Novel Productivity Models for Engineering Education

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Abstract: Models for faculty productivity are developed in a variety of scenarios, considering various factors such as enrollments, program credit hours, elective streams available, graduation rates, admissions, faculty size, graduate programs and research. Usually each of these factors is individually considered, often leading to conflicting conclusions regarding desired course of action. In the present work, novel integrated models are developed that help us see the interaction of many factors at once. We do this by developing scenarios for specific extreme situations. For example, our first model shows how one faculty member can single-handedly run a four-semester program of 48 credit hours, graduating 15 students per year. By considering the advantages and disadvantages of such extreme particular scenarios, we can develop scenarios with our desired features.

I. Background and Methodology

Models for faculty productivity are developed in a variety of scenarios, considering various factors such as enrollments, program credit hours, elective streams available, graduation rates, admissions, faculty size, graduate programs and research. As noted by Massy *et al*, usually each of these factors is individually considered, often leading to conflicting conclusions regarding desired course of action [1,2]. In the present work, novel integrated models are developed that help us see the interaction of many factors at once.

In Massy, *et al.*, [1,2] an integrated input-output approach is taken. The inputs are e.g. labor, capital, expenses, etc. The outputs are e.g. enrollment, degrees, etc. However, it is noted that productivity concepts are hard to define, due to heterogeneity of the many variables, and lack of data. Data published by National Center for Education Statistics (NCES) in the IPEDS (Integrated Post-secondary Education Data System) database is used to calculate institution-wide productivity numbers. Only instruction is considered. Research productivity is separately addressed in a separate NRC report[3].

In the present work, we focus on productivity at a program level. We do this by developing scenarios for programs with extreme features. For example, our first model shows how a faculty member can single-handedly run a four-semester program of 48 credit hours, graduating 15 students per year. We then develop an extreme scenario for a mature research-oriented program with opposite features. By considering the advantages and disadvantages of such extreme scenarios we can develop scenarios with our desired features and costs.

II. Models for Low and Medium Enrollment

2.1 Model 1: One Faculty Member, 30 students

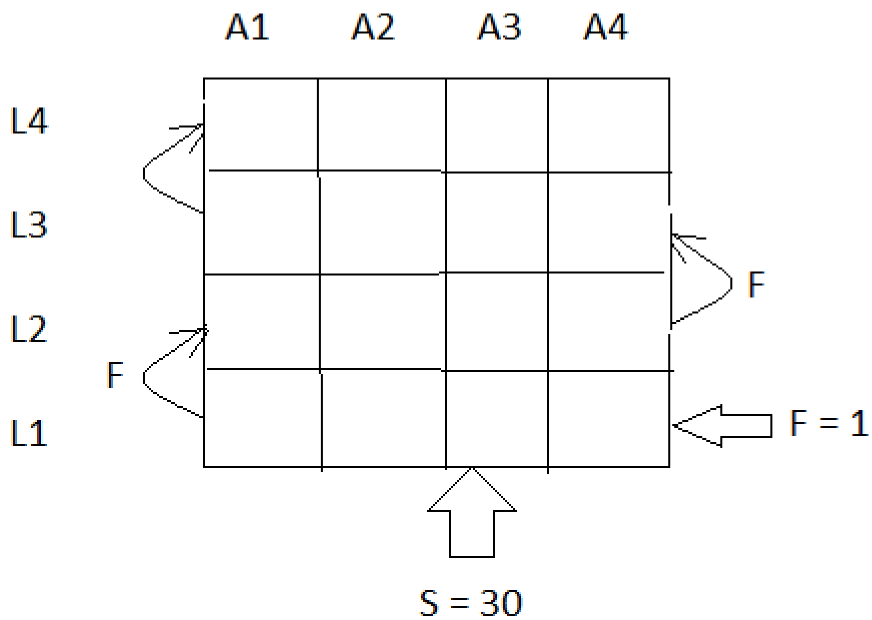

Fig. 1

First, we discuss a model that achieves semester-credit-hour (SCH) production of 360 per semester with one faculty member; the student faculty ratio (SFR) is 30; the admission rate and graduation rates are both 30 every two years.

