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Department of Industrial Engineering at the University of Jordan as a Case Study

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ABSTRACT. The course scheduling problem presents a major challenge for academic institutions as the number of students and thus the number of courses increase. The problem complexity is due to the large number of constraints it must handle. These constraints include university policy with regards to the faculty teaching load, faculty preference to teaching specific courses, physical constraints on the class size based on the room size, and the availability of rooms at different time slots. This paper presents a solution for the course scheduling problem using a heuristic that models the problem as a supply-demand problem, where students form the demand side and the department of Industrial Engineering at the University of Jordan forms the supply side. The heuristic accounts for a wide set of constraints. . The heuristic was implemented to develop the course schedule using Excel Solver®. It was found that the model results provided a more systematic and flexible schedule than the manual ad-hoc technique used.

KEYWORDS: Course Scheduling, Heuristic, Linear Programming, Higher Education.

1. Introduction

A reoccurring problem for academic institutions is the course scheduling problem which involves assigning courses to faculty members, then assigning these courses to time slots (Stallaert 1997). The nature of the solution used to solve the course scheduling problem is affected by the point of view from which the problem is tackled (Badri et al. 1996), (Ferland and Fleurent 1994), (Ferland and Roy 1985). From an organizational perspective, the problem becomes a problem of satisfying the changing student demand for different courses, while maintaining the contractual agreements on faculty teaching loads. As for the faculty members' perspective, the problem becomes a scheduling problem that accounts for personal preferences in assigning courses to faculty (Badri et al. 1998), (Sampson et al. 1995). Another perspective is the administration point of view, which deals with the physical resources in terms of available rooms for teaching (Patrovi and Arinze 1995). These perspectives are highly interrelated and any solution proposed for the course scheduling problem should accommodate these major perspectives in addition to other considerations which are related to the academic institutions itself.

The complexity of the course scheduling problem is due to the size of the problem, which may reach up to several hundreds of variables (Hertz and Robert 1998). Also the level of detail incorporated in the model to represent the different constraints that face the scheduling problem adds to the complexity of the model.

Many solutions have been proposed for the course scheduling problem (Carter et al. 1994), (Haase et al. 1998), (Werra 1997). Some of these solutions took a linear programming (LP) approach (Bronico 2000), where the objective was to optimize the assignment of faculty to courses subject to number of courses required, and the faculty teaching load. Other solutions used integer programming to solve the problem. In some solutions decision support systems was proposed to solve the problem (Liou and Wu 1996), (Partovi and Arinza 1995). In most of these solutions capacity remains fixed and demand is scheduled to provide timely service and utilize capacity (Krajewski and Ritzman 2002).

This wide range of solution approaches clearly illustrates the complexity of the problem, and the need to customize the solution for the academic institutions where the problem exists. The approach taken in this paper uses a heuristic that incorporates several LP models to account for the different constraints in the problem.

2. Problem Description

There is an increasing need for an effective and efficient scheduling system at The University of Jordan (U of J). This need stems from the fact the U of J is currently experiencing rapid growth due to the establishment of several new colleges and programs. Moreover, the number of students is increasing which is enforcing new challenges on the university to offer and schedule enough courses to satisfy the changing demands of students. Although a university-wide scheduling is needed, this paper will deal with the department of Industrial Engineering in the Faculty of Engineering and Technology (FET) as an example of how the proposed solution for the scheduling problem can be used.

The FET at the University of Jordan (U of J) consists of eight departments (Mechanical, Electrical, Civil, Chemical, Architectural, Industrial, Mechatronics, and Computer Engineering), with about 2500 students enrolled in the undergraduate program, and 240 students in the graduate program. There is about 118 academic teaching staff working in the FET.

Each department in the FET offers about 20 different graduate and undergraduate courses each semester in order to meet the demand generated by students, while adhering to the university policy in course offering. For example, the university imposes restrictions on the maximum number of students per class and the number of classes a faculty member can teach per semester. Also there are other limitations that are imposed by the actual capacity of classrooms in the FET, and that all courses offered must be scheduled in classrooms that are physically located in FET.

Typically class scheduling has been conducted by an ad-hoc manner in the FET, where manual timetabling combined with personal experience characterized the planning and the actual allocation process. This manual procedure was considered to be satisfactory. But recent changes in the university, such changes in the admission policy and launching several new programs in the FET are expected to increase the enrollment. As a result of these changes, the process of manual planning of the courses to be offered is becoming cumbersome and is expected to become even more complex.

