AN INTERACTIVE DYNAMIC SIMULATION MODEL FOR STRATEGIC UNIVERSITY MANAGEMENT

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ABSTRACT

We present an interactive simulation model, on which various problems involved in managing the academic aspects of a university can be analyzed and certain policies for overcoming these problems can be tested. More specifically, the model focuses on long-term, strategic management problems that are dynamic and persistent in nature, such as growing student-faculty ratios, poor teaching quality and low research productivity. The model yields numerous performance measures about the fundamental activities of a university, namely, teaching, research and professional project activities. The modeling process consists of two major phases. The first one is the construction of a system dynamics simulation model (the engine behind the interactive game). The second phase consists of converting the simulation model into an interactive game. The simulation model is built first, and validated/verified by standard system dynamics tests, using data from Bogazici University, Istanbul, Turkey. Next, the necessary changes are made on the equations to turn the model into an interactive one and the gaming interface is programmed. The game has been played and tested by faculty members, managers, teaching assistants and students. The game results generated by these players are compared. Differences in the results reveal that players with different orientations focus on different aspects and performance measures of the university in making decisions. Research results obtained suggest that the interactive simulation model promises to be not only a useful technology to support strategic decision making, but also a laboratory for theoretical research on how to best deal with strategic university management problems. Further research is being carried out to add enhancements both to the simulation model and the gaming interface.

I. INTRODUCTION

Contemporary universities worldwide face the challenge of maintaining the quality of the fundamental functions of a university, namely teaching, research, academic and professional service, under the pressure of limited resources in terms of faculty, facilities and income. [6], [7], [12], [19], [22]. Some typical problems that the university management must deal with are: unbalanced growth in student body in state (public) universities; infrastructures that can not keep up with the enrollment growth; increased student/faculty ratios; concerns about quality of instruction; heavy competition for limited funding for research and heavy competition among private universities for limited student demand. Such problems have been studied both on macro and micro levels by many researchers. While some of these studies have made use of certain quantitative methods (for instance, [13], [17], [18], [20]), a great portion of the existing research on university problems do not have quantitative foundations, primarily because such problems involve qualitative (human) elements that are difficult to quantify and model. Thus, there seems to be a need for research that can handle simultaneously both the quantitative and the qualitative aspects of the university management problems The purpose of this research is to construct a dynamic simulation model - a computerized platform - on which a range of problems (of both qualitative and quantitative nature) concerning the contemporary university management can be analyzed and certain policies for overcoming these problems can be tested. The research utilizes System Dynamics modeling/simulation methodology which is especially suitable for quantitative and realistic representation of variables that are typically perceived to be qualitative - yet important in socio-economic management problems.

In particular, the model will focus on those university problems that are dynamic and persistent in nature and as such must be addressed by high level, strategic policy-making mechanisms within the university. These strategic policy making mechanisms are typically the president, the deans, and the major policy-making councils at the university and divisional levels. The ultimate product of the research is the interactive gaming version of the simulation model that can be played by such policy makers. The interactive management simulators (often called microworlds or management flight simulators [1, 11, 14, 15] constitute a very promising new technology, especially for strategic management.
II. RESEARCH METHODOLOGY

The methodology used in this research is System Dynamics methodology. System Dynamics approach is appropriate for analyzing and modeling complex, large scale, non-linear, partly qualitative socio-economic systems. The main assumption of System Dynamics approach is that a problem, with all its physical, ecological, sociological, economic aspects, is a whole. Other important assumptions of System Dynamics are: i) variables that are related have a direct cause and effect relationship, ii) succession of cause and effect relations forms feedback loops, which means that the distinction between cause and effect vanishes through time. Almost every dynamic system includes a number of both negative (goal seeking) and positive (reinforcing) feedback loops, which interact and operate simultaneously through time. Large scale models include very large number of feedback loops. It is not unlikely to encounter variables which are related to several thousand feedback loops within a model with several hundred variables. Thus, the dynamic behavior of a system is a result of complex interactions of numerous loops over time. The strategic university management summarized in the INTRODUCTION section is a typical system dynamics problem. It is a long-term, complex, strategic management problem. The dynamic performance of the system is created as a result of the interaction of numerous feedback loops, as will be discussed below, in the description of the model.

System Dynamics methodology typically consists of the following steps: (1) problem description, (2) model conceptualization, (3) model construction (simulation model), (4) verification and validation of the model, (5) simulation experiments [10], [16]. Once the System Dynamics model has been thoroughly verified and validated, it can be converted into an interactive simulation game (‘microworld’). In developing an interactive simulator, the proper selection of the interactive decision variables (the player decisions) is crucial. Once these variables are selected the model must be modified accordingly. The next step is the design of the interactive interface (screen design). There are many conceptual and technical issues that must be tackled in constructing interactive dynamic games. These are discussed in the relevant literature (see, for instance, [1], [11], [14], [15]). Finally, once the conceptual design is complete, the user interface is programmed by using an appropriate interface development tool.

III. MODEL DESCRIPTION

III.1. Model Overview

The focus is long-term, academic management problems that are dynamic and persistent in nature, such as growing student-faculty ratios, poor teaching quality and low research productivity. As such, the model represents the faculty members time allocation among the main activity groups, the factors that determine this allocation and various performance indicators obtained as a result of these - often conflicting - allocations. The major activities of a faculty members are: (a) graduate instruction, (b) under-graduate instruction, (c) graduate instruction overhead, (d) under-graduate instruction overhead, (e) unsponsored research, (f) sponsored research, (g) income generating projects, (h) unofficial projects. With respect to these activities, the faculty members are grouped in two: Graduate faculty members, that are primarily involved in graduate instruction and research (but also involved in some under-graduate instruction.) and Undergraduate faculty members, that are involved only in under-graduate instruction and have limited interest in (and background for) research. Thus, graduate instruction and graduate instruction overhead loads apply only to the graduate faculty members.

The instruction activities are divided into two groups: (a) in-class instruction and (b) instruction overhead, which includes all out-of-class activities related to instruction. The second main activity group is research activities. Research activities are represented in two categories as (a) unsponsored research activities, which are not sponsored financially except for the university's own resources and (b) sponsored research activities, which are supported by governmental or private organizations. The last activity group is project (consulting) activities, which are also divided into two: (a) income generating projects, which are activities like seminars, courses or consulting realized through university channels and generate income to the university and (b) unofficial projects, which are activities like seminars or consulting realized through non-university channels and do not generate any income to the university.

