A MICROCOMPUTER PACKAGE TO TEACH THE SIMPLEX ALGORITHM

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Abstract

Basic features of a microcomputer package, BCDP, which is an auto-tutorial designed to teach the Simplex algorithm are described. The package may be used to augment lecture and text materials in introductory linear programming courses or as a review for advanced math programming courses. Preliminary evaluations of the effectiveness of the program to augment classroom instruction are very positive.

Key words: linear programming, simplex, computer aided instruction.

Linear programming (LP) is one of the primary tools of agricultural economists and several other disciplines. Major universities typically offer several courses devoted exclusively, or in part, to teaching LP. These courses usually begin by teaching the Simplex Algorithm and, possibly, some variant such as the Revised Simplex Algorithm. Once the students can perform the required manipulations by hand on small problems, the courses continue with applications using a mainframe or microcomputer LP package (Laughlin).

The program discussed in this paper, BCDP,[1] focuses on the initial portion of such a course. BCDP takes a student who has no knowledge of LP to a point where he/she understands the basic concepts and terminology and can solve a problem which is in standard (i.e., canonical) form.[2] BCDP is intended to augment textbook and classroom presentations in introductory LP courses and serves as a review for more advanced courses.

MOTIVATION AND DESIGN PHILOSOPHY FOR BCDP

The impetus for creating BCDP was the observation that classroom and textbook explanations of the Simplex Algorithm are often difficult for students to grasp. This is true both with respect to understanding the correspondence between geometric and mathematical representations of LP problems and to mastering the mechanics necessary to achieve a solution.

A classic example of such problems is the confusion which often attends learning the concept of a shadow price. Suppose that you are paid \$35 per unit for corn silage and \$50 per unit for alfalfa. In the initial tableau, it is relatively easy to believe that the shadow price for corn silage should be \$35. After the first iteration, in which alfalfa enters the solution, all of the labor may be used and the shadow price (or income penalty) for corn silage now become −\$1.11. Typical question, said and unsaid, at this point are:

Why are we not getting paid −\$1.11 for corn silage?

How could we make corn silage — there is no more labor?

How can you make corn silage out of alfalfa?

To those who already understand LP, the answers to these questions are obvious. But to those just learning the procedure, LP is rife with perplexing mysteries. Too often students give up and resort to learning by rote. They regard shadow prices as unrealistic numbers of an arcane nature and never see

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[1]BCDP is derived from the last initials of those involved with development of the product: Beilock, Correal, Drummond, and Pheasant.

[2]Standard or canonical form denotes a tableau with linear inequalities and no activity may assume negative values (Chavtal, pp. 3-12).

the resource-activity linkage which undergirds this important portrayal of opportunity costs. A major reason for such difficulties is that both classroom and textbook presentations tend to allow students to be passive.

Other problems with classroom presentations are that they are not repeatable on demand, and the clarity of the graphical depictions may be compromised by the instructor's ability to draw or by student seating arrangements. An additional problem for textbook presentations is that it is difficult to demonstrate movement, such as shifting resources between activities, in a convincing manner.

BCDP was designed to alleviate these problems. A major advantage of using the microcomputer as a teaching medium is the ability to present high quality graphics that can dynamically change. An example of use of this capability in BCDP is a sequence which presents the concept of a shadow price. BCDP activities, including slack activities, are portrayed as boxes containing portions of uniquely colored resources. The amounts of the activities and resources as well as the values of the activities (i.e. objective function coefficients times amounts) are also displayed. To demonstrate the shadow price for activity X, another box is created in which one unit of activity X is to be made. The student sees the necessary resources migrating from the other activities, the resulting changes in the amounts of the activities made, and the change in the objective function value, *which is the shadow price.*[3]

To combat passivity, the user is frequently called upon to answer quizzes and to assist in the process of reaching the optimum solution. The student immediately knows if the answers are correct and why or why not. Another feature that avoids boredom is that the lessons are short. BCDP is divided into 5 modules or lessons. With the exception of the final module, no lessons should require much in excess of a half an hour to complete. This combats fatigue by giving the student manageable intermediate goals to attain. Unlike classroom lectures, the lessons, or even parts of them, can be repeated until mastered. Finally, for students who are reticent about admitting to having difficulties, the anonymity of BCDP may also be a distinct advantage.[4]

REVIEW OF SIMILAR WORKS

To the author's knowledge, only one other software package focuses on teaching the Simplex Algorithm, *The Optimizer* by James Fugate. Using either preprogrammed or user provided data, *The Optimizer* presents the mechanics of the Simplex Algorithm, with some explanations. The program, however, does not fully convey the sense of the procedures or the basic concepts. Rather, the mechanics are presented almost in cookbook fashion without user participation or testing. Throughout the optimization procedure, the user is relegated to pressing the spacebar, without even the option of skipping ahead or paging back.

