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ABSTRACT

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THE EXPANSION OF UNIVERSITY FACILITIES
TO ACCOMMODATE INCREASING ENROLLMENTS

Robert D. Sanderson

Paper P-3

Revised November 1969

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PREFACE

This is one of a continuing series of reports of the Ford Foundation sponsored Research Program in University Administration at the University of California, Berkeley. The guiding purpose of this Program is to undertake quantitative research which will assist university administrators and other individuals seriously concerned with the management of university systems both to understand the basic functions of their complex systems and to utilize effectively the tools of modern management in the allocation of educational resources.

This Paper reports on a mathematical model of the expansion of physical facilities to accommodate the needs of increasing enrollments. This is a very complex problem which is considerably abstracted in the formulation of an optimization model which calculates the least cost expansion path for a university system facing increasing enrollment demands.

The research reported in this Paper is but one approach to the pervasive problem of university resource allocation ovaer multiple objectives and over multiple time periods. However, this Paper is an illustration of the conceptual and computational feasibility of applying sophisticated mathematical programming techniques to important aspects of university management.

ABSTRACT

A mathematical model is developed for the expansion of facilities at different campuses of the University of California for a given sequence of enrollment forecasts. Based on total projected enrollments for the University system, the model computes a minimum total cost expansion program, i.e., the stages at which to expand existing campuses or to build new ones, and the enrollments that should be allocated to those campuses. It is formulated as a network flow problem in which nonzero flows on certain arcs incur fixed charges; however, for computational purposes the problem may be reduced to a linear integer program in binary variables. The model does not include such factors as graduate-undergraduate mix, departmental mix, departmental sizes, or restrictions on tenure faculty, but rather is oriented towards a method of accommodating gross enrollments.

I. INTRODUCTION

1. The Problem

By the late 1970's, demand by qualified applicants for enrollment at the University of California will exceed the capacity of the University system unless the University initiates a program of expansion in addition to the normal growth of current campuses. Alternative components of such a program are the development of new campuses and expansion of existing campuses beyond their present enrollment ceilings. The campuses at which expansion is possible are Davis, Santa Barbara, Irvine, San Diego, and Santa Cruz. This study investigates the economic consequences of various expansion policies, and determines least cost programs that satisfy the demand for the time horizon, 1975-2005.

2. Network Flow Model

The problem is formulated as a least cost network flow model. Flow represents gross demand for enrollment; it originates at a set of source nodes each of which signifies a year in the time horizon. The flow then travels over directed arcs into a set of intermediate nodes, each of which represents a particular campus. The amount of flow on one of these arcs is the number of students accommodated by that facility in the year signified by the source. Flow proceeds from the intermediate nodes along arcs connected to a sink node. The flow on one of these arcs represents the total number of students served by the facility.

. Upper limits on arc flows are imposed corresponding to facility capacities. Initial investment and annual operating costs are considered. These costs are reflected by defining for certain arcs (i,j) fixed-charge cost functions, $C_{ij}(x_{ij})$, defined here to be

$$\begin{aligned} C_{ij}(x_{ij}) &= 0 \quad \text{if } x_{ij} = 0 \\ &= d \quad \text{if } x_{ij} > 0 \end{aligned} \tag{1}$$

where x_{ij} is the flow on arc (i,j) .

3. Computational Formulation

Because all arc cost functions are of the form (1), a minimum cost set of flows needs to be determined only to the extent of resolving $x_{ij} = 0$ versus $x_{ij} > 0$ for every arc (i,j) with a fixed charge. Once these decisions have been made, one set of feasible flows costs the same as any other. This observation allows the problem to be reformulated as a linear integer program in binary variables. Each variable x_j in the integer program corresponds to a possible new facility; if $x_j = 1$ the facility is part of an expansion program; if $x_j = 0$ the facility is not included. There are two constraints for each time period: one which requires demand to be met, and one which specifies that a new campus must be developed to 10,000 students before it is expanded to 20,000.

4. Summary of Expansion Programs

When constant 1975 dollar costs are used, a number of very different policies have very nearly equal costs. All of these programs exercise every option to expand existing campuses beyond their current ceilings. The cheapest constant dollar policy calls for three additional campuses to be developed opening in 1975, 1976, and 1984, respectively.

Because demand growth is exponential and facility growth essentially linear, the total number of 10,000 - student new campus increments is determined solely by the demand in the last year of the time horizon. In order to meet this demand, it is necessary either to start a few campuses fairly early so that they will be large by 2005, or to start a large number of campuses later on so that the University capacity can grow as fast as the demand does.

The three-new-campus policy generates more excess capacity in intermediate years than a six-new-campus policy. When costs are discounted by as little as one per cent per year, a policy calling for six new campuses, to be started in 1984, 1985, 1994, 1995, 1996 and 1997, becomes the least cost program. For discount rates from five to twelve per cent. seven-new-campus policies have the least cost, and for rates thirteen per cent or greater, a nine-new-campus "last minute" policy is called for.

II. NETWORK FLOW MODEL

1. Structure of the Network

The model presented here depicts accommodation of gross demand for student enrollment at general campuses of the University of California over the time span 1975-2005. No distinctions are made with respect to academic field or level, except that medical sciences are not included. Accommodation of demand is represented by a flow network in which there is one homogeneous commodity of flow: student-years. Flow originates at a set of source nodes and then to a terminal sink node. Flow must be conserved at the intermediate nodes.

Each source node represents a year; the flow originating at that node is the demand for student enrollment for that year. The demand includes both new and continuing students. Each intermediate node represents a possible facility, e.g., a new campus that first admits students in 1980. Thus, the flow on a source-intermediate arc (i,j) is the number of students served by facility j in year i. For intermediate nodes representing existing facilities or campuses expanded beyond their current ceiling, there is one arc from that node to the sink. Flow on an intermediate-sink arc (j,t) is the total number of student-years provided by facility j over the entire time span. Each new campus requires four intermediate nodes. The first three each represent developing facilities to accommodate 10,000 students, and the fourth depicts land acquisition and campus start-up activities. There are source-intermediate arcs (i,j) into the first three nodes, where j is a particular new campus increment.

There are arcs from each of the three nodes representing a new campus increment to the node depicting land acquisition, and an arc from that node to the sink. The total flow into the sink is the number of student-years provided by the whole University system over the time span. Figure 1 shows a sample network with two possible new campuses and one campus which could be expanded. For the flows indicated by the numbers over the arcs in Figure 1, only the first 10,000 student increment of the second new campus is used. All flows in the network are [illegible] to be nonnegative.

