SIMULATING THE FLOW OF STUDENTS THROUGH CAL POLY'S UNDERGRADUATE INDUSTRIAL ENGINEERING PROGRAM FOR POLICY ANALYSIS

A Senior Project submitted

in partial fulfillment of the requirements

for the degree Bachelor of Science in Industrial Engineering.

the Faculty of California Polytechnic State University,
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ABSTRACT

Simulating the Flow of Students through Cal Poly's Undergraduate
Industrial Engineering Program for Policy Analysis

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The purpose of this project is to analyze the flow of Industrial Engineering students at California Polytechnic University San Luis Obispo in order to measure various graduation metrics by use of a simulation. Currently, graduation rates are relatively low in comparison with the rest of the state of California and future growth and decreased budgets may threaten graduation rates for incoming students. This simulation will identify bottleneck classes [those that hold up students from graduating] and provide a basis for a sensitivity analysis in which different scenarios are constructed to determine their effects on graduation metrics. The simulation will offer a Microsoft Excel Spreadsheet as an input in which any user could alter class capacities and offerings so as to determine the effects of these decisions. This tool provides a valuable resource for the Department Chair of the Industrial and Manufacturing Department at California Polytechnic University San Luis Obispo because it provides a high-level view of the impact of important decisions for the department. The project concludes with a sensitivity analysis of eight different cases that are analyzed to provide insight into whether or not certain decisions should be made about the curriculum. Of the many conclusions determined from the sensitivity analysis, it is noted that the department can sustain a 10% increase in enrollment of new students, but not a 20% increase in enrollment, while maintaining current graduation rates. Furthermore, the elimination of pass and fail rates from the system does not provide a significant effect on graduation rates and it is recommended that they stay in place. Additionally, it is noted that a reduction in capacity of 10% across all classes is very harmful to students while the adjustment of classes based on effective capacities [the percentage of Industrial Engineering students enrolled multiplied by class capacity] is highly beneficial. It is the hope that this simulation tool can be used by the department in making decisions similar to this in the future.

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I. Introduction

With industry constantly changing to adapt to new technologies and methods, the undergraduates of today must be prepared when they graduate for employment. However, due to increasing enrollment and budget cuts, many undergraduate students do not graduate in the typical four years and the quality of education may be decreased. As a result, there is a need to examine the curriculum process in order to understand the flow of students through a college by the use of a discrete-event simulation model. With this simulation, it would be possible to perform a sensitivity analysis in order to examine how to best plan curriculum for the maximal success of students. The goal of this project is to develop a tool that supplies curriculum planners of an engineering department with information regarding graduation rates as well as flow information of students.

The idea of simulating curriculum is relatively unheard of because it is not as clear cut as subjects that are typically simulated such as a repetitive manufacturing process. However, curriculum can be adapted to fit a simulation model and yield powerful results that could benefit all stakeholders involved in the educational process. Although the simulation model would only be used by the curriculum planners, its use could benefit students and faculty by increasing graduation rates, reducing costs, and implementing a more efficient curriculum system for faculty. For this reason, the simulation model represents a clear benefit to everyone involved and its effects could be mimicked in other departments.

The Client

California Polytechnic State University San Luis Obispo's Industrial and Manufacturing Engineering (IME) Department within the College of Engineering (CENG) is the client of this project. According to the most recent Cal Poly Fact Book, the department awarded 58 Bachelor's Degrees in Industrial Engineering for the year 2010-2011. This number has steadily increased annually since 2006 with increased enrollment while at the same time, budget cuts are forcing the department to cut back on spending. For this reason, it is becoming increasingly difficult to monitor everything within the major and a simulation model that tracks the flow of students throughout the college would not only be of high value, but it could simplify department planning in the future.

Currently, the flow of students through the IME department is not tracked in real-time; rather, it is something that can be looked up on a per student basis. As a result, a simulation model tracking *all* students within the system would greatly increase the efficiency of curriculum planning and if necessary, it could be used to make high-level departmental decisions including whether or not to eliminate certain classes or alter class capacity. Essentially, the tool for tracking student flow would support the Department Chair in making decisions regarding the future of the program which will become more and more necessary as an increasing number of constraints are applied to the IME department.

The Necessity

This project idea was developed with an interest in aiding the Industrial and Manufacturing Department by the use of a simulation tool that could be used to make high-level decisions within the department. Furthermore, with the possibility of a switch from the quarter system to the semester system as is suggested by current Cal Poly President Jeffrey Armstrong, the flow of students through a department should be well understood because curriculum must be adjusted without eliminating the efficient flow of students in the present system. Because Industrial Engineers often focus on ways to improve some of the most efficient systems, it seems only right to apply a simulation model to academia that will increase overall efficiency of the department.

In developing the simulation model, many Industrial Engineering skills will be used in order to devise a useful tool for the department. Specifically, the skills developed from the following classes are found to be very applicable:

- IME 312: Data Management and Systems Design
- IME 326: Engineering Test Design & Analysis
- IME 405: Operations Research II
- IME 420: Simulation

By the use of these classes, a simulation model will be developed and a sensitivity analysis will be conducted for initial observations. In working on the project, the following objectives will constantly be the center of attention so as to have the greatest effects:

- Understand the IME departments' needs and future constraints to implement into the simulation model.

- Devise a user-friendly simulation tool that will aid the IME department for future planning.

Limitations

This project will look into the tracking of student flow through the curriculum within Cal Poly's IME department. It is important to note that the model will only look at IME classes as opposed to the entire curriculum because the model would then become too complex for useful analysis. Furthermore, the model is based on the most recent curriculum known as the 2013-2015 calendar. Although this calendar is not published at this time, the cutout presented in Figure 1 below from the 2011-2013 calendar lists a selection of identical classes from the '13-'15 calendar.

MAJOR COURSES (86)	*Units*	*Grade*	*GrdPts*
IME 101 Intro Indust & Mfg Engr	1		
IME 140 Graphics Comm & Modeling	2		
IME 141 Mfg Proc: Net Shape	1		
IME 144 Intro Design and Mfg	4		
IME 156 *or* 157	2		
IME 223 Process Improve Fundamentals	4		
IME 239 Indust Costs & Controls	3		
IME 301 Operations Research I	4		
IME 303 Project Organization & Mgmt	4		
IME 312 Data Mgmt & System Des	4		

Figure 1: Cutout of 2011 - 2013 Academic Calendar

<http://ime.calpoly.edu/media/uploads/IE-1113_CurrSheet_RevB.pdf>

This project begins with a background of the current system of measures in place aimed at improving graduation rates and how it can be built upon. Assumptions will then be made in order to simplify the system to fit a discrete-event simulation model. Then, a simulation model will be developed followed by a Microsoft Excel spreadsheet that will be used as a tool for the

department in the future. The methods of this simulation and initial sensitivity analyses will be discussed in the remainder of the report.

The Approach

This project will be approached by developing an understanding for using a simulation tool as an adaptive simulation [in this case, adapting curriculum to a simulation format] by analyzing similar research. Next, the input into the Excel model will be created so as to illustrate present data that can be manipulated to meet any conditions the user would like. Then, the actual simulation model will be developed with outputs that provide abundant data for further analysis.

Following the creation of the simulation model will be the final phase of the project in which a sensitivity analysis will be performed on a variety of factors relating to curriculum offerings. Throughout the analysis, a variety of factors affecting graduation and flow inefficiency will be identified and manipulated during the sensitivity analyses. The main objective of this analysis is to provide the department with results to a variety of questions that they may have with regards to how high-level decisions affect students in the department. The development of these methods will be described in greater detail along with the recommendations later in this report.

II. Background

California Polytechnic University San Luis Obispo's Industrial and Manufacturing Engineering Department [referred to as Cal Poly's IME Department] has always been a top-tier department for undergraduate engineering degrees with its 'learn by doing' philosophy. As a result, this

project is very important to the university because it aims to improve an already great program by looking at what can be done to streamline the graduation process and ultimately make the four year graduation track possible for more students.