The user learns to look for shadow prices of the correct sign to identify when the optimum has been reached, but almost no effort is made to communicate the meaning of shadow prices. It would be impossible from the package, for example, to learn that a shadow price on a slack variable gives information regarding the marginal value product of the associated resource. Other key concepts are either treated in passing or omitted entirely. Among the concepts not mentioned are: nonnegativity constraints, degeneracy, and convexity. Finally, there are no graphics to illustrate any of the concepts.

This is not meant to imply that *The Optimizer* is a flawed program, but rather that it has a different function than that for which BCDP was designed. *The Optimizer* is well suited for a quick review of the mechanics of the Simplex Algorithm. BCDP, on the other hand, was designed to fully acquaint the user with the underlying concepts and the sense of the procedures employed to solve linear programming problems.

OVERVIEW OF BCDP

User Prerequisites

BCDP requires only minimal prerequisites of the user. These are the ability to perform

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[3]Technically, a shadow price is the instantaneous rate of change in the objective function as a particular activity is produced. This is the same as that shown in the text as long as there is at least enough of each of the basic activities to make one of the activity for which the shadow price is calculated. This distinction is pointed out in BCDP.

[4]There is a growing literature addressing the pros and cons of Computer Aided Instruction (CAI). Hartley specifically addressed CAI for teaching mathematical concepts. Three excellent surveys of the effectiveness of CAI are Edwards et al.; Jamison et al.; and Vinsonhaler and Bass.

addition, subtraction, multiplication, division, and basic algebraic manipulations on equations and inequalities.[5] The following are *not* required: prior exposure to LP, experience with computers, and knowledge of linear algebra.

The student guide and the program itself instruct the student in computer operations from start-up to the end of the session. Given the minimal prerequisites, the package is suitable for undergraduate as well as graduate instruction. It may also have applications for extension programs. For example, BCDP could be employed to enhance county agents' understanding of the concepts underlying the linear programming packages they may use and the meaning of the output.

The BCDP Program Models

BCDP centers around developing a simple problem having two real activities. The number of activities is limited to two in order to facilitate the graphics. The presentation evolves from strictly graphical to mathematical, with frequent references back to the graphical presentation. The problem itself is typical of that found in basic linear programming texts — a farmer (Brown, of course) wishes to maximize profits by growing one or both of two crops.

BCDP consists of five modules or lessons, each on a separate diskette, Table 1. Each module ends at a logical breakpoint in the material. As previously stated, having several sublessons may lower student fatigue. It also provides tangible intermediate learning goals. Average completion times for each lesson varies from 20 to 40 minutes. Every lesson begins with a statement of the objectives and a short review of previous material. Students encounter questions throughout each lesson. Correct and incorrect answers are acknowledged.

With an incorrect response, the user is routed to an explanation of why the answer was wrong. The correct answer may then be given, or more often hints are supplied regarding how to determine the correct answer and the user is rerouted back to the question. There are no "blind alleys" to questions. In all cases, there is either a finite number of answers or an explanation of the correct answer is given after a preset number of tries.

A quiz ends each lesson. This permits the student to review what has been learned in that and in previous modules. The student is informed of wrong answers and where to find the lesson covering those concepts. Finally, the objectives of the module are reviewed and those of the next module are previewed.

The Help Menu

At any time[6], the user can access the Help Menu by entering "H" or "HELP." The Help Menu has three main features: a screen locator to allow the user to skip forward or back throughout the module, a glossary of

TABLE 1. TEACHING OBJECTIVES OF THE BCDP MODULES

Module	Objectives	Comments
BCDP 1.....	1. Orient the student to BCDP. 2. Define LP and describe types of problems LP can be used to analyze. 3. Define activity and resources.	User is forced to use the Help Menu at least once.
BCDP 2.....	1. Develop the basic components of a linear programming problem. These include: constraints, objective function, and feasible region.	
BCDP 3.....	1. Define isorevenue or isopayoff. 2. Demonstrate geometrically where the optimum solution is located.	Multiple solutions are briefly addressed.
BCDP 4.....	1. Demonstrate geometrically how in LP the path to the optimum solution is selected. 2. Define convexity and shadow price.	A detailed explanation is given of the link between resource usage and shadow prices.
BCDP 5.....	1. Show how to determine the optimum solution mathematically.	Frequent reference is made back to the geometric interpretation. User is required to assist in determining the solution.

