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Goal Programming for Academic Plans Design

Salah R. Agha
School of Industrial Engineering,
Faculty of Engineering
Islamic University, Gaza,
P.O. Box 108,
E-mail:aghasr@yahoo.com
Tel: +972 8 2083383, Fax: +972 8 2066477

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Abstract. This article describes a project undertaken at the Islamic University in Gaza. The project aims at designing a general academic departmental plan of study using binary goal programming. The design process includes balancing the assignment of courses to semesters. Soft and hard constraints are first identified based on interviews with academic experts. Then, a model that uses multiple criteria programming is built and used to construct the plan of study of the industrial engineering department at the Islamic University in Gaza. To determine the weights of the criteria, the researcher attempted to use Analytic Hierarchy Process (AHP). However, after interviewing the experts, it was concluded that pre-emptive goal programming is recommended. The model was then solved using LP-Solve software. The resulting plan of study clearly outperforms the manually designed one. A comparison between the newly designed plan of study and the existing one in terms of each of the criteria shows that the overall objective function could be greatly improved. Furthermore, the systematic formulation of the problem revealed that some constraints are unaccounted for in the manually designed plan. The model can be easily extended to include more objectives and constraints and can also be applied to other departments.

1. Introduction

A general academic plan of study is a plan that includes all the courses required to be successfully passed by students before they can get their degrees. The process of devising a general academic plan of study requires that the plan meet several objectives at varying degrees of importance. Thus, it is a difficult and time-consuming task, the complexity of which is conveyed through the different levels of constraints imposed on it. To date, the course assignment of college study plans were carried out manually and repeatedly and thus consuming a substantial amount of time and effort, in addition to the fact that experience alone may not yield optimal solution. With the increasing number of colleges and departments, there are greater needs for computerized models and programming algorithms to perform such complex processes.

Goal programming is a widely used methodology that is especially suitable for cases of multiple objective programming models. Goal programming does provide a way of striving towards more than one objective simultaneously. It establishes a specific numeric goal for each objective and then seeks for a solution that minimizes the deviations of the objectives from their corresponding goals (Ignizio, 1976; Charnes and Cooper, 1977; Taha, 1987; Lieberman and Hillier, 1990). Applications of goal programming cover a wide range of areas from academic resource planning (Albright, 1975; Joiner, 1980), accounting (Killough and Sounders, 1973), agricultural planning (Wheeler and Russel, 1977), portfolio management (Kumar *et al.*, 1979), and library management (Hannan, 1978). As mentioned earlier, the plan of study design should achieve several objectives, some of which may be conflicting, and satisfy many constraints.

Most of what has been done in this area is similar to the work of Billo and Bidanda (1994) who devised an advising system that students can use in order to custom-tailor their specific plans of study. Students are normally asked to design their plans of study based on the general plan of study provided by the department which is the topic of this paper. In other words, students select from the general study plan courses that suit them. Koskal and Egitman (1998) used quality function deployment to improve the education quality of industrial engineering curriculum, while Shea and West (1996) used analytic hierarchy process to rank the importance of integration, communication, people skill, time between courses and problem solving in forming a successful industrial engineering program. A problem that is somehow related to this study is called Balanced Academic Curriculum Problem (BACP). The BACP only considers a single objective which attempts to balance the assignment of courses to semesters through minimizing the maximum academic load for each semester (Lambart *et al.*, 2006).

The present study, however, includes several actual conflicting objectives and uses multi-criteria. Generally, multi-criteria formulation includes objectives and constraints. The objectives are called "soft constraints" where these constraints are allowed to be violated, but at a given penalty, while the other constraints are known as "hard constraints" which are not allowed to be violated at any cost since a violation of any of them would render the problem infeasible. The choice of industrial engineering department as a case study is based on its uniqueness due to the fact that the IE department draws upon many different departments in its courses such as mechanical engineering, electrical engineering, and computer science.

The following section briefly describes general plans of study and gives the preliminaries of mathematical formulation of the identified objectives and constraints. Section 3 gives a short background of the application and refines applying zero-one goal programming to generate department study plan. Finally, the study plan of the Industrial Engineering Department at the Islamic University in Gaza is generated using the built model and recommendations are given.