At this moment, a simulation package for the flow of students containing a user-implemented input does not exist for the IME department. Decisions for the future class offerings are made by several members of the department with the aid of previous enrollment data. Furthermore, the department is generally willing to increase capacity of classes, but there is no defined method to how far the capacity would expand. This is a serious topic because enrollment is increasing while there are still budgetary issues and the department could hit a breaking point in terms of scheduling classes. It is because of this trend that this simulation model will be of great value to those involved with curriculum scheduling in the department.

A sensitivity analysis will be performed on the simulation model so as to provide the department with example results in scenarios they may encounter at some point in the future. A sensitivity analysis can best be described as a systematic approach in regards to how the results of a model change as the inputs and assumptions are varied (Liu, 2006). In the case of the curriculum simulation, the inputs (class offerings defined as the number of sections of classes and their relative capacities) will be manipulated in order to analyze the effects on the students flow through the system. Whether or not students will flow more efficiently through the system based on the changes provided in the sensitivity analysis will be a key objective in this report. It is the hope that after performing the sensitivity analysis, there will be several ideas that could benefit the department and the students involved in the department.

Literature Review

This literature review will first clarify the responsibilities the department holds in planning the curriculum followed by related literature to the simulation and sensitivity analysis that will be performed. Although the literature related to the simulation of curriculum is very sparse, it serves a great purpose in providing ideas into how to best go about simulating the Industrial Engineering curriculum at Cal Poly. First, research related to simulating curriculum at other colleges will be discussed with the implications it has on this project. Next, methods and observations of enhancing curriculum will be mentioned in order to explain the importance of examining the curriculum for the IME department. Then, the use of simulation in unrelated systems will be mentioned in order to describe how simulation can adapt to so many different fields of study. Fourth, the ideas behind simulation as well as its benefits will be discussed so as to explain once again how the simulation will be a valuable tool. Finally, a simulation with cost analysis of another educational system will be analyzed to determine if any parallels may be made to the Cal Poly curriculum simulation.

The Cal Poly IME department has the main responsibility in determining the curriculum and for this reason; the simulation and sensitivity analysis generated from this project will be reported to them. The IME department generally schedules two years in advance and has projected schedules to that students can plan accordingly. However, nothing is ever set in stone and changes are destined to happen. As a result, this simulation tool will be useful in planning decisions because the department can analyze the effects of their decisions on student's graduation times. For example, if a course that has very limited capacity is only offered once a

year, the simulation would illustrate the disastrous effects on certain student's graduation rates. With the simulation, it would ideally prevent faculty planners from making these decisions.

Related Simulation Models of Curriculum

In order to develop a better understanding of simulating curricula, it became necessary to see what other research had to say about the topic. Saltzman and Roeder developed a simulation at San Francisco State's College of business in order to track the flow of students through the college for policy analysis. Although the college of business at SFSU is much bigger in size than the Department of Industrial and Manufacturing Engineering at Cal Poly, it is very easy to relate the two. Each contains complexities as the students flow through the system and SFSU has a similar amount of courses to be analyzed [19 courses to Cal Poly's 23]. Furthermore, by the end of the simulation, Saltzman and Roeder identified bottleneck classes and looked into certain scenarios to identify their effects on four and six year graduation rates. Once again, this contrasts greatly with the project at Cal Poly because one of the main focuses is to determine four year and five year graduation rates (Six year graduation is not a factor of interest). Finally, the researchers identified weaknesses of the simulation that they developed and it illustrated just how *complex* a simulation regarding curricula can really be. Much of the advice from the conclusions of this paper will be used in the Cal Poly model so as to make a great tool for the IME department (Saltzman, R.M. and Roeder, T.M., p2 – 12).

Moving towards a less related situation, Schellekens, Paas, Verbraeck, and Merrienboer describe a simulation intended to display the results of a flexible educational system. The idea behind a flexible educational system is to offer more sections of more classes so that students can fit

classes and internships in their schedules. Despite the interesting results behind this simulation, a program such as this one would not be implemented at Cal Poly because resources are so limited. However, because the flexible educational system offered such a variety of classes, it demonstrated the power of a simulation tool in planning classes. Additionally, the simulation model illustrated abundant statistics on anything from validation by questionnaires to the amount of weeks spent by various students in the system. Based on this information, it would be easier to show the amount of time spent in the system in terms of quarter rather than weeks. Although this simulation is much different than the curriculum simulation at Cal Poly, the same method of validation is going to be used in this report. Essentially, this will be done by comparing statistics from the simulation to published information about Cal Poly and its students. Next, a model using a different form of simulation will be discussed to examine elapsed time until a bachelor's degree (Schellekens, A., Paas, F., Verbraeck, A., and Van Merrienboer, JJG, p. 202, 206, 207).

Knight uses a method of path analysis in order to determine the amount of time towards the attainment of a bachelor's degree. In this study, Knight determines the strongest predictor relating to time to graduation to be the amount of semesters enrolled. Although Cal Poly is on a quarter system, it will presumably be the strongest prediction of time to graduation as well. However, since the complexity of having students that only register for certain terms would make developing the simulation for Cal Poly almost impossible, this will be excluded from the model. Additionally, based on Knight's method of path analysis, it became clear that the simulation is the better tool for Cal Poly's system since the department wants something to visually demonstrate the flow of students. Finally, the main takeaway from Knight's research is that there is a strong need to decrease the amount of time to a bachelor's degree because the cost

of education is increasing greatly and the graduates of today are carrying higher and higher levels of student debt (Knight, p. 1, 4, 5). The next study identifies another possible method of tracking the flow of students through education: Markov Chains.

The model proposed by Shah and Burke is a higher level model in that it looks at the entire educational system for Australia and uses predictors to determine if students will finish courses and estimate time in the system. Although unrelated to the specificity of the Cal Poly model, Shah and Burke identify major components of time to graduate as the time to complete classes as well as the probability of completing those classes. As a result, these two factors will be used in the IME simulation to determine the time to graduate. Pass and fail rates will be determined and there must be some method of determining the amount of time spent in each class by students. Despite this usefulness, Markov Chains will not be used in the Cal Poly model because a simulation is much more user-friendly for the IME department (Shah, C and Burke, G, p. 359-369).

Methods of Enhancing Curriculum

In order to better understand the reasoning behind tracking the flow of students, it became necessary to understand why enhancing curriculum is important. Kukreja, Ricks, and Meyer identify the constant need to analyze curriculum to maintain accreditation of the program. This is very important in understanding the purpose of the tracking of students at Cal Poly's IME department. Essentially, the department can use this simulation model to measure the impact of their decisions on the students and their respective graduation rates. If these rates go down and students are not happy, accreditation of the program may not happen and that would greatly

devastate the program. Furthermore, this study mentions the use of six sigma to increase the quality of the program at a business college. In this analysis, a cause and effect analysis is used to analyze certain aspects of the program. This type of analysis would certainly benefit the sensitivity analysis to be conducted by the end of this report (Kukreja, A., Ricks, Joe., and Meyer, J.A., p 9-14). The following study looks into enhancing Industrial Engineering curriculum specifically and how it can benefit students.