The model is constructed on sector basis. (Figure 1). The sectors of the model are determined so as to represent the dynamics of major activity groups defined above. The diagrams shown in Figure 2- Figure 5 are called...
stock-flow diagrams in System Dynamics methodology. They consist of four symbols: **Stock** variables (denoted by rectangular box) represent the fundamental accumulations over time. (Such as Number of Graduate Faculty or Number of Graduate Students in Figure 2.) **Flow** variables (denoted by a double arrow through a valve symbol) represent the rate of change of stock variables. (Such as New Graduate Faculty or Graduate Student Admission.) **Single arrows** mean the variable at the root of the arrow has an influence on the variable at the tip of the arrow. (For instance, Number of Graduate Programs has an effect on Total Graduate Instruction Hours Needed.) Variables whose names do not appear in any symbolic shape, are intermediate variables (called Auxiliary or Converter) that represent how variables influence each other, beyond the fundamental stock-flow relationship. (For example, in Figure 2, Graduate Faculty Hiring Decision is influenced by canceled lecture hours, number of existing graduate faculty, operating maximum instruction hours per graduate faculty and actual instruction load per graduate faculty. Thus, the mathematical formulation of Graduate Faculty Hiring Decision would be a function of these four variables.)

The model is constructed using Vensim software [9]. The basic time step used in the simulation is a semester.

III. 2. Graduate Instruction Sector

In this sector, the graduate faculty FTE that is available for instruction and the need for graduate instruction are calculated and the faculty FTE is assigned to graduate instruction (Figure 2). The main stock variables in this sector are Number of Graduate Faculty and Number of Graduate Students. Number of Graduate Faculty decreases through GF that Leave and increases through New Grad Faculty. New Grad Faculty is determined by GF Hiring Decision, under the constraints of Vacant Faculty Positions and Indicated GF Supply. GF Hiring Decision is a user decision variable in the game version, but in the original model, it is computed so as to eliminate the discrepancy between the need for graduate faculty and the existing graduate faculty FTE. GF Supply depends on Instruction Load per GF and Historical Average GF Salary. These variables affect GF that Leaves, as well. (Figure 2). The dependence of GF Supply on Instruction Load per GF and Historical Average GF Salary is a typical ‘multiplicative effect formulation’ and is given by:

\[
GF\; Supply = (Max\; Supply) \times \text{Effect of Instruction Load per GF on GF Supply} \times \text{Effect of Historical Average GF Salary}
\]

Each of these ‘effects’ is a graphical function of the related variable. For instance, Effect of Instruction Load per GF on GF Supply is given by:

![Effect of Instruction Load per GF on GF Supply](image)

Similarly, Effect of Historical Average GF Salary on GF Supply is given by:

![Effect of Historical Average GF Salary on GF Supply](image)

(This type of typical effect formulation is used in many other parts of the model.)
The variable that represents the graduate faculty FTE that can be assigned to instruction is Operating Total FTE (Full Time Equivalent) Grad Faculty for Instruction. Full time equivalent (FTE) is a keyword that is used throughout this study and means the equivalent number of faculty members involved full-time in a certain activity. Suppose there are 20 faculty members who spend 1/4 of their time on research activities on the average; so we have 20 * (1/4) = 5 FTE faculty members involved in research. Operating Total FTE Grad Faculty for Instruction is the product of Number of Grad Faculty and Operating Maximum Instruction Hours per Grad Faculty. This latter indicates the maximum weekly instruction hours that can be assigned to a graduate faculty member under normal conditions and is given by:

\[
\text{Operating Maximum Instruction Hours per Undergraduate Faculty} - \text{Release Time for Grad Faculty} - 3
\]

which is the normal operating maximum instruction hours per graduate faculty (Thus, graduate faculty's maximum teaching load per week is at least 3 hours less than that of undergraduate faculty, but the model equates the graduate and undergraduate faculty teaching loads as long as the graduate faculty load is less than operating maximum load.). Release Time for Grad Faculty is the amount of decrease made in the weekly instruction load per graduate faculty member on the average, in order to leave them more time for research. It is a user decision variable in the game version. Operating Maximum Instruction Hours per Undergraduate Faculty is assumed to be 9 hours per week.

Graduate students are divided into two as Graduate Students 1, who take courses and Grad Students 2, who have completed their course work and prepare their theses. The need for graduate instruction is represented by Total Grad Student Hours, which is given by:

\[
\text{Number of Graduate Students 1} \times \text{Average Hours per Grad Student}
\]

Total Graduate Instruction Hours Needed is equal to:

\[
\text{Max} \left\{ \left[ \frac{\text{Total Grad Student Hours}}{\text{Desired Average Grad Class Size}} \right], \quad \left[ \frac{\text{Number of Grad Programs} \times \text{Minimum Instruction Hours per Grad Program}}{\text{Weekly Hours per Faculty}} \right] \right\}
\]

Total FTE Needed for Grad Instruction is given by:

\[
\frac{\text{Total Graduate Instruction Hours Needed}}{\text{Weekly Hours per Faculty}}
\]

After Total FTE Needed for Grad Instruction and Operating Total FTE Grad Faculty for Instruction are calculated, these variables are compared to see whether a discrepancy exists between them. This discrepancy is represented by Extra FTE Need for Grad Instruction. This variable takes a positive value if the need is more than available FTE, and it takes the value zero otherwise. (Figure 2). Extra FTE Need for Grad Instruction is compensated by Part Time FTE for Grad Instruction. Part Time FTE for Grad Instruction can not be more than a certain percentage of the FTE graduate faculty assigned to graduate instruction (As a minimum requirement for education quality). So, it is equal to:

\[
\text{Min}\{\text{Extra FTE Need for Grad Instruction,} \quad \text{Operating Total FTE Grad Faculty for Instruction} \times \text{Max Part Time Percentage for Grad Instruction}\}
\]

If Extra FTE Need for Grad Instruction is greater than Part Time FTE for Grad Instruction, it can not be entirely compensated and a discrepancy, Grad Instruction Discrepancy, occurs. The model tries to eliminate this discrepancy by increasing the average class size. Maximum Grad Class Size Allowed sets an upper limit for the Actual Average Grad Class Size and if increasing the class size up to that limit can not eliminate the discrepancy, the variable Unsatisfied Need for Grad Instruction takes a positive value. As a result of this unsatisfied need, the model assigns extra instruction hours to graduate faculty. Weekly instruction hours that can be assigned to a graduate faculty member, in such cases of abnormally high instruction need, is limited by Absolute Maximum Instruction Hours per GF. (Assigning extra class hours to full-time faculty members increases the effective full-time FTE for instruction, thus allowing some additional increase in the part-time FTE, since part-time FTE usage is limited by a certain percentage of full-time FTE for instruction). If this extra FTE assignment is not enough to eliminate the unsatisfied need for graduate instruction, the courses that can not be assigned are canceled, so the variable Canceled Grad Lecture Hours takes a positive value.
An output of this sector and an input to Undergraduate Instruction sector, Implied FTE Grad Faculty for UG Instruction is calculated as the positive difference between Operating Total FTE Grad Faculty for Instruction and Total FTE Needed for Grad Instruction. Note that if this difference is positive, all graduate instruction need is met by graduate faculty within the limit of operating maximum instruction hours; and the surplus FTE graduate faculty for instruction is transferred to Undergraduate Instruction Sector to be used for undergraduate instruction.

