Using System Dynamics Technology to Improve Planning and Budgeting for Higher Education: Results in Arizona and Houston, Texas

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Abstract

System Dynamics was used for the first time to improve planning and budgeting in American higher education with a pioneering project launched in 1990 by the staff of the Arizona Board of Regents to help the state of Arizona anticipate and prepare to meet rapidly growing enrollment demand over a twenty-year planning horizon. Then, the University of Houston System, building on the experience of Arizona, chose to use system dynamics to help meet their goal of achieving greater diversity among their students and serve the higher education needs of a dramatically changing population in their metropolitan area.

Though system dynamics was developed close to forty years ago at MIT and has been widely used in industry, it is new to the higher education. This paper first briefly describes the actual experiences of Arizona and Houston in developing and using the system dynamics models for planning purposes, and then highlights special features built into the models.

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Arizona

Arizona is a state in the southwest United States experiencing phenomenal growth. The Arizona Board of Regents (ABOR) is overseeing the response of the state's three universities to the growth of demand for college education over the twenty years from 1990 to 2010. ABOR commissioned the development of an enrollment demand model as part of a multi-faceted long-range strategic planning process.

The comprehensive Arizona Enrollment Demand Model was built with the guidance of a task force with representatives from ABOR and each of the three constituent universities: The University of Arizona, Arizona State University, and Northern Arizona University.

The model was used to analyze the results of different state, Board and institutional strategies. As a result of using the model to compare the outcomes of alternative policy decisions, the findings, including a "most likely" projection of enrollment demand for Arizona, gained significant public credibility. This helped to strengthen ABOR in negotiations with the State Legislative Budget Committee. An increase of more than $5 million in state appropriations was made available to implement plans of the three campuses to respond to the additional demand projected, including plans by AU to sponsor the development of a new state college, plans by ASU for a new campus, and plans by NAU to develop a new "two-plus-two" program in cooperation with rural community colleges.

Significantly, the system dynamics technology, combined with rationally based strategic planning, is helping to define and inform a political process that is meeting larger social and economic needs for an educated future citizenry.

Houston

The University of Houston System is a public university system comprised of four separate institutions serving the Houston metropolitan area, which has a population of about 5 million inhabitants. The flaship is the University of Houston, a doctoral research university with approximately 33,000 students in fourteen colleges. Two of the universities, one at Clear Lake - enrolling about 8,000 students - and another at Victoria - enrolling about 1,200 students - are upper-division institutions offering junior and senior undergraduate instruction and some masters-level programs. UH-Clear Lake serves the rapidly developing area southeast of central Houston, a region of high-tech industries anchored around NASA's Johnson Space Center. UH-Victoria is located about a hundred miles southwest of Houston proper and serves a fifteen-county area surrounding the region's principal commercial, manufacturing, and service city of Victoria. The fourth university in the system is UH-Downtown, which also enrolls about 8,000 students and is an open-access undergraduate institution geared toward facilitating access to baccalaureate education for an urban clientele primarily of non-traditional students, including part-time and older, working or returning students.

Collectively, the four universities currently have education and general budgets totalling close to $400 million, of which about 50 percent comes from the state of Texas through general appropriations, 12 percent from the federal government, and the remaining 38 percent primarily from student fees, with much smaller amounts from private gifts and endowment income.

When UH System administrators first commissioned the development of a system dynamics model in the spring of 1993, they intended to use the model as a tool for forecasting the magnitude and location of an anticipated growth in enrollment demand in the rapidly expanding Houston urban area through the year 2015. A first step in the process was to establish college-going rates, by age category, for each of the major ethnic groups within their diverse population. The results of this initial analysis were surprising, even shocking, to those involved in the planning process. Due, on the one hand, to exceptionally low college-going-rates among rapidly expanding Hispanic minority populations and, on the other hand, to a declining overall white college-age population which historically has had higher college-going rates, enrollment within the system, it was discovered, was not likely to increase much at all over the next twenty years. Due to the rapid rise in the number of Hispanics in the general population, the mix of UH System potential students over this time period is likely to shift toward becoming more Hispanic and less white and African American.

