A Dynamic Enrollment Simulation Model For Planning And Decision-making In A University

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A DYNAMIC ENROLLMENT SIMULATION MODEL FOR PLANNING AND DECISION MAKING IN A UNIVERSITY

by

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ABSTRACT

Decision support systems for university management have had limited improvement in the incorporation of new cutting-edge techniques. Most decision-makers use traditional forecasting methods to base their decisions in order to maintain financially affordable programs and keep universities competitive for the last few decades.

Strategic planning for universities has always been related to enrollment revenues, and operational expenses. Enrollment models in use today are able to represent forecasting based on historical data, considering usual variables like student headcount, student credit, among others. No consideration is given to students' preferences. Retention models, associated to enrollment, deal with average retention times leaving off preferences as well.

Preferences play a major role at institutions where students are not required to declare their intentions (major) immediately. Even if they do, they may change it if they find another, more attractive major, or they may even decide to leave college for external reasons.

Enrollment models have been identified to deal with three main purposes: prediction of income from tuition (in-state, out-of-state), planning of future courses and curriculum, and allocation of resources to academic departments, This general perspective does not provide useful information to faculty and Departments for

detailed planning and allocation of resources for the next term or year. There is a need of new metrics to help faculty and Departments to reach a detailed and useful level in order to effectively plan this allocation of resources.

The dynamics in the rate-of-growth, the preferences students have for certain majors at a specific point of time, or economic hardship make a difference when decisions have to be made for budgets requests, hiring of faculty, classroom assignment, parking, transportation, or even building new facilities. Existing models do not make difference between these variables.

This simulation model is a hybrid model that considers the use of System Dynamics, Discrete-event and Agent-based simulation, which allows the representation of the general enrollment process at the University level (strategic decisions), and enrollment, retention and major selection at the College (tactical decisions) and Department level (operational decisions). This approach allows lower level to more accurately predict the number of students retained for next term or year, while allowing upper levels to decide on new students to admit (first time in college and transfers) and results in recommendations on faculty hiring, class or labs assignment, and resource allocation.

This model merges both high and low levels of student's enrollment models into one application, allowing not only representation of the current overall enrollment, but also prediction at the College and Department level. This provides information on optimal classroom assignments, faculty and student resource allocation.

"It is our choices...that show who we truly are, far more than our abilities."

J.K. Rowling

This work is dedicated to my wife, Carolina, the love of my life, and to my four beautiful daughters, the source and inspiration of our journey together.

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LIST OF ACRONYMS/ABBREVIATIONS

AA: Associate of Arts

AB: Agent-based

ABS: Agent-based Simulation

AS: Associate of Science

CCT: Community College Transfer

CECS: College of Engineering and Computer Sciences

DES: Discrete Event Simulation

DL: Distance Learning

FTE: Full Time Equivalent

FTIC: First Time in College

F2F: Face-to-Face

HES: Higher Education System

IK: Institutional Knowledge

IKM: Institutional Knowledge Management

IPEDS: Integrated Postsecondary Education Data System

IRB: Institutional Review Board

MAS: Multi-agent Simulation

OOS: Object Oriented Simulation

SCH: Student Credit Hour

SD: System Dynamics

SHC: Student Head Count

SNA: Social Network Analysis

UAPS: University Analysis Planning Support

UCF: University of Central Florida

CHAPTER ONE: INTRODUCTION

Background of Study

Universities are complex organizations that deal with different kinds of assets, some very common and easy to recognize such as people, infrastructure, and technology, and some others that are not so evident and require much effort to promote and increase: knowledge, scientific reputation, ranking, social and community commitment and involvement, among others.

Several aspects influence universities to plan ahead and manage their resources. Large metropolitan universities base their future under the scope of "Strategic Planning." This Strategic Planning becomes important when dealing with a big number of variables and a complex decision making system. Strategy is associated with how activities of the organization are selected and are consistent with the objectives and goals the university has established. Strategic planning may involve several levels. A high level where decisions are related to these goals, objectives or general trends, and lower levels where the decision may be confronted with the fact of opening a new class, calculating future enrollments, or changing the modality from live to internet-based classes by a faculty or a specific program.

Competitiveness, uncertainty, demand, and economic turmoil are some of the many aspects an adequate strategic plan must address. The University of Central Florida, as one of the leading universities of the region, has identified its own Strategic Planning Cycle for six years that started in 2009. This Plan should embrace the mission and vision for the upcoming years (UCF Strategic Plan, 2009)

Among its mission, it is important to highlight the statement that UCF serves the economic, cultural, intellectual, environmental and societal needs by providing high quality education. Its vision indicates the intention of "providing leadership and service to the central Florida city-state by pursuing new strengths by doing partnerships, with inclusiveness, excellence, and opportunity for all" (UCF creed, 2011)

Integrity, scholarship, community, creativity, and excellence are the values that conforms the foundational principles of the UCF. The 2009 Strategic Plan includes the goals that will give direction and speed to its upcoming development (UCF Goals and Key Elements, 2011):

- "Offer the best undergraduate education available in Florida.
- Achieve international prominence in key programs of graduate study and research.
- Provide international focus to curricula and research programs.
- Become more inclusive and diverse.
- Be America's leading partnership university."

All these aspects conform an overall picture that, summed and weighted, will illustrate in one way or another, the future of the University, and the way this educational enterprise addresses the emerging needs within the University as well as in the state, nation and the international community.

The UCF's strategic plan includes a final statement pointing out that "the entire university community is empowered to identify, seek, develop, and capitalize on opportunities that arise in the future and meet the vision of the university" (UCF Strategic Plan, 2009).

But what is the difference between a high ranked university and an average one? Why would high quality students want to join this university? All the answers will be related to what the university shows, and the projections it offers. If the university offers not only state of the art technology, but also high quality research-focused faculty, the natural response would be an increment in the recruitment and graduation of high quality students.

The Strategic Planning process is normally based in several indicators that allow the decision makers to predict some information. These variables are generally related to statistical facts derived from data such as enrollment, continuity of students, percentage of expected graduation, retention, course information, degrees awarded, surveys, etc.

From these factors, decision makers decide to follow or modify either the strategic plan, some of its components such as goals, or some of its key elements. When decisions have to be made, these factors are not the only influence in the process. There are several others that, without representing positive numbers or blue figures, have impact either in the community or in the educational system.

If we think of strategic planning as a financial or mathematical method, there may be little need to alter the present processes universities are carrying on. If we think that Universities behave as a highly complex, highly interactive, and sometime unpredictable system that depends on several internal and external variables, we might be inclined to see such system as a network of decisions, a network of several components, where its nodes would represent components such as "Faculty and departments," each of them with particular needs and interests, or as a network of knowledge administration and scientific collaboration, as we would identify in the undergraduate and graduate programs managed by the University. Now we see that things become a little more complicated and forecasting is just not a matter of linear models but the aggregation of several dissimilar factors.

Besides all we have mentioned, one of the key factors in University Management is money. Financing higher education involves several stakeholders: The state that provides the funds to fill the gap, the university partners that are involved in joint ventures, the donors, and of course the funds obtained from tuition, research, patents, and other revenues.

The use of modeling and simulation represents an approach in order to improve the decision-making process as a way that would allow re-creation of actual and future processes of the model of a University. The representation of the structure of a higher education institution and the decision making process involved, has been mostly limited to the use of traditional statistical techniques. These quantitative techniques have not allowed the representation of other factors that influence decisions such as national scientific trends, technology availability, community needs, new goals, enrollment policies, behavior based enrollment, among others.

Problem statement

"America is driven by innovation- advances in ideas, products, and processes that create new industries and jobs, spur economic growth, and support a high standard of living, and achieve national goals for defense, health, and energy. In the last half-century, innovation in turn has been increasingly driven by educated people and the knowledge they produce. Our nation's primary source for both new knowledge and graduates with advanced skills continues to be its research universities" (National Research Council, 2012).

The previous paragraph gives account of the concern the Government has about higher education and the difficult time research universities will have in the coming years in order to maintain the excellence in research and doctoral education to help the United States to compete, be prosper, and achieve "national goals for health, energy, the environment, and security in the global community of the 21st century" (National Research Council, 2012). After the government expressed its concern, a response from the National Research Council convened the creation of a committee that in the next two years would provide with a thoughtful response to this problem.

One of the ten recommendations the report mentions is that universities should be more efficient in managing resources. Since Federal and State funding is decreasing for now, it is necessary to improve the way universities plan and allocate their resources. Resource allocation is a key factor in any strategic plan and, one of the main components of it is enrollment forecasting, as it will provide a rough estimate of the direct incomes the university will receive in the coming future. Based on this plus other external incomes such as state support, and adding to this equation their expenses as well, universities would be able to allocate resources that finally, at the long term, would differentiate them from each other, becoming more or less attractive and competitive.

Enrollment forecasting is one of the essential components of an effective budgeting and planning system for any large University. Over the last three decades, the integration of such models to Strategic Planning has allowed decision makers to be precise and effective in their resolutions, decreasing uncertainty, and improving resource allocation. Having a flexible and responsive enrollment management process would allow Universities to capture the number of students needed to survive and grow at an adequate level, capture the amount of high quality students needed to keep their academic validity, keep - as a result of the aforementioned - a faculty body enough in quantity and quality to sustain all these and, finally, obtain as a result the financial stability the university requires (Glover, 2005).

The rapid growth of universities is a response to the need of access to an increasing number of college-degree seeking population, and to expand their graduate education and research consistent with their individual mission and vision. UCF has consistently increased its student population 4.5% annually (about 2500 new students each year) while annual fundable Full Time Equivalent (FTE) has increased 4.8% for the last five years, reflecting improved retention of students, increased course loads, and higher summer enrollments (UAPS, 2011). In its report, University Analysis Planning Support (UAPS) has identified a continuous growth in student population, and foresees headcount increment from 56,337 in fall 2010 to 67,553 in fall 2016 (including medical students).

In UCF's particular position, this growth is strengthened by its commitment to Florida Community/State College Transfer Students, particularly those from their 2+2 consortium partnership. UCF at this time enrolls more than 25% of the Community/State Colleges Graduates who continue their enrollment in the State University System. Other factors such as increasing numbers of full-time students, course loads, and summer enrollments, all result in an increment of student credit hour (SCH) production for each estimated headcount (UAPS, 2011). Furthermore, as UAPS mentions in its 2011 UCF Enrollment Plan, this higher SCH production per headcount is multiplied by increases in headcount due to UCF's first year retention rate for FTIC student from 78% in 2000 to 86.3% for the 2009 cohort, and a consequently higher numbers of returning students.

Enrollment is also a key factor in Strategic Planning, or in other words, in the way universities construct and use multiple future scenarios either to create visions of their future, establish or adequate missions and goals, or select the strategies to achieve those goals (McIntyre, 2004).

The University of Central Florida, as the second largest university in the Country with more than 57,000 students enrolled in 2011, gives priority to the definition of required policies and vision through its Strategic Planning, considering:

- Enrollment growth. From more than 33,000 students a decade ago, to more than 57,000 students this year (UAPS, 2011)
- Increasing number of courses with e-learning capability
- Tuition increment for all Florida's public universities, up to 15% each year until they hit the national average (Florida Board of Governors, 2011)
- Aggressive competition between higher education institutions, especially for national competitive research funds when the present economy has restricted their availability for this purpose
- Competition for high quality students
- Major declaration from First Time in College (FTIC), Community College Transfer (CCT) or other transfer students

The enrollment models in use today are able to forecast based on historical data. After data is provided, models are adjusted to absorb the difference with the previous year allowing further predictions. Student Headcount, Student Credit Hours, or classifications such as FTIC, CCT or other transfer students, are some of the most common input variables affecting the model. There is no information about Student's preferences when declaring a major, or if they modify their election during their studies, especially considering that FTIC and CCT behave differently since FTIC have a 4 year minimum retention time, and CCT only two, with several remaining aspects that affect this retention such as drop out rate, change in major, etc.

Enrollment models have been identified to deal with three main purposes: prediction of income from tuition (in-state, out-of-state, etc.), planning of future courses and curriculum, and allocation of resources to academic departments (Hopkins & Massy, 1981). This general perspective does not provide useful information to Faculty and Departments when they have to start detailed planning and allocation of resources for next term or year. There is a need of new metrics to help Faculty and Departments to reach a detailed and useful level in order to plan effectively this allocation of resources.

Enrollment Prediction methods are also different according to the stage the university is in. A growing environment differs from a stable university (Armacost & Wilson, 2002). The dynamics in the rate-of-growth for instance, make a good difference when decisions have to be made for budgets requests, parking, transportation, faculty, etc. Existing models do not distinguish between growing or stable universities.

Existing forecasting models have to be separated into levels. There should be different models for different categories if their retention patterns are too different. Retention patterns are based in the enrollment behavior and its cohort's categories.

Furthermore, existing models do not take into account recent changes in technology, in particular distance learning and different instruction modes (face-to-face, remote, and mixed). These particular instruction modes do affect planning and its consequences have not been measured efficiently as they are not incorporated in present enrollment models.

Finally, current enrollment models are generic and high level. They include SCH prediction and retention. Faculty and departments have no way to figure out the number of students for next term or year unless they base their guess in previous year data. We deduce from this that the allocation of resources is far from optimal, influencing several issues such as number of courses offered per term, number of students allocated per course, professors to be hired, classes to be assigned, and research to be conducted.

This dissertation will provide a way to represent, through modeling and simulation means, the Complexity of Strategic Decision-Making Process for a University's Enrollment Process for Faculty and Department level. For this, the University of Central Florida through the College of Engineering and Computer Sciences, and its Department of Industrial Engineering, will provide the environment and data required to build a simulation model, considering this as a Case Study, and finally allowing the IE Department to include the "What if" scenario in the Strategic Planning for next and future years.

Scope of research and hypothesis

A number of techniques can be applied to an enrollment simulation model as a complex strategic decision-making process:

- System Dynamics (SD) would allow the representation of factors of influence in the model, with a wide perspective and flexibility (strategic component of the model).

- Discrete-event Simulation (DES) and Agent based Simulation (ABS) would provide representation of some specific processes over time and would allow a more individual and autonomous representation of the enrollment's structure (operational component).
- Linkage between individuals, entities, or elements constituents of the model will allow passing the information through the representation of the structure, in a network representation, among its nodes with links connecting them.

Hypothesis 1: The use of simulation for the representation of a complex enrollment structure and variables a university model requires will allow linking student's behavior and preferences to operational inputs, including visualization, comparison and examination of results from several decision-making options such as enrollment according to declared major, etc.

Hypothesis 2: A complex enrollment simulation model shall be composed of two internal models that will call for hybrid simulation. This should induce the use of System Dynamics (for high level simulation) and Agent Based Simulation (for low level representation around a common simulation engine). Both techniques shall be grouped and organized as a simulation model that shall include all variables needed, turning uncertainties into qualified risks.

This simulation model should allow decision-makers to forecast enrollment and student's preferences at both university and department level, giving them the tools to anticipate upcoming students and the opportunity to adequately plan the use and allocation of resources for the following terms or financial years.

Contribution

Budget cuts, tuition increments, growth, recession increasing the number of students enrolling in universities, competition, distance learning or web based teaching modalities are some of the many factors affecting faculty and department, as part of UCF's Strategic Planning. This Strategic Planning, as a general concern of many higher education institutions (DesJardins & McCall, 2006) has the ability of managing several factors and, if well planned and executed, would decrease uncertainty, and allow including periodical estimates that will greatly affect the stand and long term objectives of these higher education institutions.

As presented in Chapter 2, enrollment models at present have not suffered major improvement in recent decades, keeping traditional optimization approaches by the use of linear regression and some other statistical and optimization techniques, but with no further interest in simulation techniques, therefore limiting the possibilities of analysis in "What if" scenarios. By the same token, traditional enrollment models have not considered the present situation affecting the Florida State University System in general, and UCF in particular, where due to the flexibility of students in declaring and changing their majors during their stay, faculty, department and colleges have no use of these enrollment models as they do not predict these fluctuations, and estimates has to be done empirically and based in previous years.

At this time, UCF bases its predictions on a general enrollment model based on headcounts - which is explained in detail further on - that gives a fairly accurate forecast, but doesn't allow obtaining further and deeper detail, like how many students in a specific major are going to be for next term, what is the success rate for these students, or what modality are these students following, among others. This weakness is manifested at Department levels where the lack of accurate forecasting results in improvisation, and a non-optimal allocation of resources (hiring faculty, planning classes, distribution of classrooms, etc.)

We suggest that building a complex enrollment simulation model would allow capturing variables that until now have been left aside. According to the literature review presented in Chapter 2, there is no practical model in existence able to provide a general forecasting perspective, and a specific behavioral approach. This simulation should be modeled as a hybrid simulation model including different levels, creating a dynamic enrollment model at a University and department level that would help forecast enrollment, and help in costs estimations, growth, etc.

We think that, based on the particular data that the University of Central Florida is able to provide, a better decision support tool is feasible, considering a high level simulation modeling provided by System Dynamics, and a low level provided by Discrete-event and Agent Based simulation. The uniqueness of this model is found in the combination of

Complex System and Multi-paradigm Simulation, allowing the representation of the topological components of the network system, and the statistical properties that they represent, with the final outcome of *new metrics* not considered until now.

The final product should help strengthen the Strategic Vision and foresee the impact of present decisions in the near future related to enrollment, and at a lower level, help faculty and staff from the Industrial Engineering Department, to adequately plan and allocate resources.

Some of the immediate questions to be answered through simulation means for the different levels are:

- Strategic component

* Student Headcounts (by type: FTIC, AA/AS Transfer, CCT without degree, Consortium Partner Transfer) for the time span of the study
* Major declaration and drop-outs for the time span of the study, identifying timing, trends and general preferences
* Students' general success rate (freshman to sophomore, etc.)
* Graduation rates
* Building and parking expansion plans
* Enrollment desired quota for long-term strategic planning, and short-term operational number of FTIC students that have declared a major
* Faculty/student ratio

- Trade-offs resulting from the analysis of the outcome
- Effects of population growth, high school graduation and continuation rates, economy, demographic changes

- Department and Faculty component:

- How many students from a specific major are we going to have for next term, for the next year, and what will be the average time remaining until graduation?
- How many students would drop off, stop-out or join the Major?
- What courses are needed to satisfy the demand? How many classrooms are needed for this? How many labs? Should the Department expand and build more classrooms or should it migrate to fully web-based courses?
- What is the need for Faculty to satisfy the demand? Should we hire more?
- How many students from other Majors would take classes in the College or Department?

The creation of an abstract representation of the enrollment process at a strategic and operational (department) level through simulation will allow exploring the behavior of the system under different and specified situations. Current models do not allow exploring large and complex systems easily. They do not allow capturing the dynamics of a complex system and the aspects that may have a major impact on the system performance. We intend to make a difference by providing a simulation model that would allow doing objective analysis, accurately predicting behavior under changed conditions, reducing therefore the risk of making poor decisions.

Dissertation outline

This thesis is organized in six chapters. Chapter one presents the problem statement, the scope of the research, the hypothesis that sustain this research, and the contribution this research intends to make.

Chapter two describes the literature review, how the search was defined including strategy and inclusion criteria, resource allocation, and enrollment management among others. This chapter also includes existing approaches for enrollment forecasting and student retention, and it shows how UCF supports its prediction according to its enrollment model in use. Also included in this chapter are strategic planning, complex networks and simulation techniques related to enrollment planning for universities.

Chapter three defines the methodology used in this research by analyzing existing methods, proposing and defining the step-by-step methodology to conduct the research and resulting simulation modeling.

Chapter four has a deeper description of the different levels of abstraction and modeling approaches. Here, we describe the rationale behind the models, relationship between levels, and projected outcome. This chapter also includes high and low level model description, and data definition and scope.

Chapter five considers system behavior and hybrid implementation of the model. In includes a High-Level representation including attrition and retention, passing rates, enrollment calculation, student parking growth, student/faculty ratio, a Monte Carlo analysis and parameter variation a Low-Level representation including the IE department, and course assignment and major selection.

Chapter six includes a summary, conclusions and further research.

CHAPTER TWO: LITERATURE REVIEW

Introduction

The following chapter covers the literature review from the year 1963 until now. The scope and the amount of techniques covered, as well as the importance of citing the initial and main papers included.

Literature Review Search Strategy

Key Research Questions

An accurate enrollment prediction model is of the utmost importance for correct budget and resource allocation. UCF has suffered an enormous increment in enrollment over the last years and, despite a well-defined strategic analysis and planning, the growth is still surprising.

Scenario planning is complex. It has to be aligned with the mission and vision of the University and it has to deal with uncertainty when planning staff attempts to identify long-term problems. Demographic trends, economy cycles, public policies and preferences are some of the factors affecting forecasting.

Despite the existence of prediction models in use by Universities, as the Office of University Analysis Planning Support (UAPS) from UCF works with a Markov Chain Prediction Model for a 10 years span, enrollment is seeing as an overall projection of general trends based on previous years. There is no specificity or detail whatsoever in predicting how these cohorts spread over the faculty or departments as the only available data is the "declaration of major" made by the students at the first stages of their studies, and there is no commitment to keep this choice over the years since the actual system allows them to change as many times as they want, with no previous requirement or constraint.

The key research questions that deals with the problem statement and the scope of this research are:

- How does enrollment affect the growth of a University and particularly their Faculty and departments?
- What are the variables that influence enrollment and how this enrollment relates to strategic planning?
- How does the social and informational network's structure of the University affect enrollment prediction?
- What has been done, what can be done to improve forecasting and what other metrics can be included?
- To what extent are forecasts and metrics understood and used by administrative units (departments)?

Search Strategy

This literature review focuses in the components of an enrollment model, including external variables such as strategic planning, or internal and specific as types of forecasting models. These will allow us later to understand the components that form a sustainable complex enrollment simulation model. This model will be a tool to improve the accuracy in forecasting, decreasing uncertainty and ulterior errors at the specific level for our research (college and department level).

This research started by selecting some keywords that represented the goals and scope of the research. The search was done by digging in some of the databases, journals, and sites (or institutions) available in the UCF library, as we can see in the table below.

Table 1 Keywords and databases

Keywords	UCF library databases and other sources
Enrollment, Management, Simulation, Strategic Planning, University Planning, Modeling, University Growth, University System, University Planning, Financial Model, Prediction, Forecasting, Knowledge Management, and Planning.	EBSCOhost, Elsevier, Science Direct, JSTOR, Springer, Econlit, ProQuest, IEEEXplore, IFORS, ISI Web of Knowledge Specific Institutions and IR and Planning Departments
Combination of keywords also provided some more specific results	

Inclusion Criteria

The inclusion criteria, based on a systematic revision of the literature, consisted in a series of keywords, a combination of them, and the use of several sources in order to obtain journals, conference proceedings, and general information required for this research. As mentioned before, the search included English-written papers dated from 1958 up to 2012. Initially there were found 295 relevant papers in the databases that had direct relationship with our topic. From these, 227 papers were preselected considering the relevance of the topic titles and the relationship with the scope of the research. Articles discarded were 9 mainly due to duplication. Articles selected were 105. After their abstract were analyzed identifying 38 as the key publications according to its relevance in the field and therefore in this research. In Figure 1 we can see the distribution of papers over time:

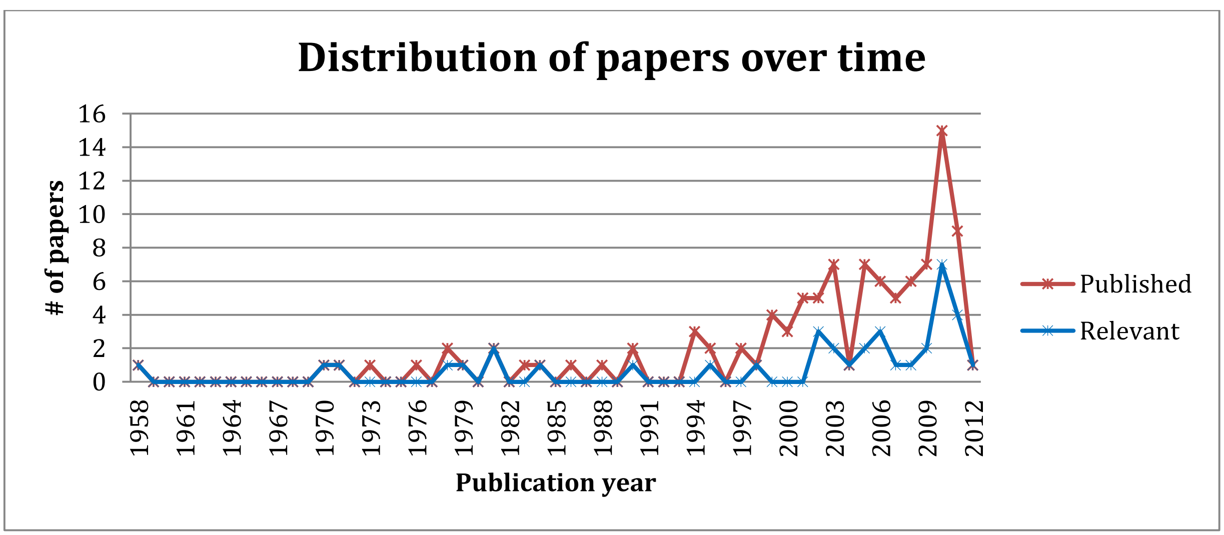

Figure 1, Distribution of findings over time

Most of the relevant documents have relationship with fundamentals and ground rules of the different areas this research involves. The 1958 paper made by Forrester for instance, the oldest included in this research, establishes the fundamentals of System Dynamics (Forrester, 1958), and is the basis of further developments in this area. By the same token, there was the need to explore the basis of university planning, budget allocation, funding, and initial models for higher education institutions (Baisuck & Wallace, 1970) (Bleau, 1981) (Dickmeyer, Hopkins, & Massy, 1978) (Hopkins D. , 1971).

How Universities Allocate Resources and Manage Enrollment

Resource Allocation

Funding and Resource Allocations may be considered the prominent factors affecting the administration of universities. The management and structure of these institutions will have a huge impact on how they operate and survive (Johnes G. , 1999).

The Goldwater Institute, an educational foundation and an independent government agency supported privately, presented an article called "Administrative Bloat at American Universities: The Real Reason for High Costs in Higher Education," (Green, 2010) avowing that enrollment at America's leading Universities has been increasing dramatically, growing nearly 15 percent between 1993 and 2007. It affirms also that higher education has not become more efficient. Instead it has acquired more administrative staff, increasing expenses.

Between 1993 and 2007, the number of full-time administrators per 100 students has increased by 39 percent among the leading universities of the U.S. The number of employees engaged in teaching, research or service grew only 18 percent, showing that there is an administrative bloat where students pay only a small amount of money required to sustain these administrative costs (Green, 2010).

These trends do not match the behavior the University of Central Florida has had over the past decade. Lately, the growth in spending and the number of administrative and institutional employees has not kept up with UCF's enrollment growth. This is accounted in the University Analysis and Planning Support Office from UCF as part of its annual report highlighting that "unlike most of its peers, UCF between 1993 and 2007 has decreased its administrative spending per student, from 34.3% to 24.4%, furthermore, it represents a ratio of two already extremely low numbers (Archer, 2010). "

Data provided by the Integrated Postsecondary Education Data System (IPEDS), sponsored by the U.S. Department of Education, reports that Higher Institutions are building their income in government subsidies, insulating students from the costs leading to a significantly less efficient financial system. "It takes more employees and more dollars to educate each student even as these leading universities grow larger." (Green, 2010)

There is still some doubt about how tuition increment affects all this but, as IPEDS say, resources are not enough and tuition doesn't cover all the costs. Meanwhile, a report made by the College Board Advocacy & Policy Center in 2010 about Trends in College Pricing (College Board Advocacy & Center, 2010) states that over the decade from 2000-01 to 2010-11, tuition and fees for four-year public colleges and universities increased at an average rate of 5.6 percent per year (82% over the period) beyond the general inflation. UCF tuition has increased more than a 100% over the last decade, from $80.06 per SCH in

2002 to $186.13 in 2012 for under graduate students (an average 8.8% rate increase each year). Tuition at private nonprofit four years institution increased up to 28 percent over the decade (UAPS, 2011).

Nationwide, enrollment is increasing too. From fall 2000 to fall 2009, full-time student enrollment increased from 4 percent to 10percent, and part-time students increased from 1 percent to 6 percent (Vogel, 2011). These increments should allow a reduction in costs to students, unfortunately, despite increased governmental subsidies the inflation-adjusted tuition increased by 66.7 percent. In Florida, tuition and fees are far below the national average. A sample of school tuition during 2011 is shown in Table 2.

Table 2, Tuition and fees from selected Public American Universities

University	***2011 Headcount***	***Tuition/Fees***	***Room/Board***	***Total***
Arizona State University	72,254	$ 9,720	$ 11,4367	$ 21,156
University of Virginia	24,297	$ 11,794	$ 9,036	$ 20,830
University of Georgia	25,947	$ 9,472	$ 8,708	$ 18,180
University of North Carolina	29,390	$ 7,008	$ 9,470	$ 16,478
University of Florida	49,827	$ 5,570	$ 8,800	$ 14,500
University of Central Florida	56,235	$ 4,158	$ 8,574	$ 13,092

A classification made by Burton R. Clark (1983) through the Higher Education System (HES) considers that there are two major ways for funding higher education: a *market* *oriented system* and a *state oriented system* (Liefner, 2003) (Clark, 1983). Many authors agree that the market-oriented system is commonly used in funding higher education institutions (Maasen & Vught, 1994) (Trow, 1997). Funding is provided by the private sector as tuition and fees, grants, research funds, and gifts, among others. This way of funding requires universities to be highly competitive in order to obtain resources.

Competitiveness entails a high quality teaching and research level, innovations and patents, and a great effort in amount of published papers per year. State-oriented funding system on the other hand, requires institutions to follow government guidelines and directives, as the government allocates funds based generally on previous year's budget plus inflation and other approved incremental expenditures. This tendency tends to be more conservative and less innovative as new projects take longer to achieve because of the slow planning process . Most private U.S. higher education institutions follow the market-oriented system in contrast with the European system of governmental funding, where all teaching and research activities are coordinated (Liefner, 2003). It is worth saying that many higher education institutions follow both market-oriented and state-oriented features but undoubtedly, the private sector is the mainstream for funding.

Competitiveness becomes the precondition for obtaining these funds. In terms of resource allocation, research plays a very important role for obtaining funds, as the impact of research universities on regional economies is prominent. Investment in research universities advances the technological base of the regional economy that, at the end, lead to the creation of new companies and industries, more jobs, and more wealth in general

(Lendel, 2010). Lendel shows that despite the difficulties of assessing the effects universities have in local economies, the new knowledge, innovation, and intellectual influence provide a local competitive advantage for the community.

Another important trend in resource allocation is the growth of University-Industry partnership. An important part of research is made under this modality. Technology policy changes for the last decade have allowed the increment of these partnerships, which have stimulated university-industry collaboration (Poyago-Theotoky, Beath, & Siegel, 2003). These partnerships have become very popular, ranging from contractual relationships to more informal arrangements such as educational partnerships.