Eskandari, Sala-Diakanda, Furterer, Rabelo, Crumpton-Young, and Williams begin with identifying the necessity of analyzing curricula for improvements on regular basis. The authors indicate continuous improvement for curricula is necessary because Industrial Engineers have moved into "sectors beyond traditional manufacturing" and should be educated as such. For this reason, a simulation tracking the flow of students through the Industrial and Manufacturing Engineering Department at Cal Poly seems highly beneficial because it will be one of many tools a department chair can use to plan classes. Furthermore, the tool can output many statistical results as is demonstrated in this study. Finally, the authors mention a need to validate models before results are drawn from them. Validation will be one of the keys to the Cal Poly model because the results of the model are not useful without it (Eskandari, H., Sala-Diakanda S., Furterer, S., Rabelo, L., Crumpton-Young, L., & Williams, K., p. 45-54)

Simulation of Unrelated Systems

Developing a model on curriculum requires the use of adaptive simulation by using simulation for a topic that is not frequently simulated. For example, a process such as the manufacturing is easily translated into simulation package software. However, curriculum is not something that is

generally simulated so it becomes very useful to study the use of discrete-event simulation in the manufacturing environment in order to attempt to draw parallels between that and curricula. In this simulation on a manufacturing plant, Greasley notes that in many cases, simulations don't provide any real solution to a problem, rather, some additional analysis must be provided in order to benefit an organization. This was monumental in determining how best to benefit the IME department with the simulation package because it was decided that a sensitivity analysis must be conducted for a true benefit. By doing so, it also increased the complexity of the process, however, it is in the best interest of the department even though it will take longer to see the result of the simulation. Additionally, Greasley mentions the importance of a "What if?" analysis in order to demonstrate several scenarios of interest. As a result, this kind of analysis will be included by the end of this report (Greasley, A., p.534 – 544)

In another manufacturing system case study, Ingemansson, Torbjörn, and Gunnar identify the need to analyze bottlenecks in a given system and find ways to eliminate them if possible. Although unrelated to curriculum, this parallels closely with the Cal Poly model because one of the main objectives is to identify the bottleneck classes and find ways to eliminate them as well. The main goal of this is to increase efficiency of the system by reducing time to graduation and increase the rate of graduation among all types of students. In another parallel to the Cal Poly model, Ingemansson, Torbjörn, and Gunnar mention the importance of comparing initial simulations with existing data to determine the reality of the system. In a manufacturing environment, this is relatively easy to do, but the curriculum of the Cal Poly simulation is much tougher in that there isn't much data to compare to besides graduation rates and average amount of time to graduate. As a result, the simulation will have to be tweaked in order to match

available data to guarantee validation. Once the model is validated, the bottleneck's of the system will be "identified by studying the simulation runs" of the input data (Ingemansson, A., Torbjörn Ylipää, & Gunnar, S. B., p. 615 – 623).

The Benefits of a Simulation Model

Now that it is clear that the simulation model is the best method of tracking student flow, research was then conducted on the benefits of a simulation model so that those benefits would be exploited to make the model better. Specifically, Robinson mentions the use of simulation for many different fields which is good assurance since the ideas of simulation in this project will be applied to something as abstract as curriculum at a university. Additionally, Robinson mentions a benefit of simulation being the visualization of a process. As a result, the Cal Poly simulation will illustrate all students that enter and exit the system so that the controller of the simulation will understand what is happening at any given time. However, the illustration of students in the system may not be very useful because a simulation package is such a huge simplification of the real world. This is presumably why Robinson mentions that despite being such a powerful tool, simulation does have its constraints and assumptions that make it stray from reality (Robinson, S. p. 619-629).

The Possibility of Simulation with Cost Analysis

In a related educational simulation in Papua New Guinea, Webster develops a model that tracks associated cost with decisions about the system. Although Webster's model is much more complex than what the Cal Poly model is projected to be, it brings up a good point in that cost can be assigned to a simulation so as to draw really useful information. Specifically, in the Cal

Poly model, it would be possible to assign cost to classes and determine an overall cost of the system. Furthermore, this information could be related to the budget and high-level decisions such as “How many classes can be offered annually?” will have instant answers. Finally, Webster identifies the importance of student flow in educational planning and because of this, it is clear that the simulation model with sensitivity analyses are of high value to the IME department (Webster, T. p. 5 -23).

Although much of the research that was just discussed does not relate exactly to simulating the flow of students through an educational system, the parallels between the research and the Cal Poly model are abundant. It is the intention of this project to use as much of this information as possible to develop the best model for the department. The remainder of the report will discuss the Design, Methods, Results, Discussion, and Conclusion of the entire project.

III. Design

The simulation for the tracking of the students throughout the College of Industrial and Manufacturing Engineering at Cal Poly SLO was developed on ProModel 2011 because it is a powerful software package that allows for the easy input of information through Microsoft Excel while outputting information in the same manner. This was an easy decision as the data would be easily transferred between Microsoft Excel and Minitab for further analysis. The layout of the entire model from inputs to outputs is displayed on the following page in Figure 2.

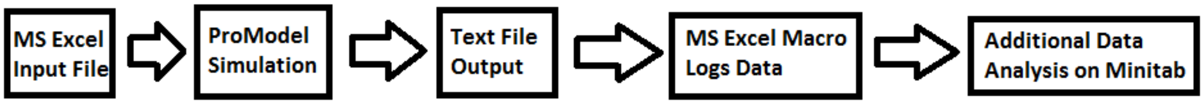

Figure 2: Simulation Model Layout with Inputs and Outputs

After developing the general layout of the model, it became necessary to define the requirements of the simulation so that by the end of the simulation, it would be easy to identify the level of success of the system. The requirements for the system are as follows and were identified through conversation with several faculty members of the IME department:

1. Develop a user-friendly interface to ensure quick and accurate use of the model.
2. Create a set of instructions about how to go about using the model.
3. Display class levels of students involved in the system.
4. Display 4-year and 6-year graduation rates by the end of the simulation.
5. Allow users to identify bottleneck classes (as those will be the classes in which capacity shall be adjusted).

Before developing the simulation, many simplifications [or constraints] had to be made to the overall system so that modeling it would be possible. The main idea of the simulation is to create a representation of how students are flowing through the curriculum at Cal Poly SLO by tracking all their movement in order to better understand the system. Important assumptions about the system are as follows:

- The Simulation model will be titled the Cal Poly Industrial Engineering Undergraduate Model (CPIUM) and it is intended to display the flow of students through IME classes that are required for graduation. General Education classes are ignored and technical

electives are excluded because students have the option to take 3 classes of a variety of IME classes, business classes, et cetera.

- There are 22 IE-required classes that undergraduates need for graduation. As a result, approximately 46% of all classes required will be analyzed as a part of CPIUM. Considering that the IME department does not have a strong influence outside of the College of Industrial and Manufacturing Engineering, the rest of the classes would be difficult to change and the analysis redundant.
- The intention of the model is to find ways to improve graduation rates, specifically the 4-year graduation rate as well as the time to graduation by looking at the possibility of offering more sections of classes. This will be accomplished by identifying bottleneck classes and altering their capacities to see if the effects are worthwhile. Finally, the idea of possibly eliminating some topics from the curriculum will be investigated so as to determine if it will have an effect on graduation rates.
- During the simulation model, student's progress towards obtaining their degrees will be constantly tracked and the use of attributes will allow for data analytics in the end. Additionally, cost will be analyzed by the end of the simulation so that the department can easily understand where money is going and how it can be saved.
- Cal Poly operates on a quarter system which includes fall, winter, spring, and summer quarter. Most students take classes during three of the four quarters [summer quarter being the exception] and many classes are not offered during summer quarter. For this reason, the model assumes students obtain their degrees in an academic year composed of three quarters.

- An hour within the simulation is equal to one quarter of a student pursuing a degree whilst at Cal Poly SLO.
- First-Time freshmen arrive every fall quarter in the model. Although there are some exceptions to this case, it is not a predictable metric and must be simplified as part of the simulation.
- Community College Transfers are assumed to arrive once a year at the beginning of fall quarter. These students generally finish their general education elsewhere and only have IME curriculum remaining. Additionally, these transfers can theoretically arrive any quarter of the year, but this model assumes the arrival to be once a year.
- Within-college transfers [defined as those students already enrolled in Cal Poly SLO transferring within the college] arrive every fall quarter. This data was obtained from the College of Engineering and although students can transfer in any one of three quarters, it was assumed that these transfers occurred on an annual basis.
- Pass and fail rates are implemented in the system in order to make the system as real as possible. Although some classes have a 0% fail rate, most classes are accounted for with at least some percentage of students not passing the class.
- Data involving types of students and their associated arrivals was acquired from Dana Azevedo of the IME department. Minitab software was used to develop distributions of this data so as to generate mean arrivals.
- Students graduate when they finish the last class (IME482) and exit the system soon after completion of said class.
- Students follow the classes in the order that is presented on the IE Flow Chart ('13) in order simplify the system [Note that this means pre-requisites are forced into

implementation, yet students cannot freely take classes they desire]. As students, most IE undergraduates attempt to follow the flowchart as closely as possible but due to competition among many students, most students deviate slightly from the flow chart.