The lesson from this model is that high productivity is possible with low enrollments by reducing the course offering frequency and increasing faculty's teaching scope. This can be a good model for new programs.

This scenario is represented in Fig. 1, which represents a four-semester, 48-credit program (16 courses, 3 credits each). The rows indicate four levels labeled L1 through L4. Each level is a semester. In each level four courses are required for the program. These are represented by columns in the table labeled A1 through A4 for four specialization areas. In a typical electrical engineering curriculum, these could be, for example, computers, communications, power, and automation. The numbers are taken to be representative of a typical engineering program, where students spend the freshman and sophomore years taking math, physics, chemistry; and enter the major program only in their junior and senior years.

30 students and one faculty member begin the program during semester L1. Students take four courses every semester. The faculty member teaches four courses every semester. At the end of the first semester both the students as well as faculty member move to semester L2. Similarly, at the end of semesters L2 and L3, they move to levels L3 and L4, respectively. The arrows

labeled F show the faculty member moving from one semester's courses to the next. At the end of two years 30 students will graduate and the faculty member repeats the same cycle again.

This scenario has obvious problems. Students can only enter the program once every two years. The faculty member has to be able to teach all 16 courses. But it shows what is possible from a productivity viewpoint.

2.2 Model 2: Four faculty, 120 students

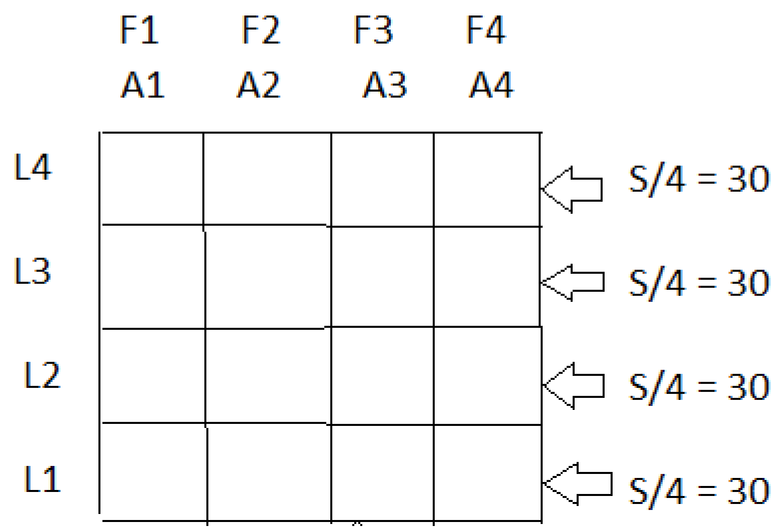

Fig. 2

An obvious extension from the model in Fig.1 is to ask: what if there is more than one faculty? For our second model, we consider four faculty and 120 students in the same 48-credit program. The advantage of this scenario over the first is that all courses are offered all the time, allowing students more flexibility to drop out and re-enter the program according to their convenience. The faculty benefit because each is allowed to specialize in one particular area. The curriculum benefits since the faculty now have time to improve the courses in their area.

The important lesson here is that higher enrollment, and resulting higher budget, allows us to support the quality goals of entrance flexibility for students and specialization area for faculty.

The productivity figures for this scenario are: Total SCH production is 1,440 per semester for four faculty members; average SCH production per faculty is still 360; total enrollment is S = 120, but SFR is still 30. The admission and graduation rates are both 30 per semester or 60 per year.

This scenario is depicted in Fig. 2, representing the same 48-credit program with four members in the faculty. In this scenario there are 30 students at each of the four levels, represented as rows in the table, for a total enrollment of S = 120. The columns represent four areas of specialization, represented by the symbols A1 through A4 along the columns in the figure. Each faculty member is associated with one specialization area. The faculty members are represented by the symbols F1 through F4 alongside the four areas A1 through A4. Each faculty member teaches four courses every semester, representing four levels in his particular area.

2.3 General Formula

The concepts of the previous two models can be encapsulated in a general mathematical relationship. Let L = number of levels, A = number of areas, F = number of faculty, and S = number of students.

