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HYBRID SIMULATION DECISION SUPPORT SYSTEM FOR UNIVERSITY MANAGEMENT

Luis F. Robledo
Jose Sepulveda

Industrial Engineering and Management Systems
University of Central Florida
Orlando, FL, 32816, USA

Sandra Archer

University Analysis Planning Support
University of Central Florida
Orlando, FL, 32816, USA

ABSTRACT

Decision support systems for university management have experienced limited improvements in the incorporation of new cutting-edge techniques. Decision-makers have used traditional forecasting methods to base their decisions in order to maintain financially affordable programs and keep universities competitive for the last few decades. We propose a new approach for enrollment modeling that would include all levels integrated into a unique and complete platform allowing hybrid simulation to respond to the decision-maker's needs. This simulation model considers the use of System Dynamics and Agent-based simulation, which allows the representation of the general enrollment process at the University level, and enrollment, retention and major's selection at the Department level. This approach allows lower level to predict more accurately the amounts of students for next term or year, faculty hiring, and class or labs assignment, and resource allocation among others.

1 INTRODUCTION

Over the last decades, public universities have dealt with constant increment in student population, and reduction in government funding. Universities, as complex organizations, deal with different kinds of assets; traditionally these assets include people, infrastructure, and technology, in addition to knowledge, reputation, ranking, social and community perception. Decision-makers have to consider all these factors in order to approach the goals of their organization. Examples of this are uncertainty, competitiveness, demand, and economic turmoil. For this, universities work based on a common concept called the "Strategic Plan" or Vision, which is a process normally based on indicators that allow decision-makers to predict some necessary information such as enrollment, continuity of students, percentage of expected graduation, retention, attrition, course information, degrees awarded, among others.

Planning and deciding is also based on financial needs. There is little to be done in the short term period but, if necessary changes are not foreseen with enough time, long-term goals may suffer and the expected growth of the university may be jeopardized (Al Hallak et al. 2009). If we think and see universities as highly complex, highly interactive, and sometimes unpredictable systems that depend on several internal and external variables, we may notice that decisions made today may not necessarily have an immediate impact in lower operational levels, which cause an alarming passivity when changes need immediate actions. Lack of faculty or inadequate student-teacher ratios, unpredicted growth in student population in some courses or majors, and parking and housing needs, may be some of the countless factors that may require immediate attention and, if not predicted timely enough, may represent a serious threat to performance.

Decision support systems at the university (generally) level have a wide definition. In general terms, we have to look at finance and enrollment as the two main trends. Enrollment forecasting now becomes 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 required to keep the university at a desired level, allowing also increment for quality, and recognition. If a university wants to capture good high quality students, a faculty body large enough in quality and quantity is required in order to sustain the financial stability for the university (Glover 2005).

Under strategic plans, operational levels should be included. This means that colleges and departments will suffer the results of a suitable or poorly designed plan. Enrollment planning and modeling is based on a general perspective that includes all incoming students either from First Time in College, Community College Transfer, or Others. No attempts have been made to link the strategic need for enrollment forecasting, with the operational needs for department planning for next term or year. At this point, colleges and departments base their predictions in last year's enrollment and attrition, and experience. Hiring faculty, classroom assignments, course planning, and even research goals become something risky and general.

2 CONCEPTUAL MODEL AND MULTI-PARADIGM SUPPORT

According to Hopkins, enrollment models in university management are used to obtain accurate forecasts in at least three major purposes: (1) Income prediction from tuition; (2) Course and curriculum planning; and (3) Allocation of marginal resources to academic departments (Hopkins and Massy 1981). We will focus on a general model that would be able to forecast enrollment and retention, from a university general strategic level, to a department specific level. For this, we consider a conceptual architecture of the model that would make use of different simulation techniques.

Due to the nature of the research, the source of the data, and the scope of the model, we identified the need of a top-down approach for modeling the enrollment process of a university at a general level, and a bottom-up approach that would consider department and college level of enrollment. The top-down approach requires the use of System Dynamics, and the bottom-up approach requires the use of discrete-event simulation and, as in this case, agent-based simulation, as it allows simulation to reach higher levels of abstraction. A general conceptual architecture can be seen in Figure 1.