There are several ways to conduct partnerships. A firm may hire a researcher from the university to conduct research on a specific subject. This relationship usually is considered as an applied research or consultancy, rather than fundamental research, where all rights are vested on the firm. Another way may be when a university research develops an idea for commercialization. Its work is included in a contract between a firm and the university, and intellectual property is vested in the university and generally the firm is used to facilitate commercialization. Finally, one common way of partnership is when a university has conducted research that generates new ideas for commercialization. But these ideas are at an early stage. All development is done by the firm, which will take the biggest risk, as the project may not reach a commercialization stage. Property rights normally are kept in the firm, but the knowledge invested is still freely available (Poyago-Theotoky, Beath, & Siegel, 2003).

Another, a slightly more difficult way, is when the university and the firm participate in a joint venture by developing a product or technology together. Rights and benefits are then shared equally.

The University of Central Florida has done a notable work in patent registration, from No. 7th ranked university in the United States on 2009, now holds the 3rd position for 2011 in Patents registration, according to IEEE, the world's leading professional association for the advancement of technology (Thomas & Breitzman, 2010). But despite this great achievement, does UCF benefit from the return of investment these products should offer? A study by Jensen and Thursby gives account that, through a survey of 62 universities, the vast majority (77 percent) of the university-based inventions require some kind of investor involvement in the product's development phase. It also reports that around 48 percent of these projects reached only the "concept stage", and a further 29 percent only reached the stage of a laboratory scale (Jensen & Thursby, 2001) (Poyago-Theotoky, Beath, & Siegel, 2003).

As we see that the economy will always be unpredictable, university decision makers will have to add also the effects of recession into the annual budget. Universities contribute not only in the education process but also in innovation. Universities serve the community in this matter by providing a space for ongoing local conversation about future technologies and markets. Economic development of universities will include patenting, licensing, and new business formation but considering the university role in the community (Lester, 2005), this strategic approach to local economic development will always be compatible with the pursuit of excellence in their primary mission of education and research, as we will see and analyze in the following sections.

Enrollment Forecasting and Student Retention

Enrollment forecasting is the central component of an effective budget planning, program and strategic planning tool. It allows decision making with an understanding of trends and variables affecting those trends in students' enrollment. Enrollment forecasting should allow addressing three main purposes: prediction of income from tuition (in-state, out-of-state, etc.), planning of future courses and curriculum, and allocation of resources to academic departments (Hopkins & Massy, 1981).

An accurate forecast of this enrollment process would allow universities, faculty and departments within universities to remain competitive, and allocate resources effectively. Several enrollment models may be required to fulfill the need for prediction. Models and methods differ from each other and depend on their inherent purpose. Prediction enrollment methods are also different according to the stage the university is in. A growing environment differs from a stable university (Armacost & Wilson, 2002). The dynamics in the rate-of-growth for instance, make a significant difference when decisions have to be made for budgets requests, parking, transportation, faculty, etc.

Enrollment forecasting traditionally has been modeled by Operation Research techniques, including optimization modeling, and statistical analysis. Linear programming is one of the best known OR techniques, where a linear function is optimized given a set of linear restrictions or requirements.

One of the modeling techniques used at the University of Central Florida is the Markov Chain Model (Fraser, Djumin, & Mager, 1999) (Armacost & Wilson, 2002). This model considers the incremental growth for forecasting undergraduate and graduate enrollment, and the characteristic of a Markov Process adjusts very well to the nature of the University, that is, dynamic and constantly growing.

A Markov process is defined as "studying the evolution of systems over… successive time periods where the state of the system in any particular time period cannot be determined with certainty. Rather transition probabilities are used to describe the manner in which the system makes transitions from one period to the next." (Anderson, Sweeney, & Williams, 2000) Predictions for a future state are based and depend on the immediately former state.

Armacost and Wilson introduced three different models for UCF's enrollment prediction: A high level model for a 5 year span, predicting FTEs by level and distributing them to different campuses; a short-term prediction model for headcount, student credit hours, and overall FTE's, shown in Figure 2; and a graduate model for predicting college enrollment, shown in Figure 3. In these models, a Markov chain is used for transition probabilities between stages and behavior of graduate students.

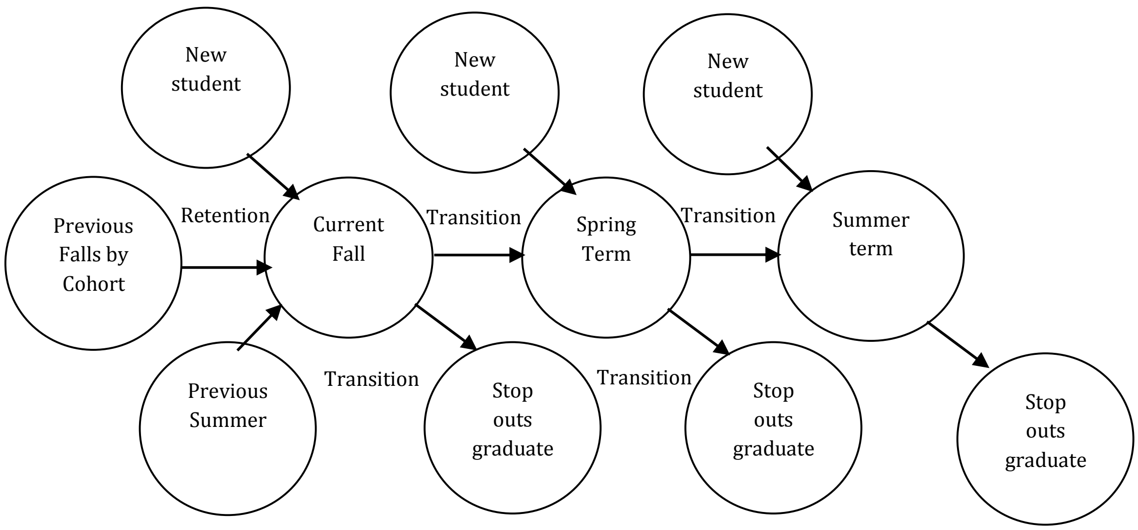

Figure 2, Short-term Prediction Model (Armacost & Wilson, 2002)

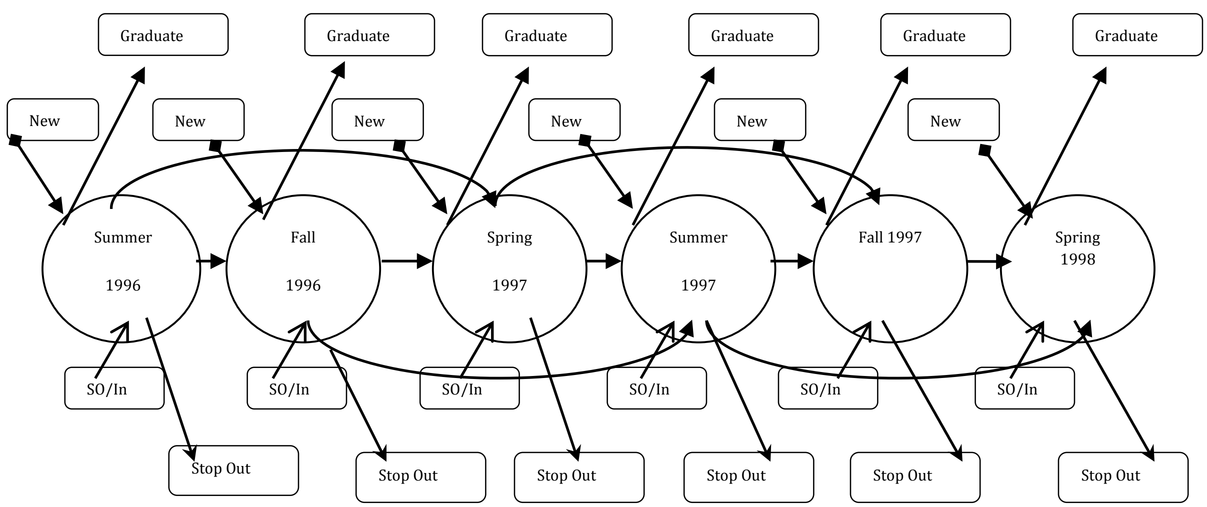

Figure 3, Full Graduate Model (Armacost & Wilson, 2002)

UCF's Enrollment Plan is based in projections of annual fundable FTE by level, residency, status, and campus. These projections are based on student demand; particularly in Florida Community/state College transfer students. This plan also makes assumptions in high school graduation and continuation rates, population growth projections, effects of the economy, and demographic changes in the Central Florida Region (UAPS U. A., 2011).

Rapid growth for UCF enrollment as well as improved retention of students requires a detailed and efficient university level enrollment prediction model. This model provides a means of estimating headcount (HC) and Student Credit Hours by student classification and semester. Based on Armacost's model, UCF developed a 5-year enrollment prediction model, as we can see in Figure 4.

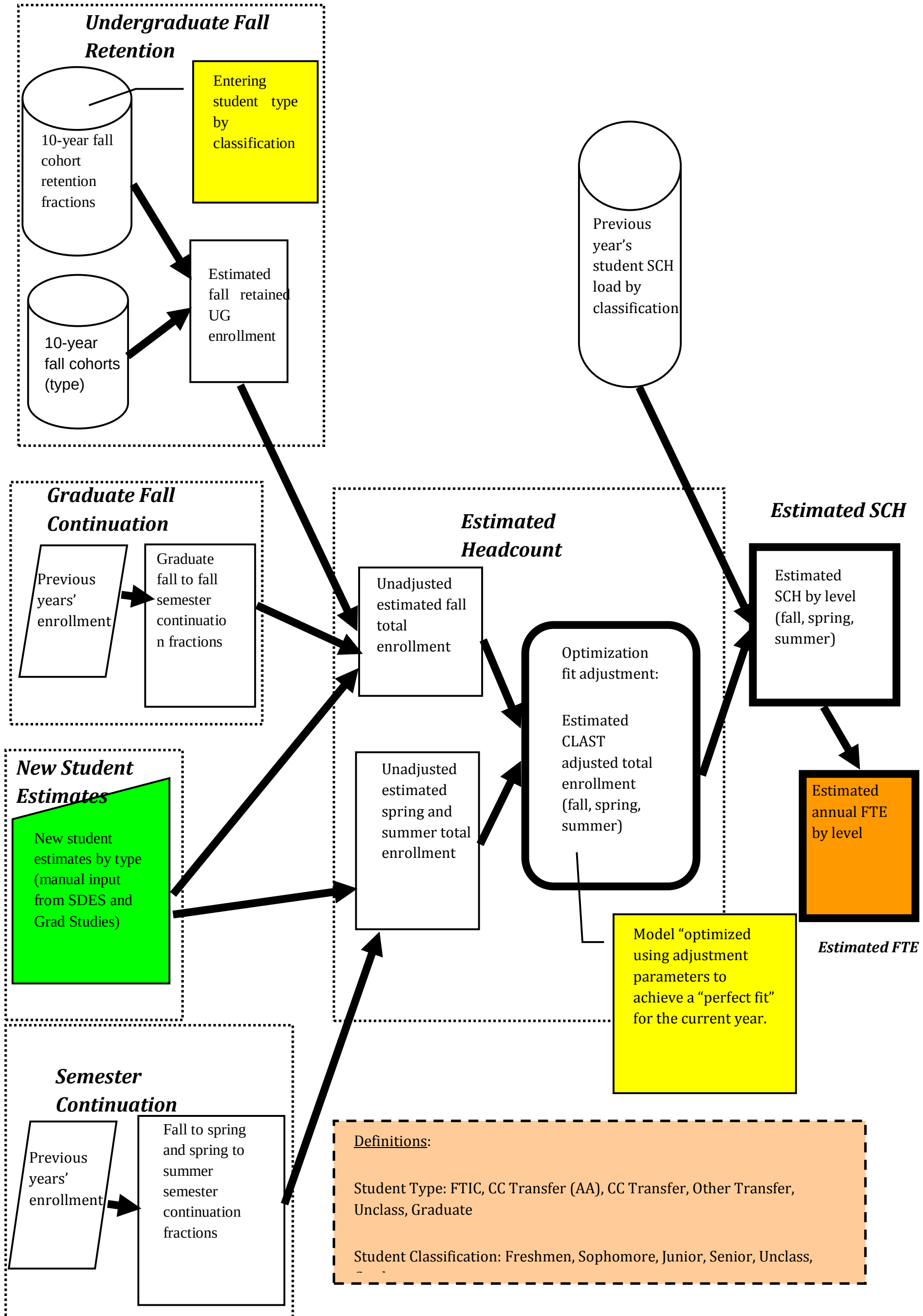

Figure 4, UCF detailed Enrollment Prediction Model (UAPS, 2012)

Regression analysis has been used to forecast enrollment as well. Choudhuri et al (2007) use regression to forecast enrollment for an upper division general education component to the program of the same name, at Grand Valley State University. Here, forecasting is aimed towards de determination of the magnitude by which students' demand exceeded the planned course capacity. Berger et al (2002) study another approach that considers the demand and supply of enrollment in public higher education. In this study, they estimate the enrollment and particularly the impact of this enrollment in financial resources using least–square optimization techniques.

Fuzzy Time Series is a well-known and popular forecasting technique. Tanuwijaya and Chen (2009) present a method that uses this series including a novel clustering technique. They base their research in a way of partitioning the enrollment sample data into different interval lengths with their clustering method, and then applying the traditional fuzzy time series in order to get a higher average forecasting rate (Tanuwijaya & Chen, 2009). Another method using Fuzzy Time Series is presented by Wong et al, where the partition method is flexible, introducing an adaptive model based on time, to improve accuracy. This model adapts itself to the size of the partition sample based on the accuracy of the prediction (Wong, Bai, & Chu, 2010). Garg et al present also an interesting approach of fuzzy Time Series considering a way of reduction of complexity in the data and an improved way to manage distributions by adding weights, maintaining consistency (Garg, Beg, Ansari, & Imran, 2011).

Data mining is also used for forecasting. The use of Support Vector Machines can be seen in Aksenova et al. Here the authors describe the use of Support Vector Machines (SVM) and Rule-Based prediction models into their paper "Enrollment Prediction through Data Mining." The difference with respect to traditional approaches is that the authors consider prediction of new (freshman and transfer), continued and returning students. Their model is built under an initial prediction model for the three input categories using SVM, and then they aggregate the predictive results to a Rule-Based predicting model (Aksenova, Zhang, & Lu, 2006).

Bayesian Networks is another data mining technique that has been used to predict student's accomplishment preferences, completion rates and enrollment (Yingkuachat, Kijsirikul, & Praneetpolgrang, 2006) (Hsia, Chen, & Shie, 2008) (Garcia, Amandi, Schiaffino, & Campo, 2007). This technique can be used for instance, to obtain the conditional probability of connecting nodes or as a classifier to obtain the probability distribution of a class node given previous attributes (Pumpuang et al, 2008).

Techniques that deal with students' enrollment and management may have different approaches but all of them coincide in dealing with the application of the best available processes and measures to obtain the best and most accurate information that relates to general enrollment, either coming from new students, returning students, or transfer students. What happens inside is the next step. For this, a general approach deals with student's retention as part of the enrollment management system.

Student retention affects budget, ranking, reputation, financial wellbeing, and student and alumni support for the university. This topic has become a big concern because of the reasons for students' attrition. Several data mining or machine learning techniques has been used to predict drop off, reaching an average of 80% accuracy (Dursun, 2010). The determination of predictors or alternatives for student retention has kept most of the researchers busy (Ho Yu, DiGangi, Jannasch-Pennell, & Kaprolet, 2010) (Hopkins D. S., 1979). They have even evaluated the trade-off between investing in a high-risk student and leaving the student on its own, especially if he has struggled for a while (Singell & Wadell, 2010).

Strategic Planning and Models

Strategic Planning

According to Webster's *New World Dictionary*, strategy is "the science of planning and directing large-scale military operations, of maneuvering forces into the most advantageous position prior to actual engagement with the enemy." (Guralnik, 1986) This term is not only applicable to military operations but to business as well. Strategic planning has been in use in organizations since the 1950s. Universities engaged in this concept as a way to "make beneficial, strategic changes… to adapt to the rapidly shifting environment." (Rowley, Lujuan, & Dolence, 1997) The results in universities, as reported by Lester, have been scarce since there are only a few successful results of dramatic transformations that would take an institution to a much better level.

In 2009, the University of Central Florida created its 2009-2014 strategic planning cycle based on the role the University has in the Central Florida City-State. This Plan includes university and community participants considering a new approached called “rolling wave” (Hitt, 2011) that would take into consideration the rapid growth, changes and uncertainty involved in higher education and university operations, as we can see in Figure 5.

This is a dynamic approach focused on strategic level, but crafted through operational and tactical plans that specifies key initiatives for mission accomplishment, growth and development.

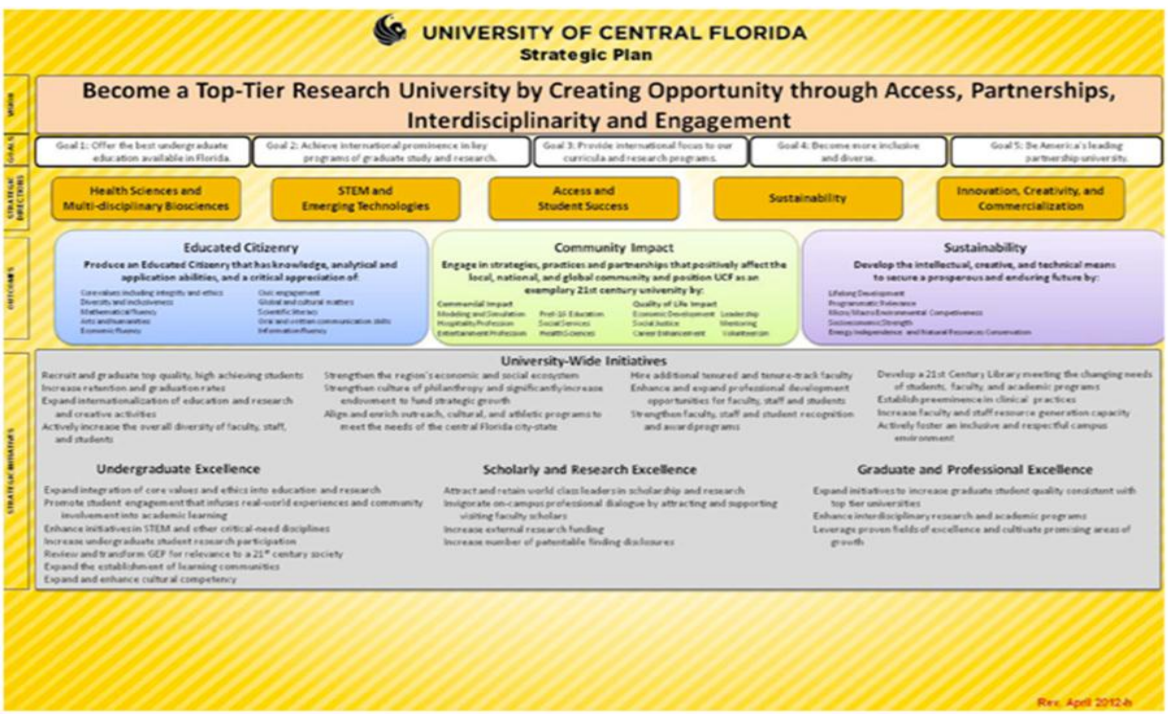

Figure 5, UCF Strategic Plan 2009-2014[1]

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[1] With permission from UCF, April 2012 (image at http://www.ucf.edu/strategic_planning/strategy_map.shtml)

Under this strategic plan, UCF established key elements: Mission, Vision, Values, Goals, and Challenges. All these elements conforms the factors that will lead the university to become the leading university of the state, and a nationally recognized research institution.

In order to fulfill its mission, UCF has established several procedures and policies being the most important the Institutional Effectiveness Assessment Process where each year, faculty and staff collects data, report results of the previous year assessment, and develop assessment for the upcoming year. The University Assessment Committee (UAC), the Divisional Review Committees (DRCs) and the Operational Excellence and Assessment Support (OEAS) work together to provide results and promote plans and measures. UCF has developed a list of peer institutions as well, that will provide benchmarking purposes. This peer list aligns with UCF's Strategic Plan, considering 14 "comparison" institutions and 8 "aspirational" institutions. This information, analysis and planning support is led by UAPS.

Strategic Planning obeys a variety of factors such as increasing demand for higher education (enrollment), decline in government funding, change in student demographics, and competitiveness by keeping up with the changing technology and social needs. Lerner describes this process in her paper "A Strategic Planning Primer for Higher Education" (Lerner, 1999), where she provides an overview of the strategic planning process, concepts, need, and dynamics of university-based strategic planning.

Decrease in government funding has reached higher education with the recession that began in late 2007. Its impact has deepened across the country and Florida continues planning in reducing the budget for next year with a cut of $217 million in college and university education and research (Padgett, 2011).

Increase in the demand according to population growth and the perception of people that a college degree is essential for their economic well-being, a change in demographics as more Latino and Asian integrate to higher education – a trend that will have a high impact in the coming years due to the continuous increment of this population- and a change in the way classes are given, switching from the traditional face to face instruction to a web-based distance learning environment are all factor that will certainly affect and increase the enrollment into higher education.

A traditional use of a model for university management is presented in a leading paper from Hopkins where he describes how to apply management science techniques to university planning through the use of models to assist in long-range planning, with the case study of the University of Stanford (Hopkins D. S., 1979). Here, the author utilizes three major variables: faculty tenure analysis, long-range financial planning, and trade-off analysis involving economic resources. It presents a 'Dynamic Budget Model" that shows the trade-offs for analysis and preference optimization that induce administrators to deviate attention from merely financial details to the academic consequences of their decisions.

How does Strategic Planning affect the organizations? Miller and Cardigan developed a contingency model that analyzes previous research in planning-performance. They studied 26 published studies and proved that not all apparently relevant literature have had a large impact and, what is more important, they proved that strategic planning do affect firm performance (Miller & Cardinal, 1994).

Public and private organizations shouldn't use the same resources in long-term planning. Bryson gives clear examples of the use of strategic planning in public and non-profit organizations by pointing out a couple of examples (Bryson, 1988).

Some efforts have been made in the use of Management Systems for Strategic Planning (Matsuo & Fujimoto, 2008). This approach considers a description of qualitative simulation-based university analysis by introducing a new perspective that divides large models (usually found in large and medium size institutions) into smaller compartments, allowing middle managers to understand strategic planning at their organization level. The use of causal modeling through a directed graph allows the authors to analyze complex situations and introduce qualitative simulation.

Strategic Models

Several models have been applied for strategic decision making as a way to assist top administrators focusing mainly in financial matters, including aspects such as faculty tenure analysis, long-range financial planning, trade-off analysis, etc. (Hopkins D. S., 1979).

Models have been used to provide direct information from numeric data and sources, and somehow to provide analytical reasoning to those not so evident problems. For this, statistical analysis has been the main way to obtain conclusions and provide forecasting (Hopkins D. S., 1979).

Strategic planning, considered a key topic in University management, was introduced in 1960's for analysts of the General Motors Corporation (USA) as a concept that integrated high level management functions and high level institutional planning, and as a way to obtain greater stakeholder returns (Sloan, 1990).

The use of strategic modeling in University Management is nothing new. In the United Kingdom, as mentioned by Buckland, educational organizations have displayed exceptional survival conditions from medieval times. They have adapted and changed their strategy constantly. UK universities have adopted those strategies from commercial and public sectors where they have attempted to focus in the outcomes that the model provides. These characteristics haven't avoided errors and weaknesses, most of them delivered by these imported models (Buckland, 2009).

Nowadays, universities employ models that include financial, operational, and investment issues among others. (Bryson, 1988) (Miller & Cardinal, 1994) (Anderson, Johnson, & Milligan, 1999). In a daily basis, Planning and Support departments provide data for decision-making authorities based on statistics and regression analysis. These data normally includes variables like enrollment, retention, course information, degrees awarded, student credit hours, admissions, graduation, etc. (Hopkins D. S., 1979).

There are some more complex techniques that have been adopted for strategic planning for universities. Simulation is present by the representation of numeric transactions and conclusions from these. Some few intents have been found as the model for Strategic Evaluation presented by Kutina, which considered the simulation of operations, finances, program investments, and market response through the use of System Dynamics (Kutina, Zullig, Starkman, & Tanski, 2002), or the analysis for business planning made by Lenzen where strategic forecasting and planning of the University's financial operations is approached. This analysis is able to estimate financial implications considering supply and demand (Lenzen, Benrimoj, & Kotic, 2010).

Complex Networks

Complexity has not been fully considered in the models in use for Strategic Decision Making for Universities. We argue that despite the validity of the data provided from analysis and planning support analysts, several factors remain excluded due to the impossibility of representing variables other than the regular ones that have being traditionally used in these models. Modeling efforts were restricted to the structural relationship of a small group of variables, leaving out aspects as the need to foresee the upcoming distance learning modality that will certainly affect strategic planning (Howel, Williams, & Lindsay, 2003), or the need to keep a course, a major, or a department for needs other than financial (Arts or Music), etc.

We think that complexity plays a very important role for strategic modeling. It provides a wider decision-making process that includes political or communal processes. The choice of a particular approach will depend not only in the type of decision being considered, but also in the stage of the decision (Lyons, Adjali, Collings, & Jensen, 2003).

Complex models can be represented through simulation techniques. We consider that this approach would allow us to capture the dynamics of a system, giving us the possibility of introducing weight to variables that are defined as more important, or just are needed to be represented in the model and not be left aside.

Some efforts have been made before with the use of networks in University management. These efforts have been restricted to budget allocation mainly, and in a hierarchical and non-dynamic structure. (Sinuany-Stern, 1984) The use of Complex Networks can be interpreted based of the knowledge of the human brain, as a collection of nerve cells connected by axons, or -based in some other versions of it- as a communication system with millions of users as nodes, or as a social network as part of a scientific collaboration system where its scientists are connected with others scientists.

Networks can be represented naturally as relationships between entities and groups or affiliations to which entities belong (Cloteaux, 2010), as the conformation of network routers and computers linked physically or by wireless communications, as the World Wide Web, or as the connection between cells exchanging chemical reactions (Réka Albert & Barabási, 2002).

Despite the importance that the scientific community has recognized in this new field, networks and its influence and complexity is practically new – only from 2010 this field has been included as a specific track in the Winter Simulation Conference, one of the main simulation conferences in the world.

But how these networks can help us to represent an enrollment model? How are we capable to see and visualize the dimensionality and effects of its connections or the weight of its components? The use of simulation becomes a key factor for analysis and representation. Simulation would allow, in a scientific way, to create a believable model of a complex system such as a network, and represent its dynamics and effects between and within existing nodes.

Simulation and Modeling

Simulation of enrollment, resource allocation and decision-making

The use of simulation methods for forecasting enrollment, resource allocation or any higher education topic, allows the introduction of "what if" scenarios. Simulation can represent complex systems where changes in variables are needed. State funding, financial aid, number of high school graduates, tuition increment, etc., are some of the parameters that affect the model and can be later modified in order to obtain future or unplanned scenarios.

The use of simulation for this kind of planning is less popular than we may think. Most of the work done relates to traditional approaches like mathematical or statistical techniques (Regression Analysis, Markov transition models, Neural Networks, Fuzzy Time Series, etc.). Most of them have not evolved much lately and references date back to the 70s and 80s.

The use of computerized simulation models allows planning and forecasting. As Baisuck shows, the ability to represent the dynamic manner how students' populations move into the educational system offers the analyst the advantage to experiment with variables and parameters, and quantify the impact of these variables in a controllable and uncontrollable change of policy (Baisuck & Wallace, 1970).

Planning models in higher education aim towards the need to provide efficiency in resource allocation. There are many ways to categorize these models. Schroeder considers four categories: a) models for student planning, b) faculty staffing models, c) optimization models, and d) resource allocation models (Schroeder, 1973). Bleau presents a good description and categorization of these models that follow Schroeder's work. In her research she develops a matrix that combines a series of classification methods and allows an in-depth analysis with regard to generalized resource allocation models (Bleau, 1981).

Among the most traditional simulation models we find: HELP/PLANTRAN, RRPM, CAMPUS, SEARCH, TRADES, and EFPM.

HELP/PLATRAN stands for Higher Education Long-range Planning system, and it was developed in early 1972 by the Midwest Research Institute of Kansas City. A very old system that deals originally with budget and allows "what if" questions.

RRPM stands for Resource Requirements Prediction Model, as a revised version of the Cost Estimation model developed by Weathersby in 1972. This model goes from enrollment projections to course demands and faculty requirements and costs (Bleau, 1981).

Peat, Marwick, Mitchell and Company developed SEARCH, System for Evaluating Alternative Resource Commitments in Higher Education in 1971. This system is highly aggregated, and its purpose was to provide management to small colleges and a way to examine the implications of alternatives (Bleau, 1981). This system doesn't allow obtaining much information in order to efficiently allocate assigned resources, as it doesn't have a cost breakdown by department or major (Schroeder, 1973).

CAMPUS, Computerized Analytical Methods for Planning University Systems was the first large simulation system able to analyze at all levels within an educational structure. It is more flexible and robust than SEARCH and RRPM. System Research Group made CAMPUS in 1970, and its operation is based on data from the University of Toronto (Hopkins D. , 1971). This model simulates the resources required over a five-year period for specific purposes such as enrollment prediction, student demand for courses, etc. (Bleau, 1981).

TRADES was first introduced in 1978 as a financial planning model implemented at Stanford University (Dickmeyer, Hopkins, & Massy, 1978). This model works from a macro university-wide simulation perspective and then it disaggregates into several forecasting sub-models allowing decision makers to alter initial variables and create new forecasts based on feasibility constraints in order to examine resulting Trade-Offs (that is why it is called TRADES). TRADES allowed policy makers to test changes to policy variables like tuition and faculty salary growth, in terms of the impact changes made had in certain constrains like balance between growth of revenue and expenses. TRADES had success at that time for three reasons: believability, controllability, and usability (Dickmeyer N. , 1983).

Finally, EFPM, EDUCOM Financial Planning Model comes as a simplified commercial off-the-shelf simulation model that allows interactive budgeting and financial planning based on the TRADES model. This version allows use in any size institution providing enough flexibility to be categorized as an institution-specific mathematical representation (Bleau, 1981). It simplifies forecasting and allows reducing costs, and is much cheaper too.

There is enough evidence that simulation models can improve management in most educational institutions. What has not yet been considered is how these models can enhance performance, help planning, and reduce costs at faculty level when input is dynamic, when students drop off, change majors or other factors as contingent preferences influence students' decisions when selecting majors.

Network science and network simulation

We should start based on the assumption that *traditional non-dynamic simulation models do not capture all interdisciplinary and complex variables needed to predict accurately*. Since faculty and department inside a university are related with each other the same way students choose their courses with no boundaries of faculty, department or professor, a student can choose a major in Industrial Engineering and a minor in Arts leaving all existing prediction models without response. For this, Network Science is needed, as we will see ahead.