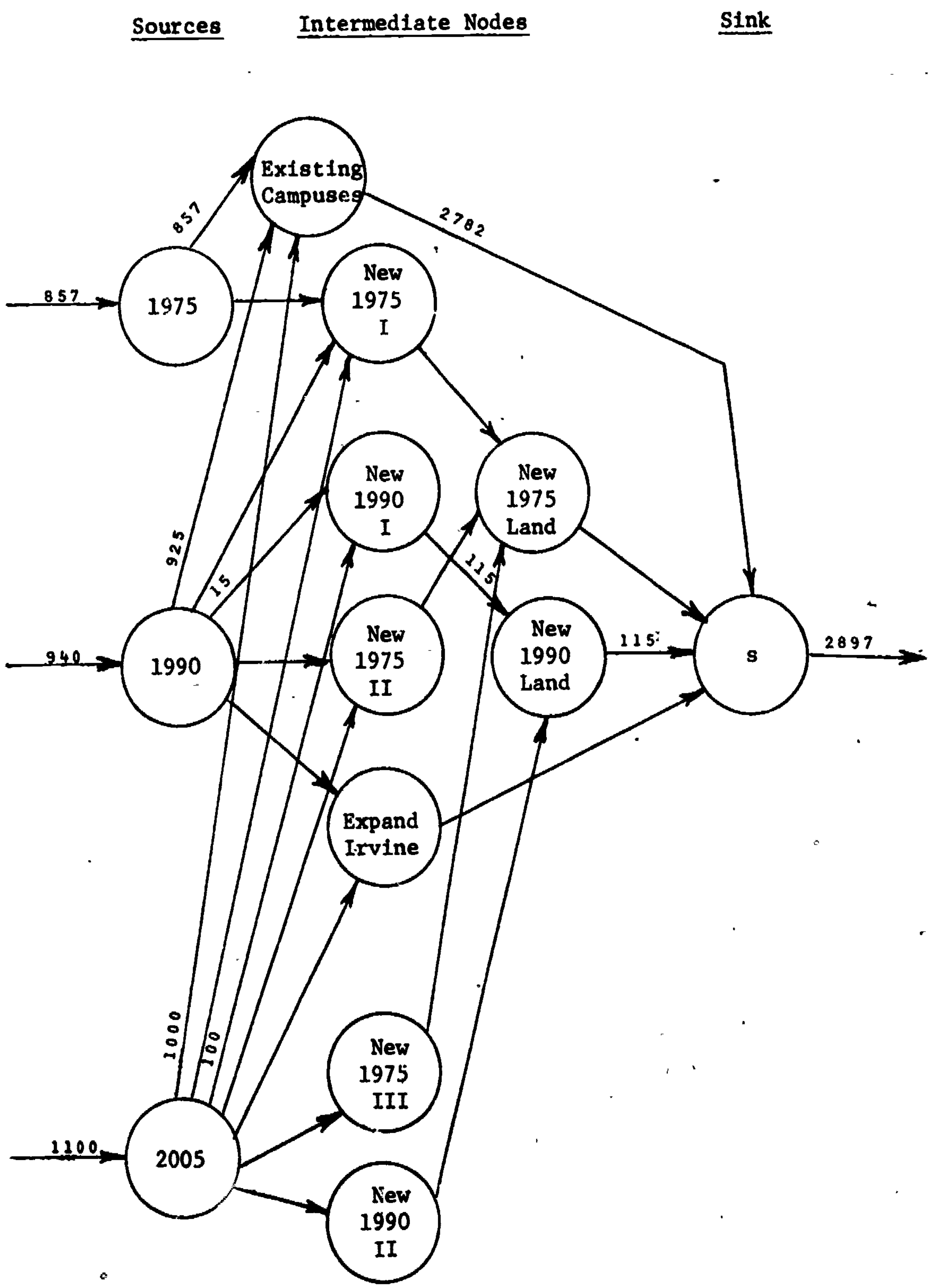


Figure 1. Sample Network
(Non-zero flows in hundreds of students)

2. Existing and Currently Planned Facilities

In each year, an increasingly large number of students can be served by the existing campuses of the University as they grow to their current enrollment ceilings. All of these existing facilities are represented by a single intermediate node. There are arcs from every source and an arc to the sink. On each source-intermediate arc, we place an upper limit on the flow, which is equal to the total capacity of the existing campuses in the year represented by the source node. The upper limit on the flow for the arc into the sink is the sum of the flow limits on the source-intermediate arcs.

In evaluating the economic consequences of any expansion program there are three types of costs to consider: initial investment, operating cost, and personal costs to the student. Because there is no aggregate data on personal costs, they are not included in the model. For the University of California, 1961-1965 operating cost as a function of total enrollment was very nearly a linear relation of the form $C(x) = a + bx$ with all campuses having the same slope [Hansen (1966), p. 15]. That is, the marginal operating cost per student was effectively constant as a function of total enrollment. Thus, since marginal operating costs are unaffected by the choice of expansion alternatives, we do not include them in the model. In the case of an existing campus, the fixed part of the operating cost will be incurred whatever the campus' enrollment. Also, the initial investment required by the growth of the existing campuses to their current ceilings is unaltered by any additional expansion. Therefore, the model does not include any costs for accommodating students at existing or currently planned facilities.

3. Expanding Campuses Beyond Current Enrollment Ceilings

At five campuses, expansion beyond the current enrollment ceilings is economically feasible. Santa Barbara's ceiling could be increased from 25,000 to 27,500; Davis' limit could be upped from 16,000 to 19,000, 23,000, or 27,500; and Irvine, San Diego, and Santa Cruz could each serve an additional 10,000 students. We assume that, if a campus is expanded beyond its current ceiling, the additional expansion will begin the year after the current ceiling is reached.

For each expansion alternative there is one intermediate node with an arc leading from it to the sink. There is also an arc from every source which signifies a year occurring later than the one in which the campus reaches its current ceiling. For example, if Irvine reaches its ceiling in 1992, there will be arcs to the "expand Irvine" node from every source after 1992. On each source-intermediate arc, the upper flow limit is equal to the additional capacity achieved by that year. Except for Santa Barbara, where the growth is done in two steps of 1200 and 1300, expansion of existing campuses to new ceilings occurs at the rate of 1000 students per year. Figure 2 indicates the pattern for Irvine, and Table 1 (Chapter 4) has the full details of each expansion alternative.

Because the fixed portions of annual operating costs at existing campuses will be incurred whether the campus is expanded or not, we consider only the initial investment required to expand an existing campus. The initial investment cost of an expansion alternative is represented by defining a cost function on the intermediate-sink arc (j, s):

$$C_{js}(x_{js}) = 0 \quad \text{if} \quad x_{js} = 0$$
$$= d_j \quad \text{if} \quad x_{js} > 0 \qquad (2)$$

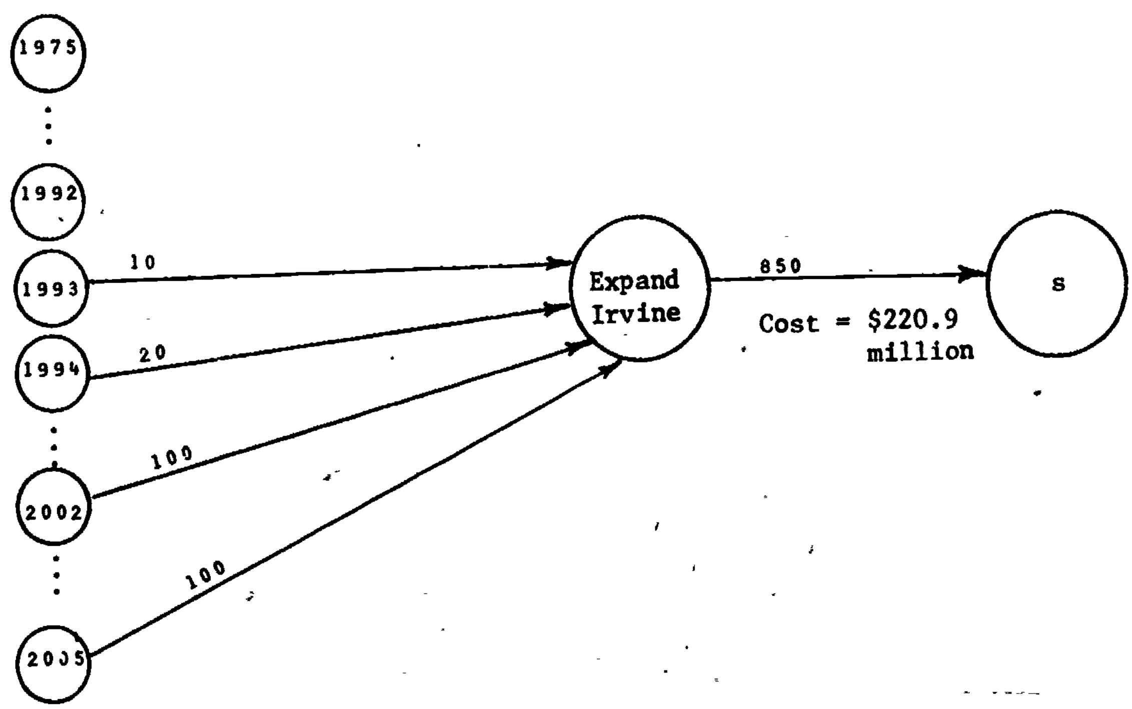


Figure 2. Expansion of Irvine
(Upper flow limits in hundreds of students)

where x_{js} is the flow and d_j is the initial investment cost of alternative j . $x_{js} = 0$ means that no students are served by facility j , i.e., facility j is not built when $x_{js} = 0$; $x_{js} > 0$ implies that alternative j is part of the expansion policy. Except for Davis, the initial investment costs of expanding an existing campus are all construction costs.