III. 3. Undergraduate Instruction Sector

In Undergraduate Instruction sector, the need for undergraduate instruction is determined and met by the undergraduate faculty time that can be assigned to instruction and the surplus graduate FTE for instruction, if any, from Graduate Instruction sector. If the need is more than the available FTE, some strategies like hiring part-time faculty and increasing class sizes, are used to eliminate the discrepancy.

This sector resembles the Graduate Instruction Sector in many aspects. The dynamics governing Number of Undergraduate Faculty are similar to the dynamics governing Number of Graduate Faculty. The total available faculty FTE for undergraduate instruction is represented by Implied Total FTE for UG Instruction and is equal to the total of Implied FTE Grad Faculty for UG Instruction and Operating Total FTE UG Faculty for Instruction. (The sector diagram is not shown due to lack of space. See [8]).

If the available faculty FTE for undergraduate instruction is more than the need, which is represented by Total FTE Needed for UG Instruction, then Extra FTE Needed for UG Instruction takes a negative value. This FTE surplus is divided among Surplus FTE Grad Faculty and Surplus FTE UG Faculty. On the other hand, if the need is more than the available faculty FTE for undergraduate instruction, then the discrepancy is first handled by part-time faculty. Here, again, the amount of part-time FTE is limited by a certain percentage of Implied Total FTE for UG Instruction.

If part-time FTE fails to compensate the extra need, average class size is increased. The class size is limited by Maximum UG Class Size Allowed. If increasing the class size even up to this limit fails to eliminate the discrepancy, the instruction loads on graduate and undergraduate faculty are increased. If increasing these loads up to absolute maximum instruction hour limits and using additional part-time faculty FTE can not compensate the need, then some undergraduate courses are canceled. As all the instruction assignments are completed, average instruction loads per graduate and undergraduate faculty member are calculated in this sector.

The dynamics and the role of Number of Programs are modeled by similar structures in Graduate Instruction Sector and Undergraduate Instruction Sector. Number of programs are determined by the historical average number of students in the respective sectors. As historical average number of students increases new programs may be opened and as this average drops below certain threshold levels, some programs are closed.

III. 4. Graduate Instruction Quality Sector

This is the sector where the graduate instruction quality indicators are calculated. (Figure 3). The main instruction quality indicators are Graduate Students/Grad Faculty Ratio, Actual Graduate Instruction Overhead per Grad Student, Actual Average Graduate Class Size and Lab Facilities for Graduate Instruction per Graduate Student. Graduate Instruction Quality Index in a semester is given by:

\[
\text{Grad Instr Quality Index} = \frac{\text{Eff of Act GI Overhead per Grad Stu on GI Quality} + \text{Eff of Grad Class Size on GI Quality} + \text{Eff of Research on GI Quality} + \text{Eff of Lab Facilities for GI on GI Quality}}{4}
\]

Each of these effects are graphical functions of the related variables. For instance, Effect of Actual GI
Overhead per Graduate Student on GI Quality is a graphical function of Actual Graduate Instruction Overhead per Graduate Student.

Assumed Graduate Instruction Quality Index represents the average graduate instruction quality goal of the faculty members, and Perceived Grad Instruction Quality Index is the historical average of Grad Instruction Quality Index which is a typical perception delay formulation that is used in System Dynamics Methodology.

Assumed Undergraduate Instruction Quality Index and Perceived Undergraduate Instruction Quality Index are similar variables that are determined in the Undergraduate Instruction Quality sector. The instruction quality indices are important in determining the Teaching Commitments of faculty members, which are indicators of the long-term attitude of the faculty members about instruction quality. Teaching Commitments are used as inputs to respective Overhead Sectors.

III. 5. Undergraduate Instruction Quality Sector

The quality indicators about undergraduate instruction are calculated in this sector. This sector resembles to Graduate Instruction Quality Sector. Actual Undergraduate Instruction Overhead per Undergraduate Student, Actual Average Undergraduate Class Size, Lab Facilities for Undergraduate Instruction per Undergraduate Student and Historical Average Research Papers per Faculty effect the Period Undergraduate Instruction Quality Index. The ratio among the historical average of this index, Perceived Undergraduate Instruction Quality Index and Assumed Undergraduate Instruction Quality Index determine Indicated UGF Teaching Commitment together with UGF Teaching Commitment. The historical average of Indicated UGF Teaching Commitment is UGF Teaching Commitment and is used as an input to Undergraduate Faculty Overhead Sector.

III. 6. Graduate Faculty Instruction Overhead Sector

In this sector the instruction overhead loads of graduate faculty members are calculated and the remaining graduate faculty time, after assigning in-class instruction and instruction overhead loads, is divided among research and project activities. (Figure 4).

Two different instruction overhead loads are calculated for graduate faculty members: graduate instruction overhead and undergraduate instruction overhead. The main variable that determines the graduate instruction overhead is Actual FTE Graduate Faculty for Graduate Instruction. By assuming that a certain amount of in-class instruction implies a certain amount of instruction overhead, Normal FTE GF for Grad Instruction Overhead is calculated as:

\[ \text{Actual FTE GF for Grad Instruction} \times \text{Normal Overhead Ratio for Grad Instruction} \]

Normal Overhead Ratio for Grad Instruction represents the instruction overhead load implied by unit in -class instruction load and is determined within certain limits by Actual Average Grad Class Size. As average class size increases, instruction overhead implied by unit in-class instruction load increases. A certain portion of Normal FTE GF for Grad Instruction Overhead is assigned to teaching assistants through the procedures explained in the detailed description of Assistants Sector. The rest of the implied instruction overhead load is represented by Indicated FTE GF for Grad Instruction Overhead.

The same approach is used for calculating Normal FTE GF for Undergraduate Instruction Overhead and assigning a certain portion of this load to teaching assistants. Thus, Indicated FTE GF for Undergraduate Instruction Overhead is determined as:

\[ \text{Normal FTE GF for Undergraduate Instruction Overhead} - \text{FTE Assistants for Undergraduate Instruction Overhead} \]

Total Indicated Non Instruction FTE Graduate Faculty is given by:

\[ \text{Total FTE Graduate Faculty} - (\text{Total In-Class FTE GF} + \text{Indicated FTE GF for Graduate Instruction Overhead} + \text{Indicated FTE GF for Undergraduate Instruction Overhead} + \text{FTE GF for Other Routine Tasks}) \]
This is the maximum amount of FTE graduate faculty that can be involved in research and project activities by working the normal Weekly Hours per Faculty, which is equal to 40 in the base and game versions of the model.

On the other hand, Desired FTE GF for Research and Projects is calculated as a function of Total Out-of-Classroom FTE GF which is equal to:

\[
\text{Total FTE GF} - \text{Total In Class FTE GF}
\]

The other variable that effects Desired FTE GF for Research and Projects is Graduate Faculty Research and Projects Commitment, which is the arithmetic average of Graduate Faculty Research Commitment and Graduate Faculty Financial Pressure. Graduate Faculty Research Commitment is explained in the Graduate Faculty Research Sector section and Graduate Faculty Financial Pressure is explained in the Graduate Faculty Projects Sector section.

