A Spreadsheet-based Scheduling Model to Create Individual Graduation Roadmaps

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We address the problem of creating individual graduation roadmaps for students on a dynamic basis. Graduation roadmaps show suggested courses to take each term, and can be valuable to students in planning their coursework. The problem is modeled using integer programming with the objective of minimizing the time to degree completion, and a simplified version is solved using the Analytic Solver Platform in Microsoft Excel. This research makes two contributions to the literature: it presents a prototype of a new tool to aid students with planning their path to degree completion; and it provides an example of a real-life problem that can be used in the classroom to demonstrate an application of optimization/prescriptive analytics using spreadsheet software.

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I. INTRODUCTION

Ensuring timely completion of a college degree is a high priority for Colleges and Universities across the nation, as evidenced by the continued focus on graduation rates. For example, The California State University (CSU) launched its *Graduation Initiative 2025* in January 2015 with a clear goal: to increase graduation rates for its 475,000 students across all 23 campuses (CSU Office of the Chancellor, 2016). As of September 2016, the initiative established a series of objectives, including increasing the four-year graduation rate for first-time freshmen from the current 17% to 40%, and the corresponding six-year rate from 57% to 70% (CSU System Plan, 2016).

As universities focus on graduation rates (and correspondingly the times to degree completion), several tools are deployed to aid in the degree planning process. According to a survey of advisors, technology is widely used to provide access to resources for course and degree planning (Pasquini and Steele, 2016). Among the advising tools available to facilitate timely completion of a degree are graduation roadmaps. These provide an overview of the requirements for degree completion, along with a way to meet the requirements in a timely manner (typically four years for first-time freshmen and two years for transfer students). However, these roadmaps are static, and generic. Further, they assume that students will typically take a full load of courses and that the courses recommended to be taken in a particular term will in fact be offered during that term. The current low four-year graduation rates for first-time freshmen and two-year graduation rates for transfer students suggest that the roadmaps may not be realistic for all students to follow. Thus there is a need to create individual roadmaps on a dynamic (term-by-term) basis, which is the motivation for this research.

Other tools for degree planning have also been rolled out at several campuses of the CSU, including Cal Poly Pomona. Two of these are My Planner (Cal Poly Pomona My Planner, 2016) and Schedule Builder (Cal Poly Pomona Schedule Builder, 2016). While both are designed to help students plan their coursework, they have limitations. My Planner does not have any optimization or constraint checking capabilities, and Schedule Builder has a short term focus on creating a detailed schedule for one term. This research considers both an optimization perspective as well as a multi-term outlook, and develops a prototype tool to support coursework planning for degree completion.

The specific context is one department in one of the campuses of the CSU system. The scheduling (course planning) problem facing a student each term is modeled as an integer linear programming problem, with the objective of minimizing the number of academic terms to degree completion (an academic term in the context of this paper is a quarter, however, it could apply to semesters as well). Constraints include hard constraints, for example: All courses/units required must be completed, a course may be taken only if prerequisites are satisfied, a course may be taken in a particular term and timeslot only if it is offered during that term and timeslot, and two courses may not be taken in the same term if they have overlapping timeslots. In addition to the hard constraints, there are soft constraints, for example, the maximum number of courses/units that may be taken in a term to balance work and school requirements, and balancing the load between different types of classes. A simplified version of the problem is then solved using the Analytic Solver Platform in Microsoft Excel.

The purpose of this research is two-fold: first, as a prototype of a new tool to supplement advising resources available to aid students with planning their path to degree completion; and second, as an example that could be used in the classroom to demonstrate an application of optimization/prescriptive analytics using spreadsheet software, with the context of a real-life problem that students can relate to.

The remainder of the paper is organized as follows. Section II provides an overview of the relevant literature. The problem is described in further detail in Section III. The integer linear programming model is presented in Section IV. Section V discusses the use of a spreadsheet approach to solve a simplified version of the model. Analytical results of the model, including solutions corresponding to different scenarios, are presented in Section VI. Section VII concludes with contributions, limitations, and suggestions for future enhancements.

II. LITERATURE REVIEW

This research approaches the degree planning problem from a constrained optimization perspective, modeling it is a mathematical programming problem with the objective of minimizing the time to degree completion. While mathematical programming is a widely used approach to model optimization problems, including in university contexts (e.g., Babaei, Karimpour, and Hadidi, 2015; Schimmelpfeng and Helber, 2007), the degree planning problem does not appear to have been widely addressed in the modeling literature. Scheduling problems in university settings have typically focused on timetabling/course scheduling issues involving scheduling classes, instructors, timeslots, and rooms for a single academic term at a time (e.g., Kassa, 2015; Rudova, Miller, and Murray, 2011).

Babaei et al (2015) present a survey of approaches for the university course timetabling problem, and identify the following categories of approaches to the problem: operations research (e.g., mathematical programming), metaheuristics (e.g., genetic algorithms), multi-criteria approaches, and intelligent approaches (e.g., artificial intelligence). Schimmelpfeng and Helber (2007) describe a mathematical programming approach to create a timetable of all courses for a term. They model the problem as an assignment problem, and incorporate constraints including core and elective courses, as well as teacher preferences. Their model is solved using CPLEX.

Kassa (2015) describes a multi-stage integer programming approach to the course scheduling problem. The first stage determines the optimal assignment of instructors to course sections, while subsequent stages focus on the assignments of rooms and times. The model is solved using an AMPL-Gurobi package. Rudova et al (2011) describe an iterative forward search algorithm for the course scheduling problem, focusing on hard constraints first, and adding soft constraints later.

While scheduling problems in university settings have primarily focused on courses, instructors, timeslots, and rooms, there has been some research on student scheduling. For example, Head and Shaban (2007) address the problem of scheduling students in a first year program. In their context, all courses are required of all students, and there are no electives. Their approach is to build the schedule and place the students into classes simultaneously. The model focuses on satisfying all the hard constraints and minimizing the violations of the soft constraints. The system uses Visual Basic with embedded SQL. Causmaecker, Demeester, and Berghe (2009) use a metaheuristic procedure where constraints are solved one by one rather than all at once. They consider student groups rather than individual students, where students are grouped according to the required courses that they need to take.

To summarize, course scheduling has been widely researched in the literature, and several solution procedures developed. However, these are typically focused on developing detailed schedules and assignments for a single term, and do not consider the path to degree planning from the perspective of individual students.

Research on specific models for individualized degree planning spanning multiple terms is limited. Wermus and Pope (1999) draw an analogy between coursework planning and Material Requirements Planning, wherein individual courses are analogous to the components that go toward the final product (the degree). However, it is more of a conceptual paper and does not present any specific model. Chen, Wang, Chen, and Luo (2014) present an integer programming approach to planning coursework from an individual student's perspective, taking into account student preferences for timeslots and elective courses, however, their model only considers a single term.

Dechter (2007, 2009) considers individualized degree planning across multiple terms. He models the degree planning problem using constraint programming as well as mathematical programming, with the objective of minimizing degree completion time. The model incorporates core and elective courses, prerequisites, and a maximum course load per term. However, the model does not consider specific timeslots for courses, planned course offerings, or student time availabilities. The underlying assumption is that courses included in the model solution will in fact be offered during the terms scheduled by the model, that there will not be any time overlaps for multiple courses scheduled in a particular term, and that there are no constraints on the student's availabilities during different times/days.

This paper draws on the research by Dechter. It includes the main elements of his model: degree planning spanning multiple terms; and the consideration of prerequisites, core and elective courses, and a maximum course load each term. Further, it extends the model by incorporating all three considerations not included in Dechter's research: timeslots for courses, planned course offerings over the planning horizon, and student availability by timeslots and terms. Dechter's solution approaches for a simplified version of the problem are ILOG for the constraint programming model, and CPLEX for the mathematical programming model. This paper uses a spreadsheet-based solution approach, using the Analytical Solver Platform. Microsoft Excel was chosen due to its wide availability, ease of use, and what-if analysis capabilities. Another reason for choosing Microsoft Excel was that it would lend itself to being used in the classroom to illustrate a real-life application of optimization using spreadsheets.

