall 2012 shows evidence that the proposed toolnot only helps the students in building optimal schedules, but also assists the registrars in finding feasible schedules for difficult cases, thus considerably reducing registration problems. Both students and CoE Registration Committee (CoE-RC) members are now able to easily use the proposed tool through a friendly-user Excel interface.

The remainder of the paper is organized as follows. Section 2 presents the CoE registration process, emphasizing the challenges that the registrars are typically facing. Section 3 provides a rough description of the proposed optimization model. The implementation of the decision support tool is discussed in Section 4.

OVERVIEW OF THE COE REGISTRATION PROCESS

College of Engineering includes six academic departments offering seven undergraduate programs. About 400 freshmen are admitted each academic year. These are generally selected among the best KSU students that have successfully passed the preparatory year scientific program. All freshmen have to study two semesters of general engineering courses before choosing one of the seven offered engineering programs to be assigned to (these students are referred to as *Not-Assigned* students).

TABLE I
COE STUDENT-PROGRAM DISTRIBUTION

Program	Number of students
Electrical Engineering (EE)	437
Civil Engineering (CE)	387
Industrial Engineering (IE)	383
Mechanical Engineering (ME)	261
Chemical Engineering (CHE)	171
Petroleum and Gas Engineering (PGE)	78
Survey Engineering (SE)	39
Not-Assigned (N-A)	699
Total	**2455**

Currently, CoE holds more than 2400 undergraduate students that are distributed over the various engineering programs as depicted in Table I. Actually, three out of the seven offered engineering programs - namely EE, CE, and CHE - are split into different tracks at the last two semesters. By the end of the eighth semester, the student who succeeded in no less than 100 credit hours has to choose one amongst the possible tracks. Moreover, a number of CoE programs are decomposed at the two last semesters into one pool of compulsory courses and two pools of elective courses. The total number of credit hours that have to be taken from each pool depends on the department policy as detailed in Table II.

TABLE II
CREDIT HOURS DISTRIBUTION OVER COMPULSORY AND ELECTIVE POOLS

Program	Compulsory Pool	Elective Pool 1	Elective Pool 2
Electrical Engineering	11	17	6
Civil Engineering	20	6	6
Mechanical Engineering	20	12	-
Chemical Engineering	25	9	-

The main mission of the CoE-RC is to help students solve their registration problems. These often present critical situations that need to be handled with a lot of care. For instance, a student that has a consistently low load (i.e. less than 12 credit hours) needs to be registered in some additional courses. Otherwise, he will most probably be harmed by spending one or more additional semesters before graduating. Anothercritical case concerns the so-called *graduating students*. Formally, a graduating student is defined as a student having no more than 23 remaining credit hours and having successfully defended the first part of his graduation project. In order not to delay their graduation, such students have to be registered in all of their remaining courses, thus creating various potential registration issues.

In the following, we detail the numerous aspects of the CoE registration process including the course level, course requisites, student's load, section capacity, and schedule conflicts.

A. Course level

All CoE programs are designed in such a way that courses are clustered into ten levels. Each level encompasses a good mix of covered areas and offers a fair balance in terms of course difficulty. Moreover, these levels are sequenced so that the knowledge is smoothly cumulated as the student advances in his academic program. Therefore, for better educational performance, the student should stick to his academic plan as much as possible. Nonetheless, due to various reasons, students -and even registrars- are often "forced" to make some level jumps in the schedules. Such deviations are most frequently induced by a failure in one or more courses. Another common and "justifiable" scenario is that a lot of students may not want to take some general courses -by arguing that they plan to take them in the summer term- creating therefore a load deficiency that must be compensated by other courses from different levels.