4. New Campuses

The model allows the possiblity of opening one new campus each year. In its first year, the campus can accommodate 1500 students, and it grows to 10,100 students in its 11th year. The second increment starts in the campus' 12th year, the third in the 23rd year. The arcs necessary to describe a new campus first admitting students in 1976 are shown in Figure 3. Upper limits on flow in source-intermediate arcs reflect the capacity of

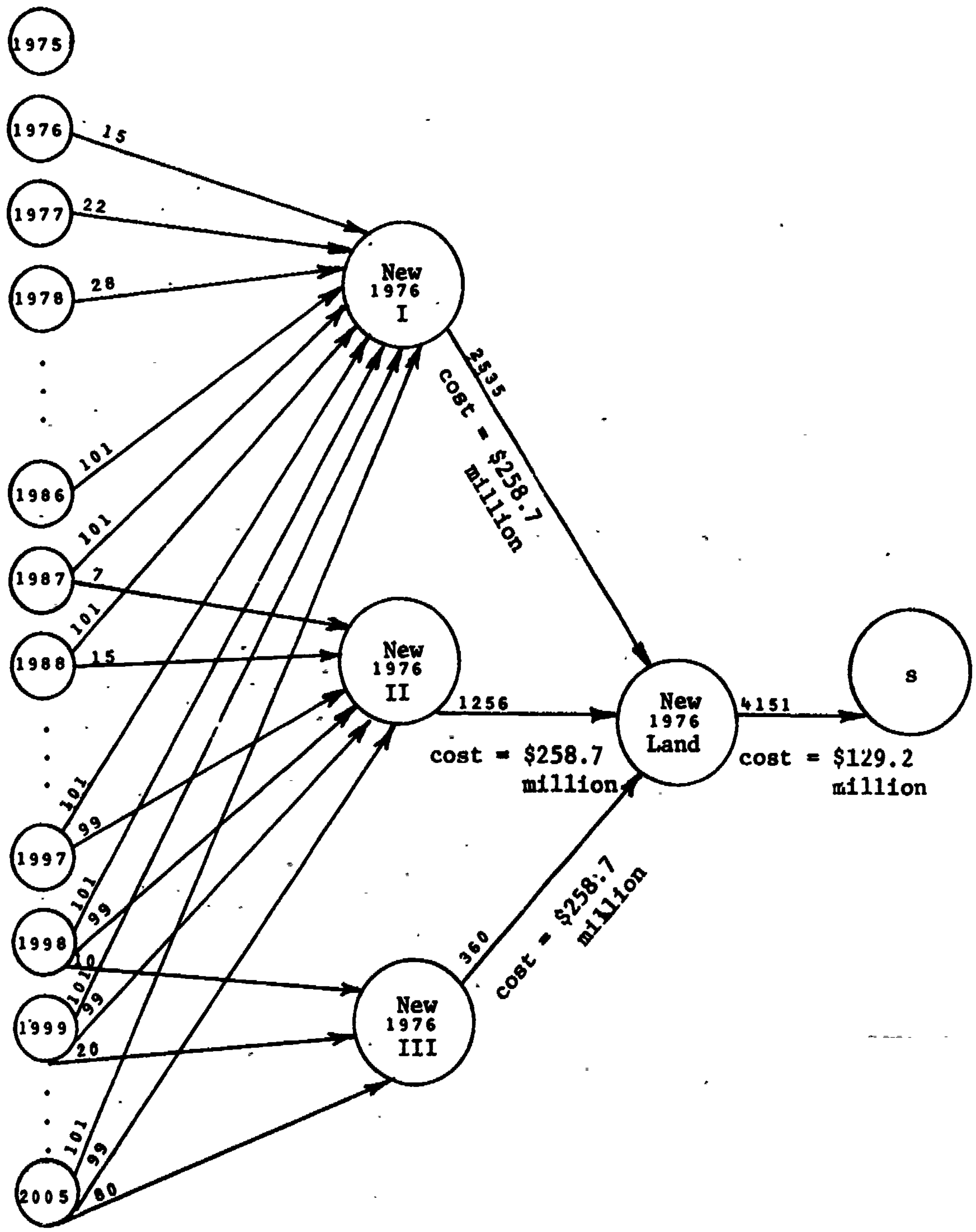


Figure 3. Arcs For a New Campus, 1976
(Flow limits in hundreds of students)

the new campus increment in the year signified by the source node. Upper limits on arcs leading out of intermediate nodes are the sum of the flow limits on the arcs into the node.

The initial investment costs for a new campus are made up of land acquisition fees and construction expenses. Although marginal operating costs per student are not included in the model, the fixed part of the operating cost for each year and a start-up operating cost are included. Each of the arcs out of the four intermediate nodes describing a new campus has a cost function of the form (2) . On the arcs out of the three nodes representing development of facilities for 10,000 students, the fixed charge is the construction cost of the increment. On the arc into the sink, the fixed charge is made up of the land acquisition, start-up, and fixed portion of the operating costs. A new campus starting in 1976 has fixed portions of operating costs for 30 years, a campus starting in 1996 for 10 years. We assume that enough land for a 30,000 student campus will be bought, even though the campus may be developed only to a size of 10,000 students by 2005.

5. Formal Statement of the Problem

Our goal is to find a program of expansion which meets the demand in every year at the least total cost. We introduce the following notation:

A - the set of all directed arcs (i, j)

D - the subset of arcs (i, j) having fixed charges

x_{ij} - flow on arc (i, j)

u_{ij} - upper limit on x_{ij}

N_1 - the set of source nodes

e_i - demand, year i

N_2 - the set of intermediate nodes

s - the sink node

A(i) - the set of nodes j such that there is an arc (i, j)

B(i) - the set of nodes j such that there is an arc (j, i)

The problem:

$$\text{minimize} \qquad C(x) = \sum_{(i,j)\varepsilon D} C_{ij}(x_{ij}) \qquad (3)$$

$$\text{subject to} \qquad \sum_{j\varepsilon A(i)} x_{ij} = e_i \quad \text{for} \quad i\varepsilon N_1 \qquad (4)$$

$$\sum_{i\varepsilon B(j)} x_{ij} - \sum_{i\varepsilon A(j)} x_{ji} = 0 \quad \text{for} \quad j\varepsilon N_2 \qquad (5)$$

$$0 \leqq x_{ij} \leqq u_{ij} \quad \text{for all} \quad (i,j)\varepsilon A \qquad (6)$$

where

$$\begin{aligned} C_{ij}(x_{ij}) &= 0 \qquad \text{if} \quad x_{ij} = 0 \\ &= d_i \qquad \text{if} \quad x_{ij} > 0 \end{aligned} \qquad (7)$$

III. COMPUTATIONAL FORMULATION

1. Basis for Simplification

Because all arc cost functions in the minimum cost flow problem (3) - (6) are of the form (7), it is possible to obtain a least cost solution more simply than by solving (3) - (6) directly. The flow values need to be determined only to the extent of resolving $x_{ij} = 0$ versus $x_{ij} > 0$ for $(i,j)\varepsilon D$. Once these decisions have been made, one set of feasible flows is as good as any other. This point of view leads to an integer programming statement of the problem.

2. Meeting Demand for Enrollment

Let the demand for new facilities in year i be represented by

$$b_i = \max\ (0,\ e_i - f_i) \tag{8}$$

where e_i is the total demand in year i and f_i is the capacity of the existing campuses in year i. The constraint that demands be met in year i has the form

$$\sum_j u_{ij}x_j - b_i \geq 0 \tag{9}$$

where u_{ij} is the capacity of new facility j in year i and x_j is the binary variable that states whether facility j is part of the expansion program.

3. Expanding Existing Campuses

Davis, Irvine, San Diego, Santa Barbara, and Santa Cruz may be expanded beyond their current enrollment ceilings. For each of the seven alternatives presented, assign one variable x_r, a cost d_r, and capacities u_{ir}.