Examples using spreadsheets with Solver for scheduling are available in the literature. For example, Ovchinnikov and Milner (2008) describe a spreadsheet model to assign medical residents to on-call and emergency rotations. The model was designed to replace the existing manual system of scheduling, and considers the different constraints for residents in different years of the residency program. With respect to specific examples of spreadsheets with Solver used to teach scheduling-related optimization concepts in a classroom setting, Birge (2005) discusses an example of scheduling a professional sports league. He uses a simplified version of the Major League Soccer scheduling problem to illustrate the Traveling Salesperson Problem methodology, and the use of Solver for integer programming.

The closest example to the context of this research in a classroom setting appears to be Winch and Yurkiewicz (2014). They describe a case to demonstrate how integer linear programming can be used to build a student's class schedule for a single term. Given available courses, meeting times, and ratings, a spreadsheet model is used to maximize the total rating of the schedule for the term. The authors have used the case successfully in an introductory management science course in a business school. Their case is limited in scope due to its focus on a single term and a small set of courses, but it shows the potential to adapt the research in this paper to a classroom context as an application of spreadsheet optimization to create individual roadmaps, a problem students can easily relate to.

In summary, this research makes two contributions to the existing literature: it extends the models by Chen et al (2014) and Dechter (2007, 2009) through the consideration of criteria such as planned course offerings, course time-slots, and student availabilities over a multi-term planning horizon; and it provides an example of a real-life problem that can be used in the classroom to demonstrate an application of optimization/prescriptive analytics using spreadsheet software.

III. PROBLEM DESCRIPTION

The schedule planning context for this research is the Technology and Operations Management Department (TOM) in the College of Business Administration at Cal Poly Pomona, one of the campuses in the CSU system. The department offers two options: TOM (Technology and Operations Management), and EBZ (e-Business). There are approximately 260 students in the TOM option, and 90 in EBZ. The TOM option will be used to illustrate the modeling and solution approach in this paper.

Each option within the College provides a roadmap/educational plan to help students plan their path to degree completion in a timely manner. The TOM 4-year roadmap provides recommendations for courses to take each term that will satisfy graduation requirements within four years for first-time freshmen (TOM Roadmap, 2016). A 2-year roadmap is available for transfer students. However, these roadmaps may not be realistic for all students to follow for some of the reasons outlined below:

- The TOM roadmap assumes that students will take 12-17 units each academic quarter, which may not be feasible for several students due to personal constraints such as work commitments.
- Students do not move through courses in cohort groups, with the result that not all students are taking the required

courses during the same term, even if they start school during the same academic term.

- Students may need to retake course(s) if they do not earn the minimum required grades.
- Department course offerings may not always align with the course plans in the roadmap (for example, the roadmap may recommend a course be taken during Fall of Year 3, but the course may not be offered each Fall).
- Students may not be able to enroll in planned course(s) due to class size limits (demand exceeding supply).
- Students may not be able to take course(s) due to schedule conflicts with the timeslot(s) during which the course(s) is offered.

These factors point to the need for roadmaps that can be customized for each student, and updated each term to reflect the current status of the student.

While tools are available to help students with planning their coursework, they have limitations. In Section I, we had mentioned two tools for Cal Poly Pomona students – My Planner and Schedule Builder. Students can use My Planner to help build their plans for degree completion using information from their degree progress report, the course catalog, and planned course offerings. Plans are built by dragging courses from the catalog and dropping them into specific terms. However, My Planner does not have any optimization or constraint checking capabilities – it is up to the student, working with an advisor, to ensure that the plan is feasible. Further, it is difficult to establish whether the plan is optimal.

Schedule Builder is a tool that can help students plan the details of their schedules before registration each term. Students can input class preferences and time availabilities to generate multiple possible class schedules, and choose the schedule that they would like to import into their course shopping cart. However, Schedule Builder has a short term focus – it helps create a detailed schedule for an academic term, but does not have the long term view. Further, while it checks for constraints such as student and course availability, the output is a set of feasible schedules, without an optimization component.

This research considers both an optimization perspective as well as a multi-term outlook, and develops a prototype tool to support degree planning. The coursework planning problem is modeled as an integer linear programming problem, as described in the next section.

IV. INTEGER PROGRAMMING MODEL

The details of the integer linear programming model are given below.

Model:

Decision Variables:

The decision variables identify the courses scheduled to be taken during particular terms and timeslots.

X_{ijt} = 1 if course i is scheduled to be taken in term j during timeslot t
= 0 otherwise

Parameters:

Course-term-timeslot offerings: Identify the courses offered during particular terms and timeslots.

C_{ijt} = 1 if course i is offered in term j during timeslot t
= 0 otherwise

Student term-timeslot availability:

Specify the timeslots during which the student is available to take courses each term.

S_{jt} = 1 if the student is available in term j during timeslot t
= 0 otherwise

Other parameters include degree requirements (required and elective courses), course prerequisites, and the maximum number of courses/units allowed to be scheduled each term (considering work or other commitments).

Objective Function:

The objective function minimizes the number of academic terms to degree completion.

Min M (where M is the Maximum term in which courses are scheduled to be taken)
To maintain a linear objective function, additional constraints are added to ensure that for each course, the term during which that course is scheduled to be taken is ≤ M

Constraints:

1. A course may be taken in a particular term and timeslot only if it is offered during that term and timeslot.

   $X_{ijt} \leq C_{ijt}$ ∀ i Є I (set of courses); ∀ j Є J (set of terms); ∀ t Є T (set of timeslots)

2. A course may be taken in a particular term and timeslot only if the student is available during that term and timeslot.

   $\sum_i X_{ijt} \leq S_{jt}$ ∀ j Є J (set of terms); ∀ t Є T (set of timeslots)

3. At most one course may be taken during a particular term and timeslot.

   $\sum_i X_{ijt} \leq 1$ ∀ j Є J (set of terms); ∀ t Є T (set of timeslots)
   (This set of constraints is redundant due to the constraints in (2) above.)

4. A course may be taken only if the prerequisites are satisfied.
   For each course scheduled, the term during which it is scheduled should be > term during which any prerequisite course is scheduled i.e., (term – 1) ≥ term of prerequisite course.
   For courses that are not scheduled, the prerequisites should not be enforced, i.e., the constraints should become redundant. This is done by adding a component to the left hand side of the constraint as shown below.

   $Z^*(1-(\sum_j\sum_t X_{ijt})) + \sum_j j^*(\sum_t X_{ijt}) - 1$
   $\geq \sum_j j^*(\sum_t X_{i'jt})$
   ∀ i Є (courses with prerequisites),
   ∀ i' where course i' is a prerequisite to course i;

   $\sum_j j^*(\sum_t X_{ijt})$ represents the term during which course i is scheduled;
   $\sum_j j^*(\sum_t X_{i'jt})$ represents the term during which course i' is scheduled;
   Z is a large enough multiplier (greater than the maximum number of terms in the scheduling horizon) so that if course i is not scheduled (i.e., $\sum_j\sum_t X_{ijt} = 0$), then the constraint becomes redundant.

5. No more than a specified number of courses may be scheduled each term (to accommodate work or other commitments).

   $\sum_i\sum_t X_{ijt} \leq N_j$

$\forall$ j where N_j is the maximum number of courses allowed to be scheduled during term j

6. All required courses, and the specified number of elective courses, must be taken (from the curriculum sheet showing the requirements to degree).

   $\sum_j \sum_t X_{ijt} = 1 \quad \forall$ i Є R (set of required courses)
   $\sum_i \sum_j \sum_t X_{ijt} = n$ where i Є E (set of elective courses) and n electives need to be taken (The same structure of the constraints applies to situations with categories of electives and different number of courses required to be taken in each category).