This paper addresses the problem of class scheduling at the Faculty of Engineering and Technology at the University of Jordan. The problem is modeled as supply-demand problem, where student form the demand side and the FET forms the supply side. The Department of Industrial Engineering will be taken as a case study in the implementation phase to illustrate how the heuristic could ease the course scheduling process, and to limit the size of the problem in this stage of conveying the concept to other researchers.

3. Class Scheduling Model Overview

A heuristic [Figure 1] was developed to tackle the problem of class scheduling at the Faculty of Engineering and Technology.

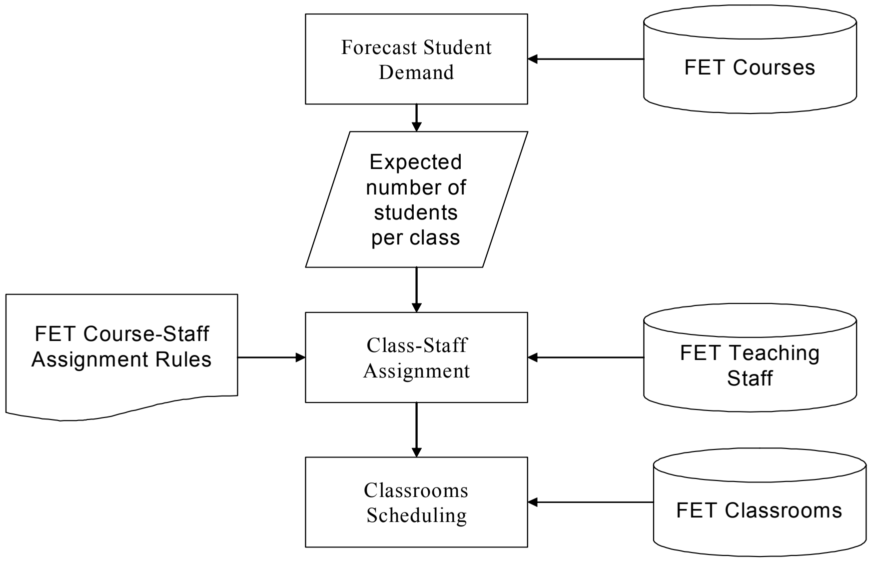

Fig. 1: Flowchart of the developed class scheduling heuristic to solve the problem of class scheduling.

Note: A class represents one section of a course taught by one professor in a single classroom.

The main steps of the class scheduling heuristic are as following:

Step 1: Forecast Student Demand

This step is concerned with determining the number of students expected to take each class to be offered. The forecasting is based on historical data adjusted by the amount of increase/decrease in the enrollment per year.

Step 2: Class – Staff Assignment

In this step courses to be offered are assigned to faculty members capable of teaching the courses needed. The assignment takes into consideration both the faculty preference to teaching a certain course and workload of each faculty member.

The assignment begins by retrieving faculty teaching preference from the FET teaching staff database. Figure 2 illustrates a sample of the retrieved data represented in a matrix. Where the preference is measured using the following scale:

2: Faculty member usually teaches the course

1: Faculty member can teach the course but usually does not

0: Faculty member usually does not teach as it is out of his/her specialty

		Faculty Member			
Course Number	1	0	1	0	2
	2	1	1	0	0
	-	0	1	2	1
	K	1	0	2	2

Fig. 2: Faculty-class teaching preference matrix used to represent the faculty members' preference to teaching different courses.

Note: if a course has more than one section (i.e. class), then all the course sections (classes) will be treated as an individual course when determining the preference for teaching.

Next, faculty workload regulations as provided by the university are taken into consideration. These regulations (Table 1) form the general guidelines for the recommended number of credit hours that can be assigned to any faculty member.

Table 1: Faculty workload regulations according to university policy

Academic Rank	Recommended Total Credit Hours	Undergraduate Projects (credit hours)	Masters Thesis (Credit hours)
Professor	9	3	6
Associate	12	3	4
Assistant	12	3	2
Lecturer	15	3	-

For example, the workload for an associate professor might be as following:

6 credit hours of classes,

2 credit hours of undergraduate projects, and

2 credit hours of master's thesis.