One could imagine the registrar headache when dealing with a not-assigned student with low load whose only solution is to register in a restricted number of courses that are common to all CoE programs. A similar situation occurs with those students that are not eligible for choosing a track (succeeding in less than 100 credit hours), where the unique way to reach an acceptable load is to register in some courses that are shared by all of the department's tracks. As a matter of fact, CoE-RC members are striving to avoid such cases (although sometimes legitimate) as much as possible. Indeed, a student who diverged once from his academic plan will most probably never be able to recover. Therefore, a dangerous snowball effect can be

created, jeopardizing thus the whole registration and course scheduling processes in the subsequent semesters.

B.Course requisites

To apply for some courses, the student may require a certain level of background knowledge in some areas. For that purpose, he has to succeed in some courses prior to taking the course he is interested in. These courses are referred to as *prerequisites*. On the other hand, some courses need to be complimented by one or more other ones. The latter courses, referred to as *co-requisites*, should be taken in conjunction with the required course unless being already passed by the student. Each academic program has its own pre/co-requisite distribution over the relative courses. Co-requisite courses belong to the same level, whereas prerequisites belong to preceding levels.

Formally, no student can register in any course if its pre/co-requisite conditions are not satisfied. However, some critical cases may lead to violate this rule under some high level restrictions. For instance, in order to exempt a student from the prerequisite condition, the department chairman has to submit an official form to the Vice-Dean of Academic Affairs stipulating that all the following conditions are fulfilled: (*i*) such an action will make the student gain one semester in his academic curriculum; (*ii*) the student has failed in the prerequisite course, and hypothetically has an overview of the required background knowledge; (*iii*) the student will register concurrently in the two courses (the desired course and its prerequisite) in the semester of interest.

Actually, there is another kind of course requisite that is common to all CoE programs. Indeed, a mandatory graduation project is required as an integral and essential part of any CoE program. The graduation project is a two-semester project involving two courses, namely graduation project 1 (gp_1) and graduation project 2 (gp_2). These courses provide the students open-ended project experiences with a variety of realistic requirements and constraints. Obviously, gp_1 is a prerequisite for gp_2. Moreover, the student needs to have a certain amount of engineering knowledge in order to be able to suitably conduct his graduation project work. Therefore, in order to be eligible to register in gp_1, the student must satisfy the two following requirements: (*a*) all remaining courses are from the eighth level or above; (*b*) the total amount of remaining credit hours does not exceed 35.

C. Student's load

According to KSU regulations, all students must have a minimum load of 12 credit hours. The student's maximum load depends however on his GPA as displayed in Table III.

TABLE III
MAXIMUM STUDENT'S LOAD CALCULATION

GPA range	Maximum load
< 2	12
[2, 2.5)	15
[2.5, 3)	16
[3, 3.5)	17
[3.5, 4)	18
[4, 4.5)	19
[4.5, 5]	20

Except graduating students (who can register in up to 23 hours), no student is supposed to have more than his maximum load. Nevertheless, the registrar can accept some students' requests to exceed their maximum load by one or two hours if he is convinced that such an action really helps the student perform better in his academic curriculum. For instance, consider a 7th-level regular student (i.e. who succeeded in all courses below level 7) whose maximum load is 16 credit hours. If the registrar would strictly follow the maximum load restriction, then the student would not be able to register in all 7th-level courses (having a total of 17 credit hours). An immediate consequence is that the student would not be eligible to take gp_1 course in the subsequent semester. However, allowing a load excess of only one hour avoids the student to lose one semester in his academic curriculum.

D. Section capacity

According to CoE regulations, each section should ideally have around twenty-five registered students. Overloaded sections have a very negative impact on the teaching/learning quality, particularly for lab experimentations. Consequently, whenever the number of registered students reaches forty, the section should be split into two separate ones. To that aim, a new section has to be created with a suitable schedule that accounts for the faculty member timetable, room availability, students' idle periods, etc. (in one word, a horrifying headache!). On the other hand, having sections with much less than twenty-five students definitely yields underutilized resources. For that reason, the KSU Deanship of Admissions and Registration asks for closing all sections with less than ten registered students, unless the department provides strong arguments to keep it open. Obviously, closing such sections leads to additional registration problems to deal with. In fact, the registered students have to either drop the course (and probably register in other courses to fill the void), or register in other sections that suit their schedules.