7. A course may not be scheduled beyond term M (since the objective function is to minimize M).

   $\sum_j j^*(\sum_t X_{ijt}) \leq M \ \forall i$

The model was simplified and solved using the Analytic Solver Platform in Microsoft Excel. Simplification allowed the problem to be computationally tractable, and Excel was chosen due to its wide availability, ease of use, and what-if analysis capabilities. Section V describes the Excel model.

V. SPREADSHEET MODEL

The model was simplified by focusing on the courses offered by the TOM department, and on the TOM option. The department offers two courses that are part of the College core, required to be taken by all students in the College of Business (additionally, a required capstone course is partially staffed by department faculty but is not included here). In addition to the courses in the College core, the department offers four core courses that are required of all students in the TOM option. Students in the TOM option choose one of three career tracks: Supply Chain Management, Service Operations Management, and Management of Technology. Students take seven elective courses based on their career track. While the core requirements are fixed, there is some flexibility in the choice of electives. TOM curriculum sheet (2016) outlines the requirements for a degree in Business Administration with the TOM option.

The department provides a two-year planning horizon: it publishes a schedule of planned course offerings over a two-year period (spanning six academic quarters/terms). The schedule includes specific courses to be offered in specific terms during specific timeslots, thus enabling students to plan their coursework effectively. There are about twenty courses, offered in a rotation schedule to provide access to students with other time constraints (e.g., work commitments). Most courses are offered 3-4 times in a two-year cycle. The two required courses in the College of Business core (TOM 301 and TOM 302) are offered each term across various timeslots (approximately 12-15 sections of each course each term). Table 1 shows the most recent two-year Planned Course Offerings for the TOM Department (TOM Projected Schedule, 2016).

The following scenario will be used to illustrate the spreadsheet model:

Scenario 1:

1. Scheduling horizon is Fall 2016 through Spring 2018
2. Student is in the Service Operations Management track
3. There are no constraints on the student's availability
4. Maximum number of courses allowed to be taken is 4 each quarter

The course-term-timeslot information from Table 1 is input into Excel as matrices: one course-term matrix (shown in Fig. 1), and one course-timeslot matrix for each term (an example shown in Fig. 2). Note that EBZ 301, included above as a department course, is not included in the spreadsheet as it is not part of the TOM option (it is part of the EBZ option).

The student's term-timeslot availability is represented in Fig. 3 (1 if the student is available during the specific term and timeslot, 0 otherwise). In our scenario, it is assumed that there are no constraints on the student's availability (Excel enables easy what-if analysis – the impact on the minimum time to degree completion if the student had other commitments during certain timeslots can be easily seen by changing the cell entries to 0 for those timeslots and re-running the Solver).

TABLE 1. PLANNED COURSE OFFERINGS.

Class	FALL 2016	WINTER 2017	SPRING 2017	FALL 2017	WINTER 2018	SPRING 2018
	Day & Time	Day & Time	Day & Time	Day & Time	Day & Time	Day & Time
TOM 309	MW 2:00-3:50 PM		MW 6:00-7:50 PM		Tu/Th 10:00-11:50 AM	
TOM 315		MW 6:00-7:50 PM	Tu/Th 10:00-11:50 AM		MW 6:00-7:50 PM	Tu/Th 1:00-2:50 PM
TOM 316	MW 6:00-7:50 PM			MW 4:00-5:50PM		
TOM 319	MW 4:00-5:50 PM		Tu/Th 6:00-7:50 PM		MWF 11:45AM-12:50PM	
TOM 320	Tu/Th 10:00-11:50 AM			MW 6:00-7:50PM		
TOM 332		MW 12:00-1:50 PM	Tu/Th 1:00-2:50 PM		MW 4:00-5:50 PM	TuTh 3:00-4:50 PM
TOM 350	TuTh 1:00-2:50 PM			Tu/Th 1:00-2:50 PM		
TOM 401		Tu/Th 3:00-4:50 PM	MW 4:00-5:50PM		Tu/Th 3:00 - 4:50 PM	Tu/Th 6:00-7:50 PM
TOM 420	Tu/Th 6:00-7:50 PM	MW 4:00-5:50 PM		TuTh 3:00-4:50PM		MW 6:00-7:50 PM
TOM 425		Tu/Th 3:00-4:50 PM		Tu/Th 10:00-11:50 AM		MW 2:00-3:50 PM
TOM 432	Tu/Th 10:00-11:50 AM		MWF 11:45AM-12:50PM		Tu/Th 1:00-2:50 PM	
TOM 434		Tu/Th 10:00-11:50 AM	Tu/Th 3:00-4:50 PM		Tu/Th 6:00-7:50 PM	Tu/Th 10:00-11:50 AM
TOM 436		Tu/Th 6:00-7:50 PM		MW 2:00-3:50 PM		MW 4:00-5:50 PM
TOM 453			MW 2:00-3:50PM		Tu/Th 1:00-2:50 PM	
EBZ 301	MW 2:00-3:50 PM		MW 2:00-3:50 PM		Tu/Th 3:00 - 4:50 PM	
EBZ 302		MW 2:00-3:50 PM		Tu/Th 6:00-7:50 PM		MW 4:00-5:50 PM
EBZ 303	TuTh 1:00-2:50 PM		Tu/Th 10:00-11:50 AM		MW 6:00-7:50 PM	
EBZ 304	MW 4:00-5:50 PM			MW 2:00 - 3:50 PM		MWF 11:45 AM -12:50PM
EBZ 305		MW 4:00-5:50 PM		Tu/Th 1:00-2:50 PM		Tu/Th 1:00-2:50 PM

NOTES: TOM 301 & 302 are offered each quarter at various times.
Internship & Senior Project are offered every quarter & need to be arranged separately with the department.

Input data

Course - term offerings

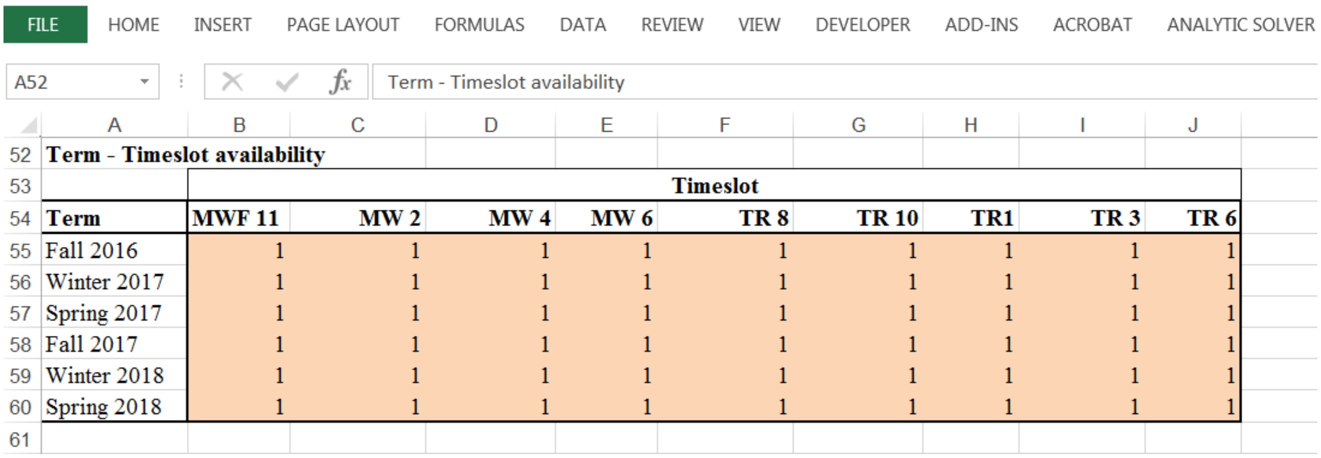
Course	Term: Fall 2016	Winter 2017	Spring 2017	Fall 2017	Winter 2018	Spring 2018
TOM 309	1	0	1	0	1	0
TOM 315	0	1	1	0	1	1
TOM 316	1	0	0	1	0	0
TOM 319	1	0	1	0	1	0
TOM 320	1	0	0	1	0	0
TOM 332	0	1	1	0	1	1
TOM 350	1	0	0	1	0	0
TOM 401	0	1	1	0	1	1
TOM 420	1	1	0	1	0	1
TOM 425	0	1	0	1	0	1
TOM 432	1	0	1	0	1	0
TOM 434	0	1	1	0	1	1
TOM 436	0	1	0	1	0	1
TOM 453	0	0	1	0	1	0
EBZ 302	0	1	0	1	0	1
EBZ 303	1	0	1	0	1	0
EBZ 304	1	0	0	1	0	1
EBZ 305	0	1	0	1	0	1

FIGURE 1. COURSE-TERM MATRIX.