This will make the total workload equals 10 credit hours which will be within university guidelines.

The University regulations allows faculty to work overload if needed, but there is a strict policy of not allowing more that 6 credit hours as an overload per faculty. This means that an associate professor may have a workload of at most 18 credit hours. It is highly recommended to minimize or even eliminate overload in order not to over work faculty members to maintain high standards of quality education. Overload is used a last resort if no other solutions (such as hiring adjunct faculty) are available.

Both the faculty teaching preference and the guidelines for workloads are incorporated into a mathematical model as following:

Objective Function

Maximize the total faculty members teaching preference

$$\text{Max} \sum_{j=1}^{K} \sum_{i=1}^{N} X_{i,j} P_{i,j} \qquad (1)$$

Where:

i = 1 → N, Number of faculty members to be assigned

j = 1 → K, Number of classes to be assigned

$P_{i,j}$: Faculty member i preference scale to teach class j

$$X_{i,j} = \begin{cases} 1, & \text{if faculty member i is assigned to teach class j} \\ 0, & \text{otherwise} \end{cases}$$

Subject To

1. The total number of credit hours that can be assigned to any faculty member cannot exceed the total number of credit hours recommended by the university guidelines.

$$\sum_{j=1}^{K} X_{i,j} * Cr_j \le R_i \qquad \forall i \qquad (1.1)$$

Where:

Cr_j : Number of credit hours of course j

R_i : Recommended workload for faculty member i

2. A course can be assigned to one and only one faculty member

$$\sum_{i=1}^{N} X_{i,j} = 1 \qquad \forall j$$
(1.2)

Step 3: Classrooms Scheduling

The Faculty of Engineering and Technology has about 35 classrooms in which lectures can be held. The capacity of the rooms is 50 seats for small rooms, and 65 seats for large rooms. The university guidelines state that the class size should not exceed 60 students under any circumstances.

Each classroom is available for either one hour time slot on Sunday, Tuesday, and Thursday starting at 8:00 am (earliest starting time) till 1:00 pm (latest starting time) or one and half hour on Monday and Wednesday starting at 8:00 am (earliest starting time) till 12:30 pm (latest starting time).

The available classrooms are categorized according to departments, and each department has a priority to schedule classes in certain classrooms over other departments. For example, there are six classrooms that are allocated to the Mechanical Engineering (ME) department, and the ME department has priority to schedule their classes in those classrooms. If the ME department can not schedule all their classes in those rooms, then they can schedule in other rooms that are allocated to other departments (such as Civil Engineering Department). Also, other departments can schedule classes in the ME classrooms if needed. The scheduling to other departments classrooms can only take place after the primary department (the department to which the rooms are originally allocated) has finished scheduling their classes.

The scheduling in this phase is performed using the heuristic shown in Figure 3.

The heuristic starts by getting a list of the unscheduled classes for a certain department, and a list of the available classrooms (we start with the rooms originally allocated for that department). The scheduling is carried out using the following assignment model:

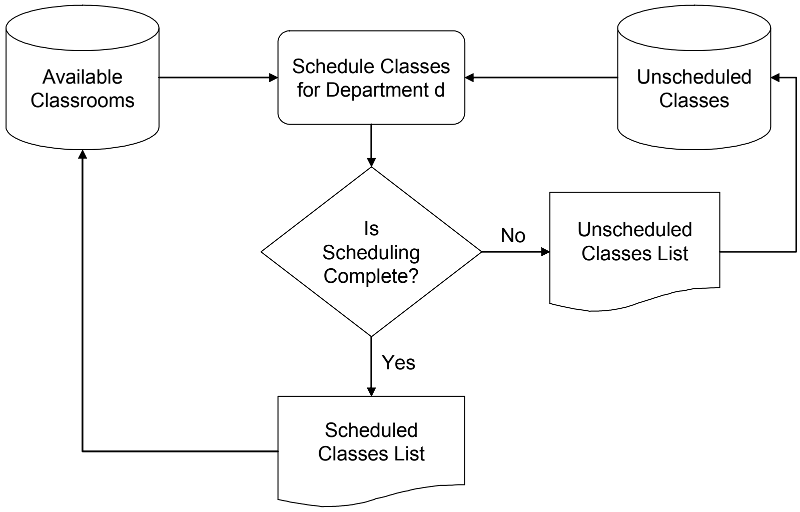

Fig. 3: Flowchart for the class–rooms scheduling heuristic

Objective Function

$$\max \sum_{k=1}^{T} \sum_{j=1}^{R} \sum_{i=1}^{C} A_{i,j,k} \tag{2}$$

Where

i = 1 → C, Classes to be scheduled
j = 1 → R, Rooms available
k = 1 → T, Time periods available per room on a three-day (Sunday, Tuesday, Thursday) or two-day (Monday, Wednesday) time frame