- The idea of a waitlist is not included within CPIUM. In some cases, classes also include students beyond their listed capacity. This cannot be portrayed in a simulation model so it is exempt from this model.
- Class capacity for the 22 required IE classes was obtained from Dana Azevedo of the IME department. Minitab software determined the average capacity of classes from data from the previous two to seven years. It is important to note that if the department experiences significant growth, the capacities will presumably change to accommodate some of that demand. Because this is unpredictable, it was not include in CPIUM.

Arriving at the Initial Model

In order to develop the initial model, it was decided that classes would be illustrated by machines in ProModel since the general flow of students through classes resemble the flow of parts through a machine shop. Each class that was represented as a machine had its own queue in which students would wait to be allowed to take the class. Furthermore, a student would be allowed to take a class if there was open capacity in terms of students enrolled in the specific class. The specific procedure involved in determining the capacity of all classes is as follows:

1. Acquire enrollment data from Dana Azevedo of the IME department
2. Determine the number of students that are specifically Industrial Engineering majors.

3. Use Minitab to determine the distribution of the enrollment numbers for the previous two to seven terms and use an average if suitable (if enrollment numbers were all over the place, an average is not suitable).

An example of the Minitab analysis used is given in Figure 3.

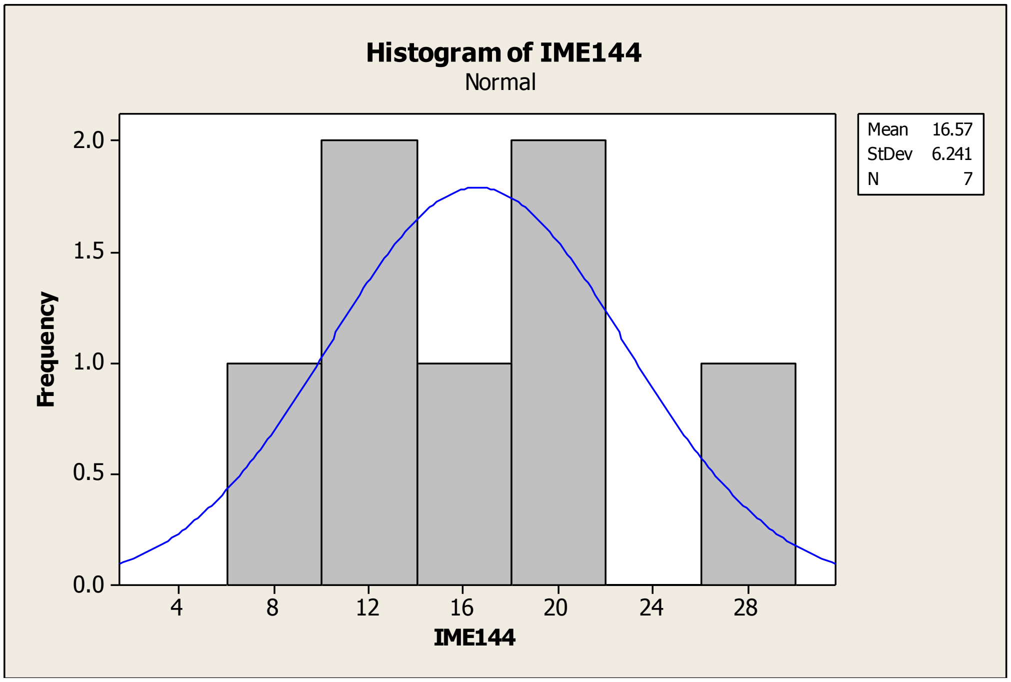

Figure 3: Minitab Output Determining Capacity

Figure 3 above shows the enrollment numbers of Industrial Engineering majors for the previous 7 sections offered. This is a great example of a class in which very few IE's are actually enrolled in the class despite it being offered by the department. Because the capacity of the class is 24 students, approximately 69.04% of students are actually IE majors and this should be represented clearly in the simulation. As a result, most capacities stated in the simulation were calculated in a similar fashion. All of the capacities weren't determined this way because the data does not tell the complete story. For example, based on previous data from IME 312, only 55 IME students took the class out of a capacity of 90. Based on knowledge of this class, that is clearly incorrect

and enrollment was used for just the previous quarter and expanded to fit the full academic year to arrive at a more accurate number. Next, the arrivals of students had to be determined in order to provide an accurate simulation.

The number of students arriving into the system was determined by looking at the Cal Poly Fact Book for the year of 2012. As can be seen in Table 1 below, it was decided that 63 first time freshmen would arrive per year based on 2012's arrivals.

Table 1: Enrollment Numbers used for the Model

By Major	Fall 2008	Fall 2009	Fall 2010	Fall 2011	Fall 2012
Industrial Engineering	45	26	47	51	63

< http://www.ipa.calpoly.edu/sites/ir.wcms.calpoly.edu/files/publications_reports/factbook/fbfall12.pdf>

As can be seen in the figure above, there is almost a clear increasing trend as the years go by, but the number of arrivals for CPIUM was deemed to be constant because the capacity of IME classes would not be changing throughout the analysis. Although this is somewhat of a deviation from reality because the department would make an attempt to increase capacity, it is a simplification that must be made so that the model may be analyzed.

In addition to first time freshmen, community college [transfer] students were assumed to arrive in the system at a rate of 5 students every fall quarter based on information from Dana Azevedo. Furthermore, within-college transfers were determined to arrive at a rate of 18 per year based on information from Dana Azevedo. Finally, the specific group of students that will be examined is named "New_Student" and these entities arrive once throughout the entire simulation for easy analysis.

Now that the arrivals were determined, the number of arrivals and frequency of students arriving into the system had to be decided upon in order to accurately demonstrate students flowing through Cal Poly. In order to achieve this, the simulation needed a warm-up period so that students were already occupying much of the classes in the system. Without this, the simulation would not yield valid results because any class could be taken at any time disregarding capacity. As a result, five years of students flow through the system before the group to be analyzed flow through so as to resemble students already being in the system as is the case at Cal Poly. The information regarding arrivals and their relative frequencies can be found in Table 2 below.

Table 2: Arrivals from ProModel Simulation

Arrivals

Entity...	Location...	Qty Each...	First Time...	Occurrences	Frequency
First_Year	INCOMING	63	0	10	180 min
Within_CalPoly_TRAN	INCOMING	18	0	10	180 min
Second_Year_TRANSFE	Year_2_Transfer	5	180 min	10	180 min
New_Student	INCOMING	63	3600 min	1	0

Table 2 above illustrates all four entities as they arrive at their incoming location and provides the quantities and the frequencies with which these students arrive. This specific step had to be verified before proceeding with the simulation because it has a major effect on the results since these are the students used for the analysis.

After determining the arrivals presented an accurate depiction of the system, variables were developed in order to track students' standing as they passed through the curriculum. The

following were used to provide real-time information on numbers in students in their respective standings:

1. Freshmen_Standing
2. Sophomore_Standing
3. Junior_Standing
4. Senior_Standing

Counting displays for this information are presented with the model as the simulation runs so that a user can determine the number of students with respective standing at any given time.

Now that the basic layout has been developed, the overall processing for the system had to be determined. With minor differences between each entity, there were approximately 45 steps that governed the movement of each entity as they flowed throughout the system. Some of the complexities in routing the students through the system are as follows:

- Pass and fail rates of classes determined whether or not students moved to the next class.
- The time in which students entered the system was tracked so as to monitor time to exit the system.
- Attributes for whether or not students have passed classes were provided.
- Service times for classes were determined by a Microsoft Excel input file.