Network Simulation has had a very rapid growth as researchers are developing new protocols and algorithms to represent complexity. As we know, networks involve different fields with different requirements and designs. For this reason, there have been investments in custom simulation (specifically constructed to represent a particular problem), test beds and small-scale evaluations. The use of specific programming code to represent complex networks either in test beds or labs in order to capture all the required details that a normal COTS simulation package may miss is expensive. Reconfiguration, sharing of data and flexibility are major issues when we refer to this way of representation.

When simulating complex networks, we must consider the best possible and more efficient experimentation tool. This election will be based on the scope of what is intended to reproduce, considering factors such as validation capacity of the software, a controlled environment that allows small and large-scale interaction, a way to compare results with other researchers, and an affordable infrastructure to support and make the research viable.

The simulation of complex networks is normally constrained to “space aware” processes. This means that most simulations are related to modeling entities in a physical space where these entities move and utilize resources. Social networks would require not only modeling the network topology, resources and processes itself, but a more complex and detailed relationship between the components of such networks and the relationships within.

Complex network simulation is crucial for studying and understanding the behavior of these networks. There are several simulation models and methodologies such as stochastic simulation, discrete event simulation, agent-based simulation, system dynamics, cellular automata, etc.

Stochastic modeling

A stochastic simulation can be interpreted as a representation of a process in a non-deterministic way, where its states are determined by some process's predictable action and random component.

Representation of multiple levels or states, and great interaction, as in biology where scientist are always looking for models that allow representation of physiological properties of cells, has led to the use of stochastic modeling, including several algorithms for simulating such chemical reactions. Gillespie's SSA is one of the most popular stochastic algorithms for simulation of chemical reactions. It is a population-based method where the state variables represent the population of species (Gillespie, 1976). For more complex representation, some other algorithms have been used like *Particle-based modeling*, and *Rule-based modeling*. Combination for this and other methods may increase efficiency and get more accurate results as described in Liu et al (Liu et al, 2010).

Discrete Event Simulation

Modeling complex systems in asynchronous occurrences of discrete events has introduced the concept of discrete simulation. This modeling technique is based on a series of fixed events over time, as a sequence, leading to a change in the system's behavior and structure. This approach is used mostly for systems such as air traffic control, automated manufacturing, computer and communications, embedded and network systems, and software systems. Garson makes a very good description of how discrete simulation and queuing theory for one hand, and neural networks using models that are based on artificial intelligence and cognitive science on the other, have helped the development of social sciences and network representation (Garson, 2009)(Bagdasaryan, 2010).

Representation and analysis of complex systems, the use of interactive agents, and the incorporation of simulation tools for this analysis are shown by Porter in a very interesting study about committees in the U.S. House of Representatives (Porter, Mucha, Newman, & Warmbrand, 2005). This research focused on the networks formed in the committees and subcommittees of the House of Representatives connected according to "interlocks" or common membership, as well as hierarchical structure within the House. This research is a real representation of network theory with stochastic simulation. An analysis of roll-call votes using singular value decomposition was made, and that successfully discovered political and organizational correlations within the House without the need to incorporate external political information.

Agent Based Simulation

We should start defining that an agent-based model (ABM) is a simulation or computational model where the representation of the entities actions and interactions are modeled as autonomous individuals, known as agents. These agents can have many capabilities: they can be programmed to make decisions, to gather data, to adapt to the environment, etc. In Social Sciences, this approach has had very good results since sociologists understand social life as a system of institutions and norms that shape individual behavior (Ang & Zaphiris, 2009) (Klügl, Bazzan, & Ossowski, 2005). Figure 6 shows an Agent-Based representation of consumers' demand in a Market's Dynamics and corresponding Supply Chain reaction.

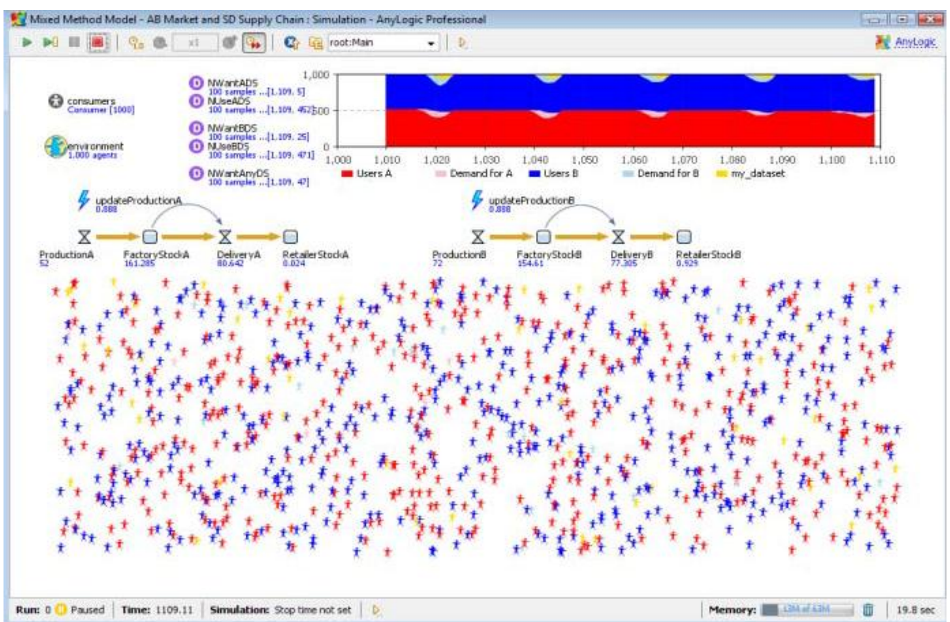


Figure 6, Anylogic agent-based/system dynamics model (Anylogic, 2012)

Agent-based modeling focuses on behaviors of its components, so called agents, as part of a whole system, and the dynamic interactions that occurs between them. Each agent interacts with other agents, and adapts to the environment and processes according to states and rules so they can move from one state to another, allowing them to evolve and make decisions.

Complexity and scale of last decade's systems has led to much larger and complex simulation, therefore a harder way to test and evaluate. ABM has become a key factor in this type of simulation since complexity has increased heavily but simulation tools and techniques have not scaled at the same rate.

The increasing use of ABM has benefited greatly with the great amount and variety of simulation languages and systems such as SWARM, RePast, Ascape, NetLogo, and Mason (Garson, 2009). ABM has reached several fields based on its capacity to adapt(Niazi & Hussain, 2009), factor that will continue making the difference between this and the remaining techniques we have covered throughout this research.

System Dynamics

This high-level simulation approach focuses on the dynamics, as its name states, of the system, its representation, interactions between components, and the behavior between the actors within the system (B. Hu et al., 2007). System Dynamics simulates processes that change over time, and is represented as a series of variables connected by arrows, including feedback loops, where the factors of influence of these variables with each other are represented with a defined direction of the corresponding arrow. It allows building relations between the elements.

System Dynamics comes from the 1950s as an innovative simulation for the social sciences (Forrester, 1958). This approach has had many applications such as industrial and urban policy, economic growth, counter-insurgency and terrorism network representation, etc. Today's System Dynamics continue to evolve. New models include agent based modeling as a hybrid approach, known as "agent dynamics", some incorporation of 3D enhancement, techniques, etc.

Cellular automata

A model made of certain number of individual cells, at a discrete space and time, where complex computations are made, based, or viewed as a finite state machine. Local interaction between components (Bagdasaryan, 2010) is a restriction for communication between its components. Individual cells are affected by their neighbors as their present states may change over time. This model can be seen as a special case of agent-based simulation since each cell can be seen as an agent that is affected by other agents.

Word of Mouth and dissemination of information is categorized as a pervasive and intriguing phenomenon as it relates to the process of personal communications (Albert & Barabasi, Statistical Mechanics of Complex Networks, 2002). Goldenber, in his research, uses a Cellular Automata technique in order to generate data and analyze the results (Goldenberg, Libai, & Muller, 2001). This research digs into the influence of personal communications considering weak ties and strong ties in the network, their parameters and effects, external marketing efforts, and network size.

Multi-agent Simulation

Multi-agent Simulation (MAS) or also known as Multi-Agent Based Simulation embraces simulation by considering several dimensions like pro-activeness, communication language spatial explicitness, mobility, adaptability, and modeling concepts, as we can see in Davidson's model (Davidson, 2001). Examples of Agent-Based models are presented in Gilbert's paper: "Agent-based Social Simulation: dealing with complexity" (Gilbert, 2005), where several dimensions are presented, along with descriptive references for these simulations.

Modeling the Social World through MAS is complicated. It requires strategies and understanding of the phenomena. Objects may represent individuals, organizations, as well as unanimated objects.

Another good example of MAS is presented by Gilbert (Gilbert, 2005), when introducing a theory of innovation networks, or a network of new ideas through the representation of actors (firms engaged in R & D), kenes (that represent the collection of technical capabilities in different technological fields, and measured in nominal values of the actors), innovation hypotheses (represent a new knowledge or discovery), a research strategy (aiming at modifying and improving the actor's kenes and assign rewards over certain thresholds), all of these based in a certain amount of actor's capital stocks that are being used when doing R&D, and being replenish when successful innovation is obtained.

MAS has been useful in disciplines such as virus disease spreading or epidemics, infectious disease transmissions, etc. A good approach is presented by Corley et al, by presenting a Dynamic Social network of intimate contact (DynSNIC) of sexually transmitted diseases and infections, based on a computer simulation that created this intimate dynamic. The results would allow health professionals to facilitate evaluation of targeted intervention strategies and public health policies.

Detecting changes in specific points of time as well as changes in the structure of the network can be obtained through the use of Discrete Event Social Simulation. This technique is used by Alt (Alt & Lieberman, 2010) in "Representing dynamic social networks in Discrete Event Social Simulation." In this study, a conceptual model of society is constructed, where population is seen as individuals and groups of individuals. The network then is represented as a collection of individual members or population segments. Parameters are represented by socio-demographic, socio-economic, and socio-cultural dimensions required to form the networks (Rodic & Engelbrecht, 2008), and weight for nodes and links, being the later a state variable that dimensions the weight between each agent and all other agents within society (Alt et al, 2010).

Promising research is also reaching some unexpected fields like Social Networks in Multi-robot Environments, presented by Rodic (Rodic & Engelbrecht, 2008). In this research, the authors obtain a novel approach for coordinating multi-agents teams, particularly multi-robots teams, based in social networks sociology models.

Other management approaches

Balance Scorecard

Management in universities can be improved through the use of performance measurement tools. Among them the adoption of Balance Scorecard has become popular. This concept of performance links different functional areas in both financial and non-financial areas, allowing institutions to continuously improve programs, support budgets, and align with strategic planning and development of such institutions (Akkermans & van Oorshot, 2005) (Philbin, 2011).

This approach was first introduced by Kaplan and Norton (1992) with a new way to measure business performance according to mission and strategy. These units of performance are grouped into four main areas (McDevitt, Giapponi, & Solomon, 2008):

- Financial;
- Internal business processes;
- Customer; and
- Innovation and learning.

In higher education there are several successful cases of good implementation of Balance Scorecard. Two educational institutions are analyzed by Beard (2009): The

University of Wisconsin and the Kenneth W. Monfort College of Business, both recognized by the Malcolm Baldridge National Quality Award in Education (Beard, 2009). This recognition is given to organizations that have been recognized as role-model organizations. Their best practices are then disseminated as well.

Data Envelope Analysis

Data Envelopment Analysis has been widely used in Decision Making as a performance measurement tool. This approach first introduced in 1978 (Charnes, Cooper, & Rhodes, 1978), and is used to measure the efficiency of homogeneous groups of decision-making units (DMU). This DMU are defined as the entities responsible in converting input into output, where the performance of the process is going to be evaluated. The main characteristic of DEA is the ability to measure the efficiency of multiple inputs and outputs with no previous weight assigned to them (Kuah & Wong, 2011).

DEA has been used to evaluate the performance of academic institutions and departments as well (Johnes & Johnes, Research Funding and Performance in U.K. University Departments of Economics: A Frontier Analysis, 1995) (Beasley, 1995) (Stern, Mehrez, & Barboy, 1994) (Johnes J. , Measuring Teaching Efficiency in Higher Education: An Application of Data Envelopment Analysis to Economics Graduates from U.K. Universities, 2006) (Bougnol & Dula, 2006).

Gaps identified in the literature

University Enrollment Models have been developed and used in traditional ways, excluding extensive use of simulation techniques. For this reason:

- The models are not able to handle high levels of complexity.
- Current models reflect a low level of detail, with the impossibility of capturing incremental or local changes. A simulation model allows handling these changes faster, avoiding re-creations of the model.

Current university enrollment models are focused on high levels of abstraction. There are no models found in the literature that shows how departments are affected by enrollment increment or decrement, specifically when dealing with how students once enrolled, declare or change their major, affecting with this lack of certainty how faculty and department do their planning.

The enrollment models found in the literature do not reflect the structure of the real systems. There is a need for visual models and languages to communicate its structure to decision makers.

Current enrollment models do not consider specific value measures for entities. Current models do not allow tracking entities through the system and add measurements and statistical analysis at particular times.

Current models do not allow animation and visualization of system behavior. Verification and debugging is a major advantage of simulation techniques.

Current models have dealt only with specific levels of abstractions. No interaction or complementation between these levels has been found. A Hybrid Network-based model that includes both high and low level of abstraction through simulation would provide the advantage of representing a more descriptive model, and the different weights and influence components of the system play in the simulation.

CHAPTER THREE: SIMULATION METHODOLOGY

Introduction

In this chapter, we will follow a general methodology for conducting a dynamic enrollment simulation study along with all requirements to conduct such study. It is conceptualized from two perspectives: a high level approach that replicates the current university enrollment model, its performance and scope, and a low level approach that enhances the high level model to a greater level of detail for the IE Department, and will address enrollment problems that until now has not been addressed.

Furthermore, this chapter follows a new Simulation Methodology approach designed specifically for hybrid simulation based on Balci's (1990) and Law's (2003) methodologies. The simulation problems to be solved are analyzed from a perspective of the entire Simulation Life Cycle and, as part of the simulation study being held. It contains processes, phases, and an integration methodology. This model is enhanced through the inclusion of different abstractions levels, different simulation paradigms, and a hybrid approach that will merge System Dynamics for a high-level simulation, and Discrete-Event and Agent-based simulation for low level simulation, over a network framework that will allow interaction, level-headedness, and fidelity for the model.

Methodology and Models

Balci's models (1990) provides a guideline for conducting a simulation study that despite being designed and presented more than two decades ago, represents an excellent approach due to its step by step and specificity to the problem through means of simulation techniques (Figure 7).

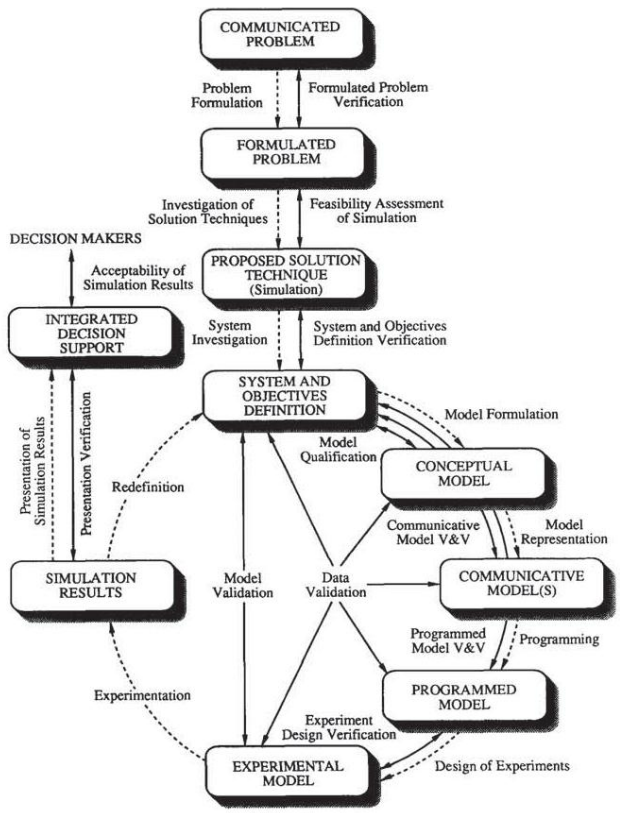


Figure 7, The Life Cycle of a Simulation Study (Balci, 1990)

Balci's definition of the life cycle of a simulation study ends up with a more detailed analysis of the hierarchy of credibility assessment stages for evaluating the acceptability of a simulation result, considering for this 10 processes, 10 phases, and 13 credibility assessments stages.

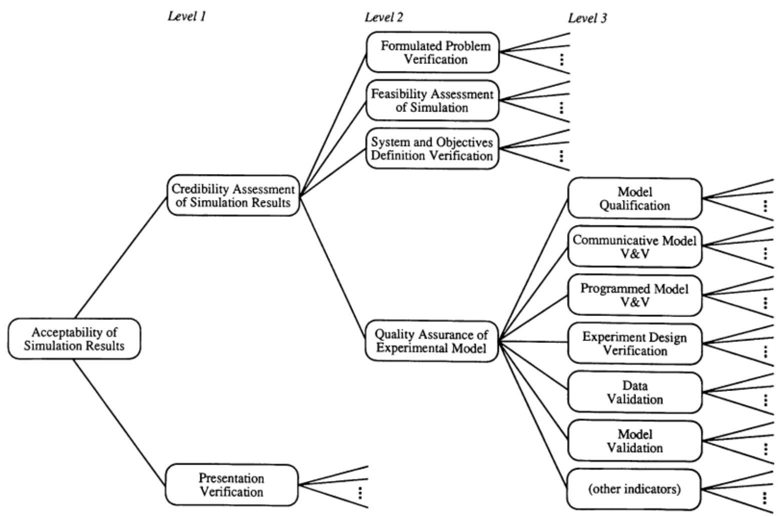


Figure 8, Hierarchy of credibility assessment stages for evaluating the acceptability of simulation results (Balci, 1990)

Another approach on design of simulation studies is presented by Law, based upon a seven step approach and more basic methodology that centers in problem formulation, data collection and analysis, programming, and design of experiments (Law, 2003)(Figure 9).

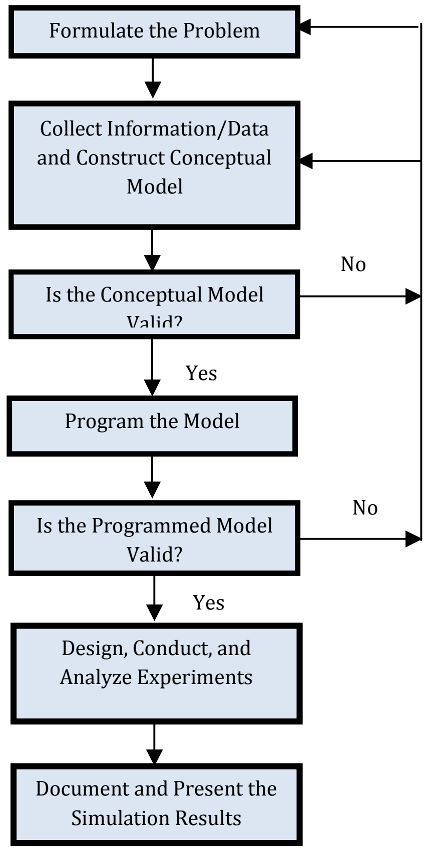


Figure 9, A seven step approach of a simulation study (Law, 2003)

Simulation Methodology

The methodology considers an ad-hoc approach made from the integration of Baldic's and Law's models, and an additional step through the enhancement of the simulation process by including –via network modeling- the interaction of several processes that relate to each other, not previously considered, and including a multi-paradigm approach to this research.

As this model enhancement includes system dynamics, discrete-event, and object-oriented (agent based) simulation, we start by defining the abstraction levels for this simulation model, as we see in figure 10.

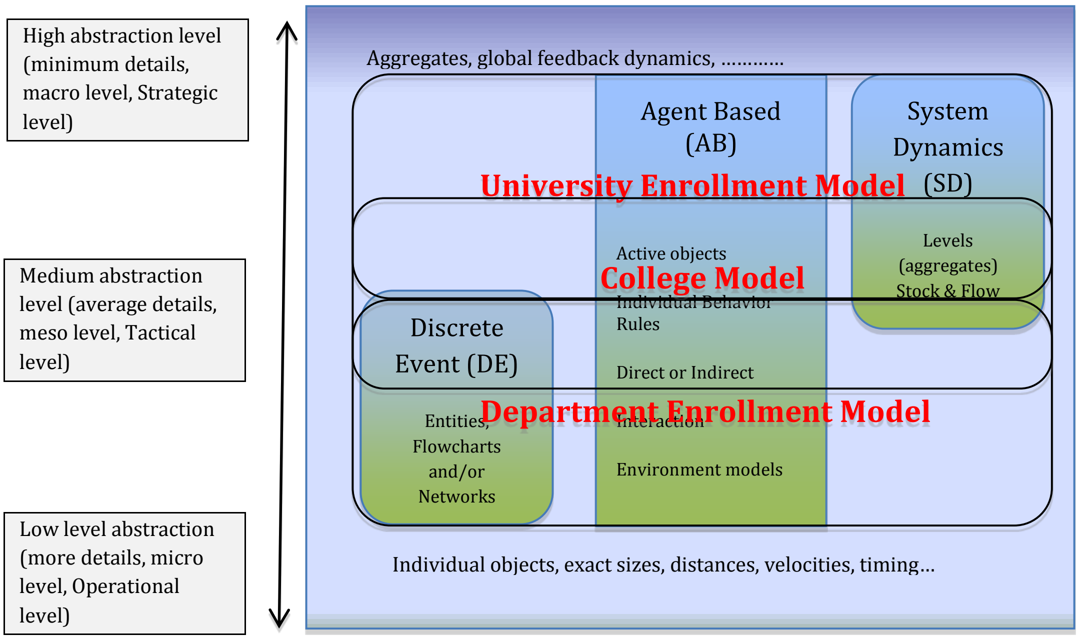


Figure 10, Simulation's levels of abstraction (Anylogic®, 2012)

The high level model represents, through System Dynamics, the overall enrollment process of UCF. This level includes modeling all incoming students, their transition through the university, and also the attrition and graduation at a general perspective. The low level model, through the use of Discrete-Event and an Agent-based approach, represents the transition from students that have declared a major in Industrial Engineering at the beginning of their studies, and those who haven't. It considers also all incoming students from other sources that haven't declared IE major, but are attending courses in the IE Department.

In Figure 11, we represent a Multi-Paradigm Simulation Methodology in order to conduct the Research Simulation Study for the UCF's Enrollment Process at the aforementioned levels.

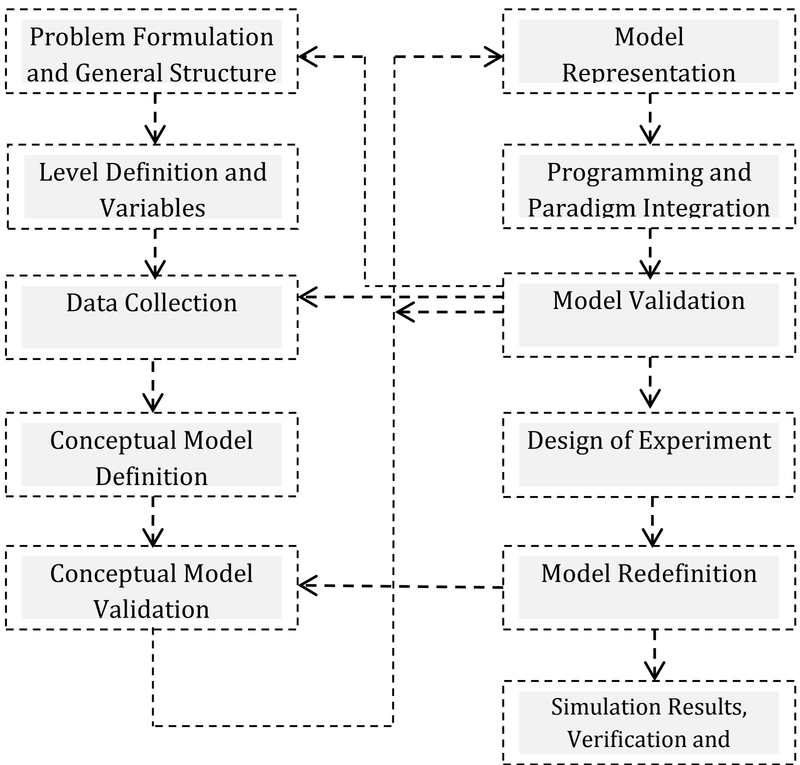


Figure 11, Multi-paradigm Simulation Methodology for Dynamic University Enrollment Process

For this simulation we considered the use of the Anylogic® platform as it allows a multi-paradigm approach within the same platform. By this, we take advantage of translating the real world problem that has no visible and physical levels, to the desired levels of abstraction by the use of the chosen modeling language.

Problem Formulation and Multi Paradigm Interaction

The structure and behavior of the enrollment process is explored by the analysis of the existing process (original system). For this, we have to consider that this simulation model must represent the enrollment process for the University and for the Department of Industrial Engineering as well, considering that both sub-models should link and feed each other in a network-based structure, including metrics and variables not considered so far.

The general structure of the model has two general levels: a high simulation level that represents the overall enrollment process, and a low simulation level that goes into the details of the enrollment process of the Industrial Engineering Department.

The high level and low level simulation - System Dynamics, Discrete-Event and Agent-based simulation models - should be connected through several points of interactions. The use of properties and conditions that each agent should follow will reflect these interactions. Agents will make decisions based on preference, demand or availability of given classes for instance, or may choose to keep or change its major. Since the high level SD model will follow strategic or general parameters (# of FTIC, CCT, STA requirement for enrollment, # of f2f, mixed mode or DL, etc.) included to form a cohort, the evolution of these cohorts through time is given by the sum of decisions each agent make.

The creation of a cohort defined and modeled in System Dynamics will follow a flow showing transitions from one year to another (freshman, sophomore, junior, and senior). The actions of an agent, in this case a student, will start from the condition that it belongs to a certain IE cohort. If the agent chooses to join a class, considering that the class is open, a requirement is defined as this agent decides to join the class, according to the demand (variability component) or preferences. The same is required for more than one agent, and the limitation is given by the size of the cohort. By the same way, if the student fails or withdraw from a class, or leaves IE, its decisions will be reflected in the cohort being diminished.

When the student's behavior is modified by either restrictions given in class conformation (size, location, frequency, etc.), or preferences (choosing new interesting classes, avoiding hard ones, etc.), the result is that the transition of a cohort from one state to the other (freshman to sophomore) is altered.

These points of interaction between SD, DE and AB will be implemented throughout the model, allowing constant update and monitoring of the amount of students in each cohort and its resulting outcomes (student's graduation rate, drop off, etc.).

The interaction between agents can be represented in many ways. In our case, relationships between agents are more or less persistent, as an agent needs to remember other agents. This is the case for colleagues, classmates, or students that belong to a major, keeping their preferences stored in variables or collections, or set up manually via agent API and/or automatically in the environment. Connections are always bi-directional: If Student A has Professor α in his list then Professor α will have Student A too.

System Definition

UCF, as a large metropolitan university, needs an enrollment model that allows optimal resource allocation at different levels. Predicting enrollment until now has been a process that considered a high level and general approach, excluding low level definition that would be useful for College and Department planning.

The enrollment process starts with the selection of students from the moment prospective students register for the first time (FTIC) and then join the undergraduate programs. By the same token, CCT (Community College transfers) students join the enrollment process when they transfer from their respective Junior Colleges, joining the third year (5^{th} semester) without an application process (part of the Consortium agreement). Other Students are classified also in the enrollment process. This classification considers all students not included in the previous two methods.

Students transition from term to term, they drop out, change majors, or they graduate. This general process is assumed to have no change during the course of the simulation study. The environmental characteristics as part of a complex system that involves two main levels will be analyzed as many variables, activities or events may take place simultaneously and may influence each other.

The enrollment system is then decomposed in two levels and a common platform. These two levels, as mentioned before are a high level for the representation of a general enrollment process for the university, and a low level for the representation of factors that influence the enrollment process at a faculty and Department level.

Level Definition and Variables

Two levels are needed to represent the overall enrollment process of this research. These levels have the following characteristics:

- High level Simulation
    - High-level detail, replication of current enrollment model adding new metrics at a macro and strategic level
    - Use of System Dynamics to replicate the current enrollment model
    - Represented by a general SD cohort-based model at University level, and a mid-level cohort-based CECS students filtrated model at College level
    - The model should predict the number of enrolled students for a 5 year span by student level (lower-level, upper-level, graduate)
    - The model should predict attrition and retention of enrolled students for a 5 year span by student level (lower-level, upper-level, graduate)
- Low level Simulation
    - Maximum details, representation of a new enrollment model at a department level
    - Use of Discrete-Event modeling for course assignment and student's major selection
    - Use of Agent-based modeling in order to represent students at different levels in their major selection process
    - Agents in the model are represented by entities that transit from one state to another following specific transition rules. Students' states include academic level (Freshman, Sophomore, Junior, Senior, with a declared or undeclared major, and possible transitions to drop-out or new major state). Agents work in an environment that account for availability of faculty, classrooms, and laboratories

- The model should predict faculty workload and faculty/student ratio based on the number of students for 5 years span by student level (lower-level, upper-level, graduate) to remain in the IE major
- This level should provide a tool for planning courses, use of facilities (classrooms, labs), and planning for faculty needed

Variables considered for the simulation are:

- High level simulation:
  - Student's unique random code IDs (for tracking purposes and based on EMPLID)
  - Student headcount by type (FTIC, AA/AS Transfer, CCT without degree, Consortium Partner Transfer)
  - Student headcount by classification (In-state, Out-of-state)
  - Enrollment desired quota for long-term strategic planning, and short-term operational number of FTIC students that have declared a major
  - Number of students with IE major
  - Number of students that changed majors to or from IE.
  - Number of non-declared major students
  - Ratio of CCT/FTIC students

- Low level Simulation
  - Student's unique random code IDs (for tracking purposes and based on EMPLID)
  - Student headcount by type (FTIC, AA/AS Transfer, CCT without degree, Consortium Partner Transfer)
  - Student academic level (Freshman, Sophomore, Junior, Senior)
  - Number of FTIC students that have declared a major
  - Number of students with IE major
  - Number of students that changed majors to or from IE
  - Number of CCT students that have and have not declared a major

Measures of performance:

- Retention: High level (overall measure), and low level (within the IE Department)
- Growth rate
- Student/faculty ratio
- Faculty academic workload
- Break-even points for classroom size and student population

Data Collection Plan for High and Low level Enrollment Scenarios

The Institutional Knowledge Management and University Analysis Planning Support office from UCF provided most of the data. Data includes a coded sample (excluding Students' IDs) of all students enrolled for the last ten years. All this information was obtained through the Student Information files, the Students Data Course Files, and the Enrollment Facts Files through UAPS, IRIS and UCF's Pegasus Mine Information Portal. This data has a direct relationship with the Operational Reports for short-term operational guidance, and Strategic Reports, both released by UAPS.

In general terms, the data considered for this research includes three major areas: Admission, Retention, and Graduation.

Enrollment information considers previous and current term enrollment data for multiple categories. Some of these categories may be given by College, Plan, Sub-plan, Gender, Ethnicity, Career, Residency, Full/Part Time, Classification, etc.