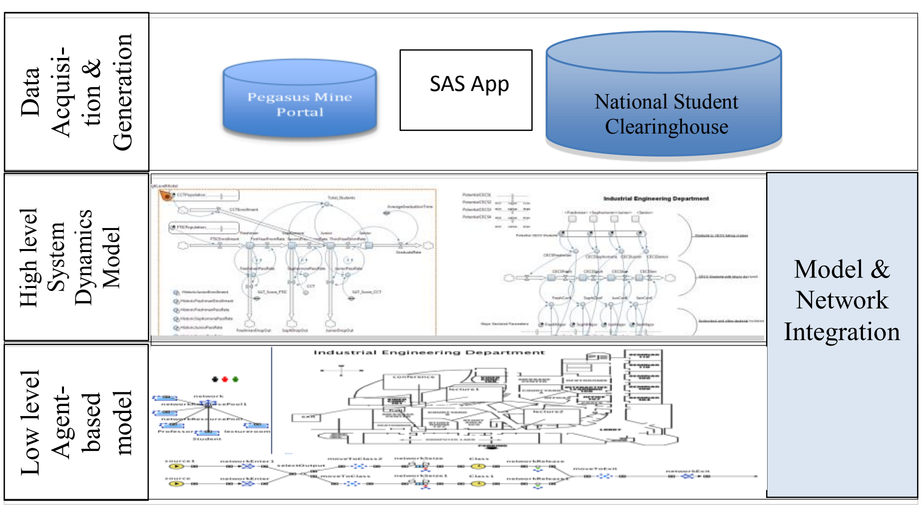

Figure 1: University enrollment model architecture and paradigm integration

System Dynamics, as a high-level simulation approach, focuses on the dynamics of the system, its representation, interactions between components, and the behavior between the actors within the system (Hu and Ma 2007; Forrester 1958). 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. For our model, it will allow us to represent the general performance of the enrollment model, with transitions between different states (levels), and diluting the process to lower levels.

DES and Agent-Based Simulation focus on a low level simulation approach representing all interactions within the College of Engineering and Computer Science and the Industrial Engineering Department. 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, lecturers, and classrooms.

With Agent-based simulation we are also able to represent the “major selection process”. This process represents decision-making based on students’ preferences. Here the students are able to choose the Industrial Engineering (IE) major, remain undecided, or withdraw from the process. To be able to choose IE major, students need to fulfill all minimum requirements.

3 METHODOLOGY

3.1 General Structure

A university decision-making enrollment model has several levels and participants. In this system, entities can be from organizations within the university, its economic units, students, or resources such as classrooms or labs. Interactions between these entities are affected by the surrounding environment. Agents at this stage can bring advantages when they can be modeled to specific requirements.

Among Decision Support Systems within higher education, we focus our attention in strategic management as it requires a comprehensive analysis of large data sets, and enables solutions at general and sometimes particular levels. Decision support systems for academic environments include areas such as (1) academic resources, academic advising, course scheduling; (2) resource allocation, planning and budgeting, corporate governance, performance assessment, strategic planning; and (3) admission policy, analysis of enrollment demand, capacity management and enrollment management (Hallak, et al. 2009).

An enrollment prediction model is a strategic tool for decision-making. It deals mainly with means of estimating headcount and student credit hours. These models consider a certain time span (5 years, 10 years or longer) and predictions are generally made over the previous year’s data.

For general use, these models work within reasonable margin of errors and predictions usually are for general decision-making. There is still the need to approach lower levels of decision-making to see in fact how the overall next year’s prediction behaves and affects department levels and specific resource allocation.

Simplistically, building a full enrollment model for a university would have to consider being general enough to allow overall prediction, and specific enough to allow departments to plan their resource allocation. It would have to consider common variables like graduation rates, student population projections, enrollment and retention, student headcount by type (FTIC, Transfer, etc.) and by classification (Undergraduate or Graduate) among others , and specific variables for a department like student headcount at that level, the selection of a major, available and planned classes, faculty, classrooms, and labs among others.