This initial analysis made clear that, unless fundamental changes took place, Houston's Hispanic and African-American populations were unlikely to participate in higher education at levels commensurate with their numbers in the metropolitan population at large. As a consequence of this finding, the Houston team shifted the focus of its model development effort from capacity planning, as such, to tackling the much more perplexing and difficult problems of developing strategies for generating new enrollment demand among Houston's Hispanic and African American populations.

The impact of this shift in emphasis from capacity planning to enrollment generation planning was profound. As an industry, higher education in the United States, in general, has avoided taking responsibility for pre-collegiate preparedness, viewing that task as the proper purview of the kindergarten-through-twelfth-grade (K-12) public school establishment. For the UH System administration and regents, however, this new challenge was of enormous social significance. As a city, Houston is expected by 2030 to become about 40 percent Hispanic, with whites representing about 40 percent, African Americans about 15 percent, and Asians, Indians, and all others about 5 percent of the population. Appropriate investment in the education of all Houston residents is deemed by the UH System as essential for the well-being of all the people living in the metropolitan area and they have set for themselves a primary task of determining their role in delivering the required educational services.

The rigor of building the system dynamics model resulted in a much more comprehensive and realistic appraisal of the current conditions and future options available to the UHS and its constituent universities than had been achieved previously. The model is being used to refine and restate the diversity goals of the UHS. It is also used to underscore the importance of working with the elementary and secondary schools because the university diversity goals can not be achieved without a higher percentage of minority students in the high schools successfully completing preparation for college. The next step in using the model will be to identify and evaluate the most effective strategies for achieving the diversity goals of the UH System.

Process of Building the Education Planning Models

First in Arizona and then in Houston the model developers worked closely for more than a year with teams composed of staff of the central administrations and advisors from the individual universities with expertise in finance, development, student services, and student financial aid. These teams helped to define the tasks to be accomplished, provided information for the development of the causal loop diagrams, assisted in collecting data, and reviewed findings. Members of the working groups also participated in training sessions designed to enable them to perform "what if" analyses, and to update the models as new information becomes available.

Software

The models were built on Macintosh computers using iThink software purchased from High Performance in Lyme, New Hampshire. When the UH System required information to be generated separately for five different race/ethnic groups, S**4 developed by Microworlds of Cambridge, Massachusetts was purchased to wrap around the iThink model to provide the array capability.

Conceptual Framework of the Models

The enrollment planning models are built with a seven subsystems as illustrated in Figure 1.

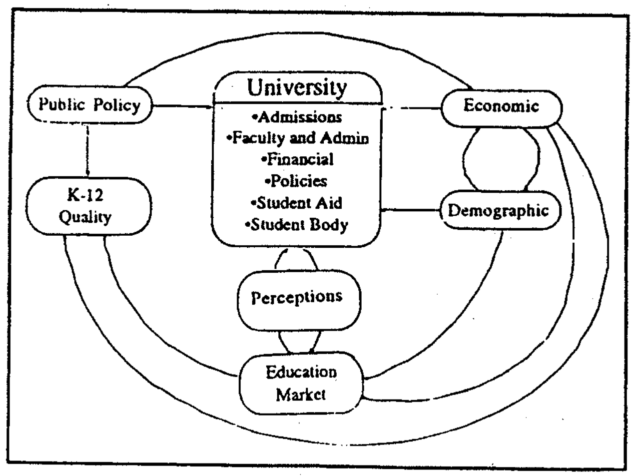

Figure 1. Basic Structure of the Enrollment Demand Models.

Subsystems of the Education Planning Models

The subsystems which drive trends that have a profound influence on the system as a whole include:

1 Demographic

The demographic subsystems were built with the population grouped by age, gender (in Arizona) and race/ethnicity (in Houston) categories relevant to education policy development.

The demographic subsystems were linked to the economic subsystems to show such factors as comparative economic performance which drives net migration, also by age and by race.

2 Education Feeder Schools, K-12 Quality

The education feeder subsystem was added for the second-generation Houston model to track the progression of students through the elementary and secondary education schools. It incorporates such information as percentage of students preparing for technical or academic programs, and the percentage of students held back to below grade level, dropping out, or graduating, by race and by academic achievement levels. The students can also be tracked as they enter the workforce, go to community colleges, technical colleges or other training programs, or enroll in four-year institutions.