The main data sources come from the Undergraduate Retention Tables administered by the Institutional Knowledge Management (IKM) Office. These tables are continuously updated and they classify the information for Cohorts from year 2000 until 2011, per student, with more than 156,000 headcount. Fields included in the table provides all necessary information to deduct, filter, and query the required variables considered in this research. Information such as COHORT_YEAR, EMPLID, STU_TYPE, ACAD_GROUP, ACAD_PLAN, and Retention for 9 consecutive years among many others, are self-explanatory and provide the source of the information needed for the study.

Collected data grouped by cohort refers to the number of students that entered the University on a given year. Initially we start the data collection by obtaining information per cohort per year, and finally all these cohorts are summed up to obtain the actual headcount. For our research, we need to get deeper in order to follow the student's trajectory and when and where he decided to follow a specific major (IE in this case).

Student's records for retention can be obtained from the data. This information will help in tracking students, form different cohorts, from different academic plans and majors, through time. Trends and distribution functions will be derived from them.

Data available for the low-level simulation model allows retrieving fields like major declaration and a follow up of the students through the years. Additionally to this kind of data, it will be required to define certain classes given by the IE department in order to see later on, how many students register for each of them. Consideration should be given also to students outside the program who join as well.

Some data was also provided by Undergraduate and Graduate Admission Department concerning prospective students, registered students, and admitted students for FTIC and CCT (consortium and non-consortium students), and some provided directly from the IE department concerning the corroboration in major declarations and changes, as well as class schedule and load, etc.

Collected data will be able to provide the source to obtain the probability distribution (PD) of the selected parameters. This PD will play a key role in the construction of the model.

Fitting a Probability Distribution to the data will be covered through three consecutive steps (Biller & Gunes, 2010):

- Selection of one or more candidate probability distribution. Although the physical characteristics of the data may provide a good basis for finding candidate distributions, if this is not possible an empirical distribution would have to be considered.
- Determination of the values for the input model parameters. Once the distribution is chosen, some of the most common methods will be used to determine the adequate parameters (maximum likelihood, matching moments, matching percentiles, least-squares estimation methods, etc.)
- Checking the selected distribution's goodness of fit through tests and graphical analysis. The use of tests likes Kolmogorov-Smirnov, Anderson-Darling, plots like density histograms and probabilities, etc.

Conceptual Model Definition, Validation, and Representation

The first stage of the structure corresponds to the High Level University Enrollment Prediction Model. The high-level enrollment model provides a general students' retention flow considering FTIC, CCT, and Other Transfers. FTIC students can be grouped as major declared or non-declared. CCT students have to declare a major when they enroll. The same situation occurs for Other Transfers. A student can be considered non-declared for the first two years, after that, a classification must be made. If a student has declared a major, he can change any time by just filling out an application, and as many times as he wants, as long as he complies with the University guide lines for graduation. The study does not consider restricted majors, or those majors that require a special application process like Medicine.

Another classification we find is “pending”. This classification applies to all declared majors that have not complied with a specific major's requirements. For instance, if a student is an Industrial Engineering (IE) major declared but has not approved statistics, he will be classified as pending until he passes the class. Figure 12 shows the high-level simulation methodology and cohort conformation for this study.

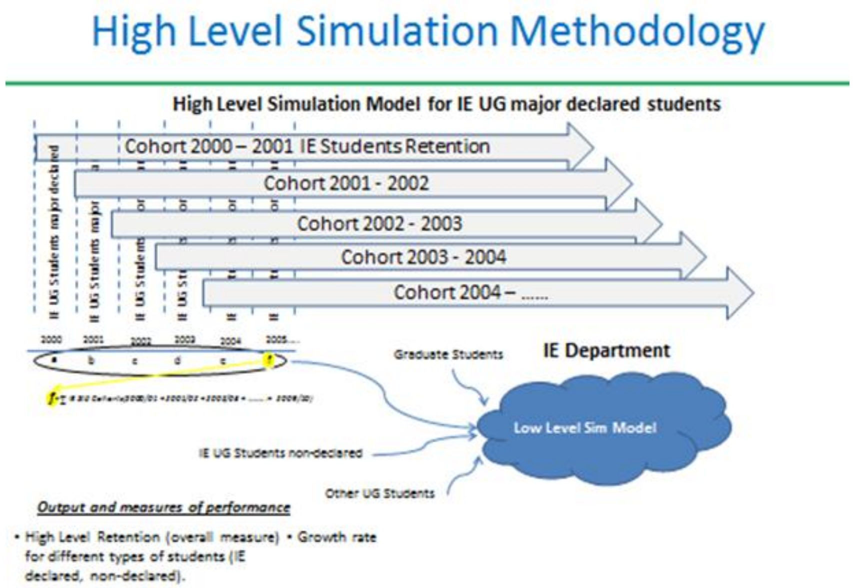


Figure 12, High-level Simulation Methodology and Cohort conformation

For a low level modeling process, all students, FTIC, CCT, and Others, that belong to a certain cohort, are then analyzed from the IE Department's perspective. It is this department that is in charge of managing IE student population, faculty, and all necessary resources to fulfill its mission. The IE department should be able to assign students to the courses that the department already planned and approved for the current term. Professors should be available and classrooms or labs as well, as we can see in Figure 13.

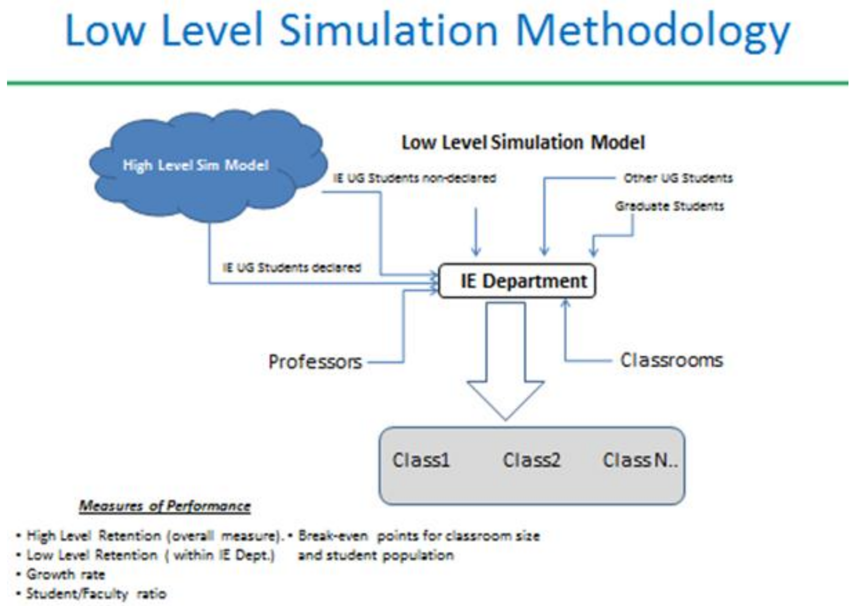


Figure 13, Low-level Simulation Methodology

Programming and Paradigm Integration

Anylogic® will provide the programming environment for both level of abstraction. The structure of the simulation should reflect the structure of the real system. This means that the enrollment process even it is not evident, will be analyzed by components, and values measured and tracked for any given entity.

SD programing is based on Stocks and Flows, Arrays, table functions, Delays, and other specific functions. For our simulation purpose, we integrate SD, DE and Agent-based modeling by supporting the interaction of these stocks and flows' structures with events, state charts, process flowcharts, and agent populations.

Our high level representation is made from a starting flow of student population, FTIC in this case, where its data may come from either a set of historical data or a PDF. This flow is linked to the first stock represented by "Freshman", or first year student population. Stocks, flows, parameters, and variables are linked and polarity is added to show influence. We consider this enrollment level as an open system where 1st year students transition to the second year with a predicted passing rate (FreshmanPassRate), and some other optional influencing variables like SAT score for FTIC, as shown in Figure 14.

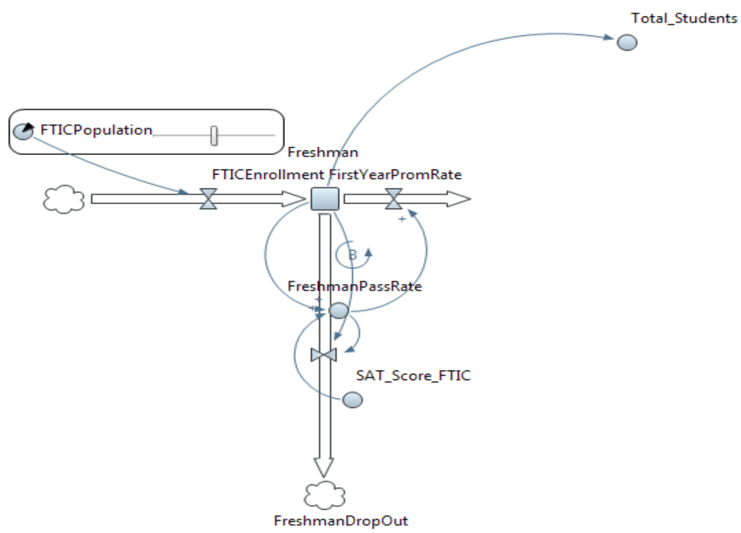


Figure 14, SD stocks, flows and loops for initial stage simulation

Shadowing has also been applied to the model as a way to simplify its view. Stocks from the initial model are replicated for the college level in order to introduce an intermediate level that would capture the College of Engineering students. This shadowing process allow us to use the same stocks, flows or variables from the initial level in other level so we can divide the work in multiple views but with homogeneous results.

Our lower level is linked to the higher ones based on state charts so we can visually define event and time driven behavior of our agents. Agents in our model will behave as entities (students), with processes within (triggering decisions of keeping or changing their major for instance), as seen in Figure 15.

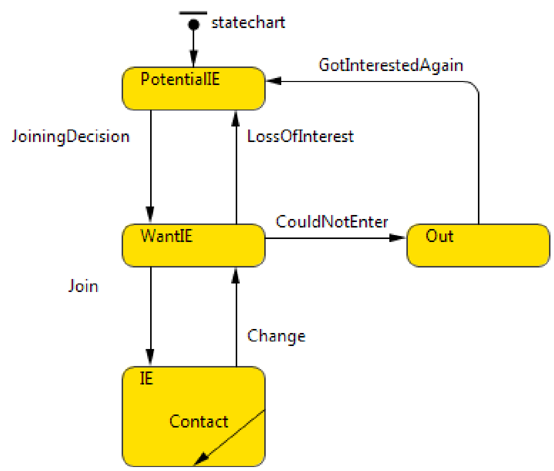


Figure 15, State chart for agent decision-making in major selection

This multi-method model takes advantage of different viewpoints merged into the same application, instead of modeling all different levels separately avoiding with this capturing the dynamics of the system and the behavior of the participating entities as a whole.

Model Validation

The model was presented to subject matter experts and departments involved in the enrollment process in order to obtain an accurate representation.

We initially used cohorts 2000 and 2004 to build the model; cohorts 2002 and 2007 are used for validation purposes as well. All results are compared to the existing Markov model UCF uses, as well as the data and statistics that are a result of the data management for the last decade. All information was requested to Institutional Knowledge Management (IKM), and UAPS, following CITI and IRB protocol.

Design of Experiment

In this stage, the process of formulating a plan to gather the information needed at minimal cost and enabling us to obtain valid inferences is shown.

The design considers two full cohorts of Engineering Students. Selection of students is random-based. This should include general enrollment information, as well as IEMS major declared. These data includes a sample for Cohort 2000-01, Cohort 2004-05, and Cohort 2008-09, but the experiment itself will consider cohorts from 2000 through 2010. All IE students are followed through the years in order to obtain a general and representative trend of students passing rate, attrition and retention, as well as major selection in IE.

Special consideration is given to the data required for the low level model. The need to forecast allocation resources requires knowing all students enrolled in certain and selected courses (for simulation purposes). This means that data considers also students outside the IE program, or the CECS, and even includes students from interdisciplinary studies, and other programs.

As we have been able to see, this simulation have multiple factors, therefore we want to get an initial estimation of how each factor affects the response. We may also be able to determine if the factors interact with each other.

Model Redefinition

The experimental model is updated in order to represent resulting changes from the previous simulation stage. Here, variables can be modified or removed, producing different set of results in order to study alternative solutions or improve performance.

Simulation Results, Verification, and Validation

Results, Verification, and validation with the already redefined model, are done in two phases: against the current Markov chain model UAPS utilizes for its university prediction, and against real time enrollment IE Department deals with (Sargent, 2011).

As mentioned before, the model was presented to all responsible departments involved in the enrollment process. The same two cohorts used in model validation (2002 and 2007), will be used for final verification and validation.

CHAPTER FOUR: MODELING HYPOTHESIS

Introduction

The modeling characteristic of the enrollment system in use at University of Central Florida is based on a flow of students through different terms. These students originate from different sources, their transition regulate retention and attrition, and the outcome provides an average number of students predicted to remain or leave the university in the coming years considering an adjustment factor as a tune up process.

The implementation of a new "Simulation-based" model requires taking the dynamically complex structure of the enrollment process, and representing it in different levels of abstraction and detail. As we wanted to consider a "whole system view", a key strength is provided by the SD approach, combining this with DE and ABM for lower levels of detail modeling that would provide details.

The hybrid model is developed in Anylogic ®, and it considers all simulation paradigms, considering the student population flow for the last decade as a representation of any typical university enrollment process that includes FTIC, CCT, and other students.

Systems approach

Assumptions

At this stage, the use of Subject Matter Experts (SME) is required. Meeting with SME is considered throughout the research. Specific questions need to be answered in order to reach the sufficient level of detail, and the performance measures to be used according to the level of detail and scope (Law, 2003).

Assumptions for Modeling Scenarios are part of the Conceptual Model as well. These assumptions were discussed with SME as part of the Conceptual Model Validation Process, considering that the model should be a simplification or abstraction of the real system, with enough and sufficient detail to fulfill the objective of the research. Among these assumptions we find:

- Simulation study considers main campus only (due to the scope and time for conducting this research)
- Only undergraduate students are considered
- Incoming students are from FTIC, CCT and Others, either to 1st or 3rd year. Not considered in this study are stop-outs or skipping students
- Only major declaration is considered. Out of the study remains change of major during the student's stay (again, due to the scope and time for conducting this research)
- Only Industrial Engineering major is modeled and followed
- Students have no restrictions to what class to take based on the IE program of study.
- Students make their own decisions in what class to take. This selection process is agent-based

The representation of the model with its three major areas (SD high level model, DE and ABM low level model), and the *integration phase* for a Hybrid Simulation Model under a Network Framework can be seen in Figure 16.

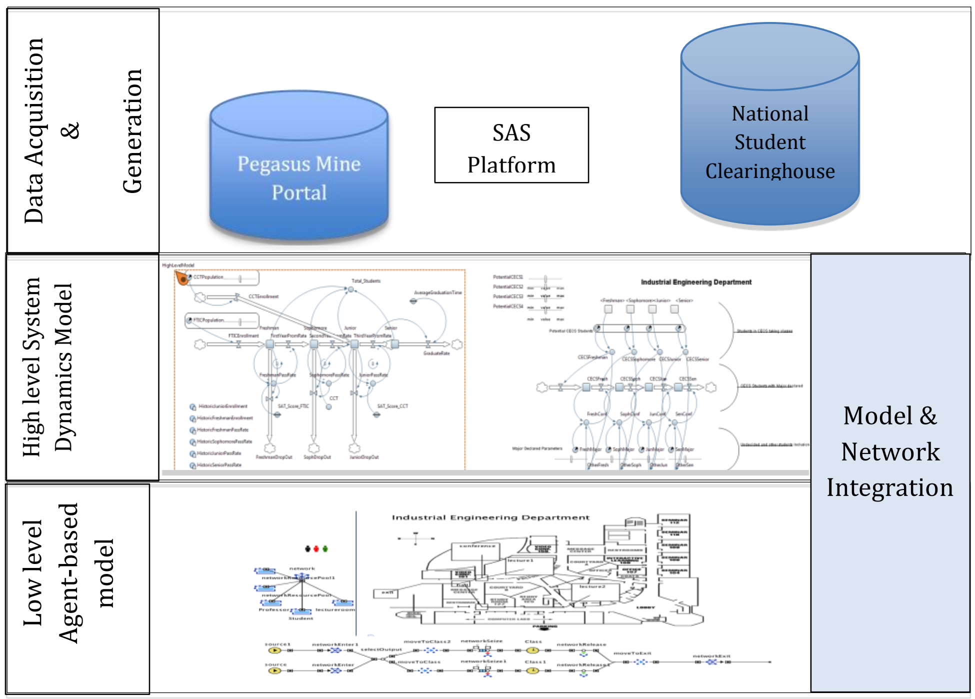


Figure 16, Model representation

Network representation is included at this stage as a way to link all components and provide the means to visualize them as part of a future major system (that would include all colleges and departments).

At the low level, the IE Department's enrollment model is used to improve the next term or next year class planning, involving the use of resources like professors, classrooms (capacity, type), day or night time schedule, etc.

High level modeling

The high level SD model consider a number of flows, stocks, variables, functions, and dataset, tables, and statistics that represent the flow of incoming and outgoing students in the university enrollment process.

Causal feedback loops represent the structure of the system and all the influencing variables that affect each other. The modeling of influences and relationship between variables are indicated by the direction of the representing arrows.

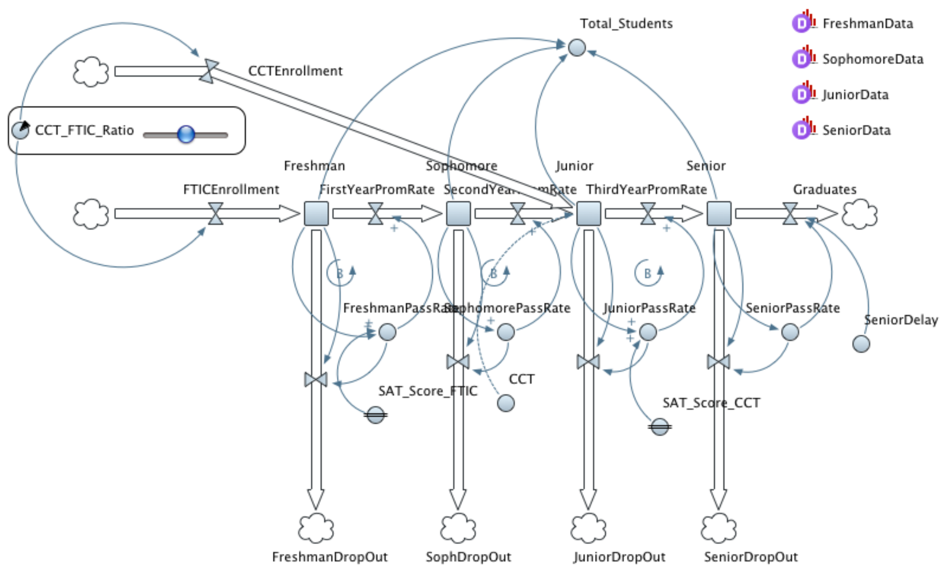


Figure 17, High-level System Dynamics Enrollment Prediction model

In this first stage, causal loops are integrated with information regarding previous years' enrollment compared to current year. Initial flow of students is based either on a Historic Freshman Enrollment Table and a CCT-FTIC Ratio horizontal slider. The Table is based on the data provided for the last 10 years considering a linear interpolation to the nearest. CCT-FTIC slider gives an additional input to the model, modifying the ratio of Community College Transfers and First Time in College. By this, we are able to experiment with different alternatives and see the results over time. A previous version of our model included sliders for FTIC and CCT, allowing increments from 0 to 10,000 entities which is best used in further experiments or manipulation as we can see in Figure 18.

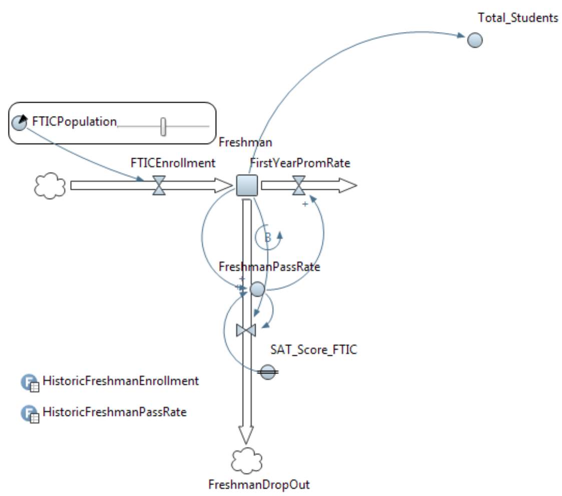


Figure 18, High Level SD Freshman conformation

FTIC/CCT ratio can be obtained by the amount of students enrolled in a specific year. As we are able to see later in Tables 8 and 9, in 2011 FTIC enrolled students reached 5,248, and CCT reached 7,770, making 41.13% for FTIC and 58.87% for CTT. By this, we are able to play with the model modifying the ratio as desired.

Going back to the general model, the initial flow falls into a first beginning stock, incrementing the variable "Total_Students" which is used to keep count of the amount of students at any given time. This variable is easily calculated by:

$$Total\_Students = \sum_{i=1}^{n} \boldsymbol{Freshman}(\boldsymbol{i}) + \sum_{j=1}^{n} \boldsymbol{Sophomore}(\boldsymbol{j}) + \sum_{k=1}^{n} \boldsymbol{Junior}(\boldsymbol{k}) + \sum_{l=1}^{n} \boldsymbol{Senior}(\boldsymbol{l}) \quad (1)$$

Where $\sum_{i=1}^{n} Freshman(i)$ represent all freshman students at a given time. For Simulation purposes, we must give a warm-up period in order to start the simulation with populated students' stocks for all years.

By the same way, the FTIC Enrollment flow is given by equation (2):

$$FTIC\ Enrollment = HistoricFreshmanEnrollment(\ time()\ ) + FTICPopulation \quad (2)$$

Additionally, we can see that the flow follows to "FirstYearPromRate", which is positively affected by the variable "FreshmanPassRate". This variable provides the passing rate for freshman students based on previous data gathered. This passing rate may be influenced as well by "SAT_Score_FTIC" which certainly gives emphasis to the correlation of SAT scores, to the passing rate for each student. Initially, we have determined that this variable will not affect the initial calculation, giving it a value of 1. By this, the Passing rate will be determined by equation (3):

$$Passing\ \_rate = Freshman * SAT\_Score\_FTIC * HistoricFreshmanPassRate\ (\ time()) \quad (3)$$

Following years are made with the same rationale. Flows are calculated the same way and they additionally consider student population coming from previous years. At the third year however, we must include again a new source of students provided by CCT. This stock is now affected by a CCT variable that is used for initiation purposes and its value is constant, a "HistoricJuniorPassRate" Table, a "HistoricJuniorEnrollment" Table, and "SAT_Score_CCT", "JuniorPassRate" and resulting "ThirdYearPromRate" similar to what was previously explained. These values influence also the amount of Total Students. All of this will determine the expected graduating students after a given graduate rate and time, as we can see in Figure 19.

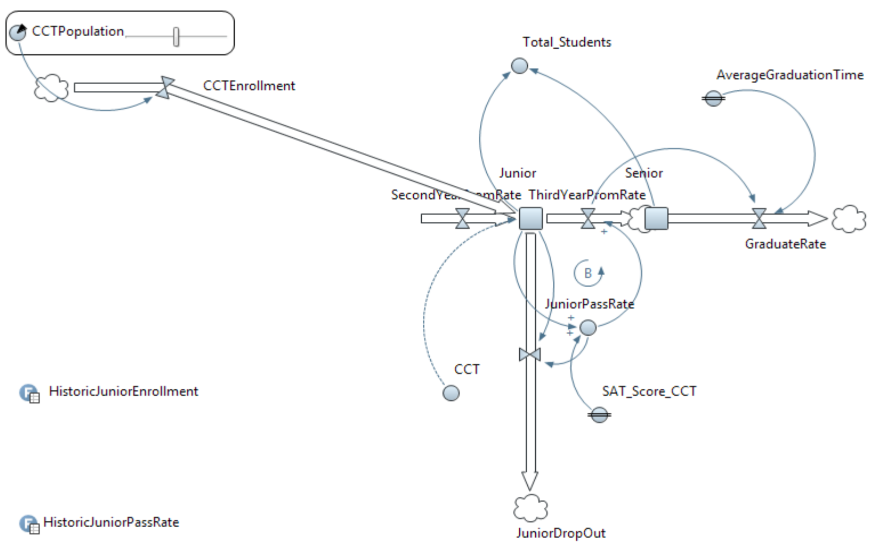


Figure 19, High Level SD Junior, Senior and Graduate conformation

Middle level abstraction

This transitory level of abstraction is necessary to transition from the general perspective enrollment model to the IE Department. The model represents the overall CECS students' flow, and represents the general trend of students that have selected IE major or are still undecided.

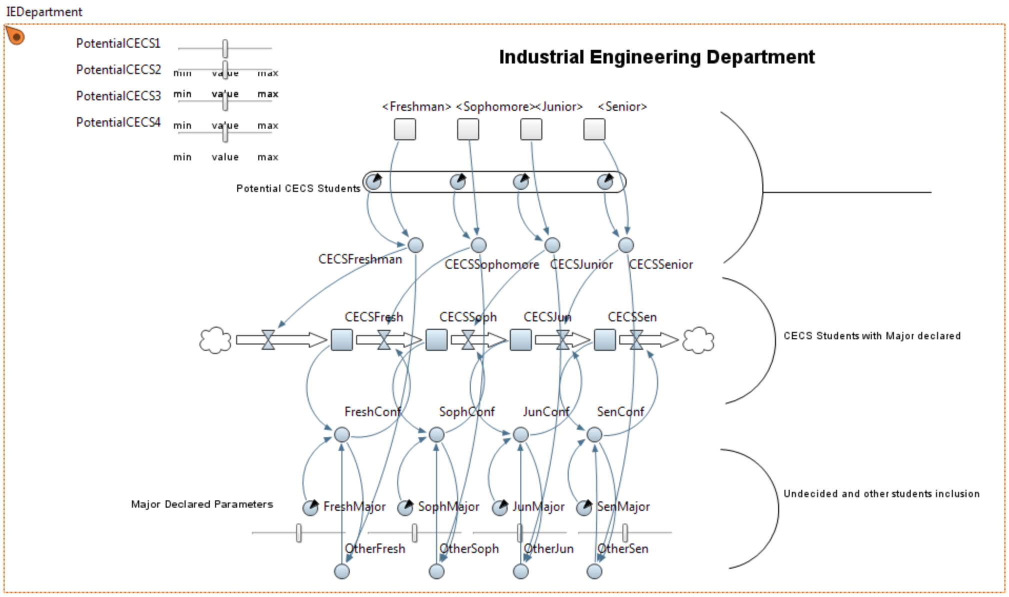


Figure 20, Middle-level abstraction model for College of Engineering

Freshman, sophomore, junior, and senior stocks have been "shadowed" from the higher-level model to avoid an excess in flows or drawing, and to simplify analysis.

"Potential CECS students" for each academic level have default values whose sum equals to 1, derived from historical observation of data. Distribution of CECS students among academic levels for 2012 – 2013 is shown in Table 3.

Table 3, 2012 – 2013 CECS academic level distribution

Academic level	Percentage
Freshman	0.33
Sophomore	0.27
Junior	0.22
Senior	0.18

These values are considered for calculation of CECS Freshman population for any given time. Potential CECS1 refers to Freshman percentage of students. This figure is then utilized to obtain CESC Freshman population, as seen in equation (4)

$$CECSFreshman = PotentialCECS1 * Freshman \quad (4)$$

The values for all auxiliary variables (from CECSFreshman to CECSSenior) are given by the historical ratio obtained from our data, as we can see in the following table:

Table 4, CECS student population

Cohort	Ratio against total student population
2001-2002	0.02
2002-2003	0.02
2003-2004	0.021
2004-2005	0.023
2005-2006	0.02
2006-2007	0.024
2007-2008	0.023
2008-2009	0.023
2009-2010	0.025
2010-2011	0.026
2011-2012	0.027

Low-level Industrial Engineering Department Enrollment Model

A discrete-event simulation model has been developed to replicate the flow of students when selecting a course. At this level, students are assigned to a class named "course". Parameters included are: Professors, Graduate Assistants, and Lecturers. All these parameters can be modified to specific experiment set up.

As we can see in Figure 21, the department level is modeled over a layout to allow better analysis, and based over a network structure that allows the allocation of different resources.

The model starts with students' arrival, where they are batched in class size. For simulation purposes we have determined an average size of 30 students per class. Once the class joins the network, it traverses through the department where different professors, lecturers or GA are assigned. These resources are released once the class has finished. Time units are days, and course length is one term of approximate 90 days.

The network is constructed based on polylines and nodes. We have determined a general structure for the department. Each classroom, hall, or location has pre-determined capacities and classes are conducted in classrooms 1 through 9. There is also a FEED implementation for online classes where there is no limit in physical space but only in resources to be used. We have established also different paths to keep some resources like professors or lecturers. As mentioned before, parameters assigned to these paths provide alternatives for resource utilization.

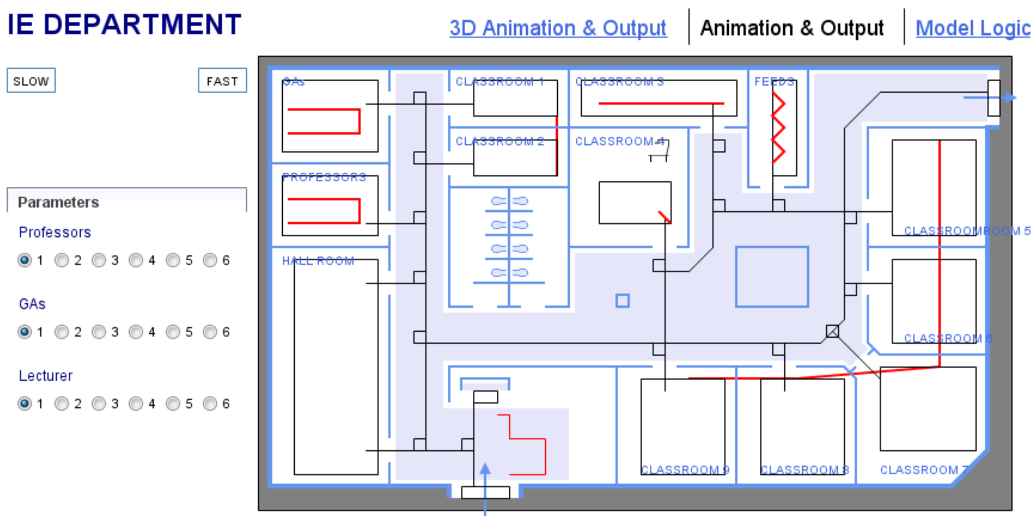


Figure 21, Low-level Industrial Engineering Department model

The process flowchart seen in Figure 22 gives the logic to the simulation model for this abstraction level. Entities arrive according to a specific rate, and then they are batched to form a course. This new type of entity then moves to different classrooms and is assigned to new and different professors until it completes the class and leaves the system. In between, we find network entering and leaving nodes that allow navigation through the layout. Courses are limited in time and capacity. Resources are always on call.