5. New Campuses

The model allows one new campus to be started in each year of the planning horizon. The campus may be developed to 10, 20, or 30 thousand students by the end of the planning period. We let x_j^1 represent opening a campus in year j and allowing it to grow to 10,000 students, x_j^2 expanding the campus to 20,000 students, and x_j^3 the additional growth to 30,000. The cost of x_j^1, denoted d_j^1, is made up of the construction cost of facilities for 10,000, land acquisition for a 30,000 student campus, start-up operating cost, and the fixed portions of annual operating costs over the planning period. The costs d_j^2 and d_j^3 each consist of the construction costs necessary to expand the campus by 10,000 students. Similarly, u_{ij}^1, u_{ij}^2, and u_{ij}^3 are the capacities of the increments in year i. In order to assure that a phantom campus isn't expanded to 20,000 students, the following constraints are required:

$$2x_j^1 - x_j^2 - x_j^3 \geq 0 \tag{10}$$

for all years j in the planning period.

5. Statement of the Problem

We can now state the integer program completely. If we let n be the number of years in the planning horizon, the the campus planner should seek to

$$\text{minimize} \quad C(x) = \sum_{k=1}^{3} \sum_{j=1}^{n} d_j^k \, x_j + \sum_{r=1}^{7} d_r x_r \tag{11}$$

$$\text{subject to} \quad \sum_{k=1}^{3} \sum_{j=1}^{n} u_{ij}^k x_j^k + \sum_{r=1}^{7} u_{ir} x_r - b_i \geq 0 \tag{12}$$

$$i = 1, \ldots, n$$

$$2x_j^1 - x_j^2 - x_j^3 \geq 0 \tag{13}$$

$$j = 1, \ldots, n$$

$$x_j^1, x_j^2, x_j^3, x_r = 0 \tag{14}$$

all variables

The problem is now in a standard mathematical programming form, and it can be solved by any pure-integer algorithm. The one we have selected is an implicit enumeration with surrogate constraints developed by A. M. Geoffrion. The key feature of the algorithm is determination of surrogate constraints by solving linear programs in continuous variables.

IV. ALTERNATE POLICIES OF EXPANSION

1. Data

Data for the problem are grouped into the three areas of facility capacities, demand estimates, and costs.

Facility capacities are given in Table 1. The existing campus capacities used in this analysis were the February 1968 Interim Projected Enrollments for 1975-1976 through 1977-78. These figures are extrapolated according to the 1966 Growth Plan guideline that a campus should grow by a maximum of 1000 students per year. This limitation is also applied to determining the growth patterns for expanding existing campuses beyond their current ceilings. The growth of a new campus is patterned after Irvine.

Demand for student enrollment in 1975 is the sum of the California Department of Finance projection of undergraduate demand and a U. C. estimate of graduate demand. [Office of Analytical Studies (1969)] These figures are annual averages, which are then adjusted to three-term averages by subtr cting the Summer Quarter increment.

1975 undergraduate demand	89,860
1975 graduate demand	47,610
Total annual average demand	137,470
3-Term average (1/1.1333 of above)	121,300

Demand increases by 4% per year until 1983, by 3% per year thereafter. The demand projections are given in Table 2.

TABLE 1: PROJECTED GENERAL CAMPUS CAPACITIES, 1975-2005
(THREE-TERM AVERAGE IN HUNDREDS OF HEADCOUNT STUDENTS)
MAXIMUM CAMPUS GROWTH RATE-1000 STUDENTS/YEAR

Year	Campus*					Total
	Irvine	Riverside	San Diego	Santa Barbara	Santa Cruz	
1975	101	86	90	175	82	1219
6	108	93	99	182	94	1261
7	116	101	106	190	103	1301
8	124	109	114	198	112	1342
9	133	117	122	206	121	1384
1980	142	125	130	214	131	1427
1	151	135	140	224	141	1476
2	160	145	150	234	151	1525
3	170	155	160	244	161	1575
4	180	165	170	250	171	1621
1985	190	175	180	250	181	1661
6	200	185	190		191	1701
7	210	195	200		201	1741
8	220	205	210		211	1781
9	230	215	220		221	1821
1990	240	225	230		231	1861
1	245	235	240		241	1896
2	250	245	245		251	1926
3	250	250	250		261	1946
4		250	250		270	1955
1995					275	1960
6					275	1960
7						1960
8						1960
9						1960
2000						1960
1						1960
2						1960
3						1960
4						1960
2005						1960

*Berkeley (275), Davis (160), and Los Angeles (250) will be at their ceilings before 1975.

TABLE 1--Continued

Year	New Campus Increments			Expand			
				Davis			Santa Barbara
	I	II	III	160-190	190-230	230-275	
1975	15			10			
6	22			20			
7	28			30			
8	33			30	10		
9	47				20		
1980	56				30		
1	65				40		
2	74				40	10	
3	83					20	
4	92					30	
1985	101					40	12
6	101	7				45	25
7		15				45	25
8		23					
9		32					
				Expand			
				Irvine	San Diego	Santa Cruz	
1990		41					
1		50					
2		59					
3		69		10			
4		79		20	10		
1995		89		30	20		
6		99		40	30	10	
7		99	10	50	40	20	
8			20	60	50	30	
9			30	70	60	40	
2000			40	80	70	50	
1			50	90	80	60	
2			60	100	90	70	
3			70	100	100	80	
4			80		100	90	
2005			90			100	

TABLE 2: DEMAND FOR STUDENT ENROLLMENT, GENERAL CAMPUSES, 1975-2005
(THREE-TERM AVERAGE IN HUNDREDS OF HEADCOUNT STUDENTS)

Year	Demand	Year	Demand	Year	Demand
1975	1213	1985	1758	1995	2362
1976	1259	1986	1811	1996	2433
1977	1309	1987	1865	1997	2506
1978	1362	1988	1921	1998	2582
1979	1416	1989	1978	1999	2659
1980	1473	1990	2035	2000	2739
1981	1532	1991	2099	2001	2821
1982	1593	1992	2162	2002	2906
1983	1651	1993	2227	2003	2993
1984	1707	1994	2294	2004	3083
				2005	3175

Cost estimates are taken directly from or according to the assumptions in "The Expansion of Existing Campuses Versus the Building of New Ones," [Hansen (1966)]. That report estimates the initial investment costs for both rural and new urban campuses. Since our goal is to determine a least cost program of expansion, we consider only rural campuses. Once a policy is determined it is straightforward to estimate the extra cost of locating a new campus in a city. However, this modified policy may no longer be optimal. Initially, all costs are expressed in constant 1975 dollars (Engineering News Record Construction cost index = 1550), but policies are also determined when costs, incurred subsequent to 1975 are discounted at 1, 2, 5, 7, and 13 percent.

In determining construction expenses, a specific mix of students according to discipline is assumed. Space requirements times building cost estimates give the costs for construction and equipment of basic and instructional facilities. Certain economies of scale in the need for additional facilities are assumed for enlarging existing campuses. Parking needs are determined from the parking planning ratios in the 1966 Capital Outlay Budget. Utilities and site clearance are estimated to be varying percentages of the non-residential construction and equipment costs, and the requirement for residential facilities is computed assuming that 40% of the students will be housed in University Facilities. A contingency factor is determined also. These computations are shown in Tables 3 - 5.

The costs of land acquisition, start-up, and the fixed portion of annual operating expenses are taken directly from the report. Land for a new rural campus is estimated to cost $4.5 million [Hansen(1966),p. 4] and the start-up cost is $4.9 million [ibid, p. 12]. In 1965 dollars (ENR = 910) the fixed portion of the operating expenses is $4 million, which is adjusted to $6.8 million in 1975 dollars.