Course - timeslot offerings

Course	Timeslot Fall 2016: MWF 11	MW 2	MW 4	MW 6	TR 8	TR 10	TR1	TR 3	TR 6
TOM 309		1							
TOM 315									
TOM 316				1					
TOM 319			1						
TOM 320						1			
TOM 332									
TOM 350							1		
TOM 401									
TOM 420									1
TOM 425									
TOM 432						1			
TOM 434									
TOM 436									
TOM 453									
EBZ 302									
EBZ 303							1		
EBZ 304			1						
EBZ 305									

FIGURE 2. COURSE-TIMESLOT MATRIX FALL 2016.



Term - Timeslot availability

	Timeslot								
Term	**MWF 11**	**MW 2**	**MW 4**	**MW 6**	**TR 8**	**TR 10**	**TR1**	**TR 3**	**TR 6**
Fall 2016	1	1	1	1	1	1	1	1	1
Winter 2017	1	1	1	1	1	1	1	1	1
Spring 2017	1	1	1	1	1	1	1	1	1
Fall 2017	1	1	1	1	1	1	1	1	1
Winter 2018	1	1	1	1	1	1	1	1	1
Spring 2018	1	1	1	1	1	1	1	1	1

FIGURE 3. STUDENT TERM-TIMESLOT AVAILABILITY.

Decision Variables:

As described in Section IV, the decision variables for the integer linear programming model are of the type course-term-timeslot. However, because each department course (other than the two courses in the college core) is offered at most once each term (as seen in Table 1), the course-term combination uniquely identifies the timeslot. The two courses in the college core (TOM 301 and TOM 302) are offered each term across various timeslots, and a simplifying assumption is made that students will fit them in the schedule after the more timeslot-constrained courses in the TOM option are scheduled. Thus the decision variables can be modeled in Excel by a course-term matrix, as shown in cells B68 through G87 of Fig. 4. (Conditional formatting is used to highlight the solution generated by Solver).

Objective Function:

The objective function is to minimize the maximum term during which classes are scheduled to be taken. In the spreadsheet, a variable 'Max term taken' is created (cell M90 in Fig. 4), and constraints are added specifying that for each course, the Term taken is ≤ Max term taken. In addition to the decision variables described earlier, Fig. 4 also shows the objective function (cell M93) and some of the constraints in the model.

The Term taken for each course is calculated using Excel's SUMPRODUCT function (SUMPRODUCT of Term # row with the row for the Course).

Constraints:

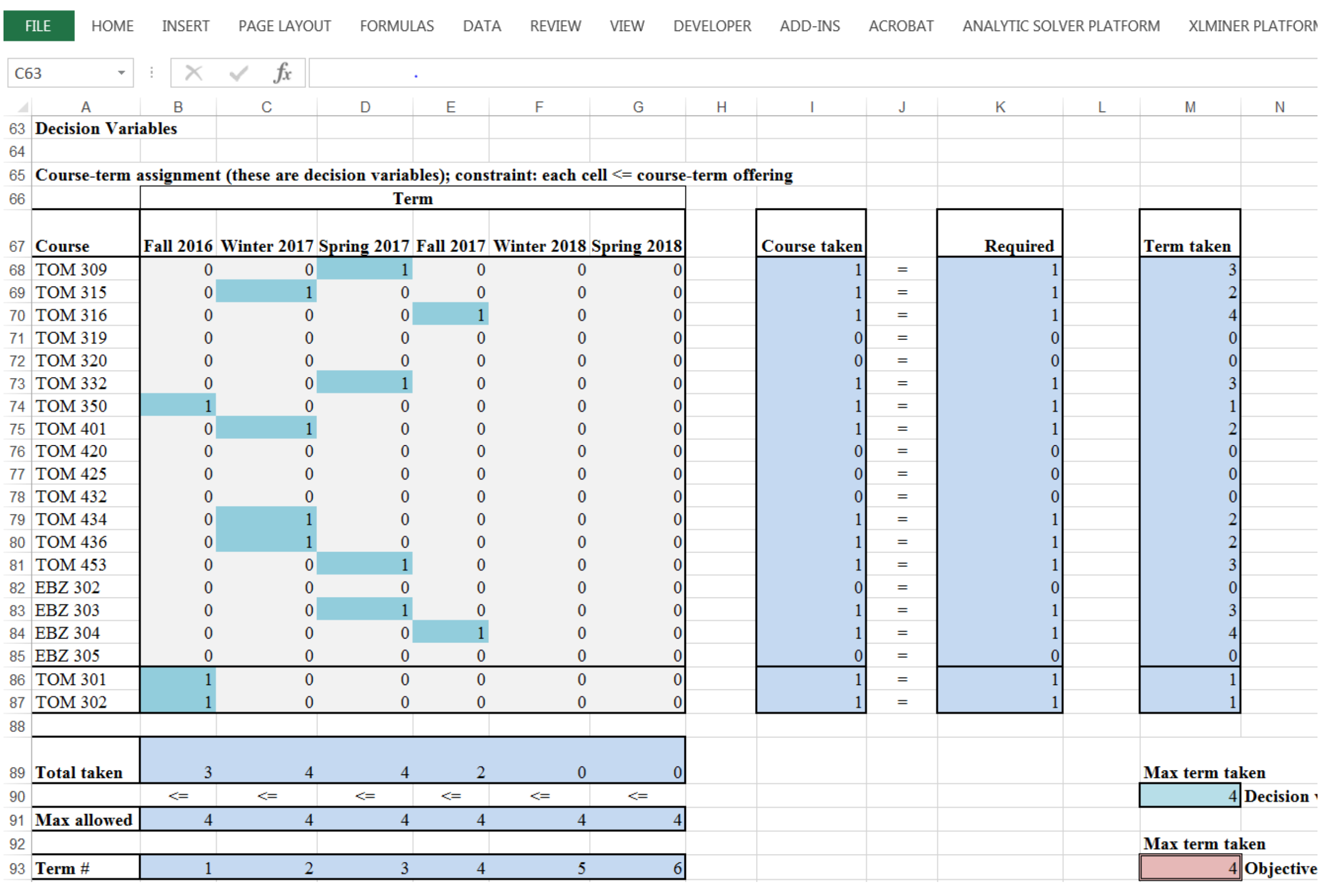
- A course may be taken in a particular term only if it is offered during that term. This is represented as Course-term assignment matrix (shown in Fig. 4) ≤ Course-term offerings matrix (shown in Fig. 1)
- No more than a specified number of courses may be scheduled each term (considering work or other commitments, and any non-TOM/EBZ courses planned for the term).
  Total taken each term (adding along each column of the course-term assignment matrix) ≤ Max allowed that

term (a parameter). In our scenario, the max # of courses allowed is 4 for each term.

- All required courses, and the specified elective courses, must be scheduled to be taken.

  Course taken (adding along each row of the course-term assignment matrix) = Required (a parameter, takes value 1 if the course is required, 0 otherwise).