Desired FTE GF for Research and Projects does not have to be equal to Total Indicated Non Instruction FTE GF. It can be more or less than this value, as well as being equal to it. If it is less, a certain amount of Inactive FTE GF occurs. This gives the total idle graduate faculty hours. If Desired FTE GF for Research and Projects is more than Total Indicated Non Instruction FTE GF, Indicated GF Extra Work Load takes a positive value. This variable represents the average extra weekly hours per graduate faculty, that must be worked in order to sustain the desired amount of time for research and project activities. If this extra load is more than a certain amount, a reduction need in overhead activities occurs; this is represented by GF Overhead Reduction Need and implies GF Overhead Reduction Coefficient, which takes values between zero and one. This coefficient depends on GF Teaching Commitment, as well. (Figure 4). As the teaching commitment increases the reduction coefficient decreases. Actual FTE GF for Grad Instruction Overhead is equal to:

\[
\text{Indicated FTE GF for Grad Instruction Overhead} \times (1 - \text{GF Overhead Reduction Coefficient})
\]

and Actual FTE GF for UG Instruction Overhead is equal to:

\[
\text{Indicated FTE GF for UG Instruction Overhead} \times (1 - \text{GF Overhead Reduction Coefficient})
\]

Actual Non Instruction FTE GF is given by:

\[
\text{Total FTE GF} - [\text{Total In-Class FTE GF} + \text{Actual FTE GF for Overhead Grad Instruction} + \text{Actual FTE GF for Overhead UG Instruction} + \text{FTE GF for Other Routine Tasks}]
\]

Reduced GF Extra Work Load represents the average extra weekly hours per graduate faculty member after reducing the instruction overhead, and is given by:

\[
\text{Desired FTE GF for Research and Projects} - \text{Actual Non Instruction FTE GF}
\]

If this extra load is more than GF Bearable Extra Work Load, which is the average maximum weekly extra hours that can be accepted by a graduate faculty member, this means that Desired FTE GF for Research and Projects can not be realized entirely. Available FTE GF for Research and Projects is calculated as:

\[
\text{Total Non Instruction FTE GF} + \min\{\text{Reduced GF Extra Work Load, GF Bearable Extra Work Load}\}
\]

Total Non Instruction FTE GF is the remaining normal weekly graduate faculty FTE for non instruction activities. Reduced GF Extra Work Load and GF Bearable Extra Work Load represent the desired and bearable extra work loads, respectively. Actual FTE GF for Research and Projects is equal to:

\[
\min\{\text{Desired FTE GF for Research and Projects, Available FTE GF for Research and Projects}\}
\]

Actual FTE GF for Research and Projects is divided among Actual FTE GF for Projects and Actual FTE GF for Research according to the relative weighs of GF Financial Pressure and GF Research Commitment.
III. 7. Undergraduate Faculty Instruction Overhead Sector

This is the sector where the instruction overhead loads of undergraduate faculty members are calculated and the undergraduate FTE for research activities and for project activities are determined. This sector resembles to Graduate Faculty Overhead Sector. The dynamics in both sectors are similar. The main difference is that only undergraduate but no graduate instruction overhead is assigned to undergraduate faculty, because they are not involved in graduate instruction. Normal FTE UGF for UG Instruction Overhead is determined as:

Actual FTE UGF for UG Instruction * Normal Overhead Ratio for UG Instruction

and then divided among undergraduate faculty members and teaching assistants. The share of undergraduate faculty is represented by Indicated FTE UGF for UG Instruction Overhead. After that, Total Indicated Non Instruction FTE UGF is determined as:

Total FTE UGF - [Total In-Class FTE UGF + FTE UGF for Other Routine Tasks]

Then, Indicated UGF Extra Work Load is calculated as:

Min { [Total Indicated Non Instruction FTE UGF - Desired FTE UGF for Research and Projects], 0}

If there is extra work load and it indicates an overhead reduction, the overhead is reduced and Actual Non Instruction FTE UGF is determined. After Actual FTE UGF for Research and Projects is calculated, it is divided among Actual FTE UGF for Projects and Actual FTE UGF for Research according to the relative weights of UGF Financial Pressure and UGF Research Commitment.

III. 8. Graduate Faculty Research Sector

In this sector the graduate faculty FTE dedicated to sponsored and unsponsored research activities are determined together with the motivations behind them and the outcomes of these activities.

Actual FTE GF for Research is divided among Actual FTE GF for Unsponsored Research and Actual FTE GF for Sponsored Research according to the relative weights of GF Unsponsored Research Commitment and GF Sponsored Research Commitment. These two indicators of commitment are the historical averages of GF Indicated Unsponsored Research Commitment and GF Indicated Sponsored Research Commitment and take values between zero and one. The variables that determine the values of the indicated commitments are GF Desired/Realized Research Papers Published, GF Research Culture and the corresponding research recognitions. GF Desired/Realized Research Papers Published is the ratio between the current historical average of research papers published each semester and the target average papers published. GF Research Culture is the long term attitude of graduate faculty members towards research. It takes values between zero and one. Higher research culture causes higher research commitment. Research recognition represents the long term attitude of the administration towards the related research activities and takes values between zero and one. Administration expresses its recognition by rewards and this increases the research commitment. Indicated Unsponsored Research Recognition depends on the unsponsored research papers productivity of the faculty members, namely:

Period Unsponsored Research Papers Published / Total FTE for Unsponsored Research

Indicated Sponsored Research Recognition depends on the financial productivity, as well as research papers productivity.

Thus, Indicated Sponsored Research Recognition is given by:

( Funds - Grants Gotten by Sponsored Research, Total FTE for Sponsored Research, Financial Concern, Period Sponsored Research Papers Published, Total FTE for Sponsored Research )

Here, Financial Concern is an index of the administrations will to get funds and grants through sponsored research.

After Actual FTE GF for Unsponsored Research and Actual FTE GF for Sponsored Research are
determined, the outcomes of research activities are calculated. These outcomes depend on the related faculty FTE and productivity indices.

III. 9. Undergraduate Faculty Research Sector

This sector is similar to Graduate Faculty Research Sector. In this sector, the portion of undergraduate faculty FTE dedicated to sponsored and unsponsored research activities, the motivations behind them and the outcomes of these activities are determined.

III. 10. Graduate Faculty Projects Sector

This sector is similar to Graduate Faculty Research Sector. In this sector, the portion of undergraduate faculty FTE dedicated to sponsored and unsponsored research activities, the motivations behind them and the outcomes of these activities are determined.

III. 11. Undergraduate Faculty Projects Sector

This sector is similar to Graduate Faculty Projects Sector. In this sector, the portion of undergraduate faculty FTE dedicated to official projects and unofficial projects, the motivations behind them and the funds gotten by official projects are determined.