3 Economic

The economic susbsystems highlight those features of the overall economy, such as trends in income, general inflation, and productivity that affect the ability to pay for education and training. The economic subsystem also generates the income that is taxed to provide revenues to pay for public sector education and training. The next phase in the development of the economic subsystem is to incorporate structural shifts in industries and occupations as they affect future demand for education and training.

4 Public Policy

The public policy subsystems reflect major priorities that are incorporated in government budgets, as well as more detailed allocations of funds to each of the education sectors. The public policy subsystems also utilize indexes comparing tax capacity and tax effort as proxies for taxpayers' willingness to pay for public sector programs, including education and training.

The public policy subsystems reflect such state-level decisions as the structure of the educational system by level, or tuition differentials charged students coming from outside the jurisdiction.

The public policy subsystems also reflect such federal-level decisions as the availability of federal student financial aid and the mix between grants and loans.

5 Perceptions

The perception subsystems are some of the most innovative and potentially useful features of the system dynamic education planning models. Surveys were conducted of current students, and their parents, and of possible future students - now in high school, community colleges, or the workforce. The questionnaires were designed to elicit information about individuals' perceptions of the geographic accessibility, costs, willingness to borrow, availability of student aid, and benefits of education, along with their expectations of future income gains that could be achieved because of the added education.

The results of the survey were analyzed by such characteristics of the respondents as race/ethnicity, age, and income.

Information drawn from the surveys about factors that would affect future demand for education or training was incorporated in the perception subsystem. The information was indexed and weighted according to survey responses to questions about the relative importance of influences on decisions to enroll.

6 Education Market Share / Competitive Position

This subsystem was added to the second generation model to examine the share of the market, in percentages or actual numbers, of students or dollars of revenue, for èducation and training gained by different providers, in both the private and public sectors.

7 Characteristics and Policies of Universities

The university characteristics and policies susbsystems profiles such features of the institution as:

- Capacity in terms of faulty resources and facilities,
- Intensity of recruitment efforts,
- Admission standards, acceptance rates, matriculation rates, retention policies, and graduation policies,
- Student aid policies,
- Financial characteristics,
  - Revenue and expenditure patterns, and
  - Financial performance ratios.

These seven subsystems are arrayed along a spectrum, beginning with those over which universities have very little influence, such as demographic and economic trends, and then moving toward those over which they have more influence, such as their own characteristics and policies.

Each of these seven subsystems contains a number of smaller or sub-systems which were initially conceptualized using causal loop diagrams as illustrated in Figure 2, before moving into iThink environment, as illustrated in Figure 3.

Types of Date Used

The comprehensive system dynamic models provide, as a joint product, single collection points for data bases with wide range of analytic or reporting uses. Typically, after reviewing initial findings generated by the models, decision makers asked new, more detailed questions, and concomitantly identified additional information needs. The models were then also used to help design data collection efforts - including the design of surveyinstruments to gather still more refined information. Thus, the models ultimately helped to produce a dynamic encyclopedia of information.