$$A_{i,j,k} = \begin{cases} 1, & \text{if Class } i \text{ is assigned to Room } j \text{ during Time period } k \\ 0, & \text{otherwise} \end{cases}$$

Subject To

1. A class can be assigned to one-and-only one classroom, and one–and-only one time period either on a three or two-day time schedule.

$$\sum_{j=1}^{R}\sum_{k=1}^{T} A_{i,j,k} = 1 \qquad , \forall i \tag{2.1}$$

2. No two classes can be assigned to the same room at the same time period, i.e.

$$\sum_{i=1}^{C} A_{i,j,k} = 1 \qquad , \forall j,k \tag{2.2}$$

3. Room capacity constraint

$$A_{i,j,k} * St_i \leq RC_j \qquad , \forall i,j,k \tag{2.3}$$

Where:

St_i: The Number of students taking class i

RC_j: The capacity of room j

$$A_{i,j,k} = \begin{cases} 1, & \text{if Class } i \text{ is assigned to Room } j \text{ during Time period } k \\ 0, & \text{otherwise} \end{cases}$$

Once the scheduling is completed for one department a list of scheduled classes is generated showing the classes, rooms, and time periods. In case of incomplete scheduling (i.e. some classes could not be scheduled), a list of the unscheduled class is generated; also a list of available classrooms is generated. The same procedure is carried out for all departments.

An aggregate list of all the unscheduled classes is generated (for all departments), and the scheduling heuristic is carried out again with the only difference being that all available rooms are used without any regard to departmental preference.

4. Implementation

The proposed heuristic was used to develop the course schedule for the Department of Industrial Engineering (IED) at the University of Jordan. The implementation procedure is presented next.

4.1 *Forecast Student Demand*

The student demands for courses during the semester were determined based on historical data. Table 2 shows the courses needed and the number of sections (classes) per course for the fall semester.

Table 2: A List of forecasted course-demand for the Department of Industrial Engineering including the number of sections needed per course.

Course No	Course Title	Cr. Hrs.	No of Sections Needed
906273	Properties Eng. Materials	3	2
906311	Manufacturing Process. (1)	3	2
906322	Engineering Economy	3	2
906346	System Dynamics & Control Lab	1.5	2
906411	Manufacturing Process (2)	3	2
906421	Production Plan. & Contr.	3	2
906437	Industrial Machines Design	3	2
906481	Human Factors Eng.	3	2
906542	Automation	3	2
906531	Computer Aided Design and Manufacturing	2	1
906423	Cost Accounting	2	1
906452	Engineering Statistics (2)	2	1
906573	Polymers and Plastics Engineering	2	1

4.2 *Class-Staff Assignment*

The assignment of faculty members to course was conducted by carrying out the assignment model previously outlined. The data used in assignment model is shown in Tables 3 and 4. Where, Table 3 lists Industrial Engineering faculty members' allowable workload, while Table 4 shows the faculty preference matrix.

Table 3: Industrial Engineering faculty members' allowable workload determined according to the University of Jordan regulations.

		Allowable Work Load (Cr. Hr)			
Faculty No	Rank	Recommended	Max OT	Grad. Projects	M.Sc. Thesis
1	Assistant	12	6	3	2
2	Professor	9	6	3	6
3	Associate	12	6	3	4
4	Assistant	12	6	3	2
5	Assistant	12	6	3	2
6	Assistant	12	6	3	2
7	Assistant	12	6	3	2
8	Assistant	12	6	3	2
9	Assistant	12	6	3	2
10	Lecturer	15	6	3	0