Of the complexities mentioned, the input excel file was the most important because it provided a solid foundation for the simulation. The Microsoft Excel Spreadsheet titled Service is meant to advise the Department Chair in terms of planning courses so as to understand those effects of the time needed to graduate. In this spreadsheet, the Department Chair inputs the number of sections offered annually for each class as well as their corresponding capacity. The spreadsheet then

determines number of students annually and develops a baseline to compare any changes to. As a result, when the input number changes, the baseline adjusts the time necessary to process students within the simulation model by using a Performance Rating. Essentially, the initial capacities were all given a baseline of 1.00 which was defined as the following:

$$Baseline = \frac{Initial\ Capacity}{Adjusted\ Capacity}$$

As the adjusted capacity starts to deviate from the initial capacity, the fraction decreases below 1.00 and this baseline is multiplied by the initial run time. As a result, the relationship between service time and capacity can be defined as: "An increased capacity beyond the initial capacity reduces the service time, thus reducing the amount of time in the system." It is important to note that this methodology assumes that an increased capacity means that students will take those additional classes. These service times are then input as the run times for the students waiting at each class and form the backbone of the entire simulation.

With the simulation essentially complete, it was now time to export data from the model into a spreadsheet. This was accomplished by writing run times of students into a text file by providing their entity type and run time. Furthermore, this text file would be output into a Microsoft Excel spreadsheet by the use of a VBA Macro. It is important to note that this Macro must be adjusted depending on which computer the program is being used because of the File Path. Figure 4 on the following page illustrates the VBA coding used to transfer the .txt file to an Excel spreadsheet:

```
Option Explicit

Sub OpenTxtFile()
Dim FilePath As String
FilePath = "C:\Users\Alex\Desktop"

Workbooks.OpenText Filename:=FilePath & "\Data_File.txt", DataType:=xlDelimited, Comma:=True

End Sub
```

Figure 4: Microsoft Excel Macro Code

The macro would then output a Microsoft Excel spreadsheet that allowed complete analysis of the model. This final spreadsheet would determine graduation rates as well as time needed to graduate which is should be really useful to the department. For example, if graduation rates are displayed close to 4 years, that would be an ideal setup since that is the generally accepted time to graduate at colleges across America. The next step would be to validate the initial trial runs to see if CPIUM provided a valid illustration of the IME curriculum and this will be discussed at length in the following section.

IV. Methodology

The design for CPIUM was validated as all simulations are to see if the results are in line with the real world results. The initial metrics from the model as obtained from the Microsoft Excel Macro and output into an Excel Spreadsheet are as follows in Table 3 and Table 4:

Table 3: Initial Time to Graduation Metrics

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	4.0906
New_Student	4.0881
Second_Year_Transfer	4.0363
Within_CalPoly_Transfer	4.3309

Table 3 above displays average time to graduation statistics based on CPIUM. In order to understand these results compared to what is actually happening at Cal Poly, it would be ideal to compare these numbers to the following actual statistics at Cal Poly. However, since that data is not readily available and CPIUM assumes a best-case scenario student flow model in which students flow freely throughout the system without pre-requisites, these metrics can be interpreted without this data.

The first important observation is that all the times listed are in line with the general trend of about four years. However, the students identified as “Within_CalPoly_Transfer” have a much higher time to graduation. Since these students are coming from other majors, they are not on the right track when they start college which accounts for the additional time. Furthermore, this Average Time to Graduation Metric considers the time from the entrance to the system in the simulation to the exit. For this reason, these transfers from within Cal Poly take approximately 4.33 years to graduation from the date of their transfer. As a result, these numbers do make sense given the circumstances and CPIUM can be partially validated.

The second part of validating the model was to determine the graduation rates of different types of students in order to compare them with actual statistics. The graduation rates as displayed in the Microsoft Excel output from CPIUM are seen below in Table 4:

Table 4: Initial Four-Year Graduation Rate Metrics

Student Type	Four-Year Graduation Rate as calculated from CPIUM (%)	Cal Poly's Industrial Engineering Four Year Graduation Rate (%)
First_Year	35.56	-
New_Student	30.16	4.183
Second_Year_Transfer	46	-
Within_CalPoly_Transfer	1.1	-

As can be seen in Table 4 above, there is really only one metric to compare CPIUM to. The student's labeled "First_Year" were put into the system for warm-up purposes, so their results are ignored. The simulation calculated a four-year graduation rate of 30.16% to the students being analyzed which is significantly higher than Cal Poly's published statistics from Fall 2003 – Fall 2008. Despite this, this large gap represents the difference from the current system and the best-case scenario student flow model that CPIUM illustrates. The main difference between CPIUM and the real system is that CPIUM ignores pre-requisites and as such, reduces time to graduation and ultimately, increases graduation rates. For this reason, the graduation rate of 30.16% is justified because it demonstrates the best-case scenario of student flow throughout Cal Poly.

For the "Second_Year_Transfer's," there was no data readily available of Industrial Engineering students at Cal Poly but the graduation rate can be interpreted based on the numerous assumptions made for the model. Considering that transfer students come in with many of their classes done, their main focus is on Industrial Engineering classes. Furthermore, they have already experienced what it is like to be in college and have a general idea of what to expect. For this reason, it is understandable why these transfer students maintain a higher graduation rate than just a first-time freshman. Despite this, it is important to understand that the four-year graduation rate for these transfers from other colleges is the rate at which these students graduation after four years at Cal Poly. As a result, it could be their fifth or sixth year in college accounting for a higher rate once again. Because of all these assumptions, the 46% rate of graduation after the fourth year is acceptable in validating the simulation.

The last metric of importance from Table 4 is the “Within_CalPoly_Transfer” students defined as those students that transfer from within Cal Poly to Industrial Engineering. Once again, data was not available in order to make a direct comparison, but the numbers can be interpreted based on the assumptions made. In CPIUM, 18 transfers arrive into Industrial Engineering every year based on information provided by the College of Engineering. Furthermore, these 18 students now have to compete with the other 63 new freshmen that want to take all the freshmen level classes. As a result, this clearly impacts the transfer students because they may not be able to register for the classes they want due to capacity requirements. Additionally, Department Chair Jose Macedo mentioned the amount of time of transfer students within the system to be larger than normal. From this information, it is understandable that the graduation rate of these students should be low. Because of this, the 1.1% four-year graduation rate from the entrance into the system seems reasonable and therefore can validate the model.

The metrics provided above all provide validation of the model so that it can be used in the Sensitivity Analysis and eventually used as a tool by the department for high-level planning in the future. Even though much of the data wasn’t compared to actual results, the simulation model can be justified because the results are in line with what is expected. The process of arriving at the initial simulation model that is presented entailed many round of tweaking the model in order to develop results that are in line with what should be expected. Most commonly, the variability of the time taken for each class was adjusted until CPIUM’s results were satisfactory. Based on the above validation, the layout for the final model can be seen on the following page in Figure 5.