Here, we see that S/AL is a key productivity parameter. L represents the depth of the program, and A represents the breadth. We would like both to be high. Here, we see that in order to support these program-quality goals, we need enrollment S to be high.

Now, the total number of courses that need to be covered is A multiplied by L, or AL. In this scenario, each faculty member teaches four courses per semester, the number of courses covered per semester is 4F. So the proportion of courses covered per semester is 4F/AL. Here, we assume a student-faculty ratio (SFR) of 30, so then F = S/30. Hence, 4F/AL = 0.133*(S/AL). This quantity, 0.133 (S/AL), will be the number of offerings per semester of a particular course. For example, when A = L = 4, with S = 120, we get the offering frequency as once per semester. Additional insight is obtained, that the number of semesters between the same course being offered again is 7.5*(AL/S) .

III. High Enrollment Case

3.1 Comparison of 1-faculty and 4-faculty model

The features of one-faculty model are: (i) faculty member has to be a “jack-of-all-trades”, and (ii) the students have no flexibility in their graduation plan. We wish to develop models with exactly opposite features. By knowing the two extreme scenarios and their features, we can try to develop mixed scenarios with our desired features and costs.

The four-faculty model offers some relaxation of the constraints of the one-faculty model. Each faculty member is able to have one area of specialization, but must teach courses at four levels every semester. Students can enter the program at any level, twice a year, but must take exactly the four courses prescribed for their level.

3.2 Expansion from Four-faculty Model

Expansion from the four-faculty model can occur in two ways: increasing the number of areas of specialization (breadth), or increasing the number of levels (depth). If the number of areas is increased, we may conclude that we will reach a situation of many faculty members, offering many areas of specialization. Thus, students have a wide selection of specialization areas. However, if we try to maintain the headcount ratio of 30, the student population would become very large. So it would be logical to split the program organizationally into multiple departments. This is how programs that started as integrated engineering/technology programs, later split into many departments such as civil, mechanical, electrical, etc.

If the number of levels is increased, clearly one faculty member cannot handle all levels, even within one area. So we will have a situation where senior faculty members deal with a small number of advanced students, while junior faculty and teaching assistants work with a large number of lower level students. This is similar to what has already happened with respect to core engineering courses at freshman and sophomore levels. Core engineering is common to all engineering students, and later, students split off into different engineering programs, e.g. mechanical, electrical, etc.

Thus we see that as a program matures, it has the potential of spinning off additional organizational units.

IV. Research

One way to reduce the headcount ratio from 30 is to assume that faculty are involved only part-time in teaching. The remainder of their time they are engaged in externally funded research or consulting. Meanwhile the students are likely to take advantage of the scheduling flexibility by becoming part-time students. They may be using the remainder of their time in some type of employment, as research or teaching assistants, or as professionals taking extension courses as advanced students. So we may conclude that mature research-oriented programs may involve a large number faculty and students taking and offering courses on a part-time basis.

V. Lessons from Other Industries

We consider three examples of R&D activity in other industries, *viz.* automotive, entertainment, and a teaching hospital. In the automotive industry, R&D effort is focused on "concept cars" with futuristic performance features not yet available in production models. Yet, today's "concept" car is tomorrow's stock car.

In a teaching hospital, the inner core activity is for faculty and advanced students to work on developing new techniques for treatment. Yet the larger day-to-day activity is that of treating a large number of patients on a "clinic" basis.

In the entertainment industry, the creative activity of writing, direction, composing, etc. is carried out by a few individuals. The creative work is then transformed into mass-distributed media through the efforts of many other people involved in day-to-day production.

In all the above, we see that the creative work of a few individuals is supported by an infrastructure, consisting of many people, that delivers the R&D results to the general public. So, higher education programs should seek such an infrastructure to support their R&D.

VI. Conclusion

By investigating features of programs with extreme scenarios, we discover features of programs at various levels of maturity. New programs with low enrollments require faculty with wide teaching scope, few students, and little program flexibility in content or scheduling. As a program matures and grows, faculty members have time to specialize and engage in research, while students have more options in curriculum and scheduling. Research and advanced education is best supported by some form of external funding.

VII. REFERENCES

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