2. General Academic Plans of Study

A general academic plan of study is a plan that includes all the courses required to be successfully passed by students in a given department before they can get their degrees. A plan of study is normally designed by assigning courses to semesters. In these plans of study, several objectives need to be achieved and several constraints are required to be met. In general, any plan of study includes three types of courses. These types are university requirements, college requirements and finally department requirements. Each of these requirements has a certain number of credit hours. University requirements are these courses that all university students need to study regardless of their colleges, and these courses are normally offered every semester. As for college requirements, they are the courses that all college students need to study regardless of their department and they are normally offered once a year in a given semester. Finally, department requirements include: (1) courses taken from the department of major, and (2) courses taken from other departments (supporting courses). In this paper, the focus will be on assigning department requirements to semesters.

2.1. Variables definition

The decision variables are defined as follows:

$$y_{ij} = \begin{cases} 1 & \textit{if course "i" is assigned to semester } j \\ 0 & \textit{otherwise} \end{cases}$$

To simplify the formulation, major courses are represented by the variable '*Y*', whereas supporting courses are designated by '*X*'.

2.2. Constraints (hard constraints)

The limitations elicited from the experts are as follows:

1. A course can only appear once in the plan of study.
2. A course cannot be placed in the plan of study prior to its prerequisites.
3. For each semester, at least two courses of major should be offered.
4. The last two semesters should only include courses of major.
5. Senior design projects must be placed in the last year.

The first constraint for "courses of major" is directly obtained from the following equation:

$$\sum_{j=1}^{n} Y_{ij} = 1 \qquad \text{For all } i \tag{1}$$

While for the (supporting) courses, they can be formulated slightly different in that the value of j can only be either "odd" or "even" depending on whether the concerned departments offer a given course in the first or second semester.

$$\sum_{j=1,3,5,7} X_{ij} = 1 \tag{2}$$

$$\sum_{j=2,4,6,8} X_{ij} = 1 \qquad (3)$$

The prerequisites' constraints imply that whenever course i depends on course i', then semester j (where course i is placed) must be larger than semester k (where course i' is placed). The constraints for "courses of major" can be written as follows:

$$Y_{ij} - \sum_{k=1}^{j-1} Y_{i'k} \leq 0 \qquad (4)$$

i and i' represent Part 1 and Part 2 of a given field. Similarly for "supporting courses", the constraints take the following form:

$$X_{ij} - \sum_{k=1}^{j-1} X_{i'k} \leq 0 \qquad (5)$$

where j and k are either odd or even for each i. As for the third constraint, at least two courses of major should be assigned to each semester.

$$\sum_{i=1}^{K} Y_{ij} \geq 2 \qquad \text{For j =1 to n-2} \qquad (6)$$

The fourth constraint, which requires that the last two semesters have only courses of major, is implemented by letting the value of j varies from 1 to n-2 for all X_{ij} and 1 to n for Y_{ij}.

Finally, senior design Projects I and II are assigned to the last two semesters by forcing their variables equal 1 at j = n-1 and n respectively.

2.3. Goals (soft constraints)

Based on experts' interviews, five goals (soft constraints) are identified and considered in this model. These goals include the following.

2.3.1. Goal 1

Number of credit hours in each semester may not exceed a given number in the first years. Normally this goal aims at avoiding overloading the students. This goal can be represented as follows:

$$\sum_{i=1}^{L} A_i X_{ij} + \sum_{i=1}^{K} B_i Y_{ij} \leq b_j \quad \text{For j=1 to n-2} \qquad (7)$$

where

A_i and B_i = number of credit hours of course i,

L = Number of supporting courses,

K = Number of major courses,

b_j and c_j = Maximum allowable credit hours per semester,

n = number of semesters.

2.3.2. Goal 2

Number of credit hours taken during the last two semesters may not exceed a given number. The purpose of this goal is twofold; first it helps giving the students more time to work on their senior design projects in addition to the daunting job search process.

$$\sum_{i=1}^{K} B_i Y_{ij} \leq c_j \qquad \text{For j = n-1, n} \qquad (8)$$

The variables are the same as defined in Goal 1.