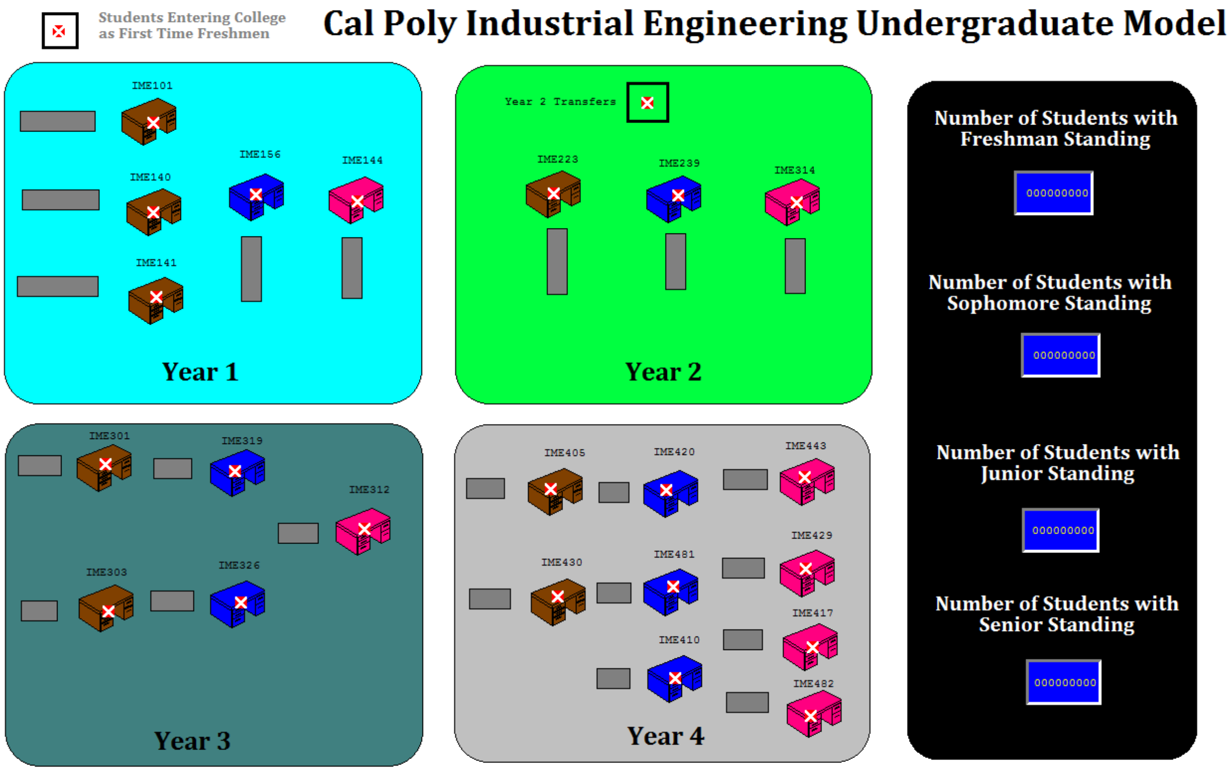

Figure 5: Layout of CPIUM

As illustrated above in Figure 5, the main objective was to display the model in a user-friendly manner so that tracking the flow of students would be easy. This layout was based on the 2013-2015 flow chart that is given to students in order to plan their classes. Essentially, each block represents a year and the flow is from left to right.

The usage of CPIUM will be discussed at length in the Sensitivity Analysis in the following section in order to develop a set of recommendations that could be given to the department in terms of what is best to maintain graduation rates for the department.

V. Results and Discussion

In order to understand the effects certain decisions have on Industrial Engineering students at Cal Poly, the Sensitivity Analysis was performed by analyzing several cases that may be presented to the department. Common issues that the department may encounter include the following:

1. Capacity-related issues (increasing or decreasing)
2. Number of sections of classes to be offered
3. Number of students interpreted to be entering the system
4. Effective capacities of classes [the adjusted capacity based on number of IE's enrolled]

These issues will be discussed in relation to eight different cases and their results and interpretations will be compared to each other to see which decisions have greatest impact. In the first case, the baseline case used to validate the model will be revisited.

Case 1 – The Baseline Case

In the initial case, nothing is changed from what was used to validate the model. The graduation rates for all types of students besides students that transfer from within Cal Poly are around four years. Furthermore, students that transfer from Within Cal Poly generally take an extra quarter beyond four years to graduate which is a significant difference from the other groups. This model will be manipulated further into alternative scenarios that the department may run into at some point so that those in charge can be better informed during their decision-making process.

Case 2 – Reduce Capacity

In this case, the idea was to reduce capacity across all classes by 10% in order to simulate the effects of the possibility of understaffing due to budget cuts. Although classes generally take on

more students than their published capacity, this scenario looks into designating a reduced-strict limit on the number of students allowed in class. The average time to graduation for each student type can be found below in Table 5:

Table 5: Time to Graduation for Case 2

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	4.5895
New_Student	4.5567
Second_Year_Transfer	4.5453
Within_CalPoly_Transfer	4.8600

Table 5 illustrates the disastrous effects a 10% cut in capacity would have on all types of Industrial Engineering students at Cal Poly. First-time freshman [designated New_Student] now have an average time of graduation time of 4.5567 years and a 2-Sample T-Test of the difference of the means between Case 1 and Case 2 was conducted for the first-time freshman. The Minitab output can be seen below in Figure 6:

Two-Sample T-Test and CI: 1 - Freshman, 2 - Freshman

```
Two-sample T for 1 - Freshman vs 2 - Freshman

               N   Mean  StDev  SE Mean
1 - Freshman  63  4.088  0.192    0.024
2 - Freshman  63  4.557  0.213    0.027


Difference = mu (1 - Freshman) - mu (2 - Freshman)
Estimate for difference:  -0.4686
95% CI for difference:  (-0.5402, -0.3970)
T-Test of difference = 0 (vs not =): T-Value = -12.96  P-Value = 0.000  DF =
     122
```

Figure 6: Minitab Output comparing Case 1 with Case 2

Based on the information above, it is clear that reducing capacity by 10% creates a significant difference between the baseline case. The remaining two types of students are affected in the

same manner and the difference in means is significant for both types of students as well. Because of these devastating effects on average time to graduation, this scenario needs to be avoided at all costs despite budget cuts and many related factors.

Case 3 – Add another Section of IME312

Case 3 identifies the main bottleneck of the system as being IME312 because it is the class that is occupied most of the time. Figure 7 below portrays some of the classes that are the most frequently occupied and as such, can benefit from increased capacity or another section being offered.

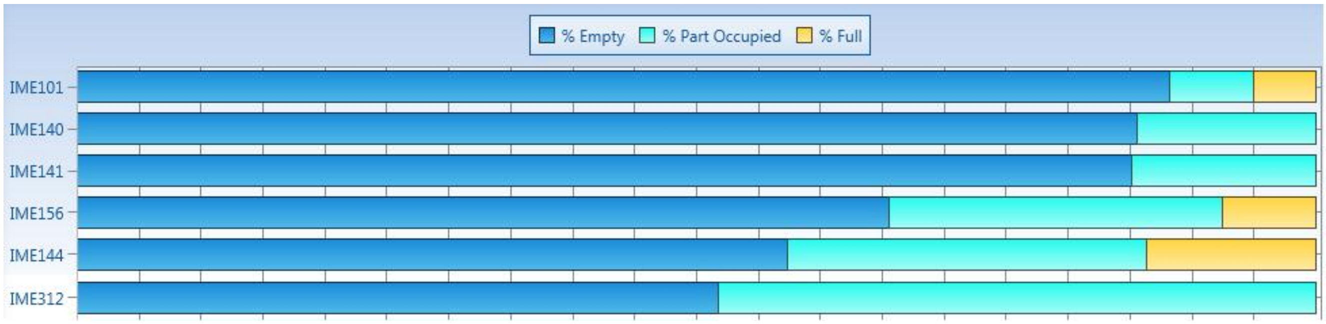

Figure 7: Identifying the Bottlenecks

Based on Figure 7 above, Case 3 aims to improve graduation rates and average time to graduation by offering another section of the bottleneck class: IME312. Table 6 below portrays the average time to graduation for all student types for Case 3:

Table 6: Time to Graduation for Case 3

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	4.0061
New_Student	3.9740
Second_Year_Transfer	3.9638
Within_CalPoly_Transfer	4.2332

By adding another section of IME312, all types of students benefit greatly; however, this benefit would not happen in the real-world situation of the IME department at Cal Poly. Because CPIUM assumes that all students will take the class when it is offered and that is not the case at Cal Poly, these results would differ if actually implemented. However, these results are significantly different when compared with the results from Case 1 and it demonstrates that adding a section of the bottleneck class is beneficial to all students. As a result, if the department decided to schedule student classes for the next 4 years as is done in CPIUM, the added section of IME312 would see benefits for everybody. Case 4 looks into an alternative method of remediating the bottleneck of IME312.