  The requirements depend on the chosen career track. Our scenario uses the curriculum for the Service Operations Management track. A total of 13 TOM/EBZ courses need to be taken (2 required for the college core, 4 required for the TOM option core, and 7 electives for the Service Operations Management track). The courses required for the college core are TOM 301 (Operations Management), and TOM 302 (Managerial Statistics). The TOM core courses, and the courses for the Service Operations Management track are shown in Tables 2 and 3 respectively.



Decision Variables

Course-term assignment (these are decision variables); constraint: each cell <= course-term offering

	Term									
Course	**Fall 2016**	**Winter 2017**	**Spring 2017**	**Fall 2017**	**Winter 2018**	**Spring 2018**	**Course taken**		**Required**	**Term taken**
TOM 309	0	0	1	0	0	0	1	=	1	3
TOM 315	0	1	0	0	0	0	1	=	1	2
TOM 316	0	0	0	1	0	0	1	=	1	4
TOM 319	0	0	0	0	0	0	0	=	0	0
TOM 320	0	0	0	0	0	0	0	=	0	0
TOM 332	0	0	1	0	0	0	1	=	1	3
TOM 350	1	0	0	0	0	0	1	=	1	1
TOM 401	0	1	0	0	0	0	1	=	1	2
TOM 420	0	0	0	0	0	0	0	=	0	0
TOM 425	0	0	0	0	0	0	0	=	0	0
TOM 432	0	0	0	0	0	0	0	=	0	0
TOM 434	0	1	0	0	0	0	1	=	1	2
TOM 436	0	1	0	0	0	0	1	=	1	2
TOM 453	0	0	1	0	0	0	1	=	1	3
EBZ 302	0	0	0	0	0	0	0	=	0	0
EBZ 303	0	0	1	0	0	0	1	=	1	3
EBZ 304	0	0	0	1	0	0	1	=	1	4
EBZ 305	0	0	0	0	0	0	0	=	0	0
TOM 301	1	0	0	0	0	0	1	=	1	1
TOM 302	1	0	0	0	0	0	1	=	1	1
Total taken	3	4	4	2	0	0				
	<=	<=	<=	<=	<=	<=				
Max allowed	4	4	4	4	4	4				
Term #	1	2	3	4	5	6				

Max term taken
4 **Decision v**

Max term taken
4 **Objective**

FIGURE 4. MODEL DETAILS.

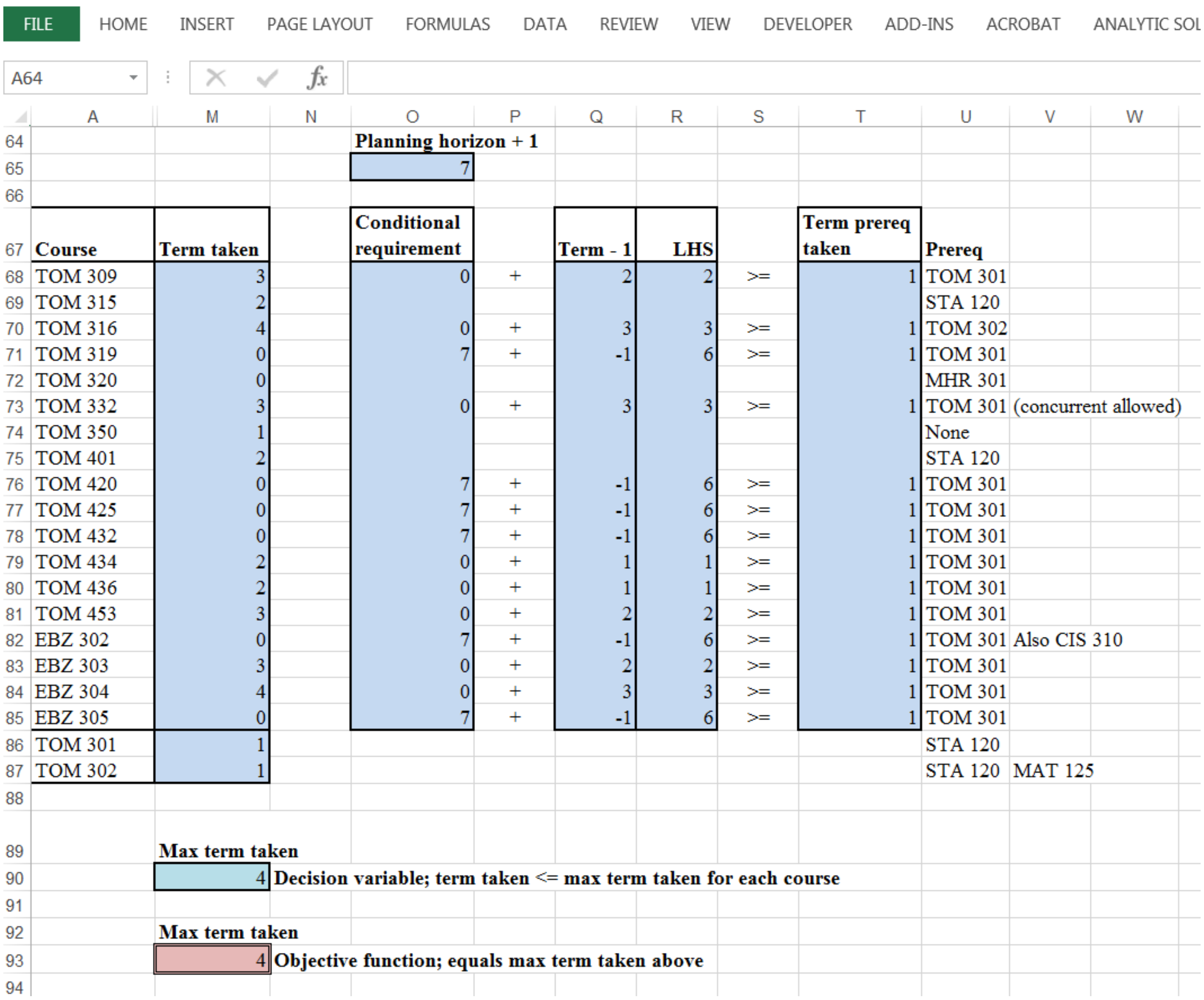
TABLE 2. TOM CORE COURSES.

TOM Core Courses	Number
Management Science	TOM 315
Production Management	TOM 332
Quality Management	TOM 401
E-Business Enabled Supply Chain Management	EBZ 304

TABLE 3. SERVICE OPERATIONS MANAGEMENT COURSES.

Service Operations Management	Number
Logistics Management	TOM 309
Business Analytics	TOM 316
Decision Support and Expert Systems	TOM 350
Modeling and Analysis	TOM 419
Purchasing Management	TOM 434
Project Management	TOM 436
Operations Management in Services	TOM 453
Customer Relationship Management	EBZ 303

- A course may be taken only if the prerequisites are satisfied.
  This requires some manipulation, as described in Section IV. Since the planning horizon for the model is 6 terms (2 years at 3 terms/quarters per year), Z is set at Planning horizon + 1 = 7. As a simplification, only the TOM prerequisites are considered in this model. Fig. 5 shows the details. The Conditional requirement column is calculated as Z*(1-course taken). Column Q = column M – 1, except for the case of concurrent prerequisite allowed, in which case Q = M. The LHS column = column O + Q. Term prerequisite taken = either M86 or M87, depending on the specific course prerequisite. Note that prerequisites are driven by the curriculum and do not change from student to student. Columns O, Q, R, and T are blank for the courses that do not have any TOM prerequisites.