[5]These are adding and subtracting equivalent amounts from both sides and multiplying both sides by a constant.
[6]The only exception to this is in the middle of the review quizzes at the end of each module.

terms, and a presentation of the example problem used throughout BCDP.

The screen locator is almost a necessity in a tutorial of this kind. Without it, the user would be confined to following the program sequentially, even if he/she simply wanted to review a few screens. Of almost equal importance is the glossary because LP is particularly littered with jargon which may be strange to the novice LP user.

Hardware and Software Requirements

To run BCDP, the user needs an IBM Personal Computer (or a compatible, such as a Zenith 150) with at least 128K random access memory, a color monitor, or a monitor with a composite video input. No other peripherals, such as a printer, are needed. The operating system used by BCDP is MS-DOS, version 2.0 or higher. This is not supplied with BCDP.

FIELD TESTING

Unlike many biological experiments, a double blind design is not possible to evaluate acceptability of the package. The students of course know if they have access to BCDP, and they are liable to swap information with other students and to ask questions of the instructor that reveals that BCDP has been used. Without a double blind structure, the potential for conscious or unconscious biasing of the test is obvious. In view of this, it was decided to teach the course as usual, but to allow all students access to BCDP as a study aid.

The test was conducted in Fall, 1985 with a class of 28 upper division undergraduate and graduate students. Students were given access to and were strongly advised to use BCDP. All used at least two modules. All but three students viewed four modules, and 21 viewed all 5 modules. Just under half the class reviewed one or more modules.

After being examined on the material, students completed a questionnaire. They were asked to give their student number, but were assured that their names would not be revealed to the instructor. Students were asked to rank the lectures, handouts,[7] homework, and BCDP in terms of contribution to understanding the subject matter. On a scale of 1 to 10 (1 = poor, and 10 = excellent), the average scores were: lectures, 6.71; homework, 7.10; handouts, 7.15; and BCDP, 8.32. The differences between the mean score for BCDP, on the one hand, and those for lectures, homework, and handouts, on the other hand, were statistically significant at the .01 level of probability. Only 3 of the 28 students rated the lectures above BCDP. Moreover, the rankings did not appear to be related to class standing (i.e., junior, senior, or graduate), performance on the exam, or familiarity with computers.[8] What makes these results particularly impressive is that the instructor has consistently received high ratings on student course evaluations.

Students were also asked to gauge the overall pace of the modules, frequency of quizzes, and ease and usefulness of the HELP MENU. With only one exception regarding the HELP MENU, no respondent chose a totally negative response.[9] A large majority judged both the

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[7]A text is not used in this course.

[8]On the questionnaire, students were asked to describe their level of computer familiarity on a 5 point scale from "very familiar" to "no prior experience."

[9]The responses were as follows:

Overall Pace

too fast	somewhat fast	about right	a little slow	too slow
0	7	16	5	0

Quizzes

too many	somewhat too many	about right	not quite enough	too few
0	2	22	4	0

Help Menu-Usefulness (5 point sliding scale)

extremely useful (1)	(2)	(3)	(4)	never useful (5)
2	10	11	4	1

Help Menu-Ease of Use (5 point sliding scale)

very easy (1)	(2)	(3)	(4)	very difficult (5)
13	7	7	0	0

(one nonrespondent to this last question)

overall pace of the lessons and the frequency of quizzes to be appropriate. Nobody appeared to have extreme difficulty using the HELP MENU, though some found its usefulness to be limited.

PROGRAM AVAILABILITY

BCDP was developed as a joint study between the IBM Corporation and the University of Florida. The package is available at a nominal fee to readers of this journal. Those interested should contact Richard Beilock, G091, McCarty Hall, University of Florida, Gainesville, Florida, 33611.

SUMMARY AND CONCLUSIONS

BCDP is a self-tutorial designed to teach students the basic concepts and terminology associated with linear programming and how to solve problems in canonical form. The package takes advantage of the computer's ability to accurately present and move graphical material and allow for user interaction. The package also has the advantage of being repeatable on demand. Results of the initial field testing indicated that students valued BCDP as a learning tool above lectures, handouts, and homework.

There are several possible extensions or improvements beyond BCDP for a math programming teaching package. These include: development of graphics to allow for a third real activity, allow for user input of a problem, presentations of problems not in standard form, sensitivity analysis explanations, and presentations of problems using nonlinear programming techniques. The authors are exploring several of these.

More generally the success indicated by the preliminary testing is suggestive of the potential of computer aided instruction for teaching agricultural economics and associated mathematical and statistical techniques. Like any medium, however, it has strengths and weaknesses. Basically it is strong on repeatability, graphics, and student interaction and weak regarding the communication of large volumes of textual materials. Teaching applications should be designed to take advantage of these characteristics.

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