2.3.3. Goal 3

To minimize the time interval among courses of the same fields (Shea and West, 1996). For example Manufacturing I and Manufacturing II.

To formulate this goal, it is noted that the course Y_{ij} is equal 1 only if course i is assigned to semester j. Hence, the semester number "j" to which course "i" can be obtained by multiplying j by Y_{ij} so that j Y_{ij} =

$$\begin{cases} j & \text{if course "}i\text{" is assigned to semester } j \\ 0 & \text{otherwise} \end{cases}$$

Therefore, the third goal can be written as follows:

$$\text{Min} \sum_{j=2}^{n} jY_{i'j} - \sum_{j=1}^{n-1} jY_{ij} \qquad (9)$$

where i and i' represent Part 1 and Part 2 of the course respectively.

2.3.4. Goal 4

To maximize the number of courses from different fields taken during the first years. In other words, to minimize the number of semesters required to cover courses from different fields (e.g. Operations Research I, Manufacturing I) in order to expose students to the different specialties in the department so that they can discover their areas of interest at an early stage of their study.

So, this goal can be obtained by minimizing the sum of semester numbers required to cover courses form different fields, i.e.

$$\text{Min} \sum_{j=1}^{n} \sum_{i} jY_{ij} \tag{10}$$

where i is a course representing the first part of a given field and assumes certain values, e.g. (1-OR1, 5-Mfg1 …).

2.3.5. Goal 5

To minimize the difference between the total number of credit hours offered during the odd and even semesters in order to make sure that faculty loads are equally distributed. In other words, faculty members are not overloaded at a given semester and underloaded during the other.

Consequently, Goal 5, which aims at minimizing the difference in credit hours between odd and even semesters, is formulated as follows:

$$\text{Min} \left| \sum_{i=1}^{K}(A_iY_{ij}+B_iX_{ij}) - \sum_{i=1}^{K}(A_iY_{ij+1}+B_iX_{ij+1}) + \sum_{i=1}^{L}(A_iY_{ij}+B_iX_{ij}) - \sum_{i=1}^{L}(A_iY_{ij+1}+B_iX_{ij+1}) \right|$$

for j is odd (11)

3. Application

The Industrial Engineering program at the Islamic University in Gaza was accredited by the Ministry of Higher Education (MOHE) in 2001. The department only offers a Bachelor's (B.Sc.) degree. The program is a five-year plan. The first year is dedicated to general college requirements. Undergraduate students have to finish a total of 176 credit hours. These credit hours include 39 credit hours of university requirements, 27 credit hours of college requirements, and finally 110 credit hours of department requirements.

Since the university requirements courses are offered in all semesters, the students are able to select such courses regardless of the semester number. College requirements are normally assigned to the first year of study; a preparatory year for general engineering. Therefore, this study will deal with the departmental classes and thus excluding both university and college requirements. Thus, undergraduates take an average of four years to cover department requirements, each year consisting of two semesters.

The department requirements include 36 courses (23 courses of major, and 13 supporting courses). The course number i would thus vary from 1 to 23 for courses of major (Y), and from 1 to 13 for supporting courses (X) as shown in Table 1 and Table 2.

Table 1. Industrial Engineering courses (courses of major)

I	Course Name	Credit	*i*	Course Name	Credit	*i*	Course Name	Credit
1	Oprtns. Res. I	3	9	Oprtns. Res. II	3	17	Project Mgmt.	3
2	Prod. Mgmt.	3	10	Quality. Ctrl.	3	18	Work Analys. II	3
3	Mat. Science	3	11	Engg. Econ.	3	19	Ctrl Sys.	3
4	Work AnalysisI	3	12	Safety & Maint.	4	20	Stats & Prob.	3
5	Manufacturing I	3	13	Fac. Plan.	3	21	Senior Project II	3
6	Computing	3	14	Measurements	4	22	Simulation	3
7	Int. Prod. Sys.I	3	15	CNC	3	23	Int. Prod. Sys. II	3
8	Manufacturing II	3	16	Senior Project I	2			

Table 2. Courses from other departments (supporting courses)