	A	M	N	O	P	Q	R	S	T	U	V
64				Planning horizon + 1							
65				7							
66											
67	Course	Term taken		Conditional requirement		Term - 1	LHS		Term prereq taken	Prereq	
68	TOM 309	3		0	+	2	2	>=	1	TOM 301	
69	TOM 315	2								STA 120	
70	TOM 316	4		0	+	3	3	>=	1	TOM 302	
71	TOM 319	0		7	+	-1	6	>=	1	TOM 301	
72	TOM 320	0								MHR 301	
73	TOM 332	3		0	+	3	3	>=	1	TOM 301	(concurrent allowed)
74	TOM 350	1								None	
75	TOM 401	2								STA 120	
76	TOM 420	0		7	+	-1	6	>=	1	TOM 301	
77	TOM 425	0		7	+	-1	6	>=	1	TOM 301	
78	TOM 432	0		7	+	-1	6	>=	1	TOM 301	
79	TOM 434	2		0	+	1	1	>=	1	TOM 301	
80	TOM 436	2		0	+	1	1	>=	1	TOM 301	
81	TOM 453	3		0	+	2	2	>=	1	TOM 301	
82	EBZ 302	0		7	+	-1	6	>=	1	TOM 301	Also CIS 310
83	EBZ 303	3		0	+	2	2	>=	1	TOM 301	
84	EBZ 304	4		0	+	3	3	>=	1	TOM 301	
85	EBZ 305	0		7	+	-1	6	>=	1	TOM 301	
86	TOM 301	1								STA 120	
87	TOM 302	1								STA 120	MAT 125
88											
89		Max term taken									
90		4	Decision variable; term taken <= max term taken for each course								
91											
92		Max term taken									
93		4	Objective function; equals max term taken above								
94											

FIGURE 5. PREREQUISITES CONSTRAINTS.

- A course may be taken in a particular term and timeslot only if the student is available during that term and timeslot. For the courses in the option, since the course-term assignment establishes the term-timeslot assignment as well (since each course is offered in only one timeslot each term), a term-timeslot assignment matrix is calculated based on the course-timeslot assignments. Fig. 6 shows the course-timeslot assignment matrix for Fall 2016 (similar matrices are created for each term). These matrices are based on the course-term assignments (Fig. 4) and course-timeslot offerings (Fig. 2). Fig. 7 shows the term-timeslot assignments. These are calculated as the respective column totals from the course-timeslot assignments (for example, cell B121 is the sum of cells B98 through B115). The constraints that a course may be taken in a particular term and timeslot only if the student is available during that term and timeslot are represented as Term-timeslot assignment matrix (Fig.

7) ≤ Term-timeslot availability matrix (Fig. 3). As in the case of the decision variables, conditional formatting is used to highlight the solution generated by Solver.

Course - timeslot taken

	Timeslot Fall 2016								
Course	**MWF 11**	**MW 2**	**MW 4**	**MW 6**	**TR 8**	**TR 10**	**TR1**	**TR 3**	**TR 6**
TOM 309		0							
TOM 315									
TOM 316				0					
TOM 319			0						
TOM 320						0			
TOM 332									
TOM 350							1		
TOM 401									
TOM 420									0
TOM 425									
TOM 432						0			
TOM 434									
TOM 436									
TOM 453									
EBZ 302									
EBZ 303							0		
EBZ 304			0						
EBZ 305									

FIGURE 6. COURSE-TIMESLOT ASSIGNMENTS (FALL 2016).

Term - Timeslot taken constraints (each cell <= term-timeslot availability)

	Timeslot								
Term	**MWF 11**	**MW 2**	**MW 4**	**MW 6**	**TR 8**	**TR 10**	**TR1**	**TR 3**	**TR 6**
Fall 2016	0	0	0	0	0	0	1	0	0
Winter 2017	0	0	0	1	0	1	0	1	1
Spring 2017	0	1	0	1	0	1	1	0	0
Fall 2017	0	1	1	0	0	0	0	0	0
Winter 2018	0	0	0	0	0	0	0	0	0
Spring 2018	0	0	0	0	0	0	0	0	0

FIGURE 7. TERM-TIMESLOT ASSIGNMENTS.

Model Solution:

The model was solved using the Analytic Solver Platform Add-in to Microsoft Excel (with the Gurobi Solver engine V6.5). The Solver dialog box with the objective function, decision variables, and constraints, is shown in Fig. 8.

In addition to the scenario outlined in this section, various additional scenarios are used to illustrate the what-if analysis capabilities of the model. Section VI describes the analytical results.

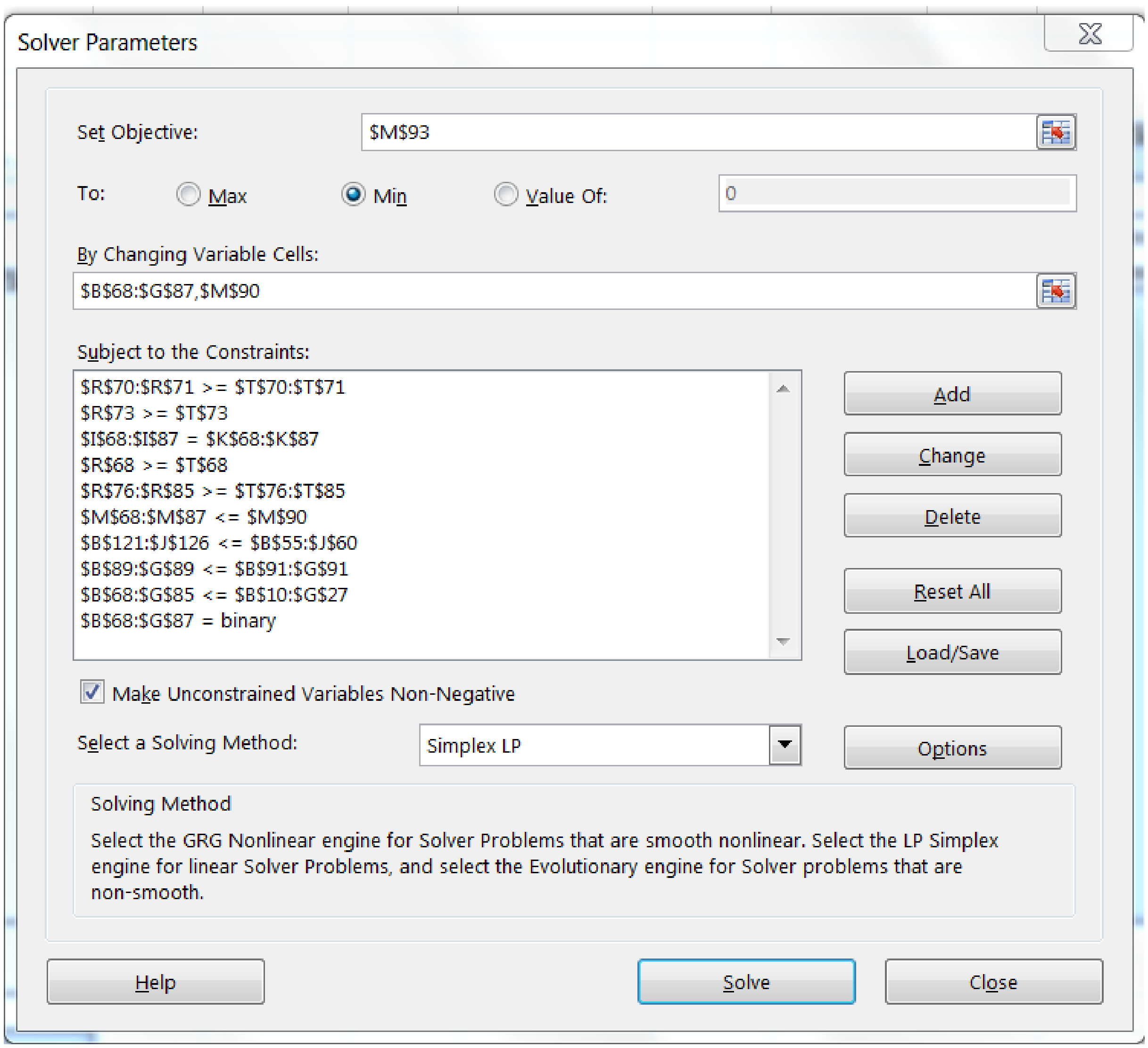


FIGURE 8. SOLVER MODEL.