TABLE 3: CONSTRUCTION AND EQUIPMENT COSTS PER 1000 STUDENTS
NEW AND EXISTING CAMPUSES
(COSTS IN 1975 DOLLARS ENR=1550)

Facility	Construction $/OGSF	Equipment $/ASF	Number of Students	New Campus *ASF/Student	New Campus $Thousand/ 1000 Stud.	Existing Campus *ASF/Student	Existing Campus $Thousand/ 1000 Stud.
Agricultural Science	54	16.30	10	1000	919	850.0	781
Biological Science	62	24.45	70	170	1323	170.0	1323
Mathematics	50	11.42	60	42	205	42.0	205
Physical Science	62	35.04	100	150	1827	135.0	1644
Engineering	50	35.04	90	230	2174	207.0	1956
Social Science	42	11.42	200	34	477	39.0	477
Anthro/Psych/Geog	50	13.03	60	73	363	69.3	345
Arts	65	9.78	60	125	755	112.5	680
Language/Literature	43	8.97	190	36	473	36.0	473
Professions	54	13.86	90	75	603	75.0	603
Business Admin.	46	13.86	50	55	215	55.0	215
Social Welfare	45	13.86	20	80	122	80.0	122
Library	54	3.27	1000	24	1892	24.0	1892
Physical Educ.	62	2.46	1000	6	535	3.6	321
Military Science	62	2.46	1000	2	178	.5	44
Administration	50	8.15	1000	3	234	1.8	140
Public Service	50	11.42	1000	2	162	.4	32
Organized Research	62	19.54	1000	15	1595	15.0	1595
Organized Activities	46	8.15	1000	2	145	1.6	116
Student Services	46	8.15	1000	4	290	4.0	290
General Services	46	8.15	1000	3	217	2.4	174
Physical Plant O&M	46	8.15	1000	2	145	1.0	72
Aux. Enterprises	46	8.15	1000	13	943	11.7	848
Total			1000		15802		14359

* 1 ASF = 1.4 OGSF

TABLE 4: SUPPLEMENTARY CONSTRUCTION COSTS PER 1000 STUDENTS
(COSTS ADJUSTED TO ENR=1550)

Description	New Campus		Existing Campus	
	Percentage	Cost (Millions)	Percentage	Cost (Millions)
Construction and Equipment of Basic, Instructional Facilities		15.80		14.35
Utilities and Site Development (Pct. of Above)	.16	2.53	.08	1.15
Parking		.19		.16
Residential Facilities		4.99		4.99
Contingency (Pct. of Sum of Above)	.10	2.35	.07	1.45
Total		25.86		22.09

TABLE 5: COSTS OF EXPANDING EXISTING CAMPUSES
(COSTS IN MILLIONS OF 1975 DOLLARS, ENR=1550)

Campus	Increment	Cost
Santa Barbara	2500	55.22
Davis 16-19	3000	66.27
Davis 19-23	4000	89.36
Davis 23-27.5	4500	100.40
Irvine	10000	220.96
San Diego	10000	220.96
Santa Cruz	10000	220.96

There is already sufficient land to carry out the possible expansion at Irvine, San Diego, Santa Cruz, and Santa Barbara. At Davis, there is enough land to go from 16,000 to 19,000, but going from 19,000 to 23,000 and from 23,000 to 27,500 would each require additional 5 acres at $200,000 an acre [Wagner (1969)].

2. Characteristics of a Policy

In this section we present the least cost program of expansion for costs in constant 1975 dollars. Moreover, the solution to this problem illustrates the structure of feasible expansion policies in general. Because of the economies of scale realized in construction costs for expanding existing campuses beyond their current enrollment ceilings and because these alternatives do not generate any additional fixed operating expenses, a least cost program of expansion for any cost discount rate includes all of the expand-existing-campus options. In addition, three new campuses, started in 1975, 1976, and 1984, are required. The first two are developed to 30,000 students by 2005, the third to 20,000 students.

The capacity generated by this policy is shown in Table 6. There are two very striking aspects to the program: (1) the number of new campus increments required is determined entirely by the demand in the last time period, 2005; and (2) throughout almost the entire time span there is excess capacity on both the existing and new campuses. In fact, expanding Davis and Santa Barbara to 27,500 each is sufficient to satisfy demand through 1988. Nonetheless, the cheapest constant dollar policy is to build campuses early in order to meet the large demands generated after the year 2000.

While growth in demand is exponential, the expansion of facilities is essentially linear. Any policy derived from this analysis which meets demand is going to have some slack capacity because the expansion alternatives feasible for this model provide for discrete capacity increments. At the end

TABLE 6: LEAST COST PROGRAM OF EXPANSION, 1975-2005, FOR CONSTANT 1975 COSTS
(Three-Term Average in Hundreds of Students)

Year	Demand	Existing Campuses	All Expansion of Existing Campuses	Demand to be Met by New Campuses	New Campus 1975	New Campus 1976	New Campus 1984	Total Excess Capacity
1975	1213	1219	10	- 16	15			31
6	1259	1261	20	- 22	22	15		59
7	1309	1301	30	- 22	28	22		72
8	1362	1342	40	- 20	33	28		81
9	1416	1384	50	- 18	47	33		98
1980	1473	1427	60	- 14	56	47		117
1	1532	1476	70	- 14	65	56		135
2	1593	1525	80	- 12	74	65		151
3	1657	1575	90	- 8	83	74		165
4	1707	1621	100	- 14	92	83	15	204
5	1758	1661	122	- 25	101	92	22	240
6	1811	1701	140	- 30	108	101	28	267
7	1865	1741	140	- 16	116	108	33	273
8	1921	1781	140	0	124	116	47	287
9	1978	1821	140	17	133	124	56	296

TABLE 6--Continued

Year	Demand	Existing Campuses	All Expansion of Existing Campuses	Demand to be Met by New Campuses	New Campus			Total Excess Capacity
					1975	1976	1984	
1990	2038	1861	140	37	142	133	65	303
1	2099	1896	140	63	151	142	74	304
2	2162	1926	140	96	160	151	83	298
3	2227	1946	150	131	170	160	92	291
4	2294	1955	180	159	180	170	101	292
5	2362	1960	200	202	190	180	108	276
6	2433	1960	230	243	200	190	116	263
7	2506	1960	260	286	210	200	124	248
8	2582	1960	290	342	220	210	133	221
9	2659	1960	320	379	230	220	142	213
2000	2739	1960	350	429	240	230	151	192
1	2821	1960	380	481	250	240	160	169
2	2906	1960	410	536	260	250	170	144
3	2993	1960	430	603	270	260	180	107
4	3083	1960	440	683	280	270	190	57
2005	3175	1960	450	765	290	280	200	5

of the planning horizon, student demand is increasing rapidly. To counter these increases it is necessary either to build ahead, creating excess capacity in the middle years, or to start a larger number of campuses in later years, enabling capacity to expand rapidly. It is slightly cheaper in constant dollars to build ahead, despite having to pay for operating "excess" capacity on campuses for a number of years. However, as the discount rate increases, it becomes cheaper to start a larger number of campuses later on.

This phenomenon of excess capacity may be interpreted in at least two ways. This model of campus expansion hypothesizes campus enrollment ceilings appraised at ten, twenty, or thirty thousand students with constand growth rates. Therefore, the campuses have to expand <u>in anticipation</u> of demand whenever the demand is growing faster than the capacity. A second interpretation of this excess capacity which transcends the current model is that campus planners whould recognize the uncertainty associated with future student enrollments and with future construction costs. If the planner is reasonably certain of his future projections, which would be reflected in his low (risk) discounting rate, then his optimal policy would be to build in anticipation of future demands and thereby incur excess capacity (see Table 7). However, if the planner is somewhat uncertain of his future projections he would apply a high (risk) discounting rate and his optimal policy would be to wait until the last moment when his projections would be more precise.

One caveat is that the times associated with the new campuses are the <u>opening</u> dates. The actual construction would have to begin five to seven years prior to the opening date and the actual cash flows would occur during these preceeding years.