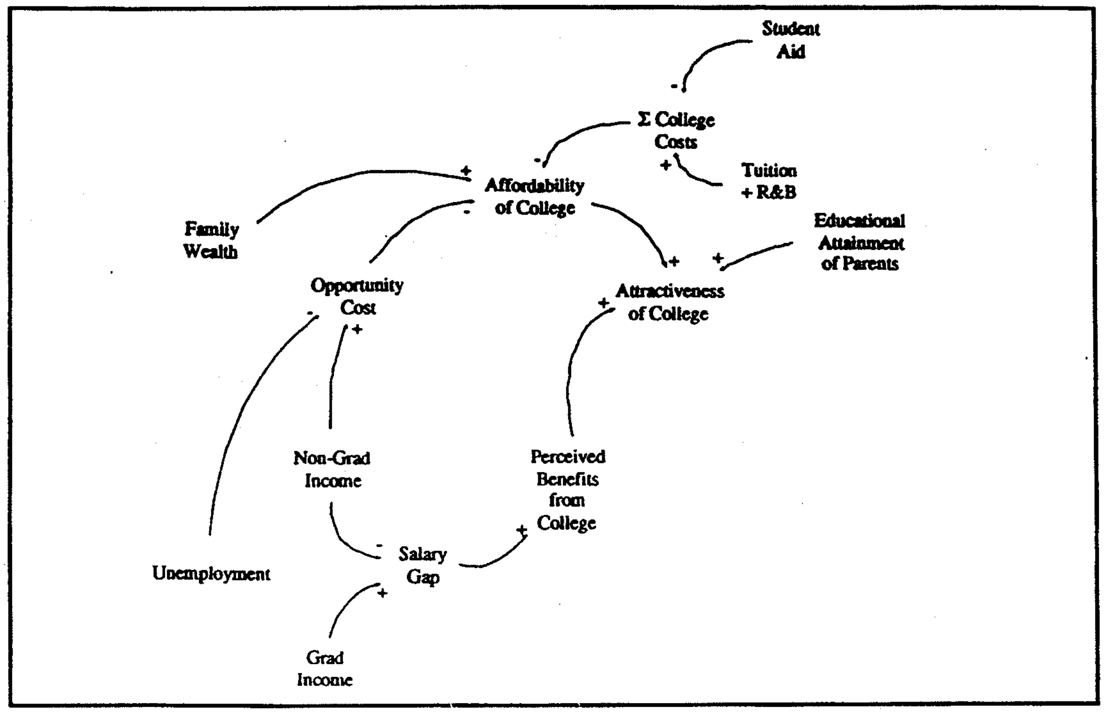

Figure 2. Illustration of Causal Loop Diagram for Student Demand

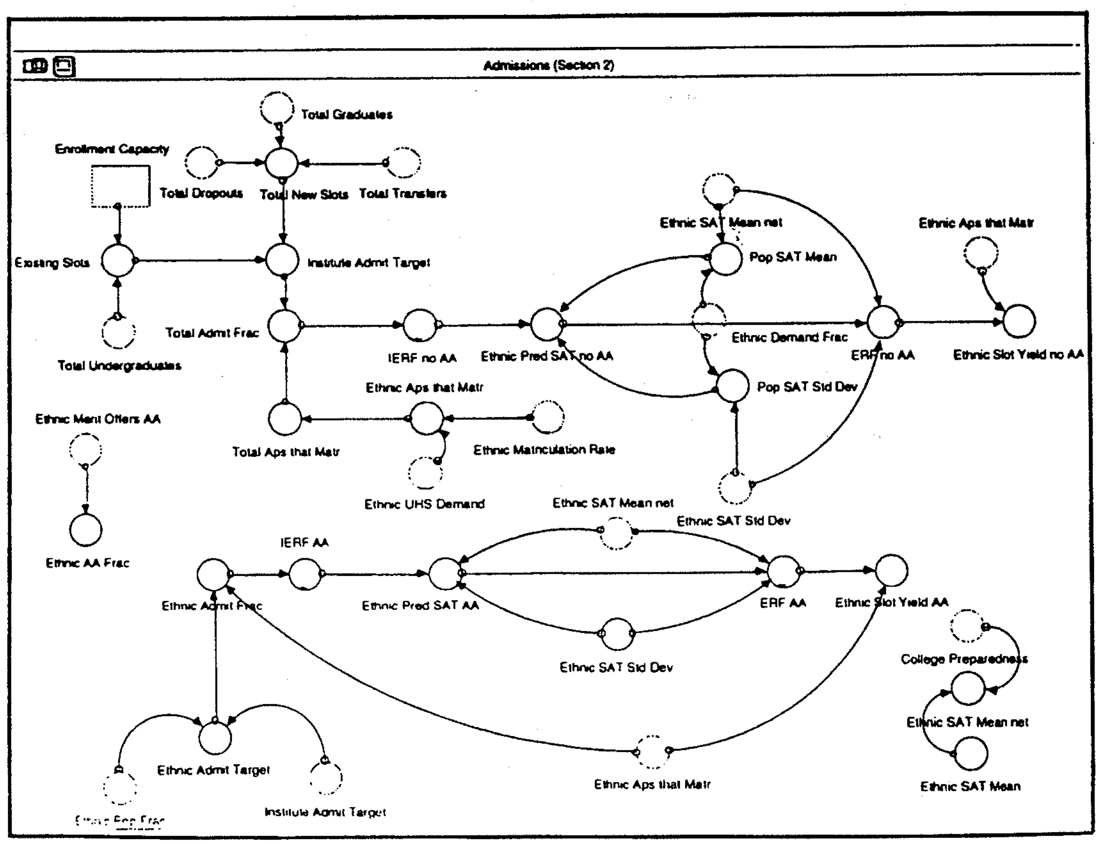

Figure 3. Illustration of an iThink Diagram for Admissions

Standard Items

The core data used in building education and training models are the data routinely collected by national and state statistical agencies on population, enrollment, finances and education and training institutional characteristics. In addition, as information is generated on learning outcomes, this can be incorporated into the models.