A large metropolitan university requires an enrollment model that would allow 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. Our network model framework for this will include a System Dynamics approach for high level simulation, and an Agent-based approach for low level simulation.

3.2 Process Definition

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, Community College Transfers students (CCT) join the enrollment process when they transfer from their respective Junior

Colleges, joining the third year (5th 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 is analyzed as many variables, activities or events that take place simultaneously and may influence each other.

The enrollment system is then divided into two levels and a common platform. These two levels 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. In Figure 2 we are able to see how different cohorts feed the enrollment model. A specific students' headcount in a particular year will then be calculated by adding all attending students at that time.

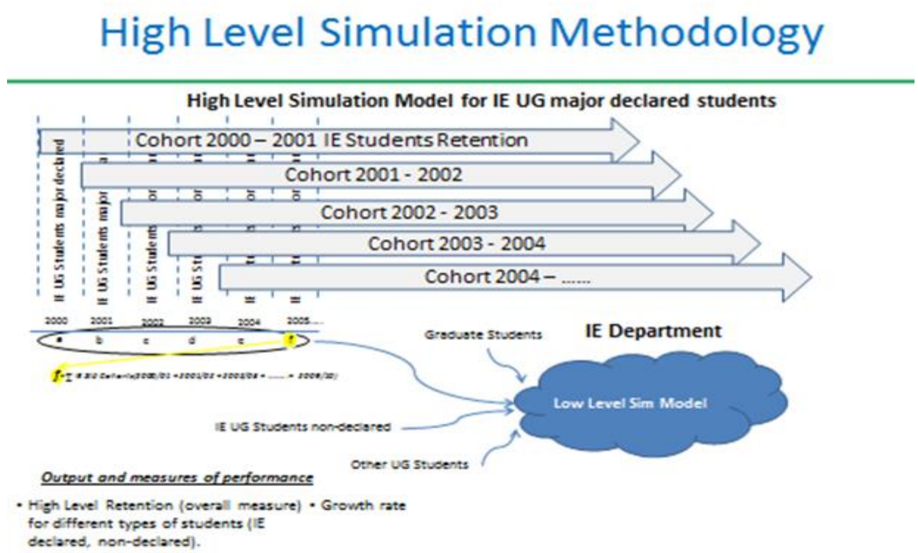

Figure 2: High Level Simulation for University Enrollment Representation

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 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, they can change any time by just filling out an application as many times as they want, as long as they comply 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 a declared Industrial Engineering (IE) major but has not passed the statistics class, they will be classified as pending until they pass the class.

For a low level modeling process considered in this simulation, all FTIC, CCT and Other students 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. The allocation of all these resources can be diagrammed as we can see in Figure 3.