TABLE 7: CHARACTERISTICS OF EXPANSION POLICIES
(All Policies Include Expanding Existing Campuses)

Increments per Campus	Years Campuses Started (1975-2005)	Excess Capacity (Hundreds of Students)					
		1980	1984	1988	1992	1996	2000
(3,3,2)	'75, '76, '84	117	204	281	298	263	192
(3,3,1,1)	'75, '76, '94, '95	117	189	240	215	197	162
(3,2,2,1)	'76, '84, '85, '95	61	112	196	212	193	150
(2,2,2,2)	'83, '84, '85, '86	14	51	164	218	206	157
(3,2,1,1,1)	'75, '84, '95, '96, '97	70	121	171	147	110	98
(3,2,1,1,1)	'77, '84, '94, '95, '96	47	103	155	129	118	110
(2,2,2,1,1)	'84, '85, '86, '94, '95	14	29	108	126	132	118
(3,1,1,1,1,1)	'77, '93, '94, '95, '96 '97	47	88	108	46	35	66
(2,2,1,1,1,1)	'84, '85, '94, '95, '96 '97	14	29	80	61	46	65
(2,1,1,1,1,1,1)	'84, '91, '93, '94, '95, '96, '97	14	29	47	19	27	89
(2,2,1,1,1,1,1)	'87, '88, '93, '94, '96 '97, '99	14	14	37	7	8	52
Last Minute: (2,2,2,2,1,1,1,1,1)	'88, '90, '91, '93, '96 '01, '02, '03, '05	14	14	15	1	9	10

TABLE 7--Continued

Increments per Campus	New Campus Costs** (Millions)						
	Constant Dollars	1 Pct. Discount	2 Pct. Discount	5 Pct. Discount	7 Pct. Discount	10 Pct. Discount	13 Pct. Discount
(3,3,2)	2660.8*	2332.1	2057.7	1474.2	1222.8	971.0	812.3
(3,3,1,1)	2676.8	2317.1	2019.8	1401.0	1143.7	896.1	748.8
(3,2,2,1)	2676.8	2291.5	1970.9	1293.6	1005.1	710.0	543.8
(2,2,2,2)	2690.4	2287.8	1950.3	1226.8	912.0	594.9	394.8
(3,2,1,1,1)	2679.2	2270.2	1933.6	1239.9	955.9	687.9	532.9
(3,2,1,1,1)	2686.0	2265.9	1919.4	1200.8	903.7	618.0	448.5
(2,2,2,1,1)	2699.6	2262.0	1898.6	1135.5	814.4	502.4	315.6
(3,1,1,1,1,1)	2695.2	2243.5	1873.8	1121.5	819.7	540.5	383.5
(2,2,1,1,1,1)	2702.0	2237.5*	1855.1*	1066.9	744.7	441.4	267.3
(2,1,1,1,1,1,1)	2758.8	2272.9	1873.3	1051.9*	718.5*	408.8	235.6
(2,2,1,1,1,1,1)	2990.2	2436.2	1985.5	1077.4	718.5*	393.5*	217.0
Last Minute: (2,2,2,2,1,1,1,1,1)	4022.6	3184.2	2522.9	1264.1	803.1	411.7	214.2*

* Least Cost Policy
** Costs include: land, construction, start-up, and fixed portion of operating expenses.

3. Programs of Expansion

Table 7 summarizes the characteristics of a number of different policies calling for three to nine new campuses each with a specified number of 10,000-student increments. All policies include carrying out each expand-existing-campus alternative. The last one listed is a "last minute" program in which new campuses are started one by one only when there is no other way to meet demand. There is very little difference in constant dollar costs among the policies, except the "last-minute" program. However, as the discount factor is increased it becomes preferable to start a larger number of campuses later in the time span. For discounts of 13 per cent and up, the "last minute" policy is cheapest. Also, by starting the campuses later there is a much looser match between demand and capacity in the intermediate years. The least cost policy for a discount rate of five per cent is given in full detail in Table 8.

A variation of this problem was investigated in which a campus would grow by 1500 students per year instead of 1000 once the enrollment reached 15,000. These accelerated campus growth rates applied to existing campuses as well as new ones, so that the campuses reached their enrollment ceilings earlier. The expansion policies generated were quite similar to those in Table 7; the only differences were that campuses which were to be developed beyond 20,000 students by 2005 could be started later. There was generally more excess capacity in the intermediate years than for similar policies in which the campuses grew more slowly because all the existing campuses grew at this higher rate from their current enrollments, which is faster than the current rate of growth in demand.

Because the number of new campus increments is determined entirely by the demand in the last period, one can directly investigate the effect of different demands. As the demand to be met by new campuses in 2005 increases from 76,500, the policies already generated remain feasible if the starting dates for incomplete increments, e.g., 1996 and 1997 in Table 8, are made earlier. However, once the new campus demand surpasses 80,000, it is necessary to formulate programs with nine new campus increments. As in the original problem, programs which call for a large number of campuses built late in the planning period will have lower discounted costs and generate less excess capacity in intermediate years than policies which call for building a smaller number of new campuses.

TABLE 8: LEAST COST PROGRAM OF EXPANSION, 1975-2005, FOR COSTS DISCOUNTED 5%
(Three-Term Average in Hundreds of Students,
Policy Includes all Expand-Existing-Campus Alternatives.)

Year	Demand to be Met by New Campuses	NEW CAMPUSES							Total Excess Capacity
		1984	1991	1993	1994	1995	1996	1997	
1975	-16								16
6	-22								22
7	-22								22
8	-20								20
9	-18								18
1980	-14								14
1	-14								14
2	-12								12
3	- 8								8
4	-14	15							29
5	-25	22							47
6	-30	28							58
7	-16	33							49
8	0	47							47
9	17	56							39

TABLE 8--Continued

Year	Demand to be Met by New Campuses	NEW CAMPUSES							Total Excess Capacity
		1984	1991	1993	1994	1995	1996	1997	
1990	37	65							28
1	63	74	15						26
2	96	83	22						19
3	131	92	28	15					4
4	159	101	33	22	15				12
5	202	108	47	28	22	15			18
6	243	116	56	33	28	22	15		27
7	286	124	65	47	33	28	22	15	48
8	342	133	74	56	47	33	28	22	51
9	379	142	83	65	56	47	33	28	75
2000	429	151	92	74	65	56	47	33	89
1	481	160	101	83	74	65	56	47	105
2	536	170	101	92	83	74	65	56	105
3	603	180	101	101	92	83	74	65	93
4	683	190	101	101	101	92	83	74	59
2005	765	200	101	101	101	101	92	83	14

APPENDIX- UXPAN: A USER'S MANUAL

This chapter is a user's manual for the FORTRAN IV computer code UXPAN, which generates and solves the integer program (11) - (14) . UXPAN is actually a specialized version of the general purpose integer programming code RIP30C developed by Geoffrion and Nelson [1968]. The first section of the chapter contains the instructions for preparing data cards, the second describes the program output, and the third tells how one can modify data that are stored internally in UXPAN. Finally, the last section gives timing results of the code's performance on the CDC 6400. We assume that the user is familiar with FORTRAN IV.

1. UXPAN Data Format

An UXPAN data deck:

1) Title card- anything in any column, but the first 12 columns are treated as a heading.

2) Parameter card:

Col.	Format	Description
1-4	I4	NST, the number of years in the planning horizon. Must be odd and $\leq$ 39.
5-8	I4	1975 enrollment demand in hundreds of students.
9-12	I4	L, the number of variables to be set to 0 or 1 initially.
13-16	I4	MAXQ, time limit in seconds
29-40	E12.4	DR, annual discount rate for costs

41-52	E12.4	ZBAR, value of the least cost solution known beforehand. If none is known, insert 0.

3) If $L > 0$, read the indices of the variables to be set to 0 or 1 initially, twelve to a card according to the format (12(I4,A1)) . For each 5 column segment:

Col.	Format	Description
1-4	I4	j -- set x_j to 1 initially -j -- set x_j to 0 initially
5	A1	Blank - x_j must be arbitrated B - x_j has been arbitrated

Figure 1 contains a pair of sample data decks for UXPAN. In the first a 23 period problem is generated and the code is allowed 2 seconds to get a solution. In the second, the same problem is restarted using the terminal conditions of the first run. (See Figure 2.)

2. Program Output

The output from UXPAN consists of three parts. The first part, which is largely self-explanatory, prints the title card, a summary of the problem parameters, and a list of variable identifiers. The first NST variables in the matrix are x_j^1 , $j = 1, \ldots,$ NST, then come the x_j^2 , x_j^3 , and finally the variables representing the expansion of existing campuses.