III. 12. Laboratory and Facilities Sector

In this sector the laboratory facilities are updated and then assigned to instruction, research and project activities. The criteria for assigning the facilities are the relative amounts of faculty FTE allocated to each
III. 13. Assistants Sector

This sector is where the number of assistants, available assistant hours per week and the instruction overhead assigned to these assistants are calculated. Number of Assistants is a function of Number of Graduate Students and Assistants/Graduate Students Ratio. This value is limited by Assistant Positions, which is a function of the total number of faculty positions and Faculty/Assistant Positions Ratio.

FTE Assistants for Instruction Overhead is first converted to faculty FTE units by dividing the total assistant hours by weekly hours per faculty. After the FTE assistants for instruction overhead is computed this way, the total available assistant FTE is distributed among FTE Assistants for Graduate Instruction Overhead and FTE Assistants for Undergraduate Instruction Overhead. According to these values, indicated instruction overhead loads for graduate and undergraduate faculty members are calculated. These values are used as input in Graduate Faculty Overhead Sector and Undergraduate Faculty Overhead Sector.

IV. BASE RUN OF THE MODEL

The Base Run of the model is the simulation run made under typical expected set of parameters and input values taken from Bogazici University. The behaviors of the variables, observed in this run are used as reference in interpreting the behaviors of the same variables in sensitivity runs.

Base dynamic behaviors of some important variables are shown in Figure 6.1 - 6.6. Figure 6.1 is the dynamic behavior of the variables Number of Undergraduate Students and Number of Graduate Students. The values of both variables increase through time, but while Number of Undergraduate Students increases in a steady pace, the rate of increase in Number of Graduate Students decreases as time passes. In Figure 6.2, it is observed that both Number of Graduate Faculty and Number of Undergraduate Faculty increase in a steady pace.

Figure 6.3 is the dynamic behaviors of the instruction loads on the graduate and undergraduate faculty members. The total instruction loads on graduate and undergraduate faculty members are at their operating maximums until period 15. After that period, instruction loads increase gradually towards absolute maximum values, due to high student body.

In Figure 6.4 are the weekly hours spent on research and projects by each graduate faculty member. While the weekly hours spent on research activities do not change substantially, weekly hours spent on official projects decrease and weekly hours spent on unofficial projects increase considerably. These behaviors are caused by the increase in GF OP Motivation and the decrease in GF UP Motivation. The dynamic behavior of GF OP Motivation and GF UP Motivation, together with that of GF Research Commitment are shown in Figure 6.5. The increase in GF UP Motivation and the decrease in GF OP Motivation are caused by the relative values of income obtained from official projects and unofficial projects, and the mentality of the faculty members.

The dynamic behaviors of Period Research Papers Published, Period Unsponsored Research Papers Published, Period Sponsored Research Papers Published are shown in Figure 6.6. Here, all there variables increase steadily.

V. VALIDITY OF THE MODEL

A crucial step in System Dynamics Methodology is model verification and validation. Verification consists of a series of tests to assure that the computer program is error-free, that the simulation model does what the modeller intends to do [3]. It is basically a question of correctness. Validation, on the other hand, has to do with the degree of realism and relevance of the model, with respect to the real problem. Although it is a philosophically deep issue, validation practically means demonstrating that the model is an adequate and useful
description of the real system, with respect to the problem(s) of concern [3].

V.1. Verification

First, the twelve sectors that form the model are simulated one by one, isolated from the other sectors. Using these isolated sector simulations, it is easier to apply verification tests and trace any erroneous/illogical results to their origins and correct the potential formulation and/or programming errors. For this purpose, a wide range of short-term test simulations are done, under various test conditions, especially extreme conditions. The built-in unit consistency checking feature of Vensim environment, which checks the equivalence of units on both sides of the equations, was also used in order to eliminate any errors that might be in the equations. After all the sectors were verified, the relationships that link the sectors to each other were verified by running the whole model under different conditions. The units equivalence check was repeated for the model as a whole and the verification tests were completed.

V.2. Validation

After the verification of the model, validation tests are done. Validation tests are grouped into two: (a) structure validation tests, which are done in order to determine whether the model has an adequate structure, (b) behavior validation tests, which are done in order to determine whether the behavior of the model resembles the behavior exhibited by the real system that was modeled. ([2], [4]). To test the structural validation of the model, extreme condition and sensitivity tests have been applied.

V.2.1. Extreme Conditions Tests

Extreme condition tests are based on the idea that the behaviors of a given model are far more predictable under extreme conditions than they are under normal conditions. Extreme condition tests are done by simulating the model after setting a certain variable to an extremely high or extremely low value and examining the behavior of key variables. The extreme value of the chosen variable implies certain predictable behaviors by other variables. If the behaviors of one or more key variables are not as they are expected to be, the validity of the model is questioned, the cause of the problematic behavior is traced to the equations which are revised accordingly. Otherwise, i.e. if the behaviors of all the key variables are as they were expected to be, the model passes the extreme condition tests. Numerous extreme condition simulation runs were done on the model. The results of a selection of the results are presented below.

No Undergraduate Students

The model is simulated for 20 periods (semesters) after setting the number of undergraduate students to zero. The undergraduate instruction and undergraduate instruction overhead loads for both graduate and undergraduate faculty members becomes zero. Some other variables such as Undergraduate Students/Faculty Ratio, Undergraduate Graduation and Average Undergraduate Class Size Needed are also equal to zero, as expected. the model, thus, passes this extreme condition validity test.

No Undergraduate Admission

Another extreme condition consists of starting with a certain undergraduate student body, but then setting the admission equal to zero. (Figure 7.1-7.5). Under this condition, Number of UG Students and UG Graduation converge to zero. So do the undergraduate instruction and instructions overhead loads of graduate and undergraduate faculty members and undergraduate students/faculty ratio. All these are logically expected behavior patterns.

Extremely High Undergraduate Admission

The model is simulated under the condition that undergraduate admission is equal to 10000 students per year. (Figure 8.1-8.5). As expected, under this extreme condition, the instruction loads of the faculty members reach to absolute maximum levels and the average undergraduate class size reaches the maximum value that is allowed, and there is still a big number of canceled undergraduate instruction hours. These performance measures are as expected, hence the model passes this test.
**No Undergraduate Faculty**

The model is simulated under the condition that the number of undergraduate faculty is zero. (Figure 9.1-9.2). Under this condition all undergraduate instruction is assigned to graduate faculty. The instruction load on graduate faculty members rises gradually because of the increasing number of undergraduate students and at period three it reaches the absolute maximum level. At this point Canceled Undergraduate Lecture Hours takes a positive value and increases through the rest of the simulation. Undergraduate FTE assigned for research and project activities is equal to zero and this causes all the outputs of these activities, like research papers published, undergraduate faculty members contribution to official projects to be equal to zero, as expected.