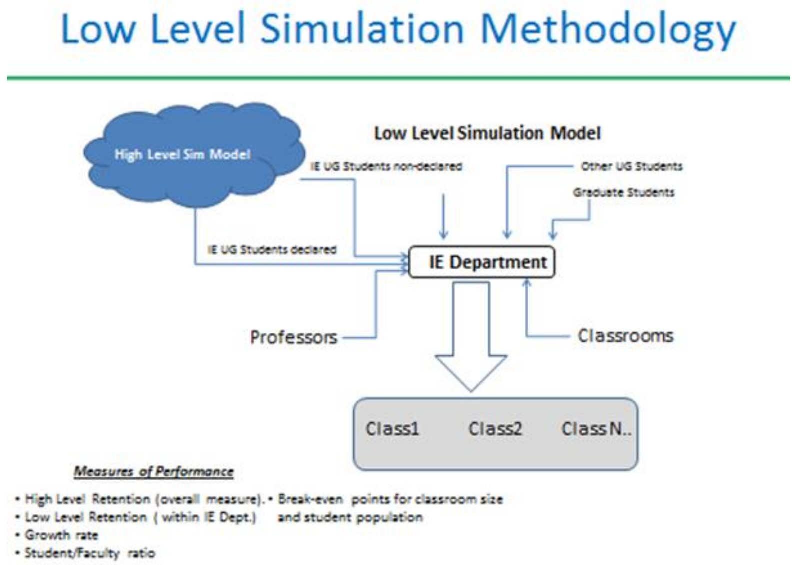

Figure 3: Low level Simulation for Department Enrollment Process

3.3 Modeling

Student population is represented in cohorts initially, and then is divided into individual entities (agents). As we start constructing the forecasting model, we shall assume that students enroll in defined time periods. We consider then that this time periods correspond to semesters and, that an academic year starts in August (Fall), and ends in July (Summer). Enrollment for simulation purposes include two discrete categories: cohort (or class) and major field of study (or simply major). In order to model students' behavior, we must be able to identify these categories within the available data. Mathematically speaking we can say that:

$$N(t) = \mathcal{F}[N(t-1), f(t-1), N(t-2), f(t-2), \ldots.] + f(t) \quad (1)$$

Where $N(t-1)$ is defined as a time period, $f(t)$ as the number of students enrolled for the time period, and $\mathcal{F}$ a mathematical function that would allow according to the available data, statistically and accurately represent the enrollment behavior.

We shall consider also that, as we want to make a difference in given categories, we need to identify these as class and major, by $N_j(t)$ and $f_j(t)$ respectively. j stands for class level (freshman, sophomore, junior or senior). Differing from Hopkins model and mathematical notations (1), new students enter the system as freshmen (FTIC) and as juniors (CCT). Other Transfers will be considered within the last two.

There are three known and general approximations for enrollment modeling (Hopkins and Massy 1981): (1) Grade Progression Ratio Model (GPR), (2) Markov Chain Model, and (3) Cohort Flow model. GPR is simple as it uses ratios of students by time units, making yearly predictions. Markov Chain Model is more complex than GPR although it uses the same basic structure; it adds up more granularity and allows the model to determine attrition between time units that, at this stage, can be based on quarters or semesters. It also requires more data. Finally, the Cohort Flow Model considers a longitudinal view of students' flow where students remaining in the system belong to different cohorts from different times in the past.

Our approach tends to be nearer to the latest model, as we consider students coming from different cohorts over time, and this projection tends to be stable over long periods of time as well.

Students are grouped into cohorts when they enter the university. From this point, a network flow is constructed so that we are able to track students throughout their stay. This approach is easily seen in the SD model for general and intermediate levels. Students flow from one year to another, in a longitudinal outlook, and they are identified according to the period they entered the university, the level of entry (freshman, sophomore, junior, senior), and the major chosen (specifically IE major that can also fall into 3 subcategories: IE declared, non-declared, and pending).

According to the IE Department, lower level students are tracked down by major selection, just as we mentioned before. It will be at this stage where they would be able to keep the chosen major, change it, or become pending as they haven't fulfilled the requirements needed.

4 INTERACTION BETWEEN PARADIGMS AND MODEL REPRESENTATION

The ability of capturing high level behavior through System Dynamics has an enormous relevance for low level multi-agent simulation. Disaggregation would allow effective resource allocation from a low level component of the organization. Replication of this would also allow us to obtain a more accurate overall predictive enrollment model.

Following a logical sequence of students' progression through time, entities (students) are grouped into cohorts that transitions from one state to another (freshman to sophomore, to junior and senior). This transition may be based on historical data from the previous 10 year enrollment registration, or based on a probability distribution given by the representation of the enrollment process though the years. This transition may be affected initially at the enrollment stage either at the first or third year, by SAT scores, and later by a predetermined passing rate. In Figure 4 we can see a System Dynamics approximation of a high level enrollment model. This System provides a transition and its corresponding probabilities, for different students cohorts from one year to another. We have estimated that the maximum retention time will be 7 years for any given student, but the median is in the fourth year.