Further, as use of the models evolves and more advanced questions are asked, users often find repositories of specialized data, some of it in computerized systems, that can be incorporated in the model to enhance the ability to respond the new demands for more refined answers.

Graphical Data

The computer software programs used to build the models are able to use graphical data. This means that if a trend can be drawn that represents the path of a variable over time, it can be incorporated in the model. This also means that analysts are not limited to linear functions.

Survey Data

A particular strength of the system dynamics model is the ability to incorporate results of survey data. Special surveys were designed to collect information on the importance students place on factors affecting demand for education and training. This information was used to attach weights, that vary by race/ethnicity, to different factors affecting demand.

Knowledgeable Judgements

Most planning models are data dependent. They include factors for which quantitative data are available but omit factors for which quantitative data are not available, even though these factors might be critical to future projections. Leaving these factors out could lead to ill-considered decisions. Knowledgeable judgements can be made, however, about the direction of change in a variable that will result from changes in the factors expected to affect that variable. These judgements about the direction of change can be usefully incorporated in the system dynamic models.

Future Scenarios and Sensitivity Analysis

An especially attractive feature of system dynamics models built for education and training planning purposes is the simplicity and relative ease of analyzing the effects of different future scenarios, constructed using different assumptions about demographic, economic, or political environmental tends, together with different sets of education policy or management decisions. The ability to ask "what if" policy questions and to examine the responsiveness of key variables is particularly useful in informing policy makers.

Output

The output of the analysis can be presented in the form of tables or graphs, as shown on Figure 4.

Assumption Switches

Assumptions about the future are specified in the second generation model using pop-up menus, as illustrated in Figure 5. Typical assumptions include future rates of inflation, balanced budget requirements, or availability of resources to invest in education and training. The values for the assumptions can be changed, or the assumptions can be toggled on or off. which makes analysis of the impacts of alternative futures very easy.