Courses have a delay time to retain the entities according to the length of the course. As this model deals only with resource utilization, we have not considered daily schedule of courses, but only term schedule and term resource utilization.

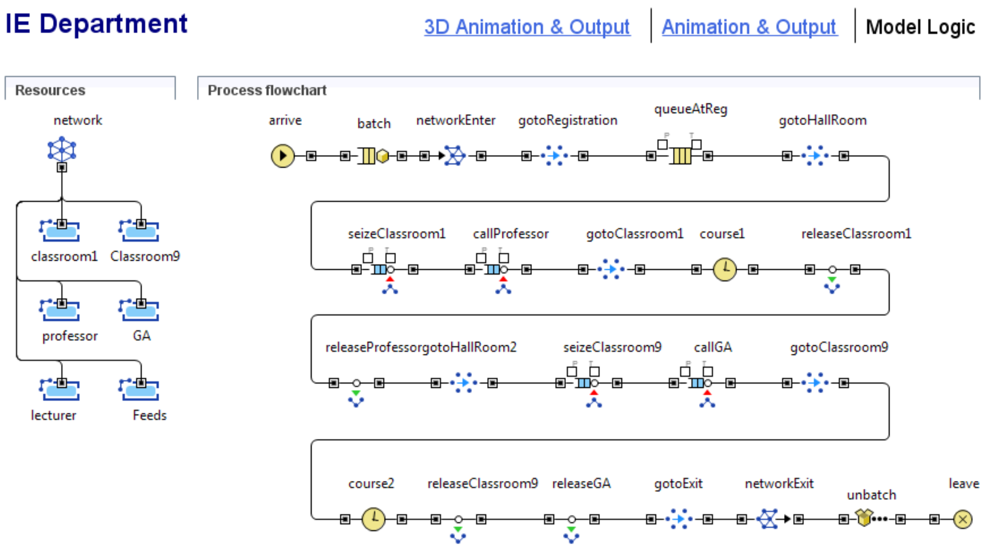


Figure 22, Low-level Industrial Engineering Department process flowchart

Resources modeling can be seen in Figure 23. Here we have defined a small network where, in simple terms, entities meet resources over the layout.

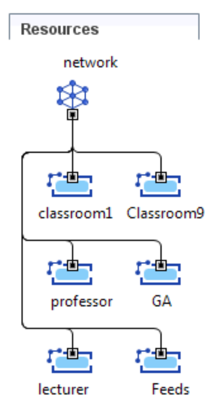


Figure 23, IE Department's resources modeled

Resource utilization and length of stay graphs has been provided for analysis of experiment, as seen in Figure 24. Resources are modeled as part of a given number of resource units from the resource pool (Figure 23). As we know, these resources defined by a graphical connection from the access port of the Seize unit, as shown in Figure 22, are added to the “LinkedList” for the resource units. This has public access in Java. The resource units, through these seize parameters include embedded objects such as Queues, where entities (a course entity of *n* students in this case) wait for the availability of the requested resource, and Ports (access and exit ports).

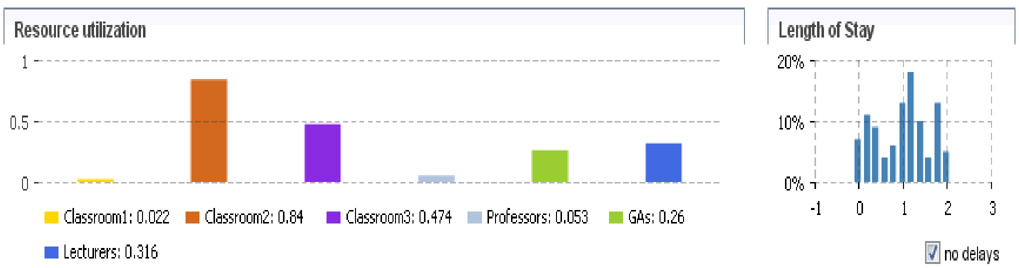


Figure 24, Resource utilization and length of stay outcome graphic results

As we see in Figure 22, students navigate through the Department. They are able to go to different classrooms, and get Professors or GA for this. They exit the system individually, being necessary to un-batch the courses.

The creation of the entities is based on time of admission, and the system is able to capture all required statistics, as we will be able to see in the next chapter.

Low-level Course Assignment and Major Selection Model

Course assignment is based on Discrete-event and agent based simulation. This hybrid component is built over a course creation (entity) that is part of the course selection process of students. These courses are available over a predetermined alternative courses retrieved from IKM data. These courses are the most representative for IE major students. Courses are created then and remain in stock for selection and delivery purposes. Course delivery refers to the course been given or taught, and able to be chosen by an agent or student. Figure 25 shows the whole process and relationship between course assignment and major selection.

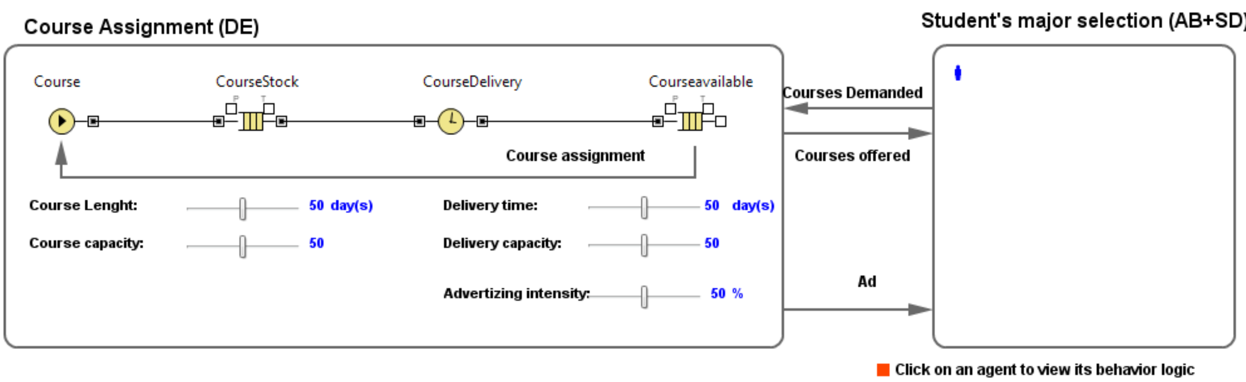


Figure 25, Low-level course assignment and major selection model

Once a course has been created, a student is able to choose. The student (agent) has logic in decision-making based on the state chart shown in Figure 26. A potential IE student is defined as a student that has all requirements for joining the major. GPA, and core courses grades are in compliance with CECS requirements.

We followed the student population that took some of the courses listed in Table 5, within the IE department. These courses are the most representative courses and also are exclusively given by IE faculty, either to IE or CECS students.

Table 5, Students' Course Data

Course	Description	Semester
EGN 1006	Intro to Eng	1st
EGN 1007	Engr. Concpt & Mthd	2nd
EGN 3211	Engr Analysis	3rd
EIN 3001	Intr to Ind Eng	4th
STA 3032	Prob & Stats for Eng	5th
EGN 3321	Engr Anal - Dynamics	6th
EGN 3613	Eng Econ Analysis	6th
EIN 3314	Work Meas & Design	7th
ESI 4312	Operations Research	7th
EIN 3354	Princ of Cost Eng	7th
EGN 3358	Therm Flds – Ht Trans	8th
ESI 4628C	IE compt Appl	9th
EIN 4891C	IE Senior Design	10th

We were able to follow students enrolled in our sample courses showing the trends as we can see in Figures 26 and 27, for FTIC and CCT. Here, students are grouped by term, starting from Fall 2000 (Table of codes can be seen in Appendix A).

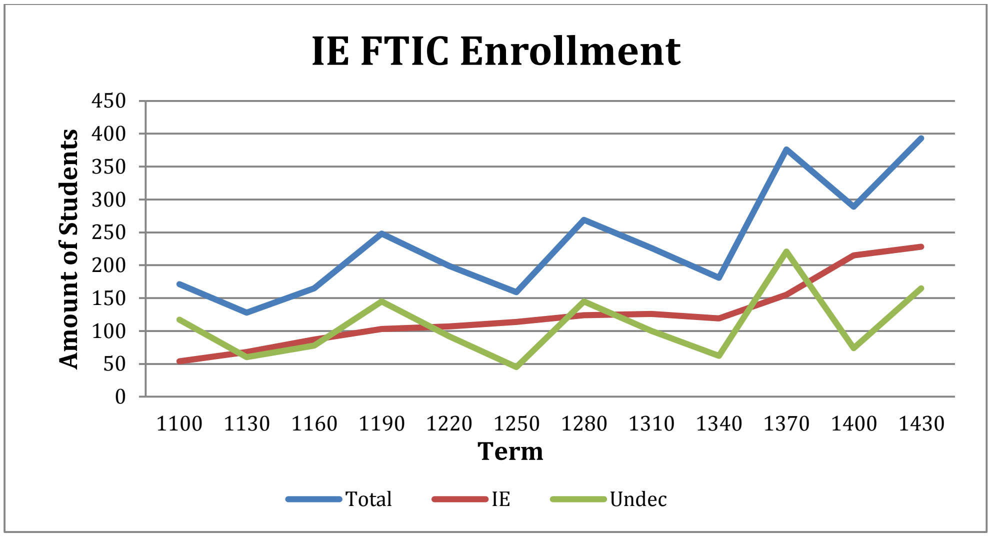


Figure 26, FTIC IE Department Historical Enrolled Population

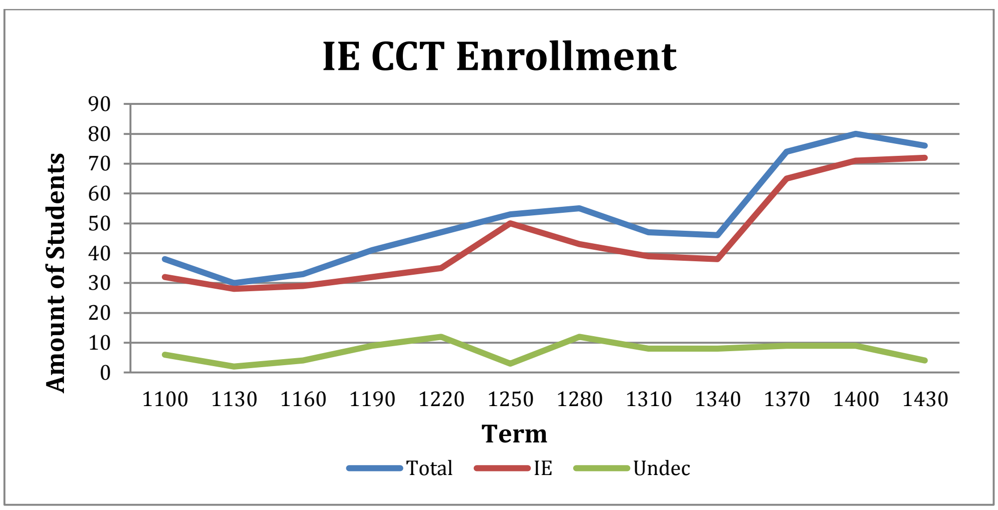


Figure 27, CCT IE Department Historical Enrolled Population

Data from Figures 26 and 27 show that IE major initially was 31.53 % of the total population (54 out of 171), ending in the last selected term with 74.39% of the student population (215 out of 289). This percentage change indicates that now there are more students that make early decisions, and that they take less time to decide as well.

A student may transition from a potential IE student once he has a pending request for IE major. This pending request may be 0 time or all term (90 days). For simulation purposes, a 0 time pending request allows a student to move to IE major. At this point he may remain there or change major at any time. If a student does not have all requirements to get into the IE major, he leaves the system.

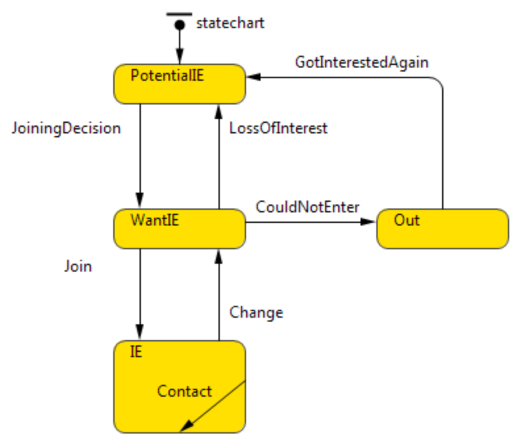


Figure 28, State chart for agent based major selection process

Decisions are made based on preferences. The decision making process established for agents or students acting independently, is based on a SD process of preferences according to an interest or decay of it over time. If a student's interest remains, he will want to join the IE major, otherwise he will change or not want to be part of it. If the Students are IE declared majors, and they maintain interest, they will keep their major and will not change.

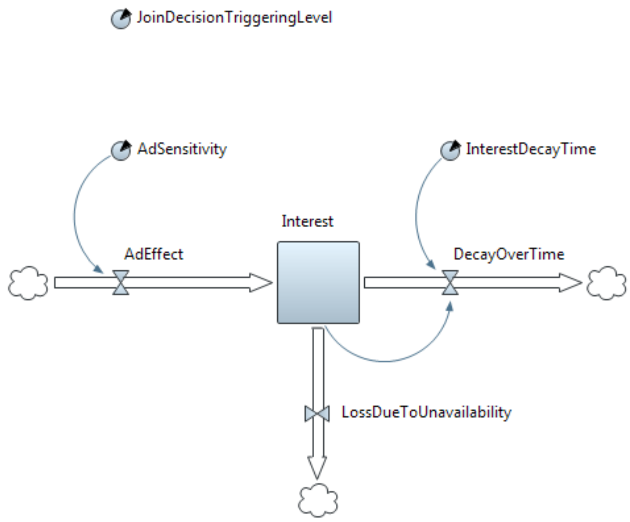


Figure 29, SD agents' decision process

But now the question is how we estimate these parameters. As we will later see in section 4.3, the estimation is based on historical data provided with all students that took classes or attended CECS and that fall into two categories: IE declared major and undecided. Both categories include FTIC and CCT. IE and undecided students have determined a pattern given by the number of students that kept their academic plan (IE major) over the years, changed it, or joined it.

The rationale for this decision process model obeys a flow that is determined initially from a decision trigger level given by an initial base level figure. This parameter relates also with the Join Decision transition flow from Figure 28.The interest that a student (entity) shows relates with the following equation:

$$AdEffect = get\_Main().MajDeclRatio * AdSensitivity \quad (5)$$

Where “MajDeclRatio” corresponds to the initial ratio between the amount of IE major declared students over the total IE department student’s population.

The variable “AdSensitivity” shows a PD uniform (0.5, 3) based on an initial sensitivity analysis.

An Interest value is then determined. Student preferences will decay over time according to:

$$DecayOverTime = Interest \,/\, InterestDecayTime \qquad (6)$$

Where “InterestDecayTime” start with a fixed number again based on an initial sensitivity analysis.

Relating the SD model from Figure 29 with the agent-based state chart from Figure 28, we are able to determine that a potential IE student will enter a transition state called “WantIE” (wants to be IE), and from there a possible IE major selection. The student “join” this state according to the following Course Assignment Policy:

```
//remove one course from the stock
Courseavailable.removeFirst();
//apply  policy
if( Courseavailable.size() <= s ) {
      int expected = CourseStock.size() + CourseDelivery.size();
      Course.inject( S - ( Courseavailable.size() + expected ) );
   }
```

This code refers to the availability of open courses for IE students, either major declared or not. If a course is available, the student takes it and the interest in remaining in

IE major remains, or if undecided, it increases. This code is part of the Course Assignment Policy Function.

The student may not select the IE major either by choice or condition. The UCF's IE department deals with students that have not met all requirements needed to join the IE major. They are considered as "Pending" until they comply with the requirements (e.g.: grades). In our model, we consider these students with a transition that allows them to start the loop again. This transition is defined by the following equation:

$$GotInterestedAgain = Interest > JoinDecisionTriggeringLevel * 2 \quad (7)$$

Students that have Interest < 0 will get out of the system.

Our "major declaration process" is given by the following code:

```
/**
 * Major
 */
public class Major implements java.io.Serializable {

        double MajorDeclared;

        double Undecided;

        double MajorChanged;
    /**
     * Default constructor
     */
    public Major(){
    }
    /**
     * Constructor initializing the fields
     */
    public Major(double MajorDeclared, double Undecided, double MajorChanged){
             this.MajorDeclared = MajorDeclared;
             this.Undecided = Undecided;
             this.MajorChanged = MajorChanged;
    }
```

```java
@Override
public String toString() {
	return
		"MajorDeclared = " + MajorDeclared +" " +
		"Undecided = " + Undecided +" " +
		"MajorChanged = " + MajorChanged +" ";
}
```

Data

Our data consist in a series of raw SAS files provided by the Institutional Knowledge Management Office of the University of Central Florida. Here we take advantage of working with the second largest university in the USA, and also with a very strong Institutional Research structure that allowed us to access student population data from the year 2000.

The data we requested is only limited in terms of research scope as they include all students, retention, course, and record data for Industrial Engineering and Undecided students, leaving out of this research all remaining students in the system. The main files accessed are described in Table 6.

We also obtained additional public data provided by UCF through the UAPS and IK websites, and PEGASUS Mine Data Warehouse and Information Portal.

Table 6, Data Files and Scope

File	Population	Time span	Relevant fields	Input
Student Course Data	Encrypted Student Id, Undergraduate IE and Undecided	2000 - 2012	Selected Courses[2], Grades, Instruction Mode,	FTIC, FCS AA Transfers; IE (BSIE) and Undecided Eng.
Student Record Data	Undergraduate IE and Undecided	1997 - 2012	Term, Term year, Academic career, Academic level, SAT, ACT, Residency, Entry date	FTIC, FCS AA Transfers; IE (BSIE) and Undecided Eng.
Retention Cohorts	Encrypted Student Id, all IE and Undecided.	2000 - 2001 to 2011 - 2012	Entry Term, Junior College, Department, Academic Plan, Academic Term (Summer, Fall, Spring) Enrollment and Retention.	FTIC, FCS AA Transfers; IE (BSIE) and Undecided Eng.
Junior Cohorts	Junior cohorts	2002 - 2003 to 2008 - 2009	Entry Term, Junior College, Department, Junior Plan (IE, Undecided) and Area (STEM), Degree Term, Degree after 4 years, Still Enrolled, Retained.	FTIC, FCS AA Transfers; IE (BSIE) and Undecided Eng.

Students IDs is coded in order to maintain compliance with FERPA regulations. Since there was a need to follow students throughout their permanence at UCF, ID codes have

[2] Courses considered are EGN 1006, EGN 1007, EGN 3211, EIN 3000, EGN 3310, EGN 3321, STA 3032, EGN 3613, EIN 3314, ESI 4312, EIN 3354, EGN 3358, ESI 4628C, EIN 49891C.

been maintained for all the study, as well as correspondence between different tables or files.

Table 7, Data file description

File	Description
Student Course Data	Data shows each course a student has taken by term, including classes that were taken in a future term as a result of a withdrawal or failed attempt in a previous term. Instructor Model field only has data beginning in term 1330 Criteria of query is based on required course list in Table 4
Student Record Data	ACAD_LEVEL field is not 100% accurate due to older terms containing conversion data Data from test scores was pulled from PeopleSoft since it provided the most matching test scores available, Test scores are also based off of the highest score a student earned. Criteria of query include term, student type, academic career, academic level, group and plan.
Retention Cohorts	Includes all data for 10 year retention Criteria of query include cohort year, academic plan, and student type.
Junior Cohorts	Data include the following years: 2002-03, 2003-04, 2004-05, 2005-06, 2006-07, 2007-08 Cohorts_Years refer to the year the student entered as a junior Degree_4years refer to what happened four years out from being a junior Criteria of query include Cohort years from 2002-03 to 2008-09 for FTIC, CCT, for Academic Plan IE and Undecided

CHAPTER FIVE: SYSTEM BEHAVIOR AND HYBRID IMPLEMENTATION

Introduction

Universities tend to compete for student market share, stimulated by the increase of government and private funding, making sometime aggressive approaches to capture and retain the best students and grow in student population. We may find that a particular course, area, or degree has “taken off” from a previously sustained growth to a non-steady growing demand (Galbraith, 1998). This new trend would require investment and new planning. If we base our model in a simplified version of enrollment and retention by just considering the performance of the last year and comparing it with the current one, we risk making decisions based on local conditions and forfeit long-term vision. If the last year is quite acceptable, then there is not much to say. If times are tough, enrollment could have decreased, making the enrollment target inaccurate as figures may increase based on non-optimal conditions (Galbraith, 1998).

The former condition was included and accepted for our approach. For this reason we developed a simulation approach using the three major modeling methods—Discrete Event, Agent Based, and System Dynamics. They are combined, and they work together.

We analyze all levels for simulation and representation, and we also include quantitative estimates to establish the relationship between some of the variables we use through correlation analysis techniques.

High Level Model Representation

The high-level enrollment model is built in System Dynamics using the SD library from Anylogic ®. This high-level model reflects its flow to the next lower level (College level). Student flow varies by several factors throughout the system either by incoming students or by drop off or graduating ones.

The distribution of students across the model depends on the average passing rates displayed for each individual level, as well as the growth rate based on historical data.

Based on this data, we were able to reproduce the enrollment process from the Markov chain model currently in use at UCF, as we will be able to see in the next pages.

Attrition and Retention

In order to calculate retention and passing rates, we based our approach's methodology on empirical data and a general scope study made by the "Delta Cost Project" (American Institues for Research, 2012) where we include all forms of departure from the systems prior to completion of a degree. We estimated University Attrition by using and analyzing the "Report Facts" data provided by the Institutional Knowledge Management Office from UCF. The methodology to determine attrition parameters for our model is based initially on the last two years of existing data for two main reasons: It is more realistic to consider attrition with the students that are attending or have attended the university in recent years, and it becomes irrelevant to determine attrition based on long historical data as the current changes are happening at the present time. The methodology is as follows:

- We found how many of last year's students who did not received a degree reenrolled in the current year. For this we considered all students enrolled at any time during 2010-2011 (second-most recent year) and classified them by the number of chronological years since first enrolled (from 1 to 9).
- For each year's "cohort," we identified all students who graduated with any credential in the same year, and we calculated a graduation rate.
- Form all remaining students who did not receive a credential, we identified those who enrolled at any time during the following year, and we calculated the retention rate.
- We estimated a returning stop-out adjustment rate by identifying all students in the most recent year (2011-2012) who are not new students but who also were not enrolled in the prior year (2010-2011). This returning student adjustment comes from the proportion of all students enrolled in 2010-2011.

We subtracted the graduates and retained students from the initial 2010-2011 cohort, and we calculated an adjusted attrition rate. For this we used the stop-out adjustment rate to create the adjusted attrition rate. In Figure 30 we can see the SAS ® query following the aforementioned methodology to determine attrition. The following results are in Tables 8 and 9.

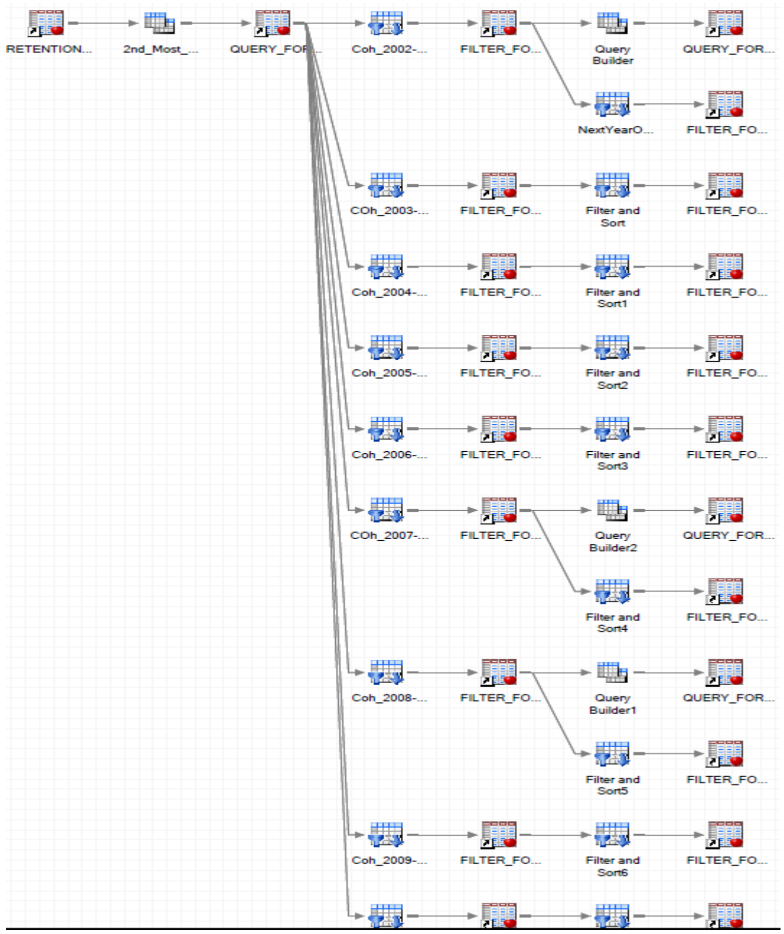


Figure 30, SAS EG® Query for Retention for the Second-Most Recent Year

Following Figure 31, we can see that the amount of FTIC students that flows into the university has a great impact on the overall student enrollment system. From 2001, FTIC enrollment situates around 5,500, reaching a peak in 2007 of near 6,900, and from that point on decreasing to remain near 6,500 steadily.

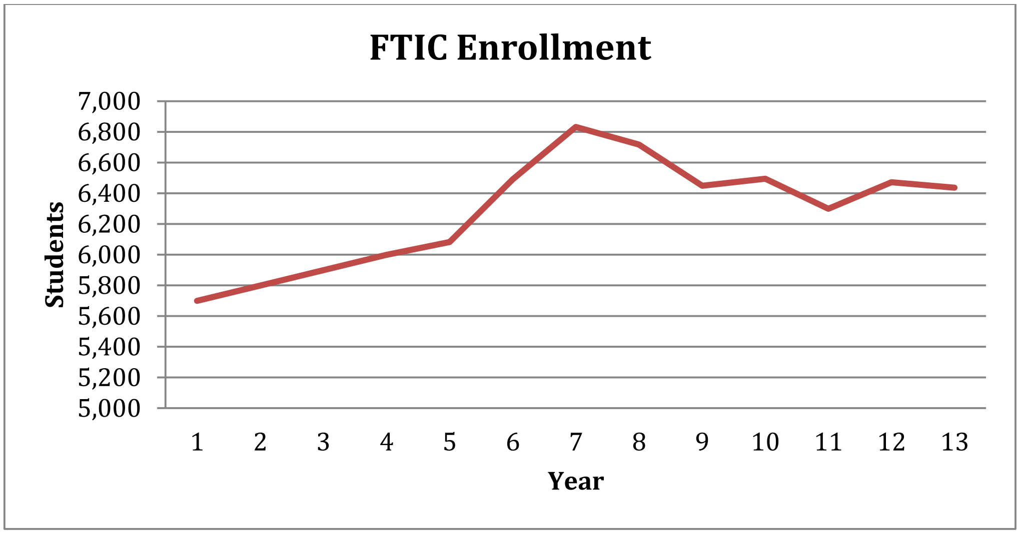


Figure 31, FTIC Enrollment

FTIC students, by entering the system from the beginning, are more susceptible to attrition. In Figures 32 and 33, we are able to see the 2011-2012 class and its corresponding attrition and retention quantities for FTIC and CCT students. Retention of unduplicated headcount will show all students that remain in the system until they leave the university. Retention rates are calculated following the amount of time a student remains enrolled and the number of students that leave the university. Figure 32 shows that in the year 2011-2012, there were 5,548 students that re-enrolled the first year and 542 that left the system. By the same token, averages show that the first year had a 10% of attrition, decreasing to less than 5% for the second, third, and fourth years. The analysis considered students up to the ninth year.

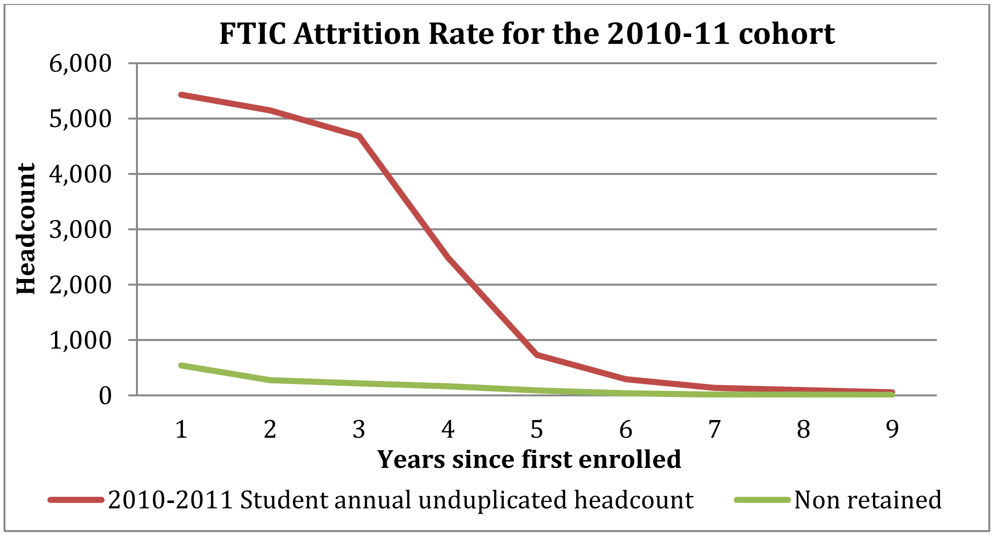


Figure 32, FTIC Attrition Rate Since Student's First Enrolled

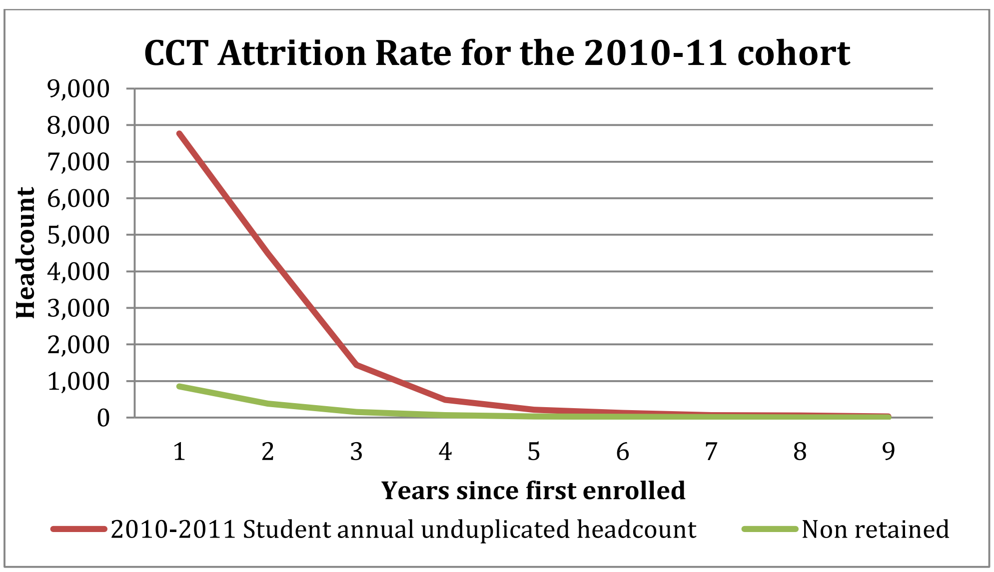


Figure 33, CCT Attrition Rate Since Students First Enrolled

Passing Rates

Passing rates are determined by the ratio between the total population and the drop off students. We have not considered probable causes for attrition. In Tables 8 and 9 we are able to see the calculation for FTIC and CCT that we have included in our SD model.