Case 4 – Increase Capacity of IME312

Case 4 examines the possibility of eliminating the bottleneck by increasing the capacity of the class from 30 to 40 students. The purpose of this case is to determine if a capacity increase is more beneficial than offering an entirely new section of the class. Results from this case can be found below in table 7:

Table 7: Time to Graduation for Case 4

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	4.0061
New_Student	3.9740
Second_Year_Transfer	3.9638
Within_CalPoly_Transfer	4.2332

The output above demonstrates the exact same results as Case 3 as the input Microsoft Excel spreadsheet uses the total number of students per year to calculate average times in systems. Because three sections of forty students are equal to four sections of thirty students, the results are identical. However, it would be more cost-effective to offer fewer sections so Case 4 is a

better choice over Case 3. Because both cases provide a significant difference over Case 1 and Case 4 the better decision, it is clear that increasing the capacity of a bottleneck class is the way to go when faced with a decision like this. Case 5 looks into another scenario the IME department may face in the near future.

Case 5 – Change Arrival Rates of Students

In this scenario, CPIUM seeks to identify the effects of increasing enrollment within the IME department at Cal Poly. Figure 8 below illustrates the number of students entering the IME department as first-time freshman:

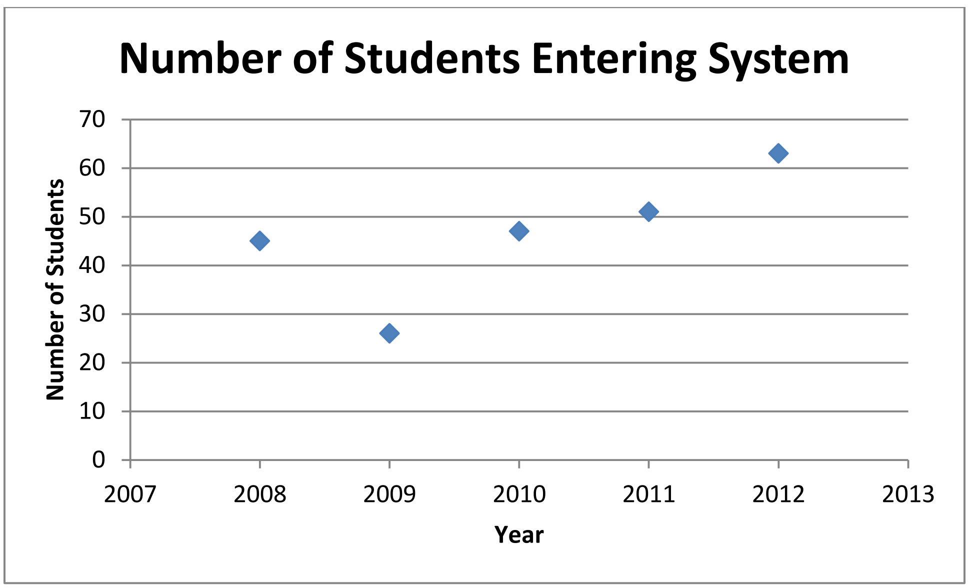

Figure 8: Number of Students Entering System

Eliminating the 2009 point, there is a gradual increasing trend of students arriving into the college. Because of this, Case 5 looks into a 10% and 20% increase in enrollment in order to examine the effects on graduation rates. Table 8 on the following page portrays the graduation rates for students from the baseline case, the graduation rate given a 10% increase in enrollment, and the graduation rate given a 20% increase in enrollment.

Table 8: Comparison of Arrival Rate Increases

Student Type	Average Graduation Rate: Baseline Case (%)	Average Graduation Rate: 10% Increase (%)	Average Graduation Rate: 20% Increase (%)
First_Year	35.56	33.71	31.04
New_Student	30.16	36.23	25.97
Second_Year_Transfer	46	38.78	36
Within_CalPoly_Transfer	1.1	1.1	0

Table 8 above shows two very interesting results about the CPIUM model. First, the 10% increase in enrollment actually increases the graduation rates for the first-time freshman students. In the 10% increased enrollment scenario, all of those students that are added graduate within the four years, so the increase is actually justified. Second, as the enrollment reaches a 20% increase, the graduation rates finally go down from the baseline case. With this information, CPIUM demonstrates that under the current system with the same operating conditions, the IME department of Cal Poly could accommodate a 10% increase in enrollment but not a 20% increase in enrollment. For this reason, if enrollment did increase by 20% or greater, the department would have to accommodate students by increasing capacity of classes or offering more sections. This data will certainly be useful for the department in terms of future planning.

Case 6 – Drop IME144

Case 6 looks into the possibility of dropping another bottleneck class in IME144. Because IME144 entails a lot of time and the use of a machine shop, it is one of the more expensive classes to operate. Furthermore, this class often holds up transfer students from graduating on time, so Case 6 will look into the effects of removing the class from the schedule. Before this option was simulated, it is important to note that all times to graduation will increase as well as the corresponding graduation rates. Whether or not the drop is justified remains to be decided by the department because the removal of courses from curriculum is something that needs to be

investigated thoroughly by the faculty members. The average time to graduation and four-year graduation rate can be found below in Tables 9 and 10:

Table 9: Time to Graduation for Case 6

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	3.7174
New_Student	3.6893
Second_Year_Transfer	3.6859
Within_CalPoly_Transfer	3.8600

Table 10: Four Year Graduation Rate for Case 6

Student Type	Four Year Graduation Rate (%)
First_Year	96.83
New_Student	98.41
Second_Year_Transfer	100.0
Within_CalPoly_Transfer	83.89

Case 6 benefits students greatly in that all the times to graduate are below four years. However, it is important to note that none of the rates given are equivalent to 3 years and 2 quarters, so the time is actually rounded up to four years. Despite that, the four year graduation rate for first-time freshman is now up to approximately 98% which is a tremendous increase beyond the base model. Furthermore, transfers from another college [student type "Second_Year_Transfer"] are at a perfect 100% rate while transfers from within Cal Poly are up significantly as well. Despite these great improvements, the elimination of a class would reduce the quality of the curriculum and the IME department would seriously have to consider dropping a class. The following case looks into a less drastic alteration in order to examine the effects on graduation.

Case 7 – Eliminate Pass and Fail Rates from Model

In this scenario, CPIUM eliminates pass and fail rates in order to examine any improvement possible. Despite the controversy of eliminating pass fail rates, it is something that may be looked at in the future. Tables 11 and 12 below provide average time to graduation as well as the graduation rates for Case 7:

Table 11: Time to Graduation for Case 7

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	4.0787
New_Student	4.0522
Second_Year_Transfer	4.0303
Within_CalPoly_Transfer	4.2908

Table 12: Four Year Graduation Rate for Case 7

Student Type	Four Year Graduation Rate (%)
First_Year	36.67
New_Student	46.03
Second_Year_Transfer	44
Within_CalPoly_Transfer	1.1

Although all metrics do increase beyond the numbers in Case 1, the added benefit is miniscule. Because pass and fail rates force students to get a certain grade to pass a class, it enhances their learning and is something that probably shouldn't be removed. In order to determine if removing these pass and fail rates had a significant effect on graduation rates, a 2-Sample T-Test was conducted and the Minitab output can be seen on the following page in Figure 9:

Two-Sample T-Test and CI: 1 - Freshman, 7 - Freshman

```
Two-sample T for 1 - Freshman vs 7 - Freshman

               N   Mean  StDev  SE Mean
1 - Freshman  63  4.088  0.192    0.024
7 - Freshman  63  4.052  0.158    0.020


Difference = mu (1 - Freshman) - mu (7 - Freshman)
Estimate for difference:  0.0358
95% CI for difference:  (-0.0263, 0.0980)
T-Test of difference = 0 (vs not =): T-Value = 1.14  P-Value = 0.256  DF = 119
```

Figure 9: Minitab Output Comparing Case 1 with Case 7

Based on the Two-Sample T-Test, it is clear that the elimination of pass and fail rates does not have a significant effect on graduation rates because of the high p-value of 0.256. As a result, it is clear that pass and fail rates shall not be removed because there is no benefit for the graduating students. Finally, removing these rates may actually reduce the quality of education and that would not be beneficial to any of Cal Poly's stakeholders.