The second section of the output lists the data for the integer program. First, a set of internal parameters is printed. Next come the matrix dimensions and the list of variables to be set to zero or one initially. The vectors of cost coefficients d_j and negatives of new facility demands $-b_i$ follow. Lastly the coefficient matrix is printed. In the matrix actually produced, demand constraints (6) are generated only

Figure 1: Sample UXPAN Data Sets

BY | DATE

WRITTEN AS:

PUNCH AS:

NOTES:

IDENTIFICATION

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80

```
XPAN SAMP                23 PERIØD SAMPLE PRØBLEM
231211  0  2         0.05
XPAN SAMP R              23 PERIØD SAMPLE PRØBLEM
231211  42 180           0.05           1689.
 2   1   3   4   5  -6B -29B -7B -30B -8B -31B -9B
32B -25B -10B -11B -12B -13B -14B -15B -16B -17B -24B -33B
34B -35B -18B -26B -19B -27B -20B -21B -22B -23B -36B -28B
39B -38B -40B -41B -42B -37B
```

36

for odd-numbered time periods. Therefore, NST must be odd.

The third section lists the results of the computation. If an optimal solution is found within the allotted time, the heading will state

"IMPLICIT ENUMERATION COMPLETE . . ."

On the other hand, if all the time is used up, a heading

".03125 OF THE SOLUTIONS HAVE BEEN ENUMERATED . . ."

is printed. This heading is followed by a list of variables in the final partial enumeration. These numbers can be used to restart the problem on a later run.

In either case, the least cost solution computed, "LEAST Z," is printed, followed by a list of the variables which yield that solution. All variables x_j are set to 0 except for those whose number appears. They are set to 1 . The last 11 lines are bookkeeping data for the integer program.

3. Modifying Costs and Campus Growth Rates

The data used to generate the University expansion networks is clearly labelled in the program UXPAN. In order to alter this data, minor changes to UXPAN are necessary.

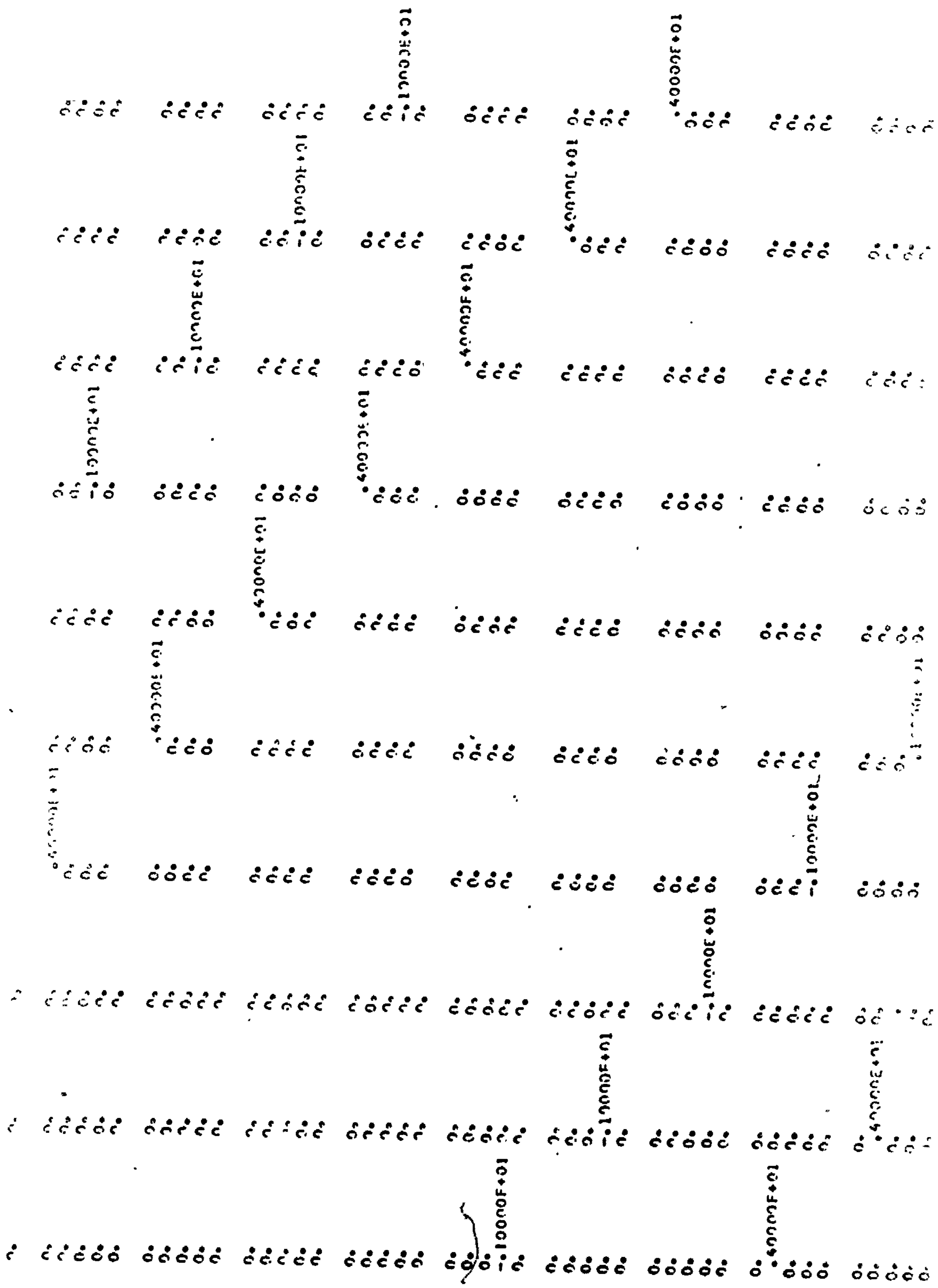
The total capacity of existing campuses from 1975 onward is stored in the vector LEXLIST. If one wants to change the rates of growth for existing campuses until they reach their current enrollment ceilings, compute the new capacities, add them up, and replace the DATA LEXLIST declaration. Similarly, the data which reflects growth of a new campus from 0 to 20,000 students is stored in INCØNE --- 0 to 10,000 --- and INCTWØ --- 10,000 to 20,000. To alter these values, replace the DATA INCØNE and DATA INCTWØ. The maximum number of students by which a campus may grow in a year is stored in IGRØ. New campuses with more than

```
UXPAN SAMP                    23 PERIOD SAMPLE PROBLEM

UNIVERSITY EXPANSION MODEL
          PARAMETERS..  YEARS   23  BASE YEAR (1975) DEMAND   1211  DEMAND GROWTH RATE  .04 THROUGH 1983, .03 AFTERWARD
          FIRST YEAR OF EXPANSION..  DAVIS   1975  IRVINE   19  SANTA CRUZ   22  SAN DIEGO   20 SANTA BARBARA   11
          ANNUAL DISCOUNT RATE       .050


VARIABLE IDENTIFICATION..
LAND,STAGE I                        1 -- 23
STAGE II                           24 -- 35
STAGE III                          36 -- 36
EXPAND DAVIS                       37 -- 39
EXPAND IRV                         40
EXPAND SC                          41
EXPAND SD                          42
EXPAND SB                          43
```