**No Faculty**

Another extreme run is made after setting both Number of Undergraduate Faculty and Number of Graduate Faculty to zero. This makes all faculty workforces and all outputs like research papers and funds gotten by OP an sponsored research equal to zero. All graduate and undergraduate lecture hours are canceled.

**Extremely Low Salary**

Another extreme simulation run is made after the salaries of faculty members are set to 50 dollars per month. (The average industry income is around 1300 dollars per month in Turkey.) This increases the number of leaving faculty members and decreases faculty supplies, (candidates for faculty positions). The number of faculty members decreases rapidly and at period eight it reaches 12, its minimum for this run. (Figure 10.1-10.3). (Setting salaries to even lower values causes similar but more steep behaviors.)

**No Faculty Supply**

Another extreme condition test is done by setting the faculty supplies (candidates) to zero. (Figure 11.1-11.2). As faculty supplies are zero, New Graduate Faculty and New Undergraduate Faculty become zero. This gradually decreases the number of faculty members, both graduate and undergraduate, because there are leaving faculty members. In the long run, the number of faculty members becomes zero.

**Extremely High Instruction Overhead Ratio**

The model is tested after increasing normal instruction overhead hours per lecture hour ratio to an average of 10 from an average of 2. (Figure 12.1-12.3). As a result, all faculty FTE that is left after graduate and undergraduate lecture hours are assigned are dedicated to instruction overhead. Thus, faculty members can not find time for research and project activities during normal work hours. This leads faculty members to do research and project activities by working extra hours. But as average extra hours per faculty are limited by bearable extra work load limits, the total time a faculty member dedicates to research and project activities also limited.

**V.2.2. Sensitivity Analyses**

After the extreme condition tests, a series of sensitivity analyses were made, in order to determine whether the sensitivity of the base model is within acceptable limits.

A set of sensitivity runs are made by simulating the model with different values of a certain variable and examining the behaviors of the key variables to determine if the behaviors of these variables differ within acceptable ranges. If the behaviors of one or more key variables differ more than expected, the validity of the model is questioned. If the differences are within acceptable ranges the hypothesis can not be rejected and other sensitivity runs with different values of some other variables are made. Numerous sensitivity tests were done in order to test the validity of the model. Some examples of these sensitivity tests are given below for illustration.

**Sensitivity Runs with Different Values of GF OP UP Mentality**

The first set of sensitivity runs are done by giving different values to GF Official Projects - Unofficial Projects Mentality, which represents the relative strength of preferring Official Projects to Unofficial Projects. (Figure 13.1-13.4). The values are changed from (0.4) to (0.1), (0.2), (0.8) and (1.0). GF OP Motivation had the
initial value 0.75 and GF UP Motivation had the initial value 0.5 in each run. It was observed that, compared to the base runs GF O P Motivation converges to higher values as the value of the variable GF OP UP Mentality is set to higher values. GF UP Motivation, on the other hand, converges to lower values as GF OP UP Mentality increases. The allocation of graduate faculty FTE for projects between Official Projects and UP also change according to the respective motivations, in each run.

**Sensitivity Runs with Different Values of Average Hours per Graduate Student**

Second set of sensitivity runs are done by giving different values to Average Hours per Graduate Student, which indicates the average weekly lecture hours needed by each graduate student. (Figure 14.1-14.3). Four runs are made and the values of Average Hours per Graduate Student during these runs were (3), (7), (15), (25). The value of this variable in the base run was (15). As expected, higher values of Average Hours per Graduate Student cause Total FTE Needed for Graduate Instruction to be higher, which increases the graduate instruction and graduate instruction overhead loads on graduate faculty members.

**Sensitivity Runs with Different Values of GF Research Papers Productivity**

Another set of sensitivity runs are done by giving different values to the variables GF Sponsored Research Papers Productivity and GF Unsponsored Research Papers Productivity. (Figure 15.1 -15.3). The values of these variables are calculated by multiplying the maximum possible productivity value by the effects of respective commitments, laboratory facilities allocated to research activities and the number of graduate students. The maximum productivity values in the sensitivity runs are (1), (2), (4) and (7) paper per FTE. This value is equal to (4) in the base run. It is observed that the related variables like Period GF Sponsored Research Papers Published, Period GF Unsponsored Research Papers Published and GF Historical Average Research Papers Published per Graduate Faculty take higher values as the maximum productivity value of GF Sponsored Research Papers Productivity and GF Unsponsored Research Papers Productivity take higher values.

**V.2.3. Behavior Validation**

After the structural validation tests were completed the behavior of the model was compared with the data from Bogazici University. (Figure 16.1-16.3 and Figure 17.1-17.3). Most of the real data were taken from the 1994 edition of the yearly document Bogazici University in Numbers [22]. This document includes a wide range of data on many aspects of Bogazici University like students, faculty members, publications and financial figures. Some other data about other aspects of the model, like official projects and available faculty and assistant positions were gathered by interviews and used for calibrating the model. However these data could not be used for behavior validation purposes, because they were mostly single or a few data points.

An exact matching between real data and model data points is not required for validating the model, because a System Dynamics model is not designed to include the internal and external details and random factors that are needed in short term forecasting [2]. The purpose of a system dynamics model is to generate the broad dynamic behavior patterns of the system, in the long term. Thus, what is required is the matching of the major patterns of behavior of the model and the real system, rather than individual data points.

All the data about Bogazici University that could be used for behavior validation were compared with the behavior of the model and a broad resemblance between the model behavior and the behavior of the real system, was obtained. (Figure 16.1-16.3 and Figure 17.1-17.3). Thus, it was concluded that the model is behaviorally acceptable.

**VI. EXPERIMENTS WITH THE MODEL**

Some demonstrative simulation experiments are made with the presented model in order to show its simulation capabilities. Two of these experiments and their results are explained below.

**Graduate Study Orientation versus Undergraduate Study Orientation**

This simulation experiment is designed to determine the effects of different ratios of undergraduate
students/graduate students. (Figure 18.1-18.6). Two simulation runs are made to compare the results of increasing and decreasing undergraduate students/graduate students ratios. The number of undergraduate students is increased slower in the second run than it is in the first run. (Figure 18.1). On the other hand, number of graduate students is increased faster in the second run. (Figure 18.2). The number of undergraduate students and the number of graduate students have the same initial values in both runs. Both simulation runs begin with a undergraduate students/graduate students ratio that is around 5. In the first run, which represents a high undergraduate study orientation, the ratio increases gradually and reaches to 12. In the second run, which represents a high graduate study orientation, this ratio decreases and finally reaches to 2.5. (Figure 18.3).

The first effect of the change in student profile is the change in instruction load allocations. The instruction load per undergraduate faculty member takes lower values in the second run because of the slower increase in the number of undergraduate students. (Figure 18.4). The total instruction load per graduate faculty also takes lower values in the second run. Though the faster increase in the number of graduate students causes the graduate instruction load per graduate faculty member to take higher values, the undergraduate instruction load per graduate faculty take substantially lower values because of the slower increase in the number of undergraduate students. (Figure 18.5).