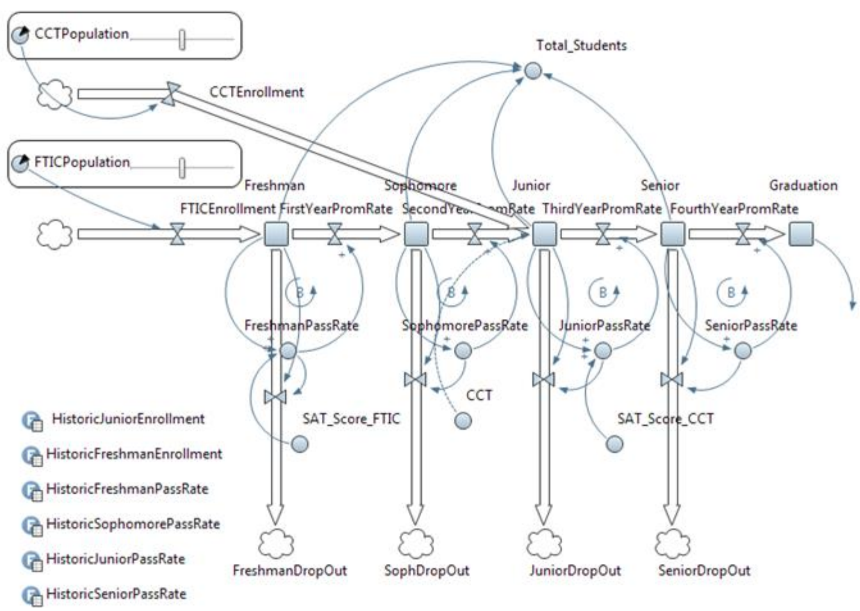

Figure 4: System Dynamics representation of a high level university enrollment model

SAT scores are one of the most influential factors for getting accepted into a university. SAT and high school GPA are good predictors of student's performance and are commonly used for predicting students' retention and attrition (National Research Council 2012). In this model, SAT can be used if decision-makers want to see how a change in score may affect enrollment and retention.

Passing rates are determined based on average retention at high level, and based on specific course achievement at low level. Student's behavior is initially determined by following selected students to see if they keep or change their major, if they fail or pass a course, or if they remain or leave the university. This behavior is emulated in the Agent's model where the agent focus on intentions as a way to constrain its reasoning. This way to approach the way agents decide limits strict commitment and allow representing the change of a major for a student that didn't make a good initial choice, or is just attracted to a new discovery as we all find in a certain point of our lives.

Allocation of resources is determined by creating batches of students according to chosen and available courses, available faculty, available classrooms with defined capacity, time schedule, etc. Entities will be able then to move to different classes as part of the transition they have to do to go from one state (freshman) to another (sophomore). The process starts with the selection of students and their transition from term to term (SD), and ends in a department level, allowing this to be able to plan for next term or year according to the amount of students in a specific IE major in this case, getting information about how many students switched major or dropped out of the department or university. It also allows planning according to faculty available, classes required and desired, classrooms and labs count and constraints, etc. Figure 5 shows the Industrial Engineering Department intermediate level within the College of Engineering and Computer Science students (CECS).

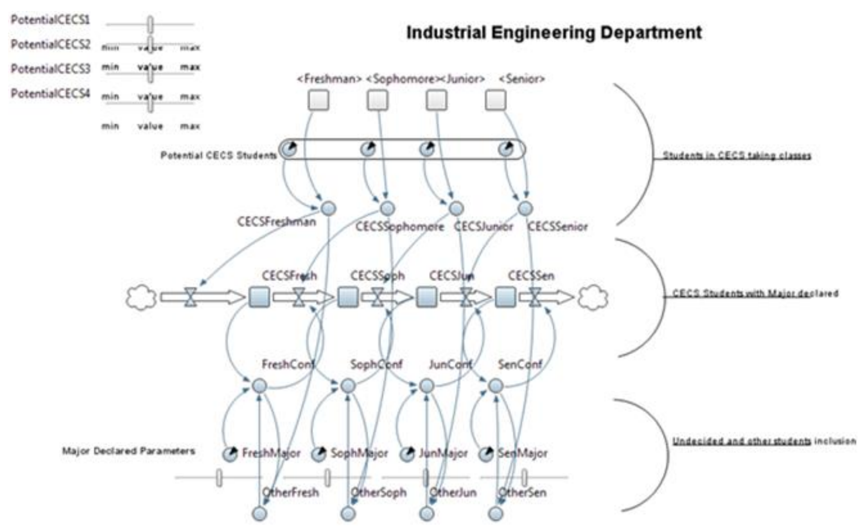

Figure 5: The Industrial Engineering SD Department level model.