Table 8, FTIC Attrition Rate Calculation for 2010-2011 Cohort

Years since 1st Enrolled	2010-11 Student Headcount	Non Retained	Graduate	% graduated	2011-12 Retained Headcount	% retained	2011-12 returning students	Return adjust	Unadjust. Attrition Rate	Adjusted Attrition Rate
1	5,428	542	22	0%	4,864	90%	0	0%	10%	10%
2	5,149	277	183	4%	4,689	91%	55	1%	5%	4%
3	4,687	217	2,321	50%	2,149	46%	76	2%	5%	3%
4	2,489	165	1,639	66%	685	28%	59	2%	7%	4%
5	731	93	384	53%	254	35%	51	7%	13%	6%
6	294	42	137	47%	115	39%	47	16%	14%	-2%
7	135	19	54	40%	62	46%	29	21%	14%	-7%
8	96	15	46	48%	35	36%	9	9%	16%	6%
9	55	13	22	40%	20	36%	5	9%	24%	15%
Total	19,064	1,383	4,808	25%	12,681	68%	331	2%	7%	6%

Table 9, CCT Attrition Rate Calculation for 2010-2011 Cohort

Years since 1st Enrolled	2010-11 Student Headcount	Non Retained	Graduate	% graduated	2011-12 Retained Headcount	% retained	2011-12 returning students	Return adjust	Unadjust. Attrition Rate	Adjusted Attrition Rate
1	7,770	850	1,945	25%	4,975	64%	0	0%	11%	11%
2	4,487	379	2,566	57%	1,542	34%	118	3%	8%	6%
3	1,438	151	818	57%	469	33%	83	6%	11%	5%
4	490	71	267	54%	152	31%	57	12%	14%	3%
5	216	33	103	48%	80	37%	38	18%	15%	-2%
6	130	20	60	46%	50	38%	19	15%	15%	1%
7	69	12	33	48%	24	35%	8	12%	17%	6%
8	54	9	22	41%	23	43%	9	17%	17%	0%
9	33	6	10	30%	17	52%	3	9%	18%	9%
Total	14,687	1,531	5,824	40%	7,332	50%	335	2%	10%	8%

We also obtained passing rates based on historical data to be included in the simulation, as seen in Table 10. These passing rates allow us to model the students' flow through the system.

Table 10, FTIC IE Passing Rates

Argument	Freshman Pass Rate	Sophomore Pass Rate	Junior Pass Rate	Senior Pass Rate
1965	0.80	0.80	0.80	0.80
1970	0.80	0.80	0.80	0.80
1980	0.80	0.80	0.80	0.80
1990	0.80	0.80	0.80	0.80
2000	0.70	0.83	0.85	0.95
2001	0.72	0.86	0.86	0.95
2002	0.75	0.87	0.85	0.94
2003	0.73	0.85	0.88	0.95
2004	0.80	0.90	0.87	0.92
2005	0.83	0.87	0.88	0.90
2006	0.77	0.89	0.90	0.94
2007	0.82	0.88	0.88	0.94
2008	0.85	0.91	0.88	0.93
2009	0.83	0.91	0.89	0.94
2010	0.88	0.92	0.90	0.95
2011	0.87	0.93	0.91	0.96
2012	0.90	0.95	0.93	0.94
2013	0.90	0.94	0.90	0.94

By analyzing the students enrolled in the IE department from 2010-11 compared with previous years, we obtained the Passing Rates as we are able to see in Figure. From the year 2000, for instance, Freshmen have increased the passing rate from 70% to 90%. We are also able to see that Sophomores, Juniors, and Seniors have a higher passing rate than Freshmen.

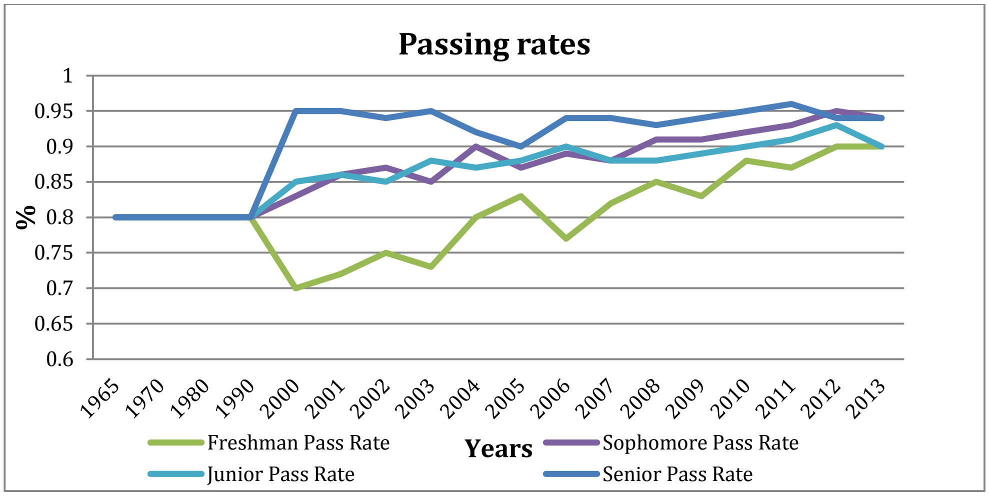


Figure 34, Passing Rates Behavior

Passing rates, as we can see, are determinant in the results of the model and have been included in the model. They dynamically adjust the amount of students in the system, but passing rates are influenced by external factors like GPA and SAT scores (or other admission tests like the ACT). This reason has forced us to include these factors in the model. Through adjustment and variation, we may be able to modify the behavior of the enrollment model. If SAT score is determinant in the amount or quality of admitted students, retention rates will experience changes. Figure 35 shows the average GPA from 1996 to 2007 for upper-level courses.

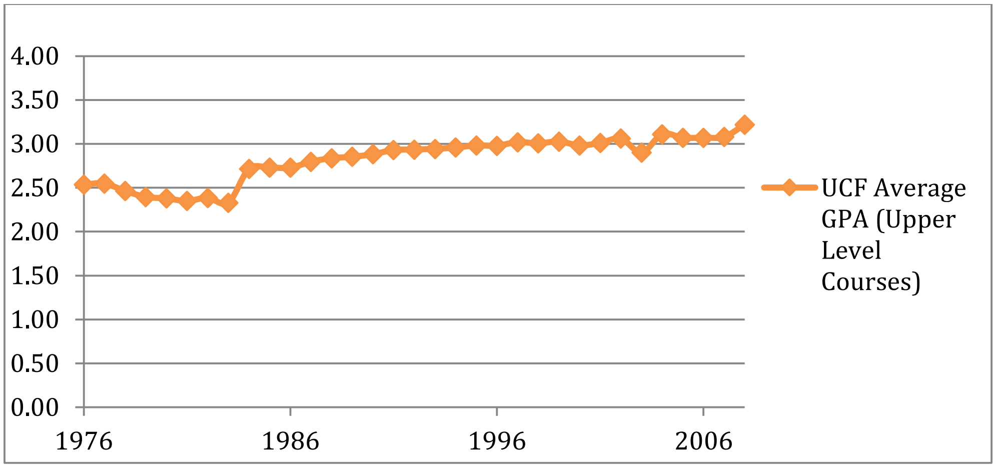


Figure 35, UCF Average GPA for Upper-Level Courses

Goodness of Fit and Enrollment Calculation

For all historical data, we have determined and calculated the discrepancy of the model. We have compared this historical data against our model, and we have obtained the absolute values of discrepancy and converted these values to fractional values, which is no more than dividing by the historical data.

In Figure 36, we are able to see how the model behaves against the historic data for enrollment projections. Even though we see a wide difference from the starting date of the simulation, 1960, we agree in the overall results as the initial values are used for the warming period of the simulation, with the useful and accurate data, from the year 2000 to 2011, following with predicted values.

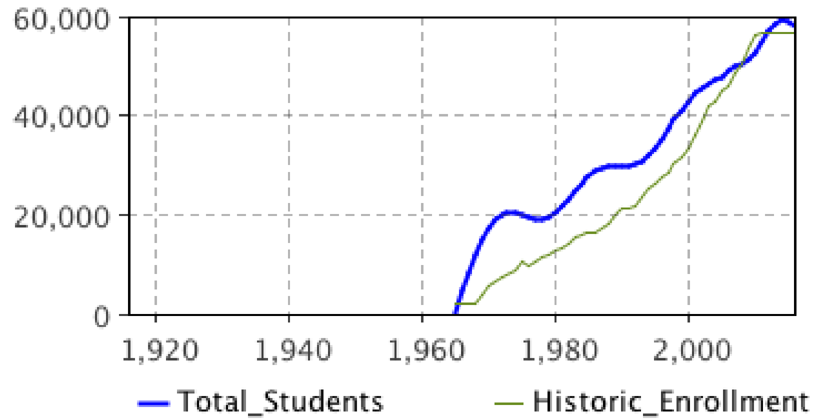


Figure 36, Historic and Simulated Enrollment Projection

Our predictive model differs by 1.3% for the year 2011, which is not optimal, but for 2012, the difference gets to 0.08%. From 2012, our historic data becomes irrelevant, but we assume the predicted values given by our model will remain under 1% for the next year, and so forth. Table 11 shows the data provided by the model and compared to the historical.

Table 11, Model and Historic Data Comparison

Year	Model	Historic	Difference	%
2000	42,849.14	33,453	9,396	21.93%
2001	44,371.14	36,013	8,358	18.84%
2002	45,635.63	38,795	6,841	14.99%
2003	46,443.53	41,685	4,759	10.25%
2004	47,066.27	42,837	4,229	8.99%
2005	47,804.51	45,090	2,715	5.68%
2006	48,956.35	45,907	3,049	6.23%
2007	49,984.70	48,699	1,286	2.57%
2008	50,380.70	50,275	106	0.21%
2009	52,177.99	53,644	1,466	2.81%
2010	54,812.42	56,337	1,525	2.78%
2011	55,970.51	56,698	727	1.30%
2012	57,076.10	57,123	47	0.08%
2013	57,582.62			
2014	58,230.36			
2015	58,411.48			
2016	58,936.04			

Student and Parking Growth

The Department of Parking and Transportation Services provided information from 1994 up to 2011. Previous records were not recorded with the exception of 1987, following a study made by Berk et al. in 2012. From dirt lots to the actual parking buildings, UCF has evolved enormously over the past 50 years. In 1968, when UCF opened its doors, only 1,948 students attended the university (then known as Florida Technological University).

Reduction in the parking count is related to construction of future parking lots or garages, involving the removal of past temporary dirt lots, to be replaced with concrete definitive parking buildings or garages. The construction of buildings is believed to be another factor that causes reduction of parking availability as lots had to be relocated during construction periods. Figure 37 shows the variations of parking spaces over time.

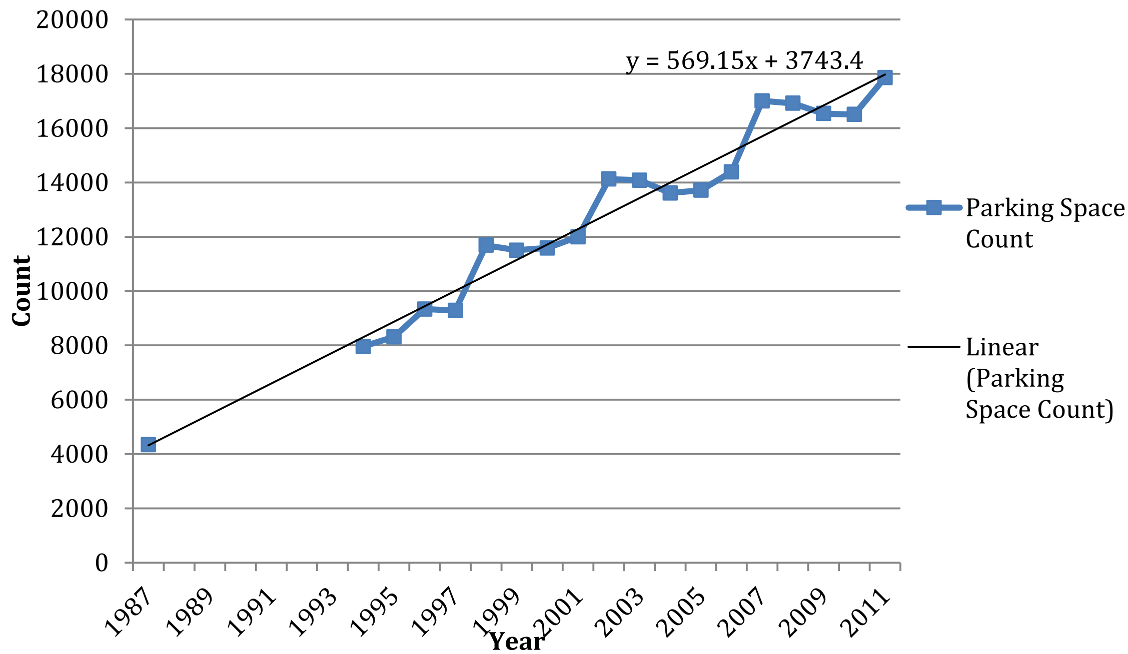


Figure 37, Number of Parking Spaces

The growth of parking spaces according to the growth in student headcount can be seen in Figure 38. Student growth rate since UCF's opening has been high. The increase in parking availability has always been a need. However, the headcount rate has grown at a rate almost three times that of parking count. Even though parking count does not represent the total amount of students, faculty, administrative staff, and visitors that utilize the campus parking, capacity is considered, and its usage would dictate further parking expansions (Berk et al, 2012).

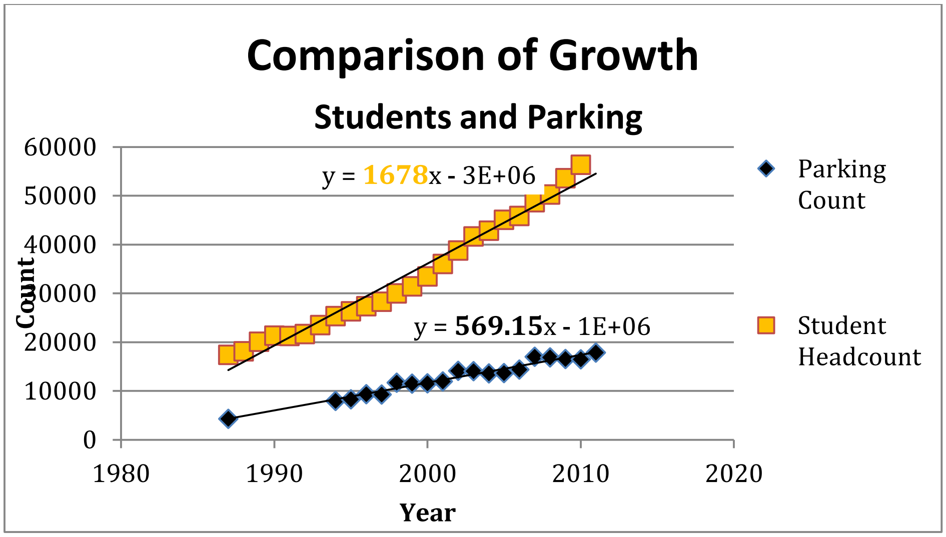


Figure 38, Growth Comparison Between Student Headcount and Parking Counts

Our simulation model has enable us to obtain a student square feet ratio based on the student growth population and the building square feet growth from the 1960s to 2010. We can see in Figure 39 that the greatest ratio is at the starting point, when the university was created—few students and starting constructions—as it tends to stabilize through time. Some small increases relate to expansions and a square feet increase as a consequence.

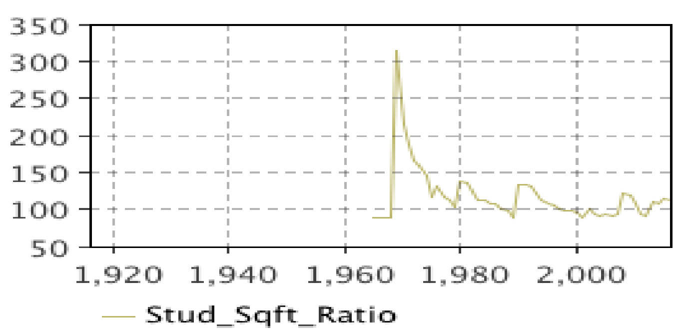


Figure 39, Predicted Student Square Feet Ratio

Student/Faculty Ratio

Our high-level model allows us to follow and forecast the student headcount, as we were able to see in Figure 36, where we presented the Historic versus Predicted Enrollment. In order to keep a desired equilibrium with respect to student/faculty ratio, a university should keep enrollment and faculty retention and hiring processes well balanced. UCF student headcounts seen in Figures 40 and 41 reach up to near 57,000 students for 2012-2013.

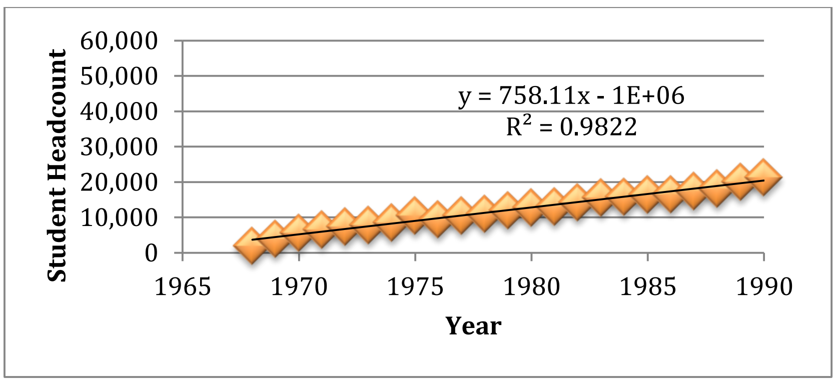


Figure 40, UCF Student Headcount Until 1990

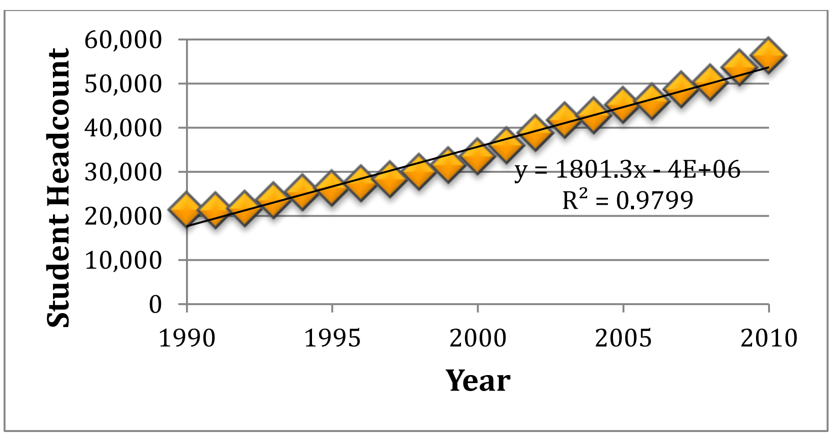


Figure 41, UCF Student Headcount from 1990 to 2010

Student and Faculty Growth and Ratio for the last 20 years are represented in Figure 42. We can see that the increase in faculty was around 50% every five years from 1970 to 1985, but from that point on, faculty growth has slowed. Figure 43 shows how a ratio of 23 students per faculty in 1970 went up to 43 students per faculty in 2010.

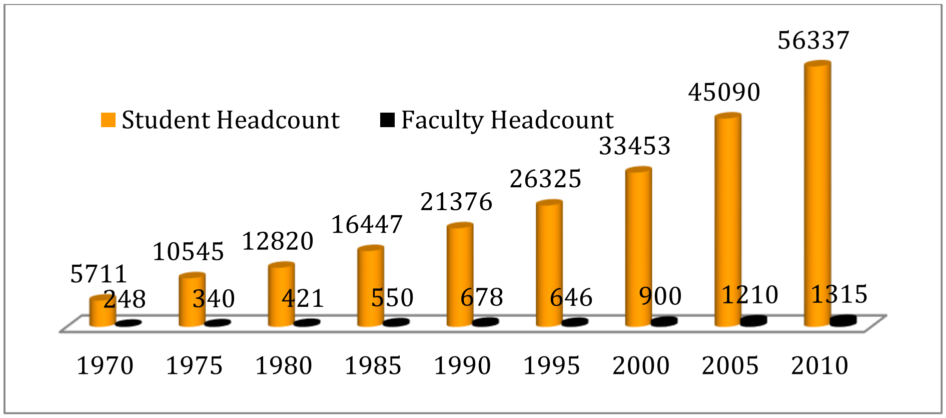


Figure 42, UCF Student and Faculty Growth

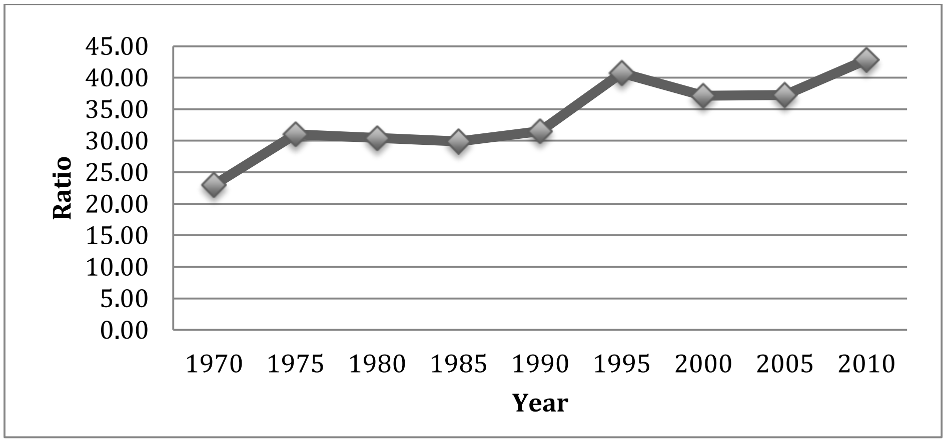


Figure 43, Student/Faculty Ratio

Our predicted Faculty/Student Ratio is shown in Figure 44, and it closely follows the historic ratio from our data.

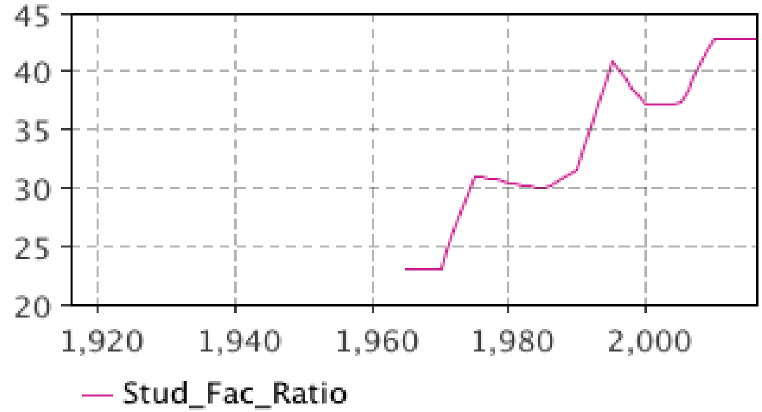


Figure 44, Predicted Student/Faculty Ratio

Monte Carlo Analyses and Parameter Variation

Our enrollment modeled allowed us to include experiments such as simulation runs or parameter variations. We were able to configure a set of parameters for use in our initial and main models. This parameter variation experiment considered several simulation runs where we are able to compare the behavior of the model with different parameters and how the variation of these parameters affected the model's behavior.

We need to summarize the results of multiple runs, and displaying or representing the stochastic processes finds one option for this in our simulation. We have represented the transitions between states and the duration of some procedures. This approach will result in a variation in the results from simulation to simulation.

As a way to be more confident in the model results, we have run a set of realizations dividing up time into specific parameters or a specific number of intervals. A form set of a specific number of intervals divides the horizontal axis (time) and the vertical axis. This 2D grid accumulates data based on trajectories included within the value of each cell, or in other words, the amount of trajectories that hold a value range over a certain time interval.

Our Monte Carlo 2D Histogram includes the following parameters, type, and values shown in Table 12.

Table 12, High Level Monte Carlo Parameter Variation Experiment

Parameter	Type	Value		
		Min	Max	Step
CCT_FTIC_Ratio	Range	1000	3000	100
Potential CECS1	Fixed	0.2	-------	-------
Potential CECS2	Fixed	0.2	-------	-------
Potential CECS3	Fixed	0.2	-------	-------
Potential CECS4	Fixed	0.2	-------	-------
FreshMajor	Fixed	.8	-------	-------
SophMajor	Fixed	.85	-------	-------
JunMajor	Fixed	.95	-------	-------
SenMajor	Fixed	.98	-------	-------

Our Monte Carlo analysis with fixed parameter values experiment is based on a collection of simulations. These simulations belong to a collection of replications that belong also to a set of runs. Results of these simulations after a period of 30 hours are seen in Figure 45, where retention trends may be observed by year. At the end of the simulation runs and following the input parameters, we can infer that from 2012 to 2015, student population will concentrate in Senior and Junior students reaching 18,100 and 16,000 respectively, followed by Freshmen with 13,400 and Sophomores with 11,000. These amounts seem logical, as retention rates have increased in recent years (better GPAs and better SAT score may be good indicators).

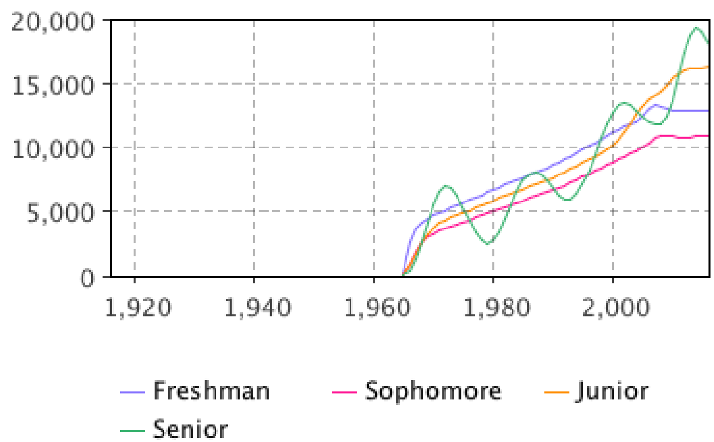


Figure 45, Retention Prediction by Type

In Figure 46 we are able to see how our simulation represented a strong decrease in dropouts. This analysis, following the rationale of the model, does not include Senior drop-outs as the amount is insignificant to be represented in this study. Also, as we expected, nearly 70% of all dropouts per year are concentrated among Freshmen and Sophomores at the end of the simulation.

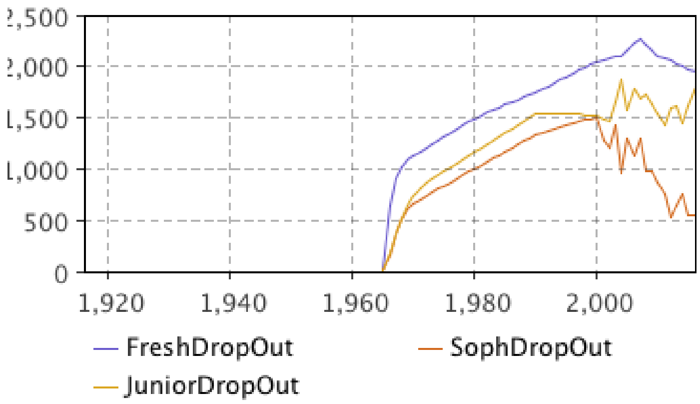


Figure 46, Dropout Prediction by Type

Following the analysis from previous graphs, Figure 47 clearly shows a great increase in passing rates that is related to the increase in the student population. Following the decreasing trends in dropouts, students tend to remain in the system longer. A special increase is shown in Junior passing rates, reaching the end of the simulation with nearly 15,000 students.

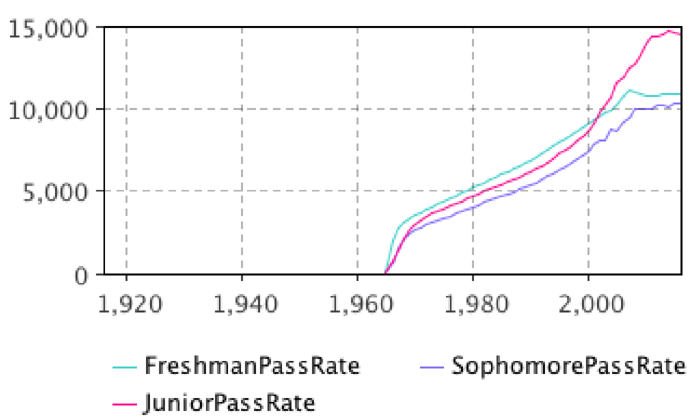


Figure 47, Predicted Passing Rate by Type

In this simulation, we are also able to see the overall input and output of the model. This simulation shows the oscillating behavior of the enrollment and graduating (including dropping out) process. Students expected to enter the system are also expected to leave it. Figure 48 shows the input and output of the system.

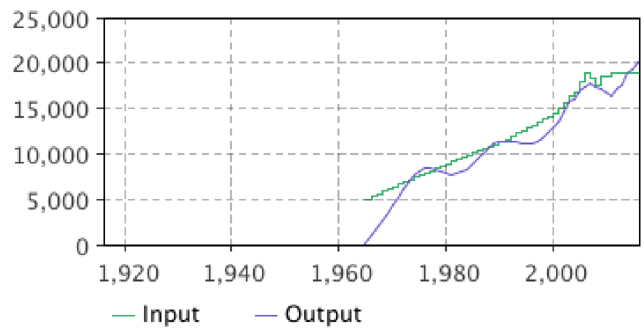


Figure 48, Input and Output from the Simulation

At a high-level enrollment simulation, we are able to visualize the predicted values by type, as we can see in Figure 49, reaching almost 60,000 students at year 2015. All four types have been assigned different colors. The growth of student population can be followed from 1964 to 2015, where the dimension and thickness represent the comparative and quantitative dimension for the Freshman, Sophomore, Junior, and Senior populations.