Lower instruction loads cause the faculty FTE dedicated to research and project activities to be higher in the second run and this brings higher research and project outputs, in terms of both research papers and funds obtained from research and project activities, namely project income. As observed from the results of the simulation runs, an important effect of higher graduate study orientation is higher research productivity per faculty member in the long run. (Figure 18.6).

Experiments with Different Undergraduate Class Sizes

Another set of simulation experiments is done in order to determine the effects of different undergraduate class sizes. (Figure 19.1-19.6). The base values for Desired Undergraduate Class Size and Maximum Allowable Undergraduate Class Size are 50 and 100, respectively. These values are used in run 2, as well. In the first run the values for Desired Undergraduate Class Size and Maximum Allowable Undergraduate Class Size are 20 and 40, respectively and in the third run they are 80 and 160.

The direct effect of different class sizes are observed on total undergraduate instruction hours needed (Figure 19.1) and total FTE for undergraduate instruction (Figure 19.2). This in turn affects the instruction loads per graduate and undergraduate faculty member. Lower undergraduate class sizes bring higher undergraduate instruction loads for both graduate (Figure 19.3) and undergraduate faculty members (Figure 19.4). Extremely high instruction loads cause more faculty members to leave and less new faculty members to apply. This causes the number of faculty members to decrease considerably. (Figure 19.5). Low undergraduate class sizes bring up a higher need for part-time faculty workforce. But the need for part-time faculty workforce is limited by a certain percentage of full-time faculty workforce. As full-time faculty workforce decreases because of the high instruction loads, the upper limit for part-time faculty workforce usage decreases, as well. The discrepancy between needed and delivered undergraduate instruction is tried to be eliminated by increasing the average class size, but if the maximum limit for class size is low (as in the first simulation run), the cancellation of some undergraduate lecture hours is inevitable. (Figure 19.6).

VII. THE UNIVERSITY GAME

In the next step of the research, the model is converted into an interactive dynamic simulation game. Venapp feature of Vensim software is used in building the game version [9]. In the game, the player plays the role of a university policy-maker, who is trying to seek a delicate balance among the main academic functions of the university, in order to get better output from these activities, both in terms of quality and quantity. The player does not have too many decision opportunities, because most of the factors are imposed by the environment the university exists in. The objective of the player is to make six decisions, so as to improve the performance indicators of the university, within the limitations imposed by outside factors. These decisions are New Graduate Students, New Undergraduate Students, Graduate Faculty Hiring Decision, Undergraduate Faculty Hiring Decision, Share on Income-generating-projects per Faculty Member and Weekly Release Time per Graduate Faculty Member (Figure 20). Sixty different performance indicators are displayed after each decision period. There is also detailed information option that the player can use in order to carry out more detailed causal analysis of the dynamics of the model (Figure 20).
The game consists of a series of screens which are linked between themselves. Only one screen can be observed at a time. Some of these screens are just query screens that ask the player which name he wants to give to the file that the current game data will be kept in, whether he wants to end the game, whether he wants to exit the simulation environment, etc. The main game screen is divided into four display boxes (Figure 20). Game Control box includes buttons to be used in order to end the game, exit the simulation environment or see the game conditions. There are also two display objects in this box, that show final time and current time.

Decisions box includes the decision entries and the Advance button. The user enters the values he decided on New Graduate Students, New Undergraduate Students, Graduate Faculty Hiring Decision and Undergraduate Faculty Hiring Decision, which represent the number of new graduate and under-graduate faculty members he wants to hire, for the current semester; Share on Income-generating projects per Faculty Member, which indicates the amount of money that will be paid to each man-hour of faculty workforce from income generating projects and Weekly Release Time per Graduate Faculty Member, which indicates the amount of reduction in maximum weekly instruction load of graduate faculty members. When Advance button is pressed the simulation proceeds one period (semester) and the new values are calculated and displayed. The Help button calls a small frame that includes information about the decision variables. Main Indicators box displays the values of the 30 variables at the current time period. The buttons which have the names of the decision and indicator variables display the behavior patterns of the related variables, when pressed. The button More Indicators calls another set of 30 variables. The button in the Detailed Analysis box executes the link to Detailed Analysis Screen, which include certain analysis tools. These are Causes Tree, which displays the tree of variables that effect a certain (active) variable, Uses Tree, which displays a tree of variables that are effected by the active variable, Loops, which displays the causal loops that include the active variable, Graph, which displays the time graph for the active variable, Causes Graph, which displays the graphs for the active variable and the variables that effect it, Causes Table, which displays a table that includes the values of the active variable and the variables that effect it.

A series of verification and validation tests were done on the interactive simulation game. The behavior of the variables in case of extreme player decisions were tested and several sensitivity tests were done. (These test results can not be shown due to space restrictions. See [8]). The necessary improvements both in the model and the game were made according to the results of these tests. The resulting game is believed to be a robust and valid interactive simulation environment.

A group of players with different academic degrees and different orientations were invited to play the game. Among the players were graduate students, teaching and research assistants, faculty members and managers. We are currently in the process of obtaining and analyzing diverse game results. Some initial results are presented below for illustration.

**Game Results of a Research Oriented Faculty Member**

The first player is a faculty member who has high research interests and little interest in income-generating projects, even if they are realized through official, university channels. During the game, except for period 6, he hires more graduate faculty than undergraduate faculty. He gives considerably release time to graduate faculty (2 h./week on the average). He decreases Official Projects share for faculty members gradually. (Figure 21.1) As a result of his emphasis on graduate study and research, he obtains a remarkable increase in the number of research papers per semester. The average research papers per faculty member has increased, as well (Figure 21.2). On the other hand, decreasing the Official Projects share for faculty members causes Official Projects motivations of the faculty members to decrease and unofficial project (UP) motivations to increase. These, in turn, causes the weekly hours dedicated to Official Projects by the faculty members to decrease and the hours dedicated to UP to increase. In Figure 21.3 the behaviors of project loads of graduate faculty members and Total FTE for Official Projects are shown; the patterns for undergraduate faculty members are similar.

**Game Results of a Balanced Faculty Member**

Another player is a faculty member who tries to strike a balance between instruction, research and project activities. He puts some emphasis on research by giving release time for graduate faculty, but also encourages official projects by giving a considerable official projects income share to faculty members. (Figure 22.1).
He obtains an increase in the number of the research papers per semester and average research papers per faculty member. (Figure 22.2). Although these figures are somewhat less than those obtained by the first player, the differences are not very significant.

The important difference between the decisions of the Research Oriented Faculty Member and the Balanced Faculty Member is that the latter put the necessary emphasis on official projects activities, which the first neglects. That causes a difference between the number of FTE faculty that deal with official projects, as well as differences in the distribution of the project loads among official and unofficial projects. (Figure 21.3 and Figure 22.3).