Transitions between levels is based on Probability Distributions Functions (PDF). All PDFs are based and fitted from available data provided by the university. Faculty and Departments require an estimation of how many students will be in a given major, how many will enroll in specific classes, etc. Figure 6 shows this transition with an inherent agent-based decision model. The information that this system provides will give the foundations for next year's budget, considering for example the need to hire faculty, build more labs, buildings, parking lots, or any variable that until now have not being considered but are important enough to influence the overall budget and resource allocation of a big organization such as a University.

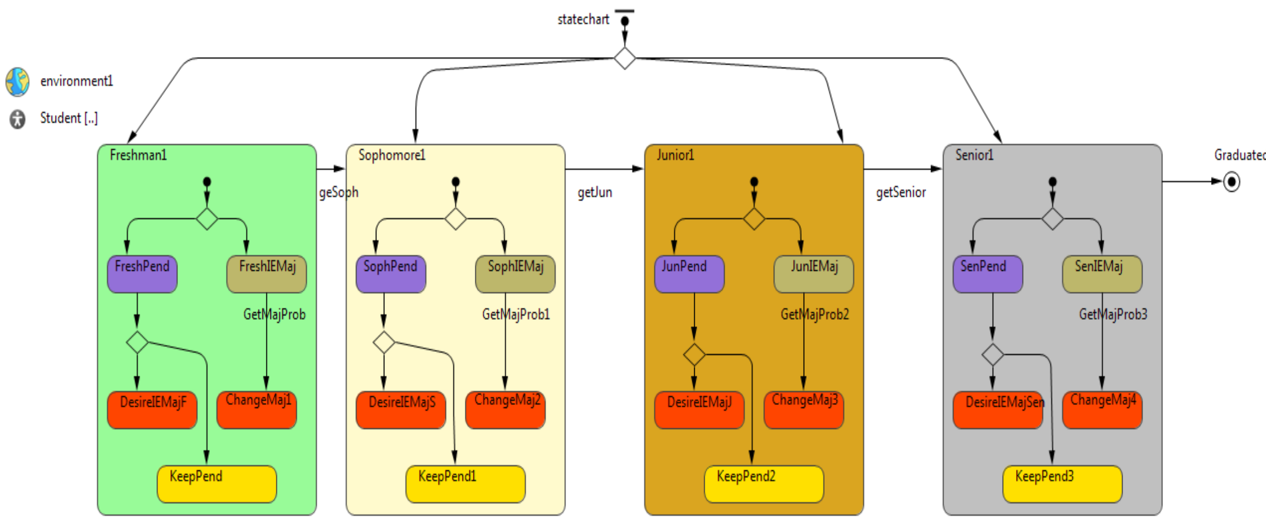

Figure 6: Agent-based representation of student transition and major selection

In Figure 6 we have to consider that for any individual student (agent) there is a list (Plan of Study) of specific courses needed at each state (Fr to Sr). Enrolling in a course depends on classroom and faculty availability. Passing a course is based on probabilities. Transitions from state to state are based on number of credits (32 credits approved to So; 64 to Jr, 96 to Sr, 128 to graduate). Transition to change major or dropout is based on probabilities as well.

Critical Path Courses, and some of the most representative ones were chosen to obtain the necessary statistics to determine student's behavior. Among them we find two main groups: (1) FTIC follow-up courses like Intro to Engr., Calculus I, Calculus II, Statistics, among others, and (2) CCT follow-up courses like Operations Research, Production and Distribution, System Simulation, Work Anal. & Design, among others. These two groups provides the necessary data to determine historical difficult courses, passing rates, attrition, and so on.