Sem.	*i*	Course Name	Credit	Sem.	*i*	Course Name	Credit
Odd	1	Statistics	3	Odd	8	Programming	4
Odd	2	Statics	3	Even	9	Electronics	3
Odd	3	Electrical Circuits	3	Even	10	Electrical Machines	3
Odd	4	Calculus C	3	Odd	11	Numerical Analysis	3
Even	5	Strength of Material	4	Even	12	General Mgmt.	3
Even	6	Differential Equations	3	Even	13	Linear Algebra	3

Table 2 shows the supporting courses or courses taken from other departments along with the semesters during which they are offered. Furthermore, it is to be noted that the offering of these courses is determined by other departments. Consequently, these courses were assigned to either even or odd semesters a priori.

3.1. Model formulation

In this model, six goals are to be achieved. Five of these goals are mentioned in Section 2.2 and the sixth is special for this case as will be shown later.

The first and second objectives: number of credit hours in each semester should not exceed 15 hours in the first three years, and 13 hours in the last year. It can be written as follows:

$$\sum_{i=1}^{13} A_i X_{ij} + \sum_{i=1}^{23} B_i Y_{ij} + d_j^{-} - d_j^{+} = 15$$

For j =1 to 6 (12)

$$\sum_{i=1}^{23} B_i Y_{ij} + d_j^{-} - d_j^{+} = 13 \text{ For j=7, 8} \qquad (13)$$

where d^+ and d^- represent the positive and negative deviations from the target values of 15 and 13 hours. The objective is thus to minimize the value of d^+, i.e.

$$\text{Min } \sum_{J=1}^{8} d_J^{+} \qquad (14)$$

It is to be noted that the plan includes four courses that are divided into two parts each. So, the third objective, minimize the time interval among parts of the same fields, is formulated as:

$$\sum_{J=1}^{8} JY_{ij} - \sum_{J'=2}^{7} J'Y_{i'J'} - Z_k = 0$$, k = 1, 2, …, 4 (i and i' represent parts 1 and 2 of the same course).

The objective function here is to minimize the value of Z_k or in other words:

$$\text{Min } \sum_{k=1}^{4} Z_k \qquad (15)$$

The fourth objective is to minimize the number of semesters required to cover courses from different fields:

$$\text{Min } \sum_{j=1}^{n} \sum_{i} jY_{ij} \qquad (16)$$

Assuming that $\sum_{j=1}^{n} \sum_{i} jY_{ij}$ = H, then the objective is to minimize the value of H:

$$\text{Min } \mathbf{H} \qquad (17)$$

For the fifth objective, which calls for minimizing the difference between total number of credit hours offered during the odd and even semesters, assume Q = difference between number of courses in odd and even semesters. Therefore, the objective function can be expressed as:

$$\text{Min } \mathbf{Q} \qquad (18)$$

Finally, an additional (sixth) objective which is related to the nature of the industrial engineering department requires that: mechanical courses should be equally distributed among odd and even semesters for balancing the mechanical engineering staff load. Assume that R equals the difference in mechanical courses hours both in odd and even semesters, the objective function is then:

$$\text{Min } \mathbf{R} \qquad (19)$$

The objective function for the model is thus a combination of the last five equations. Given the fact that a consensus was reached among the experts that the problem can be modeled as pre-emptive goal programming, the objective function can be written as follows:

Objective Function:

$$\text{Min } P_d \sum_{J=1}^{8} d_J^{+} + P_h H + P_z \sum_{J=1}^{4} Z_J + P_q Q + P_r R \qquad (20)$$

where $P_d >> P_h >> P_z >> P_q >> P_r$

where P_d is a penalty for exceeding the targeted number of credit hours. The procedure carries out optimization by considering one objective at a time. In other words, the solution obtained from the lower priority goal does not degrade the solution obtained at the higher priority goal.