Figure 2: UXPAN Output

```
PARAMETERS
 M  N   L SC KENUM    ZPAS    ISCMAX ISCEP  MAXC NEXT NMP    ZKBAR     ITR   TITLE
24 43  0  1   10  0.               5     9     0    2   1 0.              1 UXPAN SAMP

DIMENSIONS..  M =  24,  N =  43


INITIAL SOLUTION
     0

COST COEFFICIENTS
  .36200E+03  .34181E+03  .32263E+03  .30441E+03  .28710E+03  .27065E+03  .25503E+03  .24019E+03  .22609E+03  .21269E+03
  .19997E+03  .18793E+03  .17640E+03  .16549E+03  .15512E+03  .14528E+03  .13592E+03  .12704E+03  .11859E+03  .11057E+03
  .10296E+03  .95718E+02  .88842E+02  .13974E+03  .13275E+03  .12611E+03  .11981E+03  .11382E+03  .10813E+03  .10272E+03
  .97584E+02  .92704E+02  .88069E+02  .83566E+02  .79482E+02  .79482E+02  .66270E+02  .76615E+02  .80113E+02  .87768E+02
  .75250E+02  .83380E+02  .33062E+02

NEGATIVES OF NEW FACILITY DEMANDS
  0.          -.90000E+01 -.32000E+02 -.56000E+02 -.82000E+02 -.97000E+02 -.12400E+03 -.15700E+03 -.20300E+03 -.28100E+03
 -.49200E+03 -.54600E+03  0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.

CONSTRAINT MATRIX, BY ROWS
  .15000E+02  0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          .10000E+02  0.          0.          0.
  0.          0.          0.

  .28000E+02  .22000E+02  .15000E+02  0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          .30000E+02  0.          0.          0.
  0.          0.          0.

  .47000E+02  .33000E+02  .29000E+02  .22000E+02  .15000E+02  0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          .30000E+02  .20000E+02  0.          0.
  0.          0.          0.

  .65000E+02  .56000E+02  .47000E+02  .33000E+02  .28000E+02  .22000E+02  .15000E+02  0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          .30000E+02  .40000E+02  0.          0.
  0.          0.          0.

  .83000E+02  .74000E+02  .65000E+02  .56000E+02  .47000E+02  .33000E+02  .28000E+02  .22000E+02  .15000E+02  0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
  0.          0.          0.          0.          0.          0.          .30000E+02  .40000E+02  .20000E+02  0.
  0.          0.          0.

  .19100E+03  .92000E+02  .83000E+02  .74000E+02  .65000E+02  .56000E+02  .47000E+02  .33000E+02  .28000E+02  .22000E+02
  .15000E+02  0.          0.          0.          0.          0.          0.          0.          0.          0.
```

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	.33000E+02	.40000E+02	.40000E+02	0.
0.	0.	.13000E+02							
.10100E+03	.10100E+03	.10100E+03	.92000E+02	.83000E+02	.74000E+02	.65000E+02	.56000E+02	.47000E+02	.33000E+02
.28000E+02	.22000E+02	.15000E+02	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	.15000E+02	.70000E+01	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	.33000E+02	.40000E+02	.45000E+02	0.
0.	0.	.25000E+02							
.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.92000E+02	.83000E+02	.74000E+02	.65000E+02	.56000E+02
.47000E+02	.33000E+02	.28000E+02	.22000E+02	.15000E+02	0.	0.	0.	0.	0.
0.	0.	0.	.32000E+02	.23000E+02	.15000E+02	.70000E+01	0.	0.	0.
0.	0.	0.	0.	0.	0.	.30000E+02	.40000E+02	.45000E+02	0.
0.	0.	.25000E+02							
.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.92000E+02	.83000E+02	.74000E+02
.65000E+02	.56000E+02	.47000E+02	.33000E+02	.28000E+02	.22000E+02	.15000E+02	0.	0.	0.
0.	0.	0.	.59000E+02	.41000E+02	.32000E+02	.23000E+02	.15000E+02	.70000E+01	0.
0.	0.	0.	0.	0.	0.	.30000E+02	.40000E+02	.45000E+02	0.
0.	0.	.25000E+02							
.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.92000E+02
.83000E+02	.74000E+02	.65000E+02	.56000E+02	.47000E+02	.33000E+02	.28000E+02	.22000E+02	.15000E+02	0.
0.	0.	0.	.69000E+02	.59000E+02	.59000E+02	.41000E+02	.32000E+02	.23000E+02	.15000E+02
.70000E+01	0.	0.	0.	0.	0.	.33000E+02	.40000E+02	.45000E+02	.10000E+02
0.	0.	.25000E+02							
.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03
.10100E+03	.92000E+02	.83000E+02	.74000E+02	.65000E+02	.56000E+02	.47000E+02	.33000E+02	.28000E+02	.22000E+02
.15000E+02	0.	0.	.69000E+02	.79000E+02	.69000E+02	.59000E+02	.50000E+02	.41000E+02	.32000E+02
.23000E+02	.15000E+02	.70000E+01	0.	0.	0.	.30000E+02	.40000E+02	.45000E+02	.30000E+02
0.	.20000E+02	.25000E+02							
.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03	.10100E+03
.10100E+03	.10100E+03	.10100E+03	.92000E+02	.83000E+02	.74000E+02	.65000E+02	.56000E+02	.47000E+02	.33000E+02
.28000E+02	.22000E+02	.15000E+02	.99000E+02	.99000E+02	.89000E+02	.79000E+02	.69000E+02	.59000E+02	.50000E+02
.41000E+02	.32000E+02	.23000E+02	.15000E+02	.70000E+01	.10000E+02	.30000E+02	.40000E+02	.45000E+02	.50000E+02
.20000E+02	.40000E+02	.25000E+02							
.40000E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	-.10000E+01	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	-.10000E+01	0.	0.	0.	0.
0.	0.	0.							
0.	.40000E+01	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	-.10000E+01	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.							
0.	0.	.40000E+01	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	-.10000E+01	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.



.03125 OF THE SOLUTIONS HAVE BEEN ENUMERATED   TIME IN SECONDS TOTAL 2.420 ELAPSED 2.420   L= 42

FINAL PARTIAL SOLUTION

2	1	3	4	5	-68	-298	-73	-308	-88	-318	-98	-328	-258	-108
-118	-128	-138	-143	-158	-166	-178	-243	-338	-348	-358	-188	-268	-198	-278
-208	-218	-223	-233	-368	-283	-398	-388	-408	-418	-428	-378			

```
UXRAN SAMP

TIME EXCEEDED     TOTAL TIME=   2.456

SOLUTION BEFORE VARIABLE CHANGE Y(J) = 1 - X(J) IF C(J) IS NEGATIVE..
LEAST Z =  1.68805554E+03
VARIABLES SET TO ONE
    1    2    3    4    5    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0   39    0    0    0    0

NO. FEASIBLE SOLUTIONS    9
ZS GE ZBAR     0 TIMES
CONSTRAINT INFEASIBLE    1 TIMES
AUGMENTATION IMPOSSIBLE    0 TIMES
AUGMENTATION POSSIBLE   14 TIMES
INTEGER DUALS    0 TIMES
NO. OF ROUNDED INT. DUALS    0
LP FATHOMED    0 TIMES
LP CALLED    2 TIMES
NO. ITERATIONS   17
LAST FEASIBLE SOLUTION AT   2.394  SECONDS
```

20,000 students and additional capacity at Irvine, Santa Cruz, and San Diego increase by IGRØ students per year. The first years in which Irvine, Santa Cruz, San Diego, and Santa Barbara can accommodate more students than their current ceilings are stored in the vector IRVS.

Costs are stored in 1975 dollars. Capital costs for expanding Irvine, Santa Cruz, San Diego and Santa Barbara are stored in the vector CAPIRV. To use different values, replace the DATA CAPIRV declaration. The capital costs for each enlargement of Davis are stored in the vector CAPD. The vector ID2 contains the numbers of years preceding the start of each Davis increment. For instance, ID2(2) = 2 says that increment two will begin in year 3. The fixed portion of annual operating expense for a new campus is stored in CØP(1).

Demands are generated in the block of coding in UXPAN between statement numbers 19 and 20. Currently, enrollment grows by 4% annually until 1983, then 3% thereafter. Modifying this block of code to reflect other demand growth patterns should be straightforward.

4. Timing on the CDC 6400

UXPAN has been tested for problems with as many as 31 time periods. Problem dimensions and computing times are listed in Table 1. Note that computing times increase sharply as NST increases. This is due not only to larger problems being solved, but to the nature of the problem as well. When the number of time periods is small, the fraction of the optimal cost consisting of any one component d_j is large. The larger the fraction $d_j/\min C(x)$, the less searching for an optimal solution is required. Computing times for problems with more than 31 periods are likely to exceed 15 minutes.

UXPAN requires $(74000)_8$ words of memory.

TABLE 1: UXPAN PERFORMANCE

NST	Time	Dimensions		Obj. Value *	Max d_j
		Rows	Col.		
19	1.45	18	32	594.5	352.5
21	12.17	21	37	797.4	357.5
23	28.30	24	43	998.5	362.0
25	51.63	27	49	1149.1	366.1
31	334.60	36	67	1544.3	376.1

* Cost discount rate .05

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