Capturing the dynamics of a complex system such as a multi-level enrollment decision-making model, may result in outcomes and indicators that not necessarily represent something expected (Lyons et al 2003). By this, we expects to see "Emergent Behavior" (Chan, Son, and Macal, 2010) as a result of the interaction of the agents and their decisions. This emergent behavior has been addressed by several authors and constitutes a point of inflection in the understanding of the students' conduct and quantification of their decisions. We will try to identify the cause of the emergence related to major selection as well. As for a low level interpretation, students are represented by agents, and the selection of alternatives (in this initial case just choosing a major) may produce unintended consequences, its fundamentals are given in the agent-based decision process inherent to each agent (student) when facing the decision of choosing a major (figure 6).

5 POSSIBLE OUTCOMES AND SCENARIOS

Potential "What if" scenarios are the most important part in any simulation model. This is just a small sample of what can be obtained when improving the representation of a university enrollment model. The simulation in this research reaches only down to IE department but, as there is an increasing need in reducing costs and improving efficiency, the present model can easily be replicated to the whole extend of the university, allowing efficiency to reach down to the desired levels.

In Table 1, we present three areas where improvement can be reached: Student success, University Management, and Investment and Growth. Each of them shows just a small sample of the possible outcomes of the current simulation.

Table 1: Potential scenarios for enrollment modeling and simulation

Student success	University Management	Investment and Growth
Students' Performance and Follow-up At high and low level, prediction of students' performance, attrition and retention.	***Trends and Emerging Careers*** Able to determine trends as a result of students' major selection and changes.	***New facilities, parking lots, dorms*** According to accurate predictions, course size would determine need for new classrooms, labs, etc.
Faculty/Student Ratio At department level, proper assignment of faculty to courses, classrooms, and amount of students.	***Faculty hiring process improved*** Department and College level would be able to foresee the need for faculty long before, improving the hiring process.	***Ability to attract Top Faculty*** Being able to determine faculty in a timely fashion will allow improving the level of this, bringing more qualified faculty, and attracting with them more research and funding.

6 CONCLUSIONS AND FURTHER RESEARCH

University management requires efficient resource allocation. Nowadays, universities are using traditional methods for enrollment prediction and resource allocation as part of their decision-making process. We propose the use of a Hybrid simulation approach that considers a high simulation level for enrollment and retention prediction based on system dynamics at university level, and a lower simulation level enrollment, retention, major selection, and resource allocation for department level. We anticipate that by observing the behavior of the system, new useful metrics will be available that will help resource allocation and improve decision-making processes at all levels. The future use and extension of this model within the university to all remaining colleges and departments shall be the next step in simulation modeling. This further step would allow obtaining accurate, timely, and effective enrollment and retention forecast that would help reaching the university's full potential.

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AUTHOR BIOGRAPHIES

LUIS F. ROBLEDO is a Geoinformatic Engineer from the Chilean Military Polytechnic Academy and a PhD student of the Modeling & Simulation Program of the University of Central Florida. He holds a M.S. in Modeling & Simulation from UCF. He has been working and researching in Simulation and Decision Support for the last 11 years. His research interests are Decision-Making and Support, Hybrid Simulation, and Emergency and Disaster Simulation and Management. He is a member of IEEE. His email address is luis.robledo@ucf.edu.

JOSE SEPULVEDA is an Professor of the Industrial Engineering Department at University of Central Florida. He received his Ph.D. in Industrial Engineering from the University of Pittsburg. His research interests are Simulation, Production Management, Statistics, Data Mining. His email address is Jose.Sepulveda@ucf.edu.

SANDRA ARCHER is the Director for the office for University Analysis Planning Support at the University of Central Florida. She holds a PhD from the same university. Her research interests are design and development of knowledge management systems to support University operations and university-wide planning. Her email address is Sandra.Archer@ucf.edu.