Subject to:

$$\sum_{i=1}^{13} A_i X_{ij} + \sum_{i=1}^{23} B_i Y_{ij} + d_j^{-} - d_j^{+} = 15$$

For j = 1 to 6 (21)

A_i and B_i= no. credit hours for course *i*.

$$\sum_{i=1}^{23} B_i Y_{ij} + d_j^{-} - d_j^{+} = 13 \qquad \text{For j=7, 8} \quad (22)$$

- Minimize the time interval among courses of the same subjects

$$\sum_{J=3}^{8} JY_{18J} - \sum_{J'=2}^{7} J'Y_{4J'} - Z_1 = 0$$

(Work Design I & II)

$$\sum_{J=2}^{8} JY_{9J} - \sum_{J'=1}^{7} J'Y_{1J'} - Z_2 = 0$$

(Operations Research I & II)

$$\sum_{J=4}^{8} JY_{8J} - \sum_{J'=3}^{7} J'Y_{5J'} - Z_3 = 0$$

(Manufacturing I & II)

$$\sum_{J=3}^{8} JY_{23J} - \sum_{J'=2}^{7} J'_{7J'} - Z_4 = 0$$

(Integrated Production Systems I & II)

It is noted that Z represents the difference between semester j and j' and the goal is to minimize the value of Z. Note also that the duration of j values varies depending in courses prerequisites constraints.

- Minimize number of semesters required to cover the courses from different areas:

$$\sum_{J=1}^{8} JY_{1J} + \sum_{J=3}^{8} JY_{5J} + \sum_{J=2}^{8} JY_{4J} + \sum_{J=2}^{8} JY_{7J} - H = 0$$

(23)

where H is the sum of semester numbers '*j*' required to cover '*i*' courses and it is to be minimized.

- Minimize the difference in credit hours between odd and even semesters:

$$\left| \sum_{j=1,3,5,7}^{7} \sum_{i=1}^{23} (A_i Y_{ij} + B_i X_{ij}) - \sum_{j=2,4,6,8}^{8} \sum_{i=1}^{23} (A_i Y_{ij+1} + B_i X_{ij+1}) \right|$$

$$- Q = 0 \qquad (24)$$

where Q is the difference between number of courses in odd and even semesters.

- Mechanical courses should be equally distributed among odd and even semesters for balancing the mechanical engineering staff load.

$$\left| \sum_{j=1,3,5,7}^{7} \sum_{i} Y_{ij} - \sum_{j=2,4,6,8}^{8} \sum_{i} Y_{ij+1} \right| - R = 0$$

i = 3, 5, 8, 14, 15, 19 (25)

- Each class must appear in the plan only once.

$$\sum_{j=1}^{8} Y_{ij} = 1 \quad \text{For all } i \qquad (26)$$

$$\sum_{j=1,3,5,7} X_{ij} = 1, \; i = 1, 4, 7, 8, 11 \qquad (27)$$

$$\sum_{j=2,4,6,8} X_{ij} = 1, \; i = 2, 3, 5, \ldots \qquad (28)$$

- For each semester, at least two IE courses are to be assigned.

$$\sum_{i=1}^{23} Y_{ij} \geq 2 \qquad \text{For } j = 1 \text{ to } 8 \qquad (29)$$

- Senior projects must be placed in the last year.

$$Y_{167} + Y_{218} = 2 \qquad (30)$$

For brevity and clarity purposes, the prerequisites constraints are grouped together as shown in Table 3.

Table 3. Prerequisites' constraints

Course	Prerequisite	Constraint
Strength of Materials	Statics	$X_{5J} - \sum_{K=1}^{J-1} X_{2K} \le 0$
Fluid Mechanics	Statics	$X_{7J} - \sum_{K=1}^{J-1} X_{2K} \le 0$
Electronics	Electrical Circuits	$X_{9J} - \sum_{K=1}^{J-1} X_{3K} \le 0$
Electrical Machines	Electrical Circuits	$X_{10J} - \sum_{K=1}^{J-1} X_{3K} \le 0$
Numerical Analysis	Programming	$X_{11J} - \sum_{K=1}^{J-1} X_{8K} \le 0$
Numerical Analysis	Differential Equations	$X_{11J} - \sum_{K=1}^{J-1} X_{6K} \le 0$
Work Analysis I	Production Management	$Y_{4J} - \sum_{K=1}^{J-1} Y_{2K} \le 0$
Manufacturing I	Material Science	$Y_{5J} - \sum_{K=1}^{J-1} Y_{3K} \le 0$
Integrated Prod. Sys. I	Production Management	$Y_{7J} - \sum_{K=1}^{J-1} Y_{2K} \le 0$
Manufacturing II	Manufacturing I	$Y_{8J} - \sum_{K=3}^{J-1} Y_{5K} \le 0$
Operations Research II	Operations Research I	$Y_{9J} - \sum_{K=1}^{J-1} Y_{1K} \le 0$
Quality Control	Manufacturing I	$Y_{10J} - \sum_{K=3}^{J-1} Y_{5K} \le 0$
Engineering Economy	Manufacturing I	$Y_{11j} - \sum_{k=3}^{j-1} Y_{5k} \le 0$
Safety and Maintenance	Integrated Prod. Sys. I	$Y_{12j} - \sum_{k=2}^{j-1} Y_{7k} \le 0$
Safety and Maintenance	Manufacturing II	$Y_{12j} - \sum_{k=4}^{j-1} Y_{8k} \le 0$