Table 4: Industrial Engineering faculty member teaching preference matrix

	Faculty member Number									
Course No.	1	2	3	4	5	6	7	8	9	10
906273	0	1	0	0	0	0	0	0	0	0
906311	1	2	0	0	0	1	0	1	1	0
906322	1	1	1	1	1	1	1	1	1	2
906346	0	0	2	0	0	0	0	1	0	0
906411	1	2	0	0	0	0	0	1	0	0
906421	1	0	0	0	1	2	0	0	1	0
906437	1	0	0	1	0	1	0	1	1	0
906481	0	0	0	0	0	0	2	0	0	0
906542	1	0	1	1	2	1	1	1	1	0
906531	0	0	0	0	2	0	0	0	2	0
906423	0	0	0	2	0	0	0	0	0	1
906452	1	1	1	1	1	1	1	2	1	1
906573	2	1	0	0	0	0	0	0	0	0

The data shown in Tables 2, 3, and 4 is used in the assignment model, which was carried out using Excel Solver®. Figure 4 shows a partial listing of the Solver model.

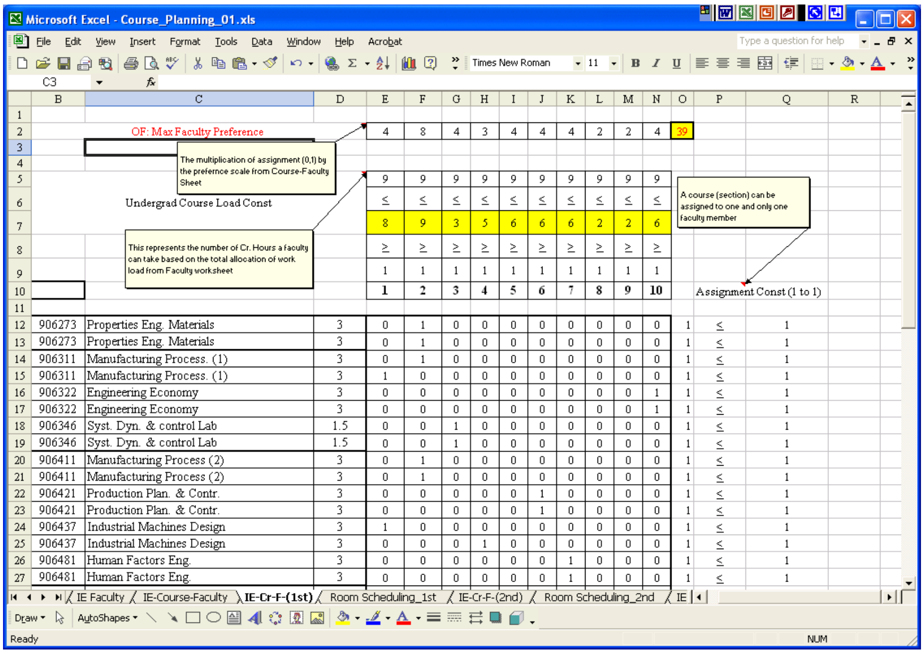

Fig. 4: Faculty member to course assignment model implementation using Excel Solver®

4.3 *Classrooms Scheduling*

In this step a list of available rooms is required. This list was obtained from the Faculty of Engineering and is shown in Table 5.

Table 5: Classrooms available for the Department of Industrial Engineering including the capacity for each room.

Room Number	Room Capacity
Mech 101	65
Mech 103	65
Mech 002	52
Mech 003	56
Mech 004	56

The next step is to schedule the course in the available rooms using the assignment models described earlier. This assignment model was implemented using Excel Solver®. A partial listing of the Solver® model is shown in Figure 5.