VI. ANALYTICAL RESULTS AND SCENARIO ANALYSIS

Scenario 1 (described in Section V) was used to illustrate the model. The basic model has about 125 variables and 350 constraints. The optimal solution (presented in Fig. 4) shows a plan to complete the 13 TOM/EBZ courses in 4 quarters. Given the requirement of this scenario to schedule 13 courses with no more than 4 per quarter, 4 quarters is the absolute minimum possible. The Analytic Solver's solve time for this problem is 12 seconds.

Among the benefits of Excel is its ease of use, and the ability to quickly evaluate various scenarios. The existing process for generating individual roadmaps is primarily manual. To get a sense for the potential benefits of the Excel model in enhancing the degree planning process for individual students, a class exercise was given in the course Operations Management in Services, taught by this author in Spring 2017. This is a course in the Service Operations Management track of the TOM option. The students were primarily juniors and seniors, with several graduating seniors. Thus they had personally experienced the process of planning coursework toward degree completion. The details of the model presented in this paper are beyond the scope of the course, however, the case of scheduling classes for a single semester outlined in Winch and Yurkiewicz (2014) had been briefly covered in the course prior to the class exercise. The details of the exercise are provided below.

Class Exercise:

Students were given the following instructions:

> "Create a schedule for a student ("Billy"), that will include all TOM and EBZ courses for the Service Operations Management track (TOM 301, TOM 302, 4 required courses for the TOM option, and 7 directed electives for the Service Operations Management track; assume no course substitutions).
> The objective is to complete the coursework in the minimum # of quarters (without taking any quarters off).
> The scheduling horizon is Fall 2016 through Spring 2018. Assume that TOM 301 and TOM 302 are offered each quarter in multiple timeslots and can be taken anytime in any quarter."

In addition, students were provided the two-year schedule of planned course offerings (shown in Table 1), the TOM degree curriculum sheet (shows the required and elective courses), and course prerequisites information (corresponding to columns A and U of Fig. 5; assume prerequisites satisfied for TOM 301 and TOM 302).

Students were asked to create schedules corresponding to three scenarios:

> *Scenario 1:*
> Billy can take a maximum of 4 courses each quarter. (This is the same Scenario 1 used to illustrate the spreadsheet model in Section V).
>
> *Scenario 2:*
> Billy can take a maximum of 3 courses each quarter.
>
> *Scenario 3:*
> Billy can take a maximum of 3 courses each in Fall 2016 and Winter 2017; and a maximum of 2 courses each in the remaining quarters. Further, due to work commitments, Billy can only take classes that meet at 1 p.m. or later.

For each scenario, students were asked to record their solution in an Excel template (provided electronically via Blackboard, the Learning Management System used in the course), and upload their completed Excel files to Blackboard. Table 4 shows the Excel template for Scenario 1 provided to students (similar templates were included for the other two scenarios).

Students were asked to work on the exercise in teams, and were given 45 minutes in class to come up with best schedules for the three scenarios. Twenty three students completed the exercise, working in eight teams with 2-4 students per team. While students did not have access to the spreadsheet model presented in this paper, they were in a computer lab with individual computers for each student, and had access to any available tools (such as My Planner and Schedule Builder).

TABLE 4. SCENARIO ANALYSIS TEMPLATE.

Scenario1:

Billy can take a maximum of 4 courses each quarter

Your solution:

Courses taken	Fall 2016	Winter 2017	Spring 2017	Fall 2017	Winter 2018	Spring 2018
1						
2						
3						
4						

Minimum # of quarters	

Class Exercise Results:

All the teams appeared to understand that as the scenarios became more restrictive, the minimum number of quarters required to complete the coursework would increase. With 13 courses to be scheduled, the lower bound on the number of quarters required is 4 for scenario 1 (maximum of 4 courses per quarter). When the maximum number of courses per quarter is restricted to 3 as in scenario 2, this lower bound increases to 5 quarters. With the additional restrictions of scenario 3, the lower bound increases further to 6 quarters. In attempting to create schedules to achieve these lower bounds, however, several teams ended up with infeasible schedules. Only two of the eight teams created optimal schedules for all three scenarios. The remaining six teams submitted infeasible schedules for at least one scenario each. The infeasibilities included:

1. Violation of timeslot constraints (scheduling two courses for the same timeslot in the same quarter).
2. Violation of prerequisite constraints (scheduling a course for a quarter without scheduling a prerequisite course for an earlier quarter).
3. Violation of time availability constraint (in scenario 3, scheduling a course for a morning timeslot).

Class Exercise Results (using the Excel model):

All three scenarios were solved using the Excel model developed in this paper. Tables 5, 6, and 7 show the optimal schedules corresponding to the three scenarios. (Multiple optimal solutions exist for each scenario).

Scenario 1:
Scenario 1 is the one that was used to illustrate the model in Section V. Thus, the solution presented in Table 5 is identical to the one illustrated in Section V (Fig. 4). The '1's in the course-term assignment matrix in Fig. 4 correspond to scheduled courses, as enumerated in Table 5. The corresponding timeslot information (for courses in the option) is available in Table 1, and also Figs. 6 and 7.

TABLE 5. SCENARIO 1: OPTIMAL SOLUTION.

Courses taken	Fall 2016	Winter 2017	Spring 2017	Fall 2017	Winter 2018	Spring 2018
1	TOM 301	TOM 315	TOM 309	TOM 316		
2	TOM 302	TOM 401	TOM 332	EBZ 304		
3	TOM 350	TOM 434	TOM 453			
4		TOM 436	EBZ 303			

Minimum # of quarters	4

TABLE 6. SCENARIO 2: OPTIMAL SOLUTION.

Courses taken	Fall 2016	Winter 2017	Spring 2017	Fall 2017	Winter 2018	Spring 2018
1	TOM 301	TOM 332	TOM 434	TOM 316	TOM 309	
2	TOM 302	TOM 401	TOM 453	EBZ 304	TOM 315	
3	TOM 350	TOM 436	EBZ 303			

Minimum # of quarters	5

TABLE 7. SCENARIO 3: OPTIMAL SOLUTION.

Courses taken	Fall 2016	Winter 2017	Spring 2017	Fall 2017	Winter 2018	Spring 2018
1	TOM 301	TOM 315	TOM 309	TOM 316	TOM 434	TOM 332
2	TOM 302	TOM 401	TOM 453	EBZ 304	EBZ 303	TOM 436
3	TOM 350					

Minimum # of quarters	6

Scenario 2:
To run this scenario in Excel, update the maximum number of courses allowed (Fig. 4, row 91) to 3 each term. Everything else stays the same. The optimal solution is summarized in Table 6.

Scenario 3:
For this scenario, update the maximum number of courses allowed (Fig. 4, row 91) to 3 for Fall 2016 and Winter 2017, and to 2 for each of the other quarters. Update the student availability (Fig. 3) by setting the cells in columns B, F, and G to 0 to indicate that the student is not available before 1 pm. Everything else stays the same. The optimal solution is summarized in Table 7.

Although the Excel model is a simplified version of what is essentially a complicated problem, it serves to illustrate a key point: a primary benefit of having access to a model such as this is the ability to quickly generate an optimal solution, and evaluate the impact of alternative scenarios on the time to degree completion. For example, running the scenarios above involves simply changing the values of the relevant parameters in the spreadsheets, and re-running the Solver. It takes about two minutes to update the parameters and start the Solver, and the solve time using the Gurobi engine is under 12 seconds in each of the above cases.