Table 3. ***Continued***

Course	Prerequisite	Constraint
Facility Planning	Manufacturing I	$Y_{13j} - \sum_{k=3}^{j-1} Y_{5k} \leq 0$
Facility Planning	Work Analysis I	$Y_{13j} - \sum_{k=2}^{j-1} Y_{4k} \leq 0$
Computer Aided Manufacturing	Manufacturing I	$Y_{15j} - \sum_{k=3}^{j-1} Y_{5k} \leq 0$
Integrated Prod. Systems II	Integrated Prod. Sys. I	$Y_{23j} - \sum_{k=2}^{j-1} Y_{7k} \leq 0$
Work Analysis I	Statistics	$\sum_{j=2a}^{m} Y_{4j} - \sum_{k=1}^{2a-1} X_{1k} \leq 0$
Manufacturing I	Strength of Materials	$\sum_{j=2a+1}^{m} Y_{5j} - \sum_{k=2}^{2a} X_{5k} \leq 0$
Computing	Programming	$\sum_{j=2a}^{m} Y_{6j} - \sum_{k=1}^{2a-1} X_{8k} \leq 0$
Operations Research II	Statistics	$\sum_{j=2a}^{m} Y_{9j} - \sum_{k=1}^{2a-1} X_{1k} \leq 0$
Measurements	Statistics	$\sum_{j=2a}^{m} Y_{14j} - \sum_{k=1}^{2a-1} X_{1k} \leq 0$
Probability and Statistics	Statistics	$\sum_{j=2a}^{m} Y_{20j} - \sum_{k=1}^{2a-1} X_{1k} \leq 0$
Simulation	Statistics	$\sum_{j=2a}^{m} Y_{22j} - \sum_{k=1}^{2a-1} X_{1k} \leq 0$
Quality Control	Statistics	$\sum_{j=2a}^{m} Y_{10j} - \sum_{k=1}^{2a-1} X_{1k} \leq 0$
Computer Numerical Control	Programming	$\sum_{j=2a+1}^{m} Y_{15j} - \sum_{k=1}^{2a} X_{8k} \leq 0$

4. Results and Analysis

The model was solved using LP-solve software. Table 4 shows the results obtained. These results show the deviation of each goal from its target value. It is clear that for the first objective, the proposed plan has 15, 12 and 13 credit hours for semesters 1, 7 and 8 instead of 18, 15, and 15 respectively. As it can be seen from Table 4, the improvement of the first goal is 86% when compared to the value obtained in the existing plan, while the second goal has improved by 90.9%. The fourth goal improved by about 80%. This implies that, in the proposed plan, students take only three semesters to cover the different fields instead of four semesters in the existing plan. As for the goal concerning minimizing the number of semesters between courses of the same field, an improvement of 25% is achieved. Finally, for the fifth and sixth goals, their values remain unchanged. In other words, their values are the same in the proposed