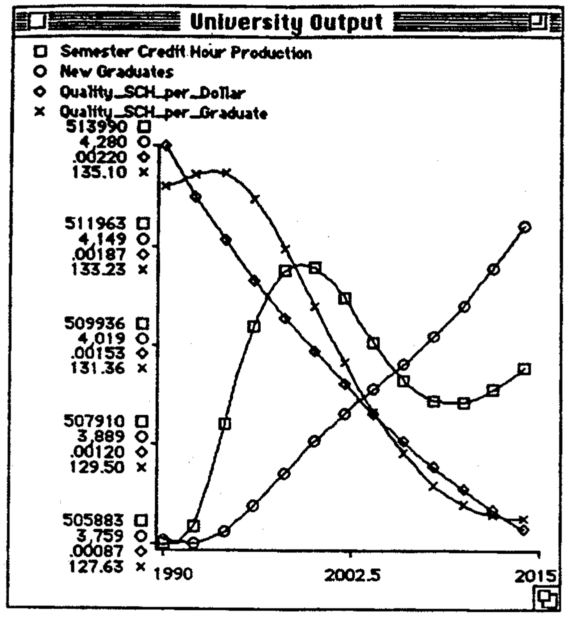

Figure 4. Sample Output Graphs

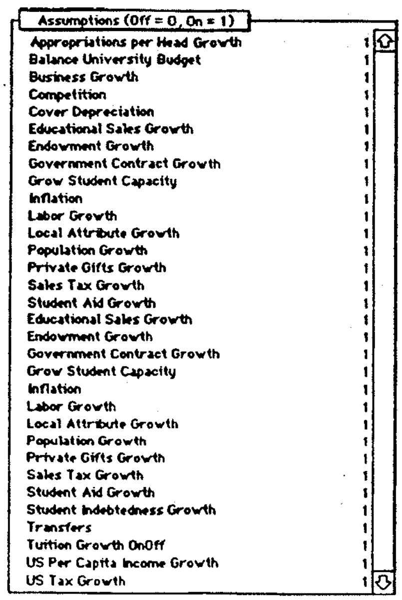

Figure 5. Sample List of Assumption Toggle Switches

Policy Rheostats

One of the most powerful new innovations incorporated into the second generation model are policy "rheostats", which permit continuously varying degrees of policy emphasis. Planners are quite familiar with policy trade-offs. In the real world, however, policy decisions are not usually either/or decisions, such as either awarding need-based student aid, or awarding merit-based student aid. Policy decisions are usually balanced combinations of policies with varying degrees of emphasis.

The system dynamics model enables planners and decision-makers to consider ranges of options with different degrees of policy emphasis, using policy rheostats, such as in the following illustrative examples:

Awarding student aid, balancing
- Need-based criteria, and
- Merit-based criteria.

Admissions policies, balancing
- Capacity controls, and
- Diversity criteria, and
- Academic standards.

Advantages of Using System Dynamics:

Ability to Build Comprehensive Models

It is easier to build comprehensive models using system dynamics technology than it is using the earlier techniques commonly employed to build computer models for education planning purposes. The first-generation Arizona model has several hundred equations, while the second-generation Houston model has several thousand equations. These models have vastly more relationships than can be readily incorporated into traditional planning models, but the large number of relationships can be kept understandable to the users by grouping them into subsystems.

Ability to Track System Flows

System dynamics models track flows. These system dynamics models which were built for education planning purposes track flows of students and flows of resources, which flows are comparatively easy to measure, to and through the universities. In at least a rudimentary way, the second-generation model also attempts the more difficult task of tracking flows of knowledge or competencies gained by students, that is, the value added by the educational institutions. An ambitious attempt was also made in the second generation model to track the quality changes of the institutions, using resources available as one driver for quality.

Balancing the stocks and flows within reasonable limits constitutes an important aspect of equilibrating and validating the models.

Greater Understanding of Causal Loops

Constructing a system dynamics model greatly intensifies the need to understand actual causal relationships - as distinguished from statistical correlations. The reason is, once again, that system dynamics models are constructed from flows. This means that it is necessary to identify causal relationships, specifying the major factors that affect a variable, and then to specify, in turn, what factors that variable affects. Clearer recognition and better understanding of causal relationships improves policy and management decisions, and reduces the likelihood of overlooking unintended consequences of decisions.

Awareness of Feedback

A characteristic feature of models built using system dynamics is feedback. Feedback results from the interconnectedness and endogeneity. The output generated in one time period becomes the input in the next time period.

The system dynamics models generate information about feedback that is very difficult to derive with standard extrapolation and/or econometric models. For instance, a system dynamic model can help analyze the conditions required for economic growth and transformation which may increase income, which may then increase the revenues available to pay for education, which may then increase the investment in education, which may increase the rate of economic growth, which may cycle through to provide still more resources for human resource development.

Added Insights Gained from Path Analysis

The system dynamics models are particularly useful in showing how sequences of policy decisions tend to become self-reinforcing, that ultimately converge over time into "paths". If a system is on a slow-growth path, it may be very difficult to alter the course of that path, but system dynamics can help identify the areas where policy or management changes have the potential of being most effective in producing desired results. Also, counter-intuitive patterns are frequently discovered. Multiple subsystems interact over time to generate results that are often beyond the casual observers' ability to project.

Another insight gained from sensitivity analysis using the models is that when wrong decisions are made and, for instance, the financial situation of an institutions deteriorates, reversing the decisions does not immediately restore the previous financial conditions. The institution may suffer the consequence of wrong decisions for a very long time. The use of the models can help to reduce the costs of wrong decisions.

Conclusion:

System Dynamics technology is helping significantly to improve education policy development and planning. Information generated by system dynamic models is being used in preparing for future growth in college enrollment, in increasing investment in higher education as part of the process of negotiating governmental budget priorities, and in assessing the effectiveness of alternative strategies for meeting the educational needs of previously underserved populations.

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