The class exercise was used to illustrate three specific scenarios. In general, many scenarios can be evaluated by the model. Some examples are:

- Two-day schedule options (for example, for students with outside work commitments): The impact of taking courses only two days a week (either Monday/Wednesday or Tuesday/Thursday) can be easily ascertained by adjusting the parameters in the Term-timeslot availability matrix (Fig. 3: run the model with only Monday and Wednesday timeslots available; and again with only Tuesday and Thursday timeslots available). In each case, Solver cannot find a feasible solution. A closer look at the data shows that TOM 350, a required course in the track, is never offered on a Monday/Wednesday schedule during the two-year planning horizon, hence the problem is infeasible if the student is only available to take classes on Mondays and Wednesdays. Likewise, restricting scheduling options to Tuesday/Thursday classes creates an infeasibility as EBZ 304, a required course, is not offered on a Tuesday/Thursday schedule during the horizon.
- Only mornings, or only afternoons and evenings available (this scenario too is applicable for students with work commitments): Adjusting the parameters in the term-timeslot availability matrix (Fig. 3) and running the model shows that there is no feasible solution if the student is only available in the mornings. With only afternoon and evening availability, the minimum time to coursework completion is 5 quarters (assuming maximum load of 4 courses per quarter). This shows that restricting availability to only afternoons and evenings would increase the completion time by one quarter.
- Increasing or decreasing the maximum number of courses allowed to be scheduled each quarter. Since this simplified model only schedules the courses offered by the TOM department, allowances can be built for scheduling other coursework by adjusting the maximum number of department courses each quarter. Further, a student could determine whether increasing the limit would potentially reduce the time to degree completion. Scenarios 1 and 2 in the class exercise illustrated this tradeoff.
- Impact of career track choice: While the Service Operations Management track was used to illustrate the model, it can be readily adjusted for the other two career tracks by changing the course requirement parameters (Fig. 4, column K).

An important issue mentioned earlier in the paper is the need to be able to update the roadmaps dynamically (term-by-term), as situations may arise in which the scheduled plan is not realized. For the Excel model, this would mean updating the parameters as needed, and re-running the model each term. To use the model in the middle of the planning horizon (e.g., from term 2 onwards): Set the maximum number of courses allowed in term 1 to 0 (Fig. 4). This will ensure that nothing is scheduled for term 1. Courses already taken can be incorporated by adjusting the parameters corresponding to specific course requirements (Fig. 4, column K).

A similar procedure can also accommodate unexpected situations such as failing a course (do not adjust the parameter to show the course as already taken, leave it as a requirement to be completed). As an example, using the optimal solution from scenario 1 (Table 5) as a baseline, if the student fails TOM 350 and the model is rerun to account for that, the Solver is able to find an optimal solution without impacting the minimum number of quarters to completion (4 quarters). However, if a student fails TOM 401, the resulting optimal solution requires a minimum of 5 quarters.

The situation with withdrawing for an entire quarter due to sick leave would follow a similar adjustment (rerun the model from the term of return onwards, following the procedure for using the model in the middle of the planning horizon outlined above). Again, using the scenario 1 optimal solution as a baseline, if a student was unable to take classes during Winter 2017, and the model rerun, the minimum number of quarters to completion would increase to 6. However, if a student were to withdraw from classes in Spring 2017, the coursework could be completed in a minimum of 5 quarters.

If the department were to offer weekend courses, or more evening courses, this can be incorporated by updating the course-term matrix and the course-timeslot matrix (Figs. 1 and 2 respectively). These matrices would also need to be updated when the department updates its planned course offerings (typically done annually).

Thus the model can be easily adapted to individual or departmental circumstances. The strength of the model is in its ability to quickly evaluate alternative scenarios; to analyze the impact of student choices with respect to maximum course loads and student availability on time to completion; and to dynamically adapt to unforeseen circumstances, adjusting the recommended course schedules in each case to provide optimum paths to coursework completion.

Degree Completion Times and Graduation Rates:

As mentioned in the introduction, ensuring timely completion of a college degree is a high priority for Colleges and Universities across the nation, as evidenced by the continued focus on graduation rates. While it is difficult to explicitly quantify the effects of using the proposed model on degree completion times and graduation rates, the following numerical example can be illustrative: Consider a 4-year graduation rate of 20%, and a 6-year graduation rate of 60% (this is in the ballpark of the actual numbers for both the College of Business Administration at Cal Poly Pomona, and the CSU as a whole). Consider an option with 60 students starting each year, on average. This would correspond to 12 students from each 'cohort' graduating in 4 years, and 36 students in 6 years. Interpolating between the 4 and 6-year marks for the number of students completing their degree requirements each quarter, even if just one student were to reduce their time to completion by one quarter, this would increase the 4-year graduation rate from 20% to 21.7%, and the 6-year rate from 60% to 61.7%. With two students reducing their degree completion time by one quarter, the 4-year rate would be 23.3%, and the 6-year rate 63.3%. This illustrates the very concrete impact of reducing degree completion times on graduation rates, an important metric for Colleges and Universities. The proposed model would be one tool in the portfolio of resources available to help students minimize time to degree.

VII. CONCLUSIONS

This paper presents an integer linear programming model and a spreadsheet-based solution approach to the problem of creating individual graduation roadmaps for students, and dynamically adjusting them as needed to account for changes in individual circumstances. The problem is motivated by the fact that currently existing graduation roadmaps are typically static and may not be realistic for all students to follow. While there are several examples in the university scheduling literature for course, instructor, and timeslot scheduling, there is not much research in the area of optimization models for individualized course planning toward degree completion. This research extends existing models (Chen et al, 2014; Dechter, 2007, 2009) through the consideration of planned course offerings, course time-slots, and student availabilities over a multi-term planning horizon.

The Excel model may be considered a prototype of a new tool to supplement the advising resources available to aid students with planning their path to degree completion. Two tools currently available to Cal Poly Pomona students are My Planner and Schedule Builder (described in Section III). As mentioned therein, My Planner does not include constraint checking or optimization, while Schedule Builder does not have a multi-term horizon. The Excel model presented in this research includes constraint checking and optimization, as well as a multi-term horizon, albeit on a small scale. The model would be most relevant to juniors and seniors who have completed most of their general education coursework and are primarily focused on core and option level courses. The spreadsheet environment is attractive due to its ease of use and quick scenario analysis capabilities.

Model testing on several example scenarios shows that the Solver is able to generate optimal solutions (or conclude that the problem is infeasible) within seconds, thereby enabling quick evaluation of alternatives. However, the spreadsheet implementation is limited by the simplifying assumptions (focusing on the courses in one department), and the computational complexity would make it difficult to implement the full model in a spreadsheet. Future enhancements include relaxing some of the simplifying assumptions, exploring other solution approaches, increasing the user-friendliness of the model, and integrating with other advising tools. Needless to say, individual academic planning will continue to be a complex problem and no tool will substitute for the human role in advising.

Another contribution of this research is to provide an example of a real-life problem that can be used in the classroom to demonstrate an application of optimization/prescriptive analytics using spreadsheet software. The context of the problem is one that students can relate to, and help make the material more relevant to them. While there are examples in the literature of using spreadsheets to teach optimization, this particular problem does not appear to have been addressed. As mentioned in Section II, the closest example to the context of this research in a classroom setting appears to be Winch and Yurkiewicz (2014), however, that work was restricted to planning a student's schedule for a single term, while this research considers a planning horizon spanning multiple terms.

The class exercise piloted in the Operations Management in Services course in Spring 2017 helps illustrate the power of this model to quickly evaluate various scenarios for individualized coursework planning toward degree completion, a process that can be daunting when attempted manually. This problem and solution procedure would work particularly well as a case study in courses that focus on topics related to optimization. In addition to covering the basics of the model and some example scenarios, students could be asked to create schedules incorporating their own sets of parameters and constraints, enabling them to see the impact of their choices with respect to factors such as work constraints, time availability, and course loads on the time to complete degree requirements. The TOM department at Cal Poly Pomona offers a course in Management Science (required for all students in the TOM option), and one in Business Analytics (elective for students in the Service Operations Management and Management of Technology tracks). Both courses typically integrate spreadsheets throughout, and either could use this effectively as a case study.

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