Table 4. Comparison of the deviations between existing plan and the proposed on

	Value in the existing	Value in the proposed plan	Improvement
1st objective	7	0	-
2nd objective	11	1	90.9%
3rd objective	4	3	25%
4th objective	5	1	80%
5th objective	0	0	-
6th objective	0	0	-

plan and the existing one. This might be partially explained by the fact that the department mainly used adjunct professors at its inception. Copies of the resulting plan were shown to the academic staff, students and those concerned in the academic affairs in the university. In general, professors and students preferred the proposed plan and considered it better than the existing one in many aspects. Students, however, argued against the presence of some courses together in the same semester. It was then realized that the real load (level of difficulty of some courses) are perceived differently by staff and students. Some students suggested the use of level difficulty (actual amount of study) load of each course in the criteria and they showed readiness in assigning a difficulty level to each of the courses based on their views. The academic quality unit in the university asked for a copy of the study in order to study the potential of applying it to the existing departments after modifying it and developing a user friendly version of the suggested methodology. Appendix 1 shows the resulting plan of study.

5. Conclusions

The study shows that in comparison with the current Industrial Engineering plan of study schedule, the proposed one performs better with respect to the overall objective function and thus achieving a balance between the conflicting objectives. Moreover, the current manual schedule may bias towards one or two goals more than others. Another advantage of automated schedule is that it allows the academic planners to discover any important constraints that were not included in the plan, like what happened with computing class. The linear programming model is also flexible and new constraints or goals can be easily added or changed to test the results. The proposed methodology can be very useful, especially for newly opened departments where most of the newly hired staff have no experience, especially in developing countries, in designing study plans and it is very conceivable that some of the goals and constraints may not be taken into account.

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Appendices

Appendix 1. Proposed plan of study

First Year

Semester (1)	Semester(2)
X1 Statistics 3	X5 Strength of material 4
X2 Statics 3	Y4 Work design I 3
Y3 Material science 3	Y7 Integrated production systems I 3
Y1 Operations research 3	Y9 Operations research II 3
Y2 Production management 3	
Total=15	*Total=13*

Second Year

Semester (3)	Semester(4)
X8 Programming 4	X6 Diff. equations 3
Y18 Work design II 3	X13 Linear algebra 3
Y5 Manufacturing I 3	Y8 Manufacturing II 3
X3 Electric Circuits 3	Y17 Project management 3
	Y23 Integrated prod. systems II 3
Total=13	*Total=15*

Third Year

Semester(5)	Semester(6)
X4 Calculus C 3	X12 General management 3
X7 Fluid mechanics 3	X13 Linear Algebra 3
X11 Numerical analysis 3	Y20 Statistics and probabilities 3
Y11 Engineering economy 3	X10 E- machines 3
Y13 Facility planning 3	Y22 Simulation 3
Total=15	*Total=15*

Fourth Year

Semester (7)	Semester (8)
Y12 Safety and maintenance 4	Y15 CNC 3
Y16 Senior design project I 2	Y10 Quality control 3
Y19 Industrial control systems 3	Y14 Measurements 4
Y6 Computing in IE 3	Y21 Senior design project II 3
Total=12	*Total=13*
Grand Total= 55	***Grand Total= 56***

Appendix 2. Existing plan of study

First Year

Semester (1)	Semester(2)
X1 Statistics 3	X5 Strength of material
X2 Statics 3	Y3 Material science
X3 E-circuits 3	Y7 Production systems I
Y1 Operations research I 3	X6 Diff. equations
Y2 Production management 3	
X4 Calculus C	
Total=18	*Total=13*

Second Year

Semester (3)	Semester(4)
Y4 Work design I	Y5 Manufacturing I
X7 Fluid mechanics	X9 Electronics
X8 Programming	X10 E- machines
	Y6 Computing
Total=10	*Total=13*

Third Year

Semester(5)	Semester(6)
Y8 Manufacturing II	X12 General management
X11 Numerical analysis	X13 Linear Algebra
Y11 Engineering economy	Y12 Safety and maintenance
Y14 Operations Research II	Y13 Facility planning
Y10 Quality control	
Total=15	*Total=13*

Fourth Year

Semester (7)	Semester (8)
Y15 CNC	Y19 Control systems
Y16 Senior design Project I	Y22 Simulation
Y17 Project management	Y20 Statistics and probabilities
Y18 Work design II	Y23 Production systems II
Y14 Measurements	Y21 Senior design project II
Total=15	*Total=15*
Grand Total= 58	***Grand Total= 53***