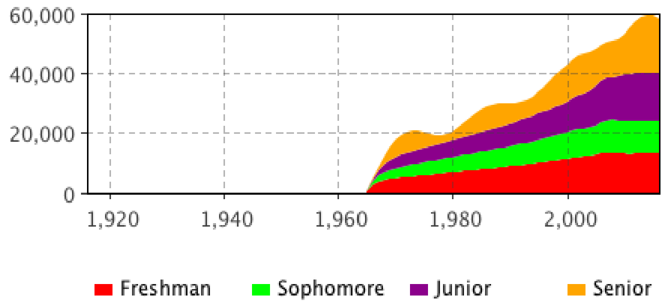


Figure 49, Predicted Student Growth by Type

According to the predictions for the year 2015, for a nearly 60,000 students population, with a FTIC/CCT ratio of 0.4113 (2011 historic ratio) our model is able to predict a student/faculty ratio of 1 assistant professor every 43 students, with a square footage of 114 sqf per student, and a parking count of 18,662 units.

For 2020, with the same FTIC/CCT ratio, the student population is predicted to reach 62,500 students, our model is able to predict a student/faculty ratio of 1 assistant professor every 47 students, with a square footage of 95 sqf per student, and a parking count of 19,980 units.

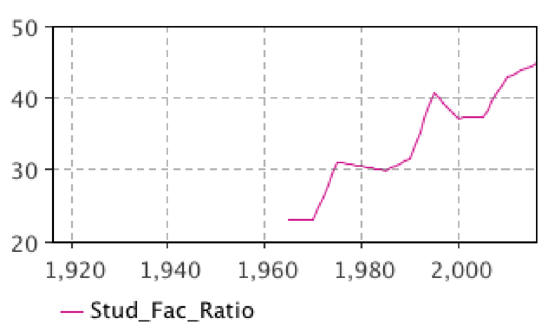


Figure 50, Student/Faculty ratio of 1/47 for a population of 62,500 students

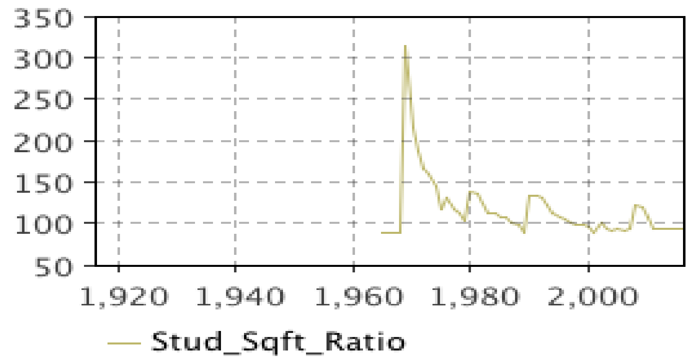


Figure 51, Square feet ratio per student for the year 2020

With a variation of the Student/Faculty ratio, let's say to 1 every 30 students, the amount of faculty required would have to increase from 1,325 for an average amount for the year 2013, to near 1,900, meaning an increase of 43%. No increase for square feet or new parking lots result from this as the amount of students remains steady.

For the year 2020, where the student population would reach 62,500, the amount of faculty needed for a 1/30 ratio is 2,084, which means an increase of 57% of the present amount.

On the other hand, the University may want to explore what happens if the FTIC/CCT ratio varies. In Figure 52, keeping a Student/Faculty ratio steady, we are able to see that for 2015 considering an enrolled population of 75% for FTIC and 25% for CCT, the total undergraduate enrollment decreases to 55,500 students. This may be influenced by the increase in the amount of time the average student would spend enrolled – which should lead to a bigger amount of students – and the passing rates that affect FTIC students during their staying. Historic passing rates show that FTIC students have a higher drop out percentage than CCT.

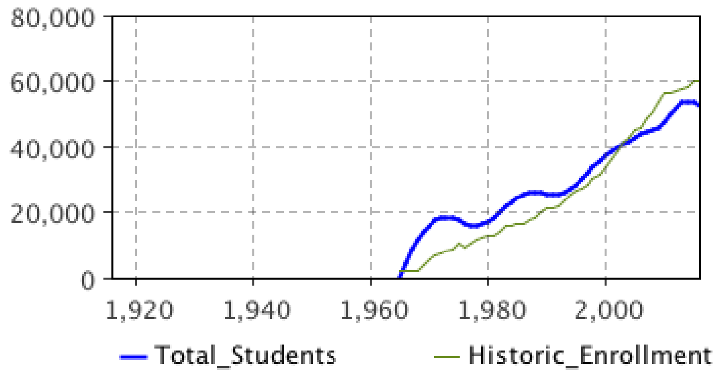


Figure 52, Decrease in student headcount as a result of a FTIC/CCT ratio variation

With this ratio, the amount of students may vary if we start to consider the SAT score as a measure of future performance. For this, a deeper study over the years should be done in order to follow students and their scores, over the years, to obtain trends. Once this is obtained, we would be able to incorporate it to the model and start analyzing fluctuations.

Several combinations can be done with the parameters we included in the model. For this, in order to take full advantage of the model, it is recommended to work with the full professional version of Anylogic ®, as it allows a full spectrum of experiments that in the student version are very limited.

Low-Level Representation

Low-Level Industrial Engineering Department

Our simulation considers the use of different resources: professors, graduate assistants, and classrooms, among others. From a DE implementation, the simulation needs to run over a time horizon but must be restricted by availability of resources. There is a limit in professors available as well as classrooms.

As we already saw in chapter 4, batches are created in order to form 30 students' classes, an amount that can be modified if required. This framework, the representation of the system, and the relationship of the components give us the chance to play with the resources.

Our experiment considers initially the use of five professors and five GAs. These resources will be combined with two classrooms for recording, but with a total of nine. Figure 53 shows that, with this initial set of resources, classroom 1 will be busy 94.7% of the time, classroom 2 61.3%; professors will be busy 76.3% of the time, and GAs 62.6%.

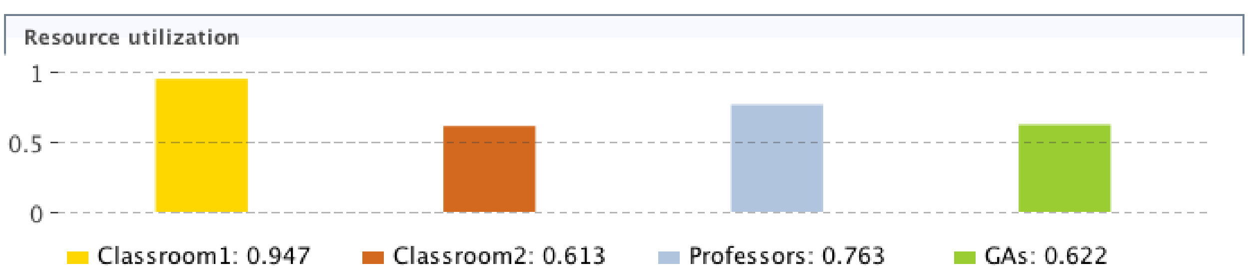


Figure 53, Resource Usage

In our Model Logic, we are able to see that while the system is busy, data is gathered by its components, from batch components to classrooms and professors resources, as we can see in Figure 54.

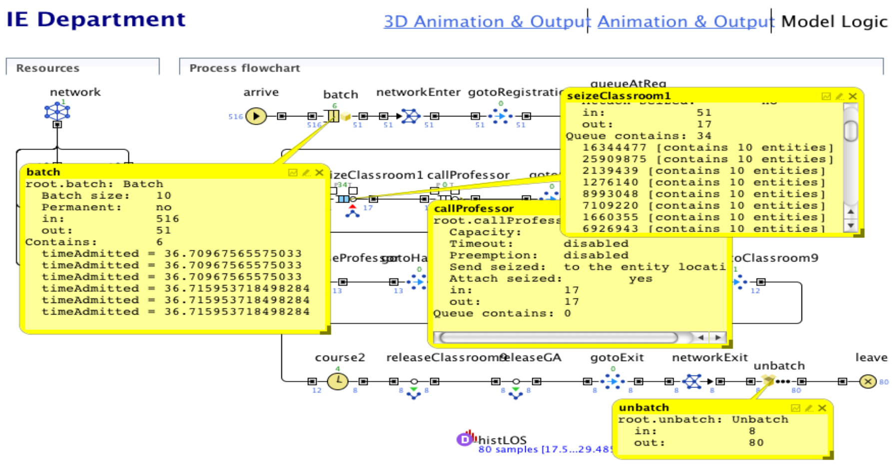


Figure 54, Model Logic

Following the simulation with parameter variation, we are able to see in Figure 55 that with the use of 1 professor and 1 GA mentioned, utilization of classroom 1 rise to 99.6%, professors are 100% busy, and GAs rise to 97.8%.

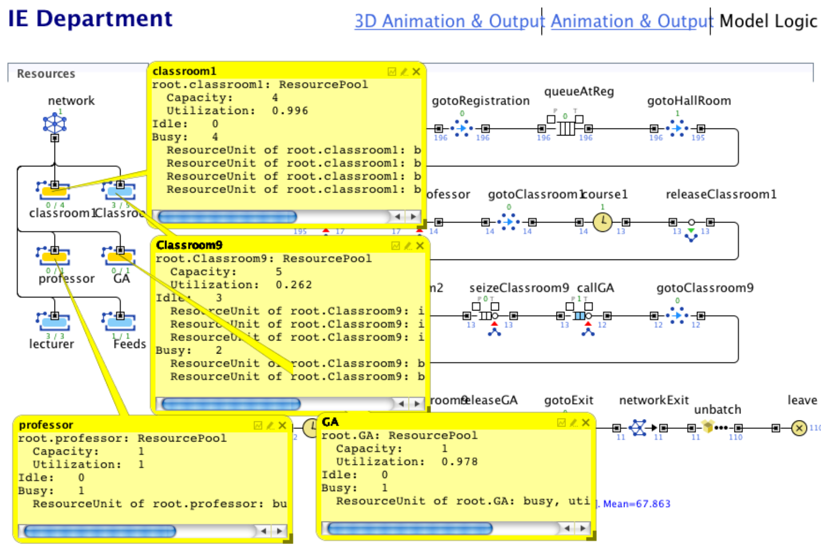


Figure 55, 1 Professor and 1 GA Resource Allocated

By the same token, if resources Professors and GAs are modified to 5 each, as we can see in Figure 56, their utilization drops to 79.2% and 74.2%, respectively. Classroom 1 remains 98.3% busy for simulation purposes.

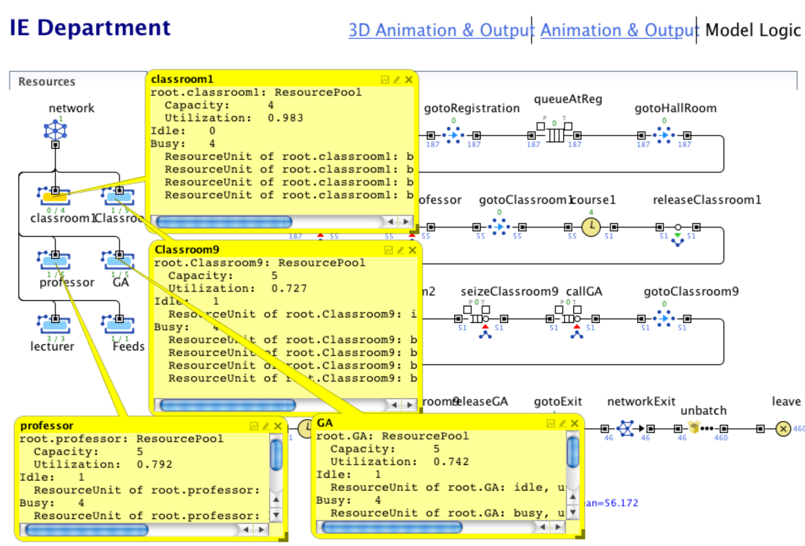


Figure 56, 5 Professors and 5 GAs Resource Allocated

For Classroom 1, resource utilization can be tracked and analyzed according to the following report:

root.classroom1: ResourcePool

Capacity: 4

Utilization: 0.996

Idle: 0

Busy: 4

ResourceUnit of root.classroom1: busy, utilization: 0.993

ResourceUnit of root.classroom1: busy, utilization: 0.995

ResourceUnit of root.classroom1: busy, utilization: 0.997

ResourceUnit of root.classroom1: busy, utilization: 0.998

For Classroom 9 resource use, we found the following:

root.Classroom9: ResourcePool

Capacity: 5

Utilization: 0.809

Idle: 1

ResourceUnit of root.Classroom9: idle, utilization: 0.826

Busy: 4

ResourceUnit of root.Classroom9: busy, utilization: 0.794

ResourceUnit of root.Classroom9: busy, utilization: 0.839

ResourceUnit of root.Classroom9: busy, utilization: 0.796

ResourceUnit of root.Classroom9: busy, utilization: 0.792

For Professors, resource use is the following:

root.professor: ResourcePool

Capacity: 5

Utilization: 0.803

Idle: 1

ResourceUnit of root.professor: idle, utilization: 0.809

Busy: 4

ResourceUnit of root.professor: busy, utilization: 0.786

ResourceUnit of root.professor: busy, utilization: 0.808

ResourceUnit of root.professor: busy, utilization: 0.798

ResourceUnit of root.professor: busy, utilization: 0.811

root.GA: ResourcePool

Capacity: 5

Utilization: 0.836

Idle: 0

Busy: 5

ResourceUnit of root.GA: busy, utilization: 0.841

ResourceUnit of root.GA: busy, utilization: 0.839

ResourceUnit of root.GA: busy, utilization: 0.83

ResourceUnit of root.GA: busy, utilization: 0.841

ResourceUnit of root.GA: busy, utilization: 0.828

Usage and time admission for batches (courses) are as follows:

root.batch: Batch

Batch size: 10

Permanent: yes

in: 9,838

out: 983

Contains: 8

timeAdmitted = 1963.9706464918206

timeAdmitted = 1964.1416720533848

timeAdmitted = 1964.188746983814

timeAdmitted = 1964.2855362241905

timeAdmitted = 1964.298739874166

timeAdmitted = 1964.8679646777287

timeAdmitted = 1964.9106848046274

Low-Level Course Assignment and Major Selection

In this low-level approach, we focus on how agents (students in this case) are able to choose majors according to certain parameters. We have determined certain assumptions that would help in estimating the amount of students that choose the IE major. As mentioned in chapter 4, students can be either Potential IE, may want to be in the IE major, or may be out of the election process due to certain reasons (low GPA, major change, dropout, etc.)

Figure 54 shows a run with the following parameters: Time for the simulation: one semester (August 10, 2012 to December 10, 2012), Course length: 90 days, Course capacity: 30 students, Delivery time: 90 days (it means that we assume no gaps in between), Availability: 100% (we assume no restrictions for registration), and Ratio: 40% (related to the decision of choosing the IE major).

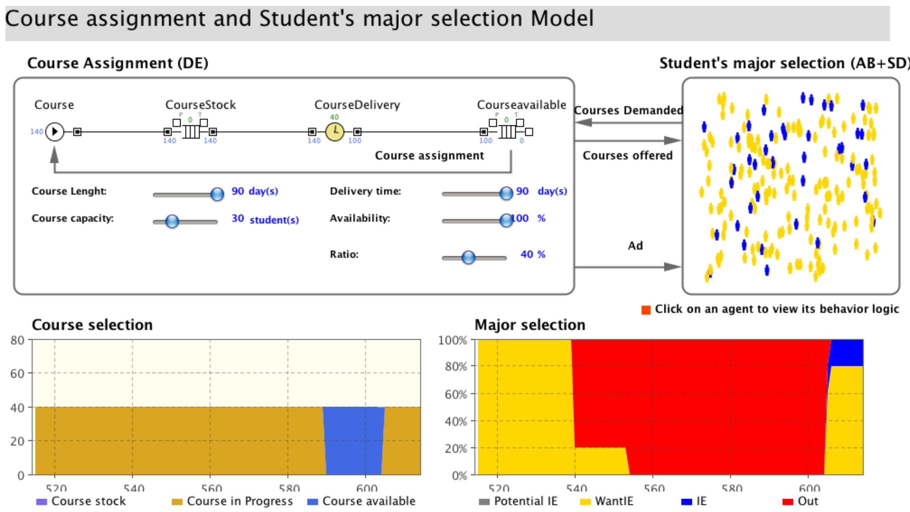


Figure 57, Course Assignment and Major Selection Simulation Run

In this simulation we are able to see the availability of courses (among 40) based on the demand provided by the agents. These agents remain in a status, shown in the right hand side graph, where we are able to see the percentage of students that are out of the system, have chosen a major, or still want to be IE. If we randomly select any of the agents, we will be able to see the state and in which internal process he or she is. Figure 55 shows agent #89, in blue, that is in the IE phase or selection.

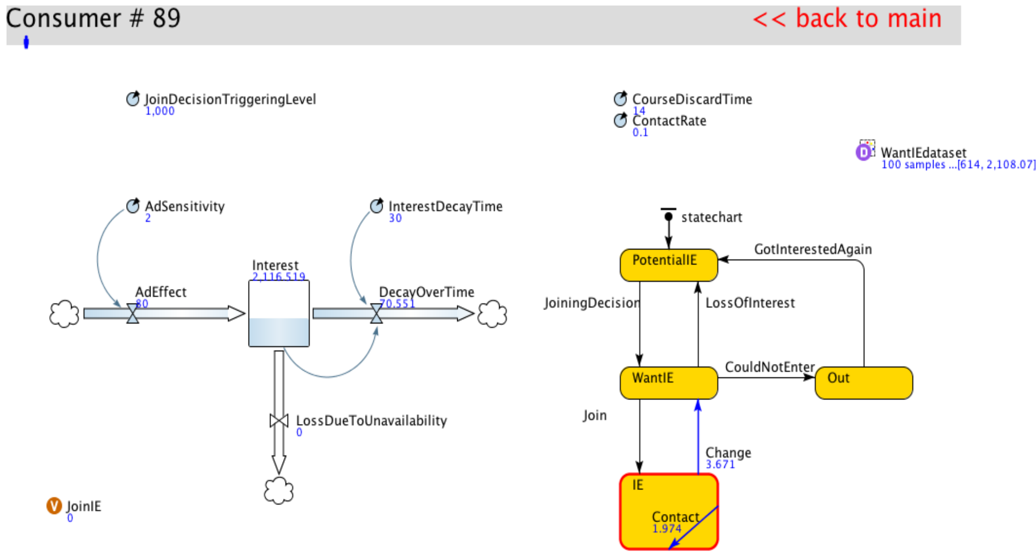


Figure 58, Decision-Making Process for Agent-Based Modeling

Each agent has the opportunity to choose. Statistics are formed based on the randomness of the process. We can also see in Figure 59 the usage and capacity of the logic model.

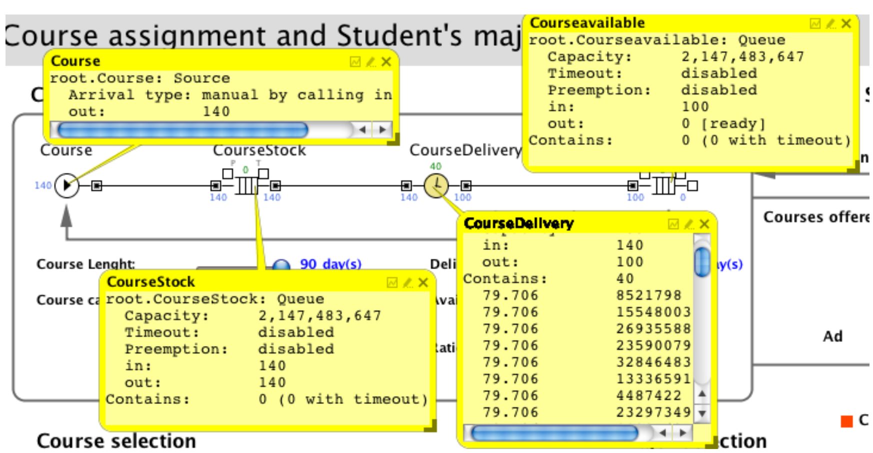


Figure 59, Logic Model for Course Assignment and Major Selection

If we alter the ratio and make a variation for 100%—which means that all students will be able to choose, there will be no drop-outs, and all student should meet the requirements for the IE major—the simulation indicates that there is no availability in the courses offered because the demand is too high. We can see this in Figure 60.

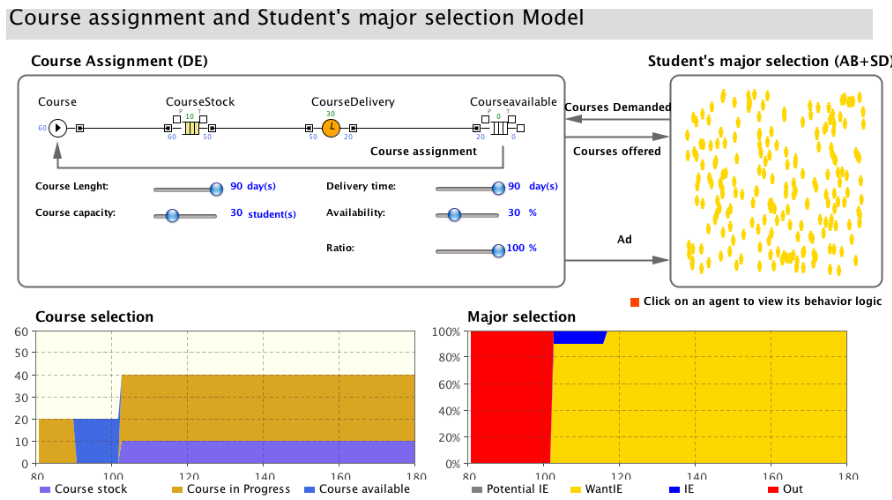


Figure 60, Course Assignment and Major Selection Run with 100% Ratio

Major selection is more exploratory than empirical. This simulation will require following students' decision patterns that were not available for this research. Despite the exploratory approach of this simulation, we believe that a lot can be done with use of parameter variation, or just multiple runs followed by valid data.

Despite we were able to make variations in the runs, we were not able to validate results as there is no enough data to follow students' decision patterns. There is an evident need in a way to gather data related to students' preferences. This information needs to be gathered at College and Department level, through surveys and data from enrollment at Department level, excluding students that do not belong to CECS.

CHAPTER SIX: SUMMARY, CONCLUSIONS AND FURTHER RESEARCH

Summary

Decision Support Systems and Computer Models are necessary for predicting future resource requirements (Hopkins D. , 1971). Universities, as complex organizations, have used traditional ways to predict enrollment and allocate resources, and they have not taken advantage of new technologies and techniques. Universities have dealt with Strategic Planning as a way to manage and allocate their resources. This planning usually establishes objectives and goals based on the authorities' guidelines and of course, their base information or previous data.

Strategic Planning can be understood as a mathematical method that represents all processes carried on by a university. These processes are linked and influenced by one another and, from an overall perspective, become a highly interactive and complex network of decisions. Within this network we find nodes represented by Colleges, Faculty, and Departments, each of them with particular needs and interests, and all of them influenced by the most important factor: Students' attendance or, in other words, "The Enrollment Process."

The Enrollment Process deals with the enrollment and graduation of students, at undergraduate and graduate levels. This process is complex and is a key factor for the Strategic Planning and long-term objectives or goals of any university. Enrollment rates, passing rates, graduation rates, and dropout rates affect university finances, even though state systems, like the Florida University System, provide most of the funds universities need for the academic year. Although these large amounts of funds are allocated to each state university, the money is not always enough to cover expenses, forcing universities to capture revenues from tuition, research, patents, and donations.

Efficiency in managing resources is becoming more and more important, considering the difficult time universities will have in the coming years due to difficulty in keeping the appropriate amount of money from state funding, the competitiveness from state and private universities (involving research funds, high-GPA student enrollment, among others), the excellence of the university level, and the long-term goals each university establishes (e.g., position itself as a high ranked research university), among other issues.

Resource allocation, as a key factor or essential component of an effective budget and planning system, needs to integrate good tools for decision planning and decision-making in order to decrease uncertainty. The Enrollment Management Process, as a way to capture the number of students needed for a university to survive and grow, is also a representation of how the university is doing and how it is perceived by the community—minimum SAT scores, and average SAT scores and, the amount of prospective students are some of the factors that differentiate universities from each other.

This study proposes another way to represent the complexity of decision-making for a university enrollment model, through means of modeling and simulation. The use of simulation for this complex representation will allow the inclusion of structure and variables for a university enrollment model that represents the overall process, adding a low-level perspective that reaches College and Department Levels. This new approach strengthens the Strategic Vision and foresees the impact of present decisions in the near future related to enrollment. At a lower level, this approach helps faculty and staff to adequately plan and allocate resources.

In this study, we selected the University of Central Florida as a case study. We selected the College of Engineering and the Department of Industrial Engineering in order to build a model and represent the simulation process from a general and high-level perspective, to a College and Department (low level) perspective, including course assignment and major selection.

We started by replicating the enrollment model in use (UAPS, 2013), and we replicated the overall and high-level enrollment decision process. We also incorporated a lower level that included College and Department, related to Industrial Engineering students.

The Institutional Knowledge Management and University Analysis Planning Support office from UCF provided all the data needed, including coded samples of all students enrolled from the year 2000. This included Student Information Files, Student Data Course Files, and the Enrollment Facts Files through UAPS, IRIS, and UCF Pegasus Mine Portal.

Enrollment information considered previous and current term enrollment data for multiple categories such as College, Plan, SubPlan, Gender, Ethnicity, Career, Residency, Full Time or Part Time classification, etc. These files included more than 156,000 headcount fields queried and filtered to obtain information with respect to the required variables considered in this study, such as COHORT_YEAR, EMPLID, STU,_TYPE, ACAD_GROUP, ACAD_PLAN, and Retention for 9 consecutive years among others.

Collected data from student records also provided information for low-level models with respect to cohorts, academic plans and majors, major declaration, and the ability to follow up students through time, specifically reaching the Engineering College and the IE Department.

Also included in the study is the data provided by the Undergraduate and Graduate Admission Department concerning prospective, registered, and admitted students for FTIC and CCT, as well as major declaration and changes for students from the IE Department, class schedule, classroom assignments, and load.

In order to represent the general enrollment process at a high-level perspective, we followed a System Dynamics approach. This representation included all incoming students and their transition through the university until graduation or dropout. This general high-level perspective starts with students joining the undergraduate program for the first time (First Time in College, FTIC) and in the first year, and with students coming from Community College Transfer (CCT) joining in the third year (5^{th} semester).

Students transition form term to term, drop out, change majors, or graduate. System Dynamics allowed us to represent interactions at a high level among all these components. Its dynamic structure provided us with the ability to represent all these interactions by use of stocks, flows, arrays, table functions, delays, and come other specific functions.

Causal feedback loops modeled the influences and relationships between several variables, integrating previous years' enrollment data to the current year. The SD models included use of Historic Enrollment Tables based on the last 10 years, Historic Passing Rates, and SAT scores. All these variables allowed the system to obtain several outputs like the amount of students at any point in time, the amount of FTIC and CCT students that remained in the system, dropped out, or graduated, and of course the graduation rates.

Our approach considered a middle level of abstraction, but still belonging to the high-level simulation, necessary to transition from the general enrollment to the College of Engineering and the IE Department. This model represented the overall flow from CECS students and a general trend of students that decide on a major or are still undecided, the only two trends programmed at this level. Historical data has been used to replicate the CECS student population as a ratio against UCF general population, as seen in table 4.

In our approach, a low-level simulation was necessary to replicate the flow of students when selecting a course initially for course assignment and when deciding a major. These models were made under a Discrete-Event and Agent-Based approach.

For course selection, we built a simulation layout that included several parameters like the amount of professors, graduate assistants, and classrooms needed to satisfy the demand of the flow of students, gathered as "course" formed by an specific amount of students.

In this model, students transition from their arrival, are batched in class size, and then start moving through a network traversing the IE Department where different professors or GAs are assigned. These resources are released after the class is dismissed. The course length is predetermined for 90 days, an amount that can easily be modified. Classrooms, halls, and hallways have capacities that define resource allocation throughout the model. Resource utilization and length of stay are the outcomes of the model.

For course assignment and major selection, we added the Agent-Based approach to the Discrete-Event modeling. We wanted to build a system that replicated the course creation (planning, formation, and running), and later a course selection process where students are compelled to select their major based on interest.

A student transitions from being a potential IE major to a declared IE major. Decisions for this are based on historical data and modeled in parameters leaving the agents (students) to independently start their decision processes. The choice to remain in the major or change major is considered part of the decision process as well.

Finally, this hybrid simulation replicates a general enrollment process, but it also helps in low-level decision-making as it reaches College and Department levels. If the model presented in this study is fed with long-term, continuous, systematic, and validated data, the use of it may become a great tool for planning at both levels, making this planning process something more scientific and precise, especially when there are numerous new variables that need to be considered today and that were not considered in previous and older models because there was no need for their consideration. Some of these newly considered variables are web-based courses, distance-learning degrees, distance-learning faculties (need for physical space?), steadiness in student population, reduction in face-to-face courses, and expansion plans, among others.

Conclusions

This study demonstrated that a new simulation-based approach can be used to help university decision makers improve their strategic planning and resource allocation. This research proposed a simulation approach not only to predict enrollment and retention but also to include other variables that may influence enrollment and retention. Our perspective included a high-level approach, as has been commonly used by universities, and lower levels as well.

Our retention and passing rate calculation showed to be a useful way to obtain these figures by analyzing all forms of departure previous to completion of a degree and by including the last two years of data, making these rates more realistic by considering students still attending the university, and leaving irrelevant historical data out of this process (American Institutes for Research, 2012).

As expected, we found that FTIC students are more susceptible to attrition. We also found that Freshmen' passing rate, over the last 10 years, has increased from 70% to 90%, increasing student retention and graduation rates as a consequence.

We compared and analyzed our model against real enrollment data, and we were able to see that our prediction differed from the actual values a 1.3% in 2011 and 0.08% for 2012.

To illustrate the impact of growth, we considered student headcount, new buildings, and parking. We analyzed the growth of student parking spaces and building square feet growth against student headcount, and we obtained, through our simulation, a student-to-square-feet ratio based on these factors. Our predicted results show a stepped growth (Figure 39) that reflects sporadic square feet expansion through the construction of new academic buildings and parking garages.

The simulated high-level student/faculty ratio replicates the data and, unless something drastic occurs, predicts a ratio of 1 faculty for every 43 students for the year 2015, something that is far from 1/30 from 1980. It is important to note that there has been a huge increase in this ratio between the years 2004 and 2012, which makes sense when we see the increase in student population and a lower increase in faculty hiring.

Through parameter variations, replications, and multiple runs, we were able to represent retention trends through time. Results of these simulations showed that, from 2012 to 2015, student population would concentrate among Juniors and Seniors, with 16,000 and 18,100, respectively, where Seniors show a bigger increase than the rest.

We were able to represent dropout behavior. This analysis showed that nearly 70% of all dropouts are between Freshmen and Sophomores (Figure 46). We were also able to replicate the increase in passing rates and student population from 2002 on, following a decrease in dropouts and therefore an increase in retention (Figure 47).