VIII. CONCLUSIONS

We present an interactive simulation model, on which various problems involved in managing the academic aspects of a university can be analyzed and certain policies for overcoming these problems can be tested. The research consists of two phases: A system dynamics model (the engine behind the game) of the academic aspects of a university system is built first. Numerous verification, validation and sensitivity tests are carried out on the model. The model is calibrated using data from Bogazici University and the dynamic behavior patterns of the model are found to be consistent with the major historical time patterns obtained from Bogazici University.

The interactive simulation game, based on the system dynamics model was constructed using Venapp facility of Vensim software. This game version of the model was validated by a series of tests and the necessary improvements were made in the model and the gaming interface. A group of players with different academic degrees, backgrounds and orientations played the game. The comparison of the game results of the players reveals that players with different orientations emphasize different performance measures of the university.

Research results obtained so far suggest that the interactive simulation model promises to be not only a useful technology to support strategic management, but also a laboratory for theoretical research on how to best deal with strategic university problems. We are currently in the process of initiating further research on the existing model and the gaming interface. The model will be extended to include more aspects of the university system, such as budget considerations, support staff and in general more detailed representations of variables such as facilities, infrastructure and projects. Also, the gaming interface will be enhanced to include various additional user-friendly features.

REFERENCES


Figure 1. Global Sector Diagram
Figure 2. Stock-Flow Diagram of the Graduate Instruction Sector
Figure 3. Graduate Instruction Quality Sector
Figure 4. Graduate Faculty Overhead Sector
Figure 5. Graduate Faculty Projects Sector
FIGURES 6.1-6.6 Dynamic Behavior of the Model in the Base Run (Reference Run)
FIGURES 7.1 - 7.5 Results of Extreme Condition Test: No Undergraduate Admission

FIGURE 8.1 Result of Extreme Condition Test: Extreme Undergraduate Admission (10,000/year) Admission
Graduate Faculty Instruction Loads

Graph for Cancelled UG Lecture Hours

Figure 8.2. Instruction Loads per Graduate Faculty under Extreme Undergraduate Admission

Figure 8.5. Canceled UG Lecture Hours under Extreme Undergraduate Admission

Graph for Act Instr Load per UGF

Graduate Faculty Instruction Loads

Figure 8.3. UG Instruction Load per UG Faculty under Extreme Undergraduate Admission

Figure 9.1. GF Instruction Loads in Case of No Undergraduate Faculty

Graph for Act Average UG Class Size

Graph for Cancelled UG Lecture Hours

Figure 8.4. Average UG Class Size under Extreme Undergraduate Admission

Figure 9.2. Canceled UG Lecture Hours in Case of No Undergraduate Faculty

FIGURES 8.2-8.5 Results of Extreme Condition Test: Extreme Undergraduate Admission (10,000/year) Admission

FIGURES 9.1-9.2 Results of Extreme Condition Test: No Undergraduate Faculty
FIGURES 10.1 - 10.3 Results of Extreme Condition Test: Extremely Low Salary ($50/m.)

FIGURES 11.1 - 11.2 Results of Extreme Condition Test: Zero Faculty Supply

FIGURE 12.1 Result of Extreme Condition Test: Extremely High Instruction Overhead Ratio (10 times the base value)
FIGURES 12.2-12.3. Results of Extreme Condition Test: Extremely High Instruction Overhead Ratio (10 times the base value)

FIGURES 13.1-13.4. Results of Sensitivity Test: Different Values of GF OP UP Mentality; (decreased to 0.1 in run 01, to 0.2 in run 02 and increased to 0.8 in run 03, 1.0 in run 04 from 0.4 in the base run.)
FIGURES 14.1-14.3. Results of Sensitivity Test: Different Values of Average Hours per Graduate Student; (decreased to 3 in run 01, to 7 in run 02 and increased to 20 in run 04 from 15 in the base run and run 03.)

FIGURES 15.1-15.3. Results of Sensitivity Test: Different Values of GF Research Papers Productivity; (decreased to 1 in run 01, to 2 in run 02 and increased to 7 in run 04 from 4 in the base run and run 03.)
Number of Graduate and Undergraduate Students

![Graph of Number of Graduate and Undergraduate Students]

- Number of Grad Students - BASE_RUN
- Number of UG Students - BASE_RUN

Figure 16.1. Dynamic Behavior of Number of Students in the Base Run

Number of Faculty

![Graph of Number of Faculty Members]

- Number of Faculty - BASE_RUN

Figure 16.2. Dynamic Behavior of Number of Faculty Members in the Base Run

Research Papers per Faculty Member

![Graph of Research Papers per Faculty Member]

- Hist Avg Res Pap per Faculty - BASE_RUN

Figure 16.3. Dynamic Behavior of Number of Research Papers per Faculty Member in the Base Run
Number of Graduate and Undergraduate Students

Figure 17.1. Real System Behavior According to Data from Bogazici University

Number of Faculty Members

Figure 17.2. Real System Behavior According to Data from Bogazici University

Research Papers per Faculty Member

Figure 17.3. Real System Behavior According to Data from Bogazici University
Figure 18.1. Number of Undergraduate Students in Experiments with Graduate versus Undergraduate Study Orientation

Figure 18.2. Number of Graduate Students in Experiments with Graduate versus Undergraduate Study Orientation

Figure 18.3. Undergraduate Students / Graduate Students Ratio in Experiments with Graduate versus Undergraduate Study Orientation

Figure 18.4. Instruction Loads per Undergraduate Faculty in Experiments with Graduate versus Undergraduate Study Orientation

Figure 18.5. Instruction Loads per Graduate Faculty in Experiments with Graduate versus Undergraduate Study Orientation

Figure 18.6. Research Papers Published in Experiments with Graduate versus Undergraduate Study Orientation

FIGURES 18.1-18.6. Results of Experiments with Graduate versus Undergraduate Study Orientation (Higher Undergraduate and Lower Graduate Admission in run 1 versus Lower Undergraduate and Higher Graduate Admission in run 2)
FIGURES 19.1 - 19.6. Results of Experiments with Different Desired and Maximum UG Class Sizes (Desired=20, Maximum=40 in run 1; Desired=80, Maximum=160 in run 3 Desired=50, Maximum=100 in the base run and run 2)
Figure 20. Main Game Screen of the University Game
Figure 21.1. Decisions of the Research Oriented Faculty Member

Figure 21.2. Figures about Research Papers in the game played by the Research Oriented Faculty Member

Figure 21.3. Figures about Project Motivations and Loads of Graduate Faculty Members in the game played by the Research Oriented Faculty Member

Figure 22.1. Decisions of the Balanced Faculty Member

Figure 22.2. Figures about Research Papers in the game played by the Balanced Faculty Member

Figure 22.3. Comparison of the behaviors of total FTE faculty for official projects in the games played by the Balanced Faculty Member (BALANFAC) and the Research Oriented Faculty Member (RESORFAC)