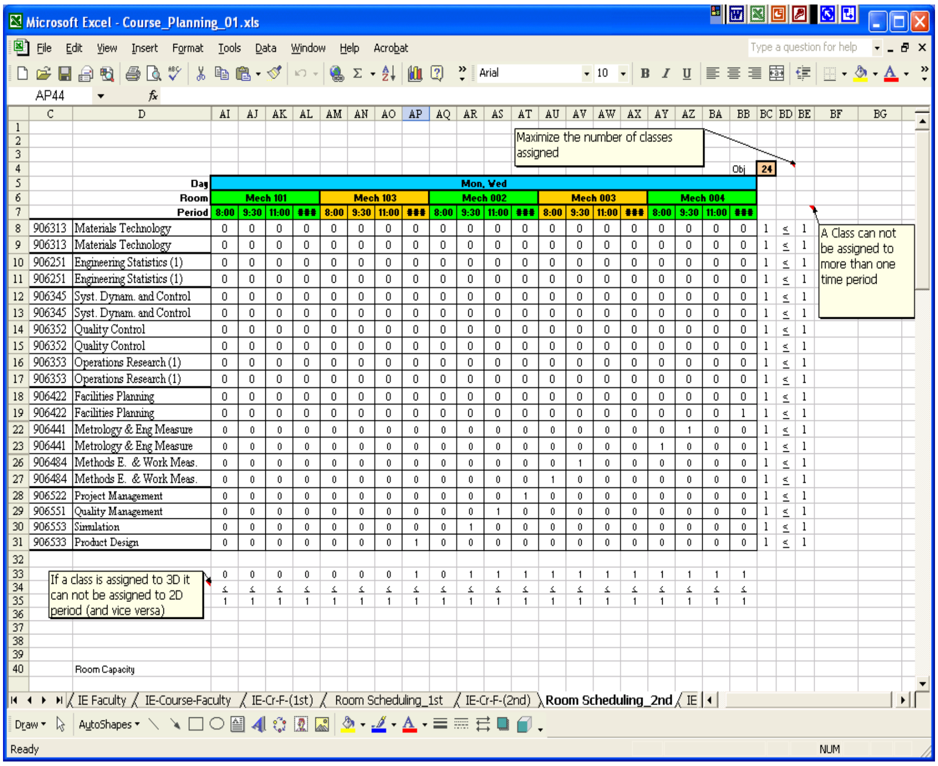

Fig. 5: Course scheduling modeling implementation using Excel Solver®.

5. Model Validation

The scheduling problem addressed by the heuristic had 22 courses, 5 classrooms, and 10 time periods, and was handled efficiently by the heuristic without producing any computational problems or causing any instability in terms of the solution generated.

The above obtained course scheduling were discussed with the officials at the IED and the FET and compared with those reached by manual scheduling approach. The results obtained using the developed heuristic was found to provide a systematic and more flexible scheduling approach.

6. Conclusion

A course-scheduling model was developed to address the problem of course scheduling at the Faculty of Engineering and Technology. The model is based on a three-step demand driven heuristic

In the first step, the demand for classes was forecasted and used to determine the number of classes needed per course.

In step two, the classes were assigned to staff members while taking into account the university policy with regards to the faculty teaching load, faculty preference to teaching specific courses, and physical constraints on the class size based on the room size.

Finally in step three, the classrooms are scheduled based on the availability of rooms at different time slots.

The developed model was tested by preparing the initial schedule for the courses offered in the fall term for the Department of Industrial Engineering. It was found that the model results provided a more systematic and flexible schedule than the manual ad-hoc technique used. Further development of the implementation of the heuristics is still needed in order to account for a College/University-wide scheduling.

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طريقة حل تجريبية لمشكلة جدولة المواد الدراسية: قسم الهندسة الصناعية في الجامعة الأردنية كنموذج للدراسة

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المستخلص: تشكل عملية جدولة المواد الدراسية تحديًا كبيرًا للمؤسسات الأكاديمية نتيجة للزيادة في عدد الطلاب والمواد الدراسية. هذا التحدي يتمثل في درجة تعقيد عملية الجدولة النابعة من العدد الضخم للمحددات والشروط التي يجب أن تتعامل معها عملية الجدولة. هذه المحددات تشمل قوانين المؤسسات الأكاديمية المتعلقة بالعبء التدريسي لأعضاء الهيئة التدريسية, ورغبة أعضاء الهيئة التدريسية بتدريس بعض المواد، وسعة القاعات الصفية، ومدى توفر القاعات الصفية في الأوقات المختلفة. تقدم هذه الورقة البحثية حلاً لمشكلة جدولة المواد الدراسية باستخدام طريقة حل تجريبية موجهة تمثل المشكلة باستخدام نموذج العرض والطلب بحيث يشكل الطلاب جانب الطلب ويمثل قسم الهندسة الصناعية في الجامعة الأردنية جانب العرض. طريقة الحل تأخذ بعين الاعتبار عدد كبير من المحددات. علما بأنه قد تم استخدام برمجية (Excel Solver) لتنفيذ الطريقة. وقد تبين أن الطريقة تؤدي إلى جدولة ذات كفاءة أفضل من الجدولة الناتجة عن الأساليب اليدوية التقليدية.