In our experiments, we were also able to obtain student/faculty ratio, square footage and parking count according to FTIC/CCT ratio for different years. We simulated a change of the Student/Faculty ratio from the present one, 1 faculty for every 47 students, to 1 faculty for every 30 students (UCF's ratio in 1980), to predict the amount of faculty needed to fulfill the expected 2015 demand. The results indicate that the number of faculty should increase from 1,325 to 1,900, meaning and increase of 43%, to attain the ratio observed at the university in 1980. We also determined the amount of faculty needed for 2020 for a 1/30 ratio, representing this in an increase of 57% from the present figure. We also explored variations in FTIC/CCT ratios to predict student headcount and we concluded that several combinations could be done with the parameters considered in the model like SAT and passing rates. For these parameters we established the need to gather data over the years, following students with different SAT scores and performance as a way to obtain trends useful to be incorporated in the simulation.

The Operational Level Simulation reflects acceptable Classroom and Instructor utilization. Agents worked with faculty and classrooms resources, given a specific amount of time (term) for the simulation. Our ABM consisted on a first approach for Department resource management and didn't represent the actual UCF IE Department.

For course assignment and major selection, the agent-based model included behavior based on certain parameters and assumptions. This part of the study shows the interaction between students that demand courses and how the department satisfies that demand, and also how students become interested, how this interest remains, and how it decreases over time, affecting the decision of choosing IE as a major, changing their preference or not being able to join due to requirements. We were able to make variations in the runs, but we were not able to validate results as there is not enough data to follow students' decision patterns. Collection of well-planned, structured data over students' decisions on choosing majors, timing for this decision (Freshman, Sophomore, or Junior), and willingness to change their decision should be valuable if backed up by well-defined surveys.

The applicability of the model can be considered within UCF, or within any University Enrollment Process, at a general (University-level) perspective (decisions on number of new students to accept, academic facilities and parking garages to build, and faculty to hire), and to the corresponding components of this process, at a lower perspective (Colleges and Departments or any facility that deal with students, such as research labs, among others, and decisions on resources such as teachers, researchers, adjuncts, and graduate assistants) to meet the students' needs. Other fields that can benefit from this model are major corporations, government organizations, defense, security, and emergency agencies that deal with training, enrollment, and any type of recruiting system. These organizations usually have different levels and make use of specific training periods, faculty or instructors, facilities, and other resources that can be dynamically modeled in our system. The use of ABM can also help explore autonomous decisions within the organizations.

The use of this simulation approach should help decision-makers to effectively allocate resources more accurately, as general trends in enrollment can be easily identified by several methods.

This study should help strategic planning. It should help Faculty and Departments to make better and well-informed decisions about class formation, faculty needed to fulfill the demand, and resource allocation. Universities must not consider Enrollment and Retention processes and models only as financial or mathematical methods. They should be considered as highly complex, highly interactive, and sometimes unpredictable processes. Internal and external variables may influence decisions in an overall perspective, but there is still a need to integrate strategic planning to lower levels, especially at Faculty and Department levels, which are sometimes isolated from the decision-making process.

Further Research

The use of simulation provides a new approach for planning and resource allocation for universities. The flexibility of a simulation approach has allowed the inclusion of several variables that may have a weight in enrollment, attrition, and graduation of students, affecting decision-making at all levels.

Enrollment models should not be understood as single isolated models that help only high-level decision makers. This model should include not only high-level data, but data provided by lower levels. It should be considered more than a model, but a system, where all participants should provide data, use it, provide conclusions, and improve it by giving necessary feedback. At this moment, only specific entities within universities deal with this type of data, develop models, and present analysis, leaving outside the loop some interesting and useful points of view from the participants of the system itself.

For a better understanding, we will give some level-based suggestions for further research as follows:

i. High-Level Simulation

   a. This simulation used data provided by official entities of a university. The re-creation of the process has followed the regular approach universities use. However, the inclusion of certain variables and the manipulation of them require them to be available permanently. Among these variables, we find passing rates, SAT scores, and any other test that limits or affects the entrance of students. SAT scores are not included in this simulation.
   b. Research should be conducted on the impact of the FCAT (Florida Test required for High School graduation) scores and how the students succeed in college.
   c. For the SAT test taken by all FTIC students and the PERT test that Community College students take, there is a need to research how well high-scoring students perform through the university. Relationships between SAT (and PERT) scores and attrition should be researched, as test scores may be significant predictors of how successful students are while studying, how their GPA increases or decreases, and how attrition is affected. We believe that this

research can improve the current model's capability to determine, for instance, possible correlations between retention and academic levels, and between certain majors and graduation rates.

ii. Low-Level Simulation

a. A higher fidelity operational model should include agents to simulate each departmental faculty following rules for course assignment (limits in the number of courses taught per term and matching between faculty's desires and expertise and course assignment) and an agent (under-graduate coordinator) who handles all details concerning the number, capacity, and schedule-availability of the rooms available to the department in a given semester, the specific courses to be offered following a regular student flow requirement, the assignment of courses to faculty, and the decision on the hiring of adjuncts

b. The study should be continued and spread to all Colleges and Departments. At this time, UCF's IEMS will not be able to use the model with the way data is being used. There is a need for better data. This new approach requires multiple tasks far beyond the capacity of a single researcher, therefore a team must be formed, and exclusive dedication should be given. This team, working for the high-level modeling, may be included as part of the IKM Office staff, facilitating access to data, and being placed under the office that supports decision-making at different levels throughout the university. With this new approach, the university will be able to model student population, professors needed, courses to be offered, and the corresponding interaction among these resources at department and college levels. By including the course scheduling requirements, the courses each professor is able to teach, and number and capacity of classrooms, departments will be able to project the need for new facilities and, more important, new faculty (and their specialties) to adequately fulfill the expected demand over the next few years. With this, if there is a need for hiring professors, the department will be able to start the required process and avoid last minute decisions, especially considering the cost of hiring professors, and the time and effort invested in this.

c. Colleges should start collecting their own data related to major selection, class formation, and faculty current and future use, selection, and retirement. This data should be shared with the IKM Office in order to be included in the analysis.

d. Departments, following this data collection need, should support Colleges and work together by gathering their own data. The use of a simulation approach should help with tactical decisions like class assignments, course formation, faculty assignment, and hiring, etc. If Departments are able to be part of this system, high-level decisions like building more parking lots or buildings will be backed up by this lower-level data and analysis that should be able to interpret and show students' behavior.

e. Our current model includes total student enrollment, but how would the IE student population affect the System Dynamic's enrollment model? Our topdown model starts from general enrollment and reaches lower level up to IE major declared students. At IE Department, the amount of students varies, and a further step in this process would be to complement the model with an alternative bottom-up approach. If this is replicated to all University, Departments and Colleges would be able to see how their fluctuations in enrollment and attrition affects the overall University Enrollment Process, as well as changes in policies, or even costs.

APPENDIX A: TERM CODES FROM YEAR 2000 TO 2012

Term	Code
Fall 2000	1100
Spring 2001	1110
Summer 2001	1120
Fall 2001	1130
Spring 2002	1140
Summer 2002	1150
Fall 2002	1160
Spring 2003	1170
Summer 2003	1180
Fall 2003	1190
Spring 2004	1200
Summer 2004	1210
Fall 2004	1220
Spring 2005	1230
Summer 2005	1240
Fall 2005	1250
Spring 2006	1260
Summer 2006	1270
Fall 2006	1280
Spring 2007	1290
Summer 2007	1300
Fall 2007	1310
Spring 2008	1320
Summer 2008	1330
Fall 2008	1340
Spring 2009	1350
Summer 2009	1360

Fall 2009	1370
Spring 2010	1380
Summer 2010	1390
Fall 2010	1400
Spring 2011	1410
Summer 2011	1420
Fall 2011	1430
Spring 2012	1440
Summer 2012	1450

APPENDIX B: MODEL DOCUMENTATION

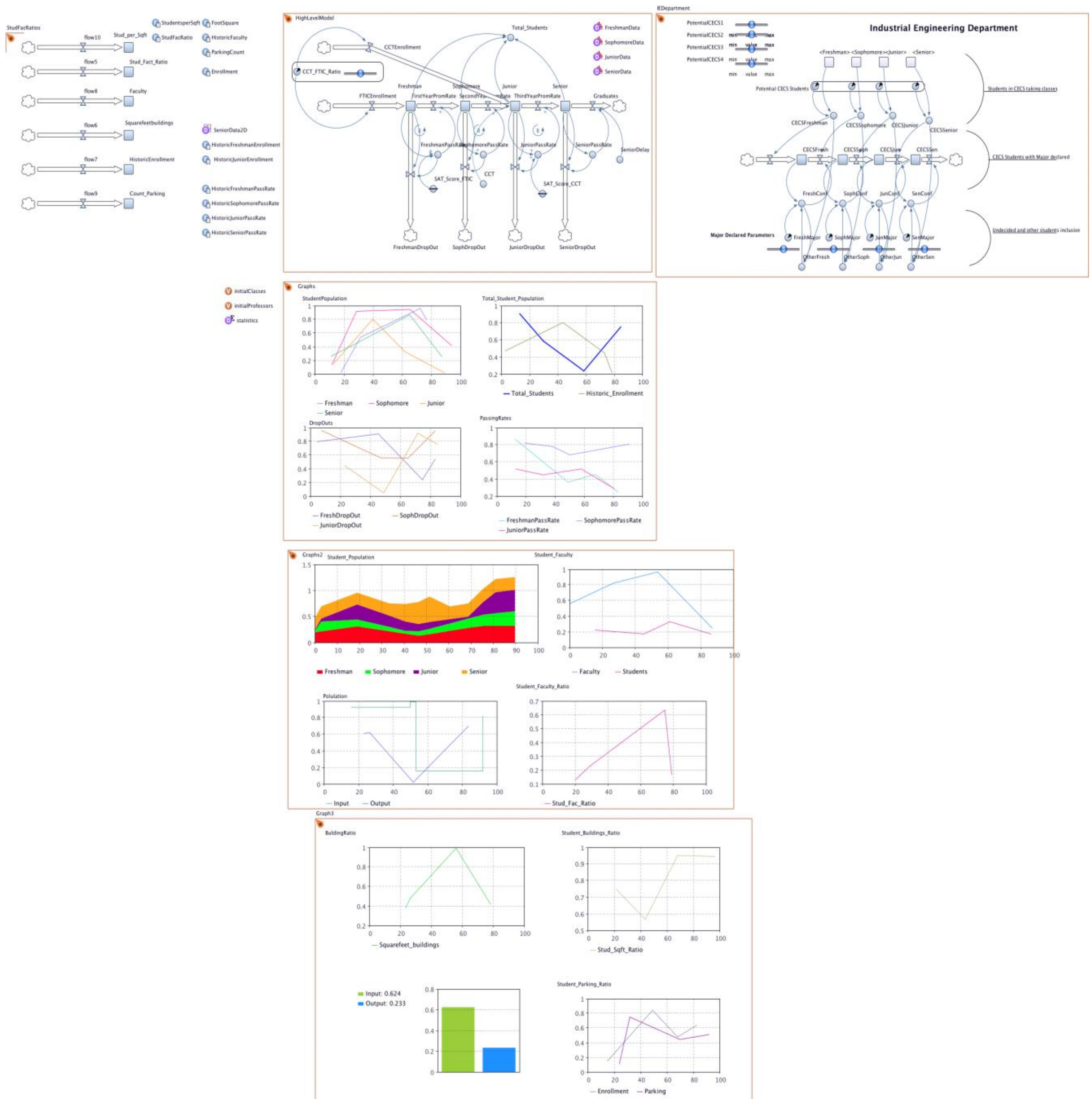
Model: Final High Level_6

Name	Value
General	
Java Package Name	high_level_01
File Name	/Users/Felipe/Desktop/Robledo Dissertation/Final High Level_6/Final High Level_6.alp
Model Time	
Model Time Units	Day

Active Object Class: Main

Description: Factor for the potential amount of students that join CECS, originally from their Freshman cohort

Name	Value
Advanced	
Auto-create Datasets	true
Recurrence	1
Dataset Samples To Keep	100


StudFacRatios
HighLevelModel
IEDepartment
Industrial Engineering Department
Students in CECS taking classes
CECS Students with Major declared
Undecided and other students inclusion
Major Declared Parameters
Graphs
StudentPopulation
Total_Student_Population
DropOuts
PassingRates
Graphs2
Student_Population
Student_Faculty
Polulation
Student_Faculty_Ratio
Graph3
BuildingRatio
Student_Buildings_Ratio
Student_Parking_Ratio
Input: 0.624
Output: 0.233

Parameter: CCT_FTIC_Ratio

Name	Value
General	
Type	double
Editor	
Editor Control	TEXT_BOX

Parameter: PotentialCECS1

Description: Factor for the potential amount of students that joinm CECS, originally from their Freshman cohort

Name	Value
General	
Type	double
Default Value	.02
Editor	
Editor Control	TEXT_BOX

Parameter: PotentialCECS2

Description: Factor for the potential amount of students that joinm CECS, originally from their Sophomore cohort

Name	Value
General	
Type	double
Default Value	.02
Editor	
Editor Control	TEXT_BOX

Parameter: PotentialCECS4

Description: Factor for the potential amount of students that joinm CECS, originally from their Senior cohort

Name	Value
General	
Type	double
Default Value	.02
Editor	
Editor Control	TEXT_BOX

Parameter: PotentialCECS3

Description: Factor for the potential amount of students that joinm CECS, originally from their Junior cohort

Name	Value
General	
Type	double
Default Value	.02
Editor	
Editor Control	TEXT_BOX

Parameter: FreshMajor

Name	Value
General	
Type	double
Default Value	.8
Editor	
Editor Control	TEXT_BOX

Parameter: SophMajor

Name	Value
General	
Type	double
Default Value	.85
Editor	
Editor Control	TEXT_BOX

Parameter: JunMajor

Name	Value
General	
Type	double
Default Value	.95
Editor	
Editor Control	TEXT_BOX

Parameter: SenMajor

Name	Value
General	
Type	double
Default Value	.98
Editor	
Editor Control	TEXT_BOX

Table Function: HistoricFreshmanPassRate

Name	Value
General	
Public	false
Interpolation	APPROXIMATION
Approximation Order	1
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1965.0	0.8
1970.0	0.8
1980.0	0.8
1990.0	0.8
2000.0	0.7
2001.0	0.72
2002.0	0.75
2003.0	0.73
2004.0	0.8
2005.0	0.81
2006.0	0.77
2007.0	0.82
2008.0	0.85
2009.0	0.83

Table Data:

Argument	Value
2010.0	0.88
2011.0	0.87
2012.0	0.9
2013.0	0.9
2014.0	0.9
2015.0	0.9

Table Function: HistoricSophomorePassRate

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1965.0	0.8
1970.0	0.8
1980.0	0.8
1990.0	0.8
2000.0	0.83
2001.0	0.86
2002.0	0.87
2003.0	0.85
2004.0	0.9
2005.0	0.87
2006.0	0.89
2007.0	0.88
2008.0	0.91
2009.0	0.91
2010.0	0.92
2011.0	0.93
2012.0	0.95
2013.0	0.94
2014.0	0.93
2015.0	0.95
2016.0	0.95

Table Function: HistoricJuniorPassRate

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1965.0	0.8
1970.0	0.8
1980.0	0.8
1990.0	0.8
2000.0	0.85
2001.0	0.86
2002.0	0.87
2003.0	0.86
2004.0	0.85
2005.0	0.88
2006.0	0.87
2007.0	0.88
2008.0	0.88
2009.0	0.89
2010.0	0.9
2011.0	0.91
2012.0	0.9
2013.0	0.9
2014.0	0.91
2015.0	0.9
2016.0	0.89

Table Function: HistoricSeniorPassRate

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1965.0	0.8
1970.0	0.8
1980.0	0.8
1990.0	0.8
2000.0	0.95
2001.0	0.95
2002.0	0.94
2003.0	0.95
2004.0	0.96
2005.0	0.935
2006.0	0.94
2007.0	0.94
2008.0	0.9345
2009.0	0.945
2010.0	0.95
2011.0	0.96

Table Data:

Argument	Value
2012.0	0.94
2013.0	0.954
2014.0	0.93
2015.0	0.95
2016.0	0.95

Table Function: HistoricFreshmanEnrollment

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Function: HistoricJuniorEnrollment

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1965.0	1000.0
1970.0	1500.0
1980.0	2000.0
1990.0	2500.0

Table Data:

Argument	Value
2000.0	3000.0
2001.0	3500.0
2002.0	3760.0
2003.0	4342.0
2004.0	4563.0
2005.0	4898.0
2006.0	5210.0
2007.0	4876.0
2008.0	4678.0
2009.0	5500.0
2010.0	6000.0
2011.0	5960.0
2012.0	5980.0
2013.0	6000.0

Table Function: HistoricFaculty

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1970.0	248.0
1980.0	421.0
1985.0	550.0
1990.0	678.0
1995.0	646.0
2000.0	900.0
2005.0	1210.0
2010.0	1315.0

Table Function: ParkingCount

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1987.0	4338.0
1994.0	7957.0
1995.0	8311.0
1996.0	9334.0

Table Data:

Argument	Value
1997.0	9281.0
1998.0	11685.0
1999.0	11503.0
2000.0	11586.0
2001.0	11998.0
2002.0	14122.0
2003.0	14085.0
2004.0	13614.0
2005.0	13711.0
2006.0	14388.0
2007.0	17005.0
2008.0	16915.0
2009.0	16540.0
2010.0	16503.0
2011.0	17854.0

Table Function: FootSquare

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1968.0	171105.0
1969.0	1235897.0
1980.0	1764171.0
1990.0	2845956.0
1998.0	2934319.0
1999.0	3077782.0
2000.0	3175814.0
2001.0	3175814.0
2002.0	3881524.0
2003.0	3910804.0
2004.0	3950809.0
2005.0	4186445.0
2006.0	4186445.0
2007.0	4541473.0
2008.0	6142966.0
2009.0	6431811.0
2010.0	6091717.0
2011.0	5250331.0

Table Function: Enrollment

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

:

TABLE DATA

Argument	Value
1969.0	3944.0
1970.0	5711.0
1971.0	6596.0
1972.0	7405.0
1973.0	7814.0
1974.0	8529.0
1975.0	10545.0
1976.0	9504.0
1977.0	10605.0
1978.0	11405.0
1979.0	12022.0
1980.0	12820.0
1981.0	13093.0
1982.0	14239.0
1983.0	15648.0
1984.0	15853.0
1985.0	16447.0
1986.0	16530.0
1987.0	17398.0
1988.0	18158.0
1989.0	20084.0
1990.0	21376.0
1991.0	21267.0
1992.0	21682.0
1993.0	23531.0
1994.0	25363.0
1995.0	26325.0
1996.0	27411.0
1997.0	28302.0
1998.0	30009.0
1999.0	31472.0
2000.0	33453.0
2001.0	36013.0
2002.0	38795.0
2003.0	41685.0
2004.0	42837.0
2005.0	45090.0
2006.0	45907.0
2007.0	48699.0
2008.0	50275.0
2009.0	53644.0

Table Data:

Argument	Value
2010.0	56337.0
2011.0	56698.0

Table Function: StudentsperSqft

Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1968.0	88.0
1969.0	313.0
1970.0	216.0
1971.0	187.0
1972.0	167.0
1973.0	158.0
1974.0	145.0
1975.0	117.0
1976.0	130.0
1977.0	117.0
1978.0	112.0
1979.0	103.0
1980.0	138.0
1981.0	135.0
1982.0	124.0
1983.0	113.0
1984.0	111.0
1985.0	107.0
1986.0	107.0
1987.0	101.0
1988.0	97.0
1989.0	88.0
1990.0	133.0
1991.0	134.0
1992.0	131.0
1993.0	121.0
1994.0	112.0
1995.0	108.0

Argument	Value
1997.0	101.0
1998.0	98.0
1999.0	98.0
2000.0	95.0
2001.0	88.0
2002.0	100.0

Table Data:

Argument	Value
2003.0	94.0
2004.0	92.0
2005.0	93.0
2006.0	91.0
2007.0	93.0
2008.0	122.0
2009.0	120.0
2010.0	108.0
2011.0	93.0

Table Function: StudFacRatio

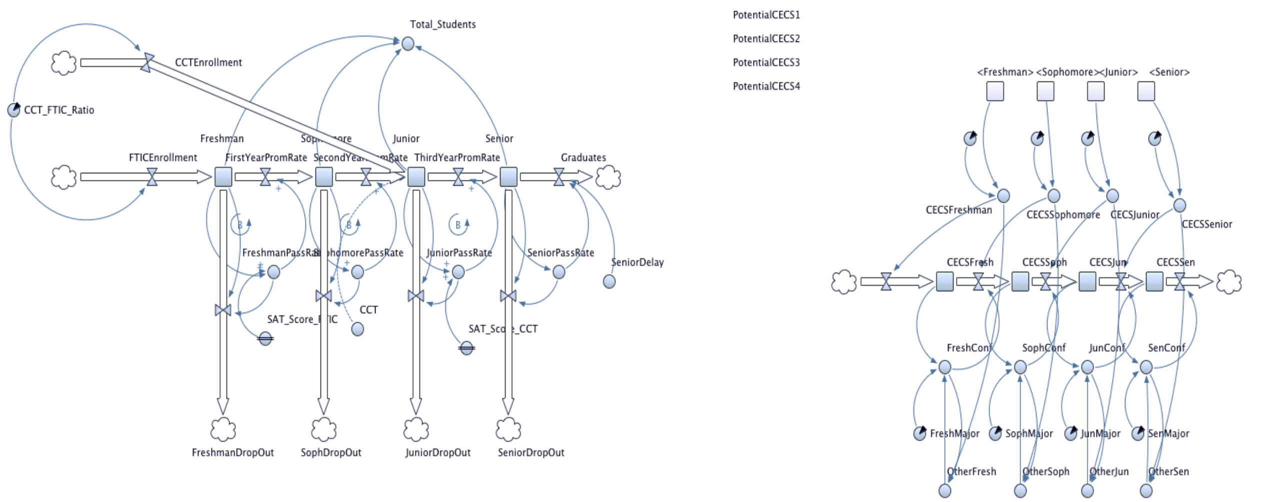
Name	Value
General	
Public	false
Interpolation	LINEAR
Out Of Range Behaviour	NEAREST

Table Data:

Argument	Value
1970.0	23.03
1975.0	31.01
1980.0	30.45
1985.0	29.9
1990.0	31.53
1995.0	40.75
2000.0	37.17
2005.0	37.26
2010.0	42.84

Variable: initialProfessors

Name	Value
General	
Type	int
Initial Value	4



Auxiliary: CCT

Name	Value
General	
Formula	1

Stock: Junior

Name	Value
General	
Initial Value	CCT
Expression	-Flow

Auxiliary: Total_Students

Name	Value
General	
Formula	Freshman + Sophomore + Junior + Senior

Stock: Freshman

Name	Value
General	
Initial Value	1
Expression	-Flow

Stock: Sophomore

Name	Value
General	
Initial Value	1
Expression	Flow

Stock: Senior

Name	Value
General	
Initial Value	1
Expression	ThirdYearPromRate - SeniorDropOut - Graduates

Auxiliary: FreshmanPassRate

Name	Value
General	
Formula	Freshman * SAT_Score_FTIC * HistoricFreshmanPassRate (time())

Auxiliary: SAT_Score_FTIC

Name	Value
General	
Constant	true
Value	1

Flow: FirstYearPromRate

Name	Value
General	
Formula	FreshmanPassRate

Auxiliary: JuniorPassRate

Name	Value
General	
Formula	Junior * SAT_Score_CCT * HistoricJuniorPassRate (time())

Auxiliary: SAT_Score_CCT

Name	Value
General	
Constant	true
Value	1

Flow: ThirdYearPromRate

Name	Value
General	
Formula	JuniorPassRate

Auxiliary: SophomorePassRate

Name	Value
General	
Formula	Sophomore * HistoricSophomorePassRate (time())

Flow: SecondYearPromRate

Name	Value
General	
Formula	SophomorePassRate

Auxiliary: CECSFreshman

Name	Value
General	
Formula	PotentialCECS1 * Freshman

Auxiliary: CECSSophomore

Name	Value
General	
Formula	PotentialCECS2 * Sophomore

Auxiliary: CECSJunior

Name	Value
General	
Formula	PotentialCECS3 * Junior

Auxiliary: CECSSenior

Name	Value
General	
Formula	PotentialCECS4 * Senior

Flow: flow

Name	Value
General	
Show name	false
Formula	CECSFreshman

Flow: flow1

Name	Value
General	
Show name	false
Formula	CECSSophomore + FreshConf

Flow: flow2

Name	Value
General	
Show name	false
Formula	CECSJunior + SophConf

Flow: flow3

Name	Value
General	
Show name	false
Formula	CECSSenior + JunConf

Auxiliary: FreshConf

Name	Value
General	
Formula	CECSFresh * FreshMajor + OtherFresh

Stock: CECSFresh

Name	Value
General	
Initial Value	0

Auxiliary: SophConf

Name	Value
General	
Formula	CECSSoph * SophMajor + OtherSoph

Stock: CECSSoph

Name	Value
General	
Initial Value	0

Auxiliary: JunConf

Name	Value
General	
Formula	CECSJun * JunMajor + OtherJun

Stock: CECSJun

Name	Value
General	
Initial Value	0

Auxiliary: OtherFresh

Name	Value
General	
Formula	(1 - FreshConf) * CECSFreshman

Auxiliary: OtherSoph

Name	Value
Formula	(1 - SophConf) * CECSSophomore

Auxiliary: OtherJun

Name	Value
General	
Formula	(1 - JunConf) * CECSJunior

Auxiliary: OtherSen

Name	Value
General	
Formula	(1 - SenConf) * CECSSenior

Auxiliary: SenConf

Name	Value
General	
Formula	CECSSen * SenMajor + OtherSen

Stock: CECSSen

Name	Value
General	
Initial Value	0

Flow: flow4

Name	Value
General	
Show name	false
Formula	SenConf

Flow: JuniorDropOut

Name	Value
General	
Formula	Junior - JuniorPassRate

Flow: SophDropOut

Name	Value
General	
Formula	Sophomore - SophomorePassRate
Use Units	true

Flow: FreshmanDropOut

Name	Value
Formula	Freshman - FreshmanPassRate

Auxiliary: SeniorPassRate

Name	Value
General	
Formula	Senior * HistoricSeniorPassRate (time())

Flow: SeniorDropOut

Name	Value
General	
Formula	Senior - SeniorPassRate

Flow: Graduates

Name	Value
General	
Formula	delay3(SeniorPassRate, SeniorDelay)

Auxiliary: SeniorDelay

Name	Value
General	
Formula	5

Flow: FirstYearPromRate

Name	Value
General	
Formula	FreshmanPassRate

Flow: ThirdYearPromRate

Name	Value
General	
Formula	JuniorPassRate

Flow: SecondYearPromRate

Name	Value
General	
Formula	SophomorePassRate

Flow: FreshmanDropOut

Name	Value
General	
Formula	Freshman - FreshmanPassRate

Flow: SophDropOut

Name	Value
General	
Formula	Sophomore - SophomorePassRate
Use Units	true

Flow: JuniorDropOut

Name	Value
General	
Formula	Junior - JuniorPassRate

Flow: FTICEnrollment

Name	Value
General	
Formula	HistoricFreshmanEnrollment(time()) * (2 - (CCT_FTIC_Ratio))

Flow: CCTEnrollment

Name	Value
General	
Formula	HistoricJuniorEnrollment(time()) * (1 + CCT_FTIC_Ratio)

Flow: CCTEnrollment

Name	Value
General	
Formula	HistoricJuniorEnrollment(time()) * (1 + CCT_FTIC_Ratio)

Flow: flow

Name	Value
General	
Show name	false
Formula	CECSFreshman

Flow: flow1

Name	Value
General	
Show name	false
Formula	CECSSophomore + FreshConf

Flow: flow2

Name	Value
General	
Show name	false
Formula	CECSJunior + SophConf

Flow: flow3

Name	Value
General	
Show name	false
Formula	CECSSenior + JunConf

Flow: flow4

Name	Value
General	
Show name	false
Formula	SenConf

Flow: SeniorDropOut

Name	Value
General	
Formula	Senior - SeniorPassRate

Flow: Graduates

Name	Value
General	
Formula	delay3(SeniorPassRate, SeniorDelay)

Stock: Squarefeetbuildings

Name	Value
General	
Initial Value	0

Flow: flow6

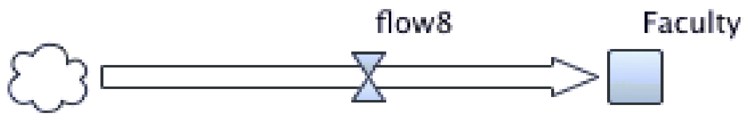
Name	Value
General	
Formula	FootSquare (time())

Stock: HistoricEnrollment

Name	Value
General	
Initial Value	0

Flow: flow7

Name	Value
General	
Formula	Enrollment (time())

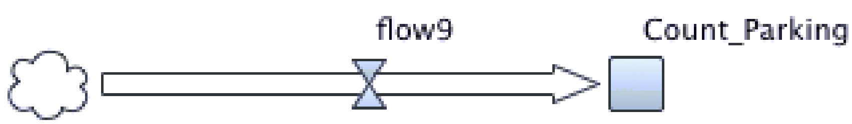


Stock: Faculty

General	
Initial Value	0

Flow: flow8

General	
Formula	HistoricFaculty (time())

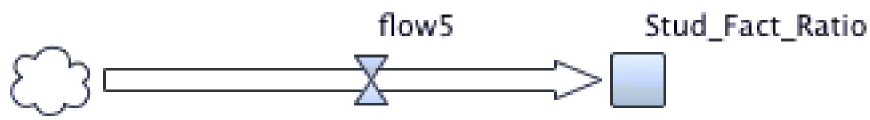


Stock: Count_Parking

General	
Initial Value	0

Flow: flow9

General	
Formula	ParkingCount (time())

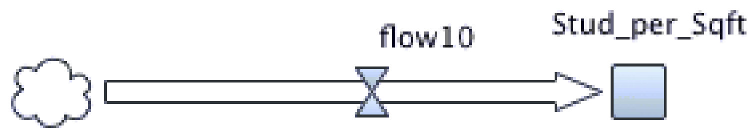


Stock: Stud_Fact_Ratio

General	
Initial Value	0

Flow: flow5

General	
Formula	StudFacRatio (time())



Stock: Stud_per_Sqft

General	
Initial Value	0

Flow: flow10

General	
Formula	StudentsperSqft (time())

Bar Chart: Balance_Chart

General	
Scale Type	AUTO

Analysis Auto Update	true
Recurrence	1
Advanced	
x	160
y	1980
Width	380
Height	210
Appearance	
Show Legend	true
Legend Place	WEST
Bars Direction	UP
Bars Relative Width	0.8

Chart Items:

Title	Color	Value
Input	yellowGreen	FTICEnrollment + CCTEnrollment
Output	dodgerBlue	FreshmanDropOut + SophDropOut + JuniorDropOut + SeniorDropOut + Graduates

Time Plot: StudentPopulation

General	
Show name	true
Time Window	100
Vertical Scale	AUTO
Analysis Auto Update	true
Recurrence	1
Dataset Samples To Keep	8000
Advanced	
x	10
y	580
Width	400
Height	250
Appearance	
Show Legend	true
Legend Place	SOUTH
Label Format	MODEL_TIME_UNITS

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