From this point of view, CoE-RC members should do their best to have balanced sections with about twenty-five students. Obviously, each department has the authority to extend/reduce its sections' capacities within a reasonable range. Moreover, in order to provide some kind of flexibility, the KSU registration system allows the registrars to exceed the capacity of *any* KSU section by no more than 20%.

Whenever the number of registered students of a CoE section reaches its extended capacity, the registrars that do not belong to the corresponding department (and thus having no capacity extension authority for that section) should submit a request to the CoE-RC Chairman, asking for registering an additional student and providing arguments that the student deserves such an exceptional action. Such requests may be rejected by the CoE-RC Chairman if he is not convinced by the validity of these arguments.

E. Schedule conflicts

As it has been stated in Section 2.A, some students may need to be registered in a set of courses that do not belong to the same level. Although all CoE courses are scheduled using well-thought procedures and high-level of expertise, it may happen that the lecture/lab/tutorial periods of those required courses overlap. In this case, one possible solution for the registrar is to ask for changing the schedule of one or more conflicting courses. An immediate consequence of such an action is that the schedules of all registered students in that modified course would be turned upside down. Indeed, a course schedule change is actually made by having the registered students agree with their instructor on a suitable time. This is translated in practice by taking the course either early in the morning (7 am-8 am), or late in the afternoon (after 5 pm), or during the lunch break (12 pm-1 pm). Obviously, all these alternatives are highly disliked by all of the students, the faculty members, and the CoE management.

In order to induce minimum damage, the registrar seeks the course whose schedule change affects the minimum number of students. Moreover, the registrar tries to change the course activity with the minimum number of contact hours. For instance, the most suitable way to solve the schedule conflict would be to change the tutorial's period. Indeed, a tutorial consists only of one weekly hour and an alternative schedule should be easy to find. Also, changing a two-hour lab schedule would be better than changing a three-hour lecture schedule. To conclude, solving a course conflict needs to be handled with a lot of care and should be the last solution in dealing with a registration problem. For that purpose, having recourse to such actions in CoE is restricted only to very critical cases.

Another form of schedule conflicts concerns the final exam sessions. Indeed, all KSU final exams are scheduled prior to the registration period. This actually ensures that no conflicting issues would occur during the final exam period. For that purpose, no student should be allowed to register in two courses whose exam periods overlap. However, in order to solve a critical case, the registrar may be enforced to register the student in two such courses. Therefore, the exam period of one of these courses has to be changed. This practically means that the problem is transferred to the CoE Exam Committee to deal with it once the registration period is closed. Although such an action is highly disliked as well, it is by far preferred to a course schedule change.

THE OPTIMIZATION MODEL

The proposed optimization model consists on selecting the set of sections that best fit the student needs in terms of requested load and wanted/undesired courses/sections while respecting a large number of hard and soft constraints. The model also attempts to optimize a number of objectives with various priorities that represent the goals of the registrationcommittee.

a. Formulating hard constraints

The obtained optimized schedule must satisfy all the following constraints:

- The total number of credit hours of the suggested courses is equal to the number of hours requested by the user.
- If a course is selected, then exactly one related section must be selected. Otherwise, no related section is selected.
- The total credit hours of registered and passed elective courses cannot exceed the allowed amount of the corresponding pool.
- Undesired courses cannot be selected.
- Undesired sections cannot be selected.
- Desired courses must be selected:
- Desired sections must be selected
- gp_1 must be selected if the total remaining credit hours is no more than 35 hours and all remaining courses are from level 8 or above. Otherwise, gp_1 must not be selected.
- If the student has succeeded in gp_1, then gp_2 must be selected. Otherwise, gp_2 must not be selected.
- No section of an out-of-CoE course whose number of registered students has reached its augmented capacity (i.e. its regular capacity increased by 20%) will be suggested, unless the student is already registered in that section.
- Graduating students must register in all compulsory courses.
- No lecture/lab/tutorial schedule conflicts.
- Only selected sections may have a schedule change:

b. Formulating soft constraints

The generated optimized schedule attempts to satisfy the following goals as much as possible:

- No conflicting exam periods.
- Fulfill co-requisite conditions.

c. Objective function

The objective function consists on minimizing the weighted summation of the following sub-functions, ranked according to the decreasing order of their importance:

1- Lecture schedule changes.
2- Lab schedule changes.
3- Tutorial schedule changes.
4- Exam period changes.
5- Prerequisite violations.
6- Co-requisite violations.
7- Course level jumps.
8- External capacity extension requests.
9- Internal capacity extensions.
10- Changes in the current student's schedule.
11- Use of the 20% extra capacity.
12- Under-utilization of sections' remaining capacities.
13- Use of sections that are not assigned to CoE.

IMPLEMENTATION

In order to assess the pertinence of our approach on the real ground, we embedded our optimization model within a spreadsheet-based decision support system.This implementation phase actually constitutes a preliminary and crucial step that enables the CoE decision makers to have a good picture of the performance and usability of our approach,before deciding to move forward to a full integration with the existing web-based registration system by a professional computer designer. The implemented tool, referred to as *ORTool* (standing for *Optimized Registration Tool*),consistsin three major components: a friendly-user spreadsheet interface, a database containing all section and student information, and an automatic link to the commercial optimization solver Lingo 13. In the following, we provide a brief description of the implemented tool.

After entering the student ID, *ORTool* shows the following information:

- Student GPA
- Department
- Track
- Total number of registered credit hours
- Maximum load (according to the student GPA)
- Remaining credits
- List of remaining courses sorted by increasing level
- List of available sections for each remaining course
- List of registered sections

In addition, *ORTool* allows the user to choose the desired/undesired courses/sections. The final step before getting an optimized schedule is to enter the desired load and to click on the *Run* icon.After about thirty seconds of running time, *ORTool* provides one of the following possible outputs:

- *Feasible schedule*: In this case, *ORTool* shows the details of the suggested schedule in terms of suggested courses and corresponding sections/credit hours/levels. Moreover, it provides the student with a summary of the actions that should be taken (in terms of which sections to add/remove) in order to obtain the suggested schedule.Accordingly, he can either register in the suggested sections through the web portal, or submit a registration form to his department registrar indicating the sections that he wants to add/drop according to what has been suggested by *ORTool*.

- *Registration problems*:This situation means that the student cannot obtain the desired load according to his entered desired/undesired courses/sections unless all the displayed registration problems are solved.In this case, *ORTool*depicts the least registration problems (in terms of requisite violations and conflicting lectures/tutorials/labs/exams) that could occur in any schedule satisfying the user's requests.

- *Infeasible settings*:This situation means that there is no way to get the desired load according to the entered desired/undesired courses/sections.

The successful implementation on the real ground since Fall 2012 shows evidence that *ORTool* not only helps the students in building optimal schedules, but also assists the registrars in finding feasible schedules for difficult cases, thus considerably reducing registration problems. Both students and CoE Registration Committee members are now able to easily use *ORTool* through the friendly-user Excel interface. As a consequence, much less time is dedicated to deal with registration problems. Indeed, the registration task presently takes one week rather than three weeks in previous semesters. Moreover, much fewer people are now involved in the registration task. In addition, too few situations requiring change in schedules occur after the use of *ORTool.* More importantly, the number of students asking to solve their registration problems has been substantially reduced, since many of the bad initial tentative solutions are dealt with through *ORTool*.

To conclude, this project was a real success story as it has been stated by the CoE Dean. Moreover, this in-house designed tool is much attractive from the cost viewpoint.As a matter of fact, the KSU decision makers decided to extend *ORTool* implementation to all colleges through a web-based interface. The extension phase is expected to start in the very near future.

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