Case 8 – Rebalance Classes in accordance with IE Capacity

In the final scenario, the capacity of classes is adjusted based on the percentage of each class that represents Industrial Engineering students. Essentially, this re-distribution of capacity would increase the chances of students being able to enroll in certain classes possibly allowing them to graduate earlier. For example, IME144 and IME156 both have a tremendous capacity since both classes are required by a variety of engineering majors, however; Industrial Engineering students only account for approximately 18% of the entire capacity. Table 13 on the following page illustrates the current distribution of students that are Industrial Engineering majors among all 22 classes by providing capacity and percentage of Industrial Engineering students for all classes.

Table 13: Determining Effective Capacity

Class	Capacity*	Number of Sections Annually*	Fraction IE Students*	Effective Annual Capacity
IME101	45	2	0.6111	55
IME140	30	3	0.7111	64
IME141	24	13	0.2692	84
IME144	24	11	0.1894	50
IME156	24	18	0.1759	76
IME223	30	3	0.9000	81
IME239	45	2	0.9000	81
IME314	30	13.5	0.2148	87
IME301	30	3	0.7778	70
IME303	30	3	0.7667	69
IME319	40	3	0.5750	69
IME326	35	3	1.0000	105
IME312	30	3	1.0000	90
IME405	30	3	0.9667	87
IME430	40	3	0.8750	105
IME420	30	3	0.8556	77
IME481	30	2	0.7000	42
IME410	30	3	0.9333	84
IME443	30	3	0.8667	78
IME429	24	3	0.7917	57
IME417	40	3	0.8000	96
IME482	30	2	0.7833	47

*** Designates data received from the IME department from 2007-2012**

Table 13's effective capacities provide an insight into how many students can really flow through each class during any given academic year. Classes designated in red font [IME101, IME144, IME481, IME429, IME482] maintain the lowest effective capacities and therefore are the contenders to be adjusted in Case 8. As a result, it was decided to adjust these capacities to the next highest number that is not marked in red – IME140 with an effective capacity of 64. This was done by adjusting the capacity because in a scenario such as this, manipulating the

capacity is easier done than altering the number of sections offered. The results of this rebalancing can be found in Tables 14 and 15 below:

Table 14: Time to Graduation for Case 8

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	3.9151
New_Student	3.8869
Second_Year_Transfer	3.9081
Within_CalPoly_Transfer	4.0806

Table 15: Four Year Graduation Rate for Case 8

Student Type	Average Time to Graduation as calculated from CPIUM(in years)
First_Year	74.13
New_Student	79.37
Second_Year_Transfer	78
Within_CalPoly_Transfer	24.44

The metrics from Case 8 demonstrate that by adjusting the effective capacities, most students will see an improvement in time to graduation as well as graduation rates. It is important to note, however, that first-time freshman and transfers from another college experience a realistic time to graduation of 4 years since decimal quarters do not exist. Despite this setback, Case 8 provided an increased benefit for Industrial Engineering students from the base Case 1. Furthermore, graduation rates for all students besides transfers from another college see an increase more than twofold. From these results, it is clear that analyzing annual capacities and adjusting them is a beneficial method of increasing graduation metrics and the IME department may use this method for future scheduling.

Additional Observations

In generating the eight cases mentioned above, several observations were noted about the current system that is in place. First, the data provided by the department in terms of enrollment, capacity of classes and frequency of classes contained a large variance and oftentimes, the data had to be manipulated to create a reasonable number for capacity. For example, data provided for IME223 dates back to 1996 when the enrollment capacity is not provided and number of students enrolled is much different as a result of growth within the department. For this reason, the data is highly variable and may not represent the system as accurately as it could be. Despite this, much of the results fall in line with what should have been expected although some cases provided insightful information to the department.

The Usage of CPIUM

Despite the limitations of the model, CPIUM did provide useful information and the summary of the sensitivity analysis is as follows:

- Case 1: Graduation rates are approximately 4 years and 4 and a quarter for transfers from within Cal Poly.
- Case 2: A 10% reduction in capacity across all classes adds about half a year to the average time to graduation for all types students.
- Case 3: Adding another section of the bottleneck class IME312 benefits all students and brings first-time freshman to a sub-four year time to graduation.
- Case 4: Increasing capacity of the bottleneck class IME312 by 33% has the same outcome as Case 3 cutting all students' graduation times.
- Case 5: Increasing enrollment by 10% actually benefits graduation rates whereas a 20% increase in enrollment starts to lower graduation metrics across the board.

- Case 6: Dropping the second bottleneck class IME144 benefits all students with time to graduation below four years for all types of students. However, this scenario is hypothetical since the intention is not to make curricular changes to the program.
- Case 7: The elimination of pass and fail rates is not significantly different than the base case and therefore does not affect graduation rates. For this reason, it is suggested that Cal Poly keep pass and fail rates in place once again to maintain quality of education.
- Case 8: Adjusting effective capacity benefits all types of students and brings the time to graduation to below four years for all students except transfers within Cal Poly.

Although CPIUM provided great information during the sensitivity analysis of Cases 1 -8, the real world implementation of the simulation in the department may not be as useful as previously expected. Some of the downfalls of the model are as follows and may prevent the simulation from being as helpful as it could be:

- CPIUM assumed students follow the flowchart perfectly which is a strong assumption.
- The model uses strict capacity limits and in reality, additional students are generally added.
- The model does not account for technical electives which can vary from student to student.

Based on the research presented in this document, it is clear that the CPIUM simulation has provided a good insight into the effect of class capacity on graduation metrics. Most importantly, the transfers from within Cal Poly tend to have the worst graduation metrics and when using CPIUM, high-level decisions by the department should be made with them in

mind. Although CPIUM represents a vast simplification of the real-world system, the tool shall be useful for the IME department when considering curriculum based issues.

VI. Conclusion

This project attempted to track the flow of students through Cal Poly's IME department by developing a simulation model titled CPIUM that could be used by the department as a tool for making high-level decisions. The objective was to develop a simulation model that could use a Microsoft Excel Spreadsheet input and present results in an easy to read manner. The project was completed by obtaining abundant data about the IME department and related metrics and then developing a list of assumptions for the simulation model. Next, CPIUM was created and validated with the four year graduation rate of Industrial Engineers at Cal Poly. Finally, a sensitivity analysis consisting of 8 scenarios was performed by manipulating the input and analyzing the output. Significant results derived from the sensitivity analysis are as follows:

- A reduction in class capacity of 10% is harmful to students' graduation times.
- Increasing capacity or offering another section of IME312 aids students in their graduations.
- Under current conditions, the IME department can sustain a 10% growth in enrollment, but not a 20% growth.
- Analysis shows that although the elimination of bottleneck classes such as IME144 is very beneficial for all students, curricular decisions should be made very carefully so as to not depreciate the value of Cal Poly's educational quality.
- Pass and fail rates shall *not* be eliminated from the current system because it doesn't aid graduation rates.
- Adjusting classes based on the percentage of Industrial Engineering students enrolled is highly beneficial to all types of Industrial Engineering students.

Based on these results, simulation provided a solid foundation for the analysis of curriculum at Cal Poly's IME department. Although simplifications had to be made, the results are beneficial to the department.

In this project, I learned the usefulness of simulation and how it can be adapted to simulations that aren't necessarily perfectly suited for simulation. Furthermore, I was able to combine various data into one solid model that could be used for a sensitivity analysis. If I were to attempt this project again, I would seek to add complications to the model in order to make it more realistic. Based on the findings from CPIUM, I would suggest following the recommendations that were previously mentioned in order to keep graduation rates as high as possible and the time to graduation as low as possible. Hopefully, CPIUM can be a useful tool for the department in the future.

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APPENDICES

Appendix A: Enrollment Data

College of Engineering — Admissions

Enrolled First-Time Freshmen

By Major	Fall 2008	Fall 2009	Fall 2010	Fall 2011	Fall 2012
Aerospace Engineering	132	104	100	89	103
Biomedical Engineering	79	121	81	97	62
Civil Engineering	123	138	101	153	111
Computer Engineering	105	114	84	137	134
Computer Science	91	134	76	152	129
Electrical Engineering	74	122	108	185	161
Environmental Engineering	39	61	41	59	43
General Engineering	153	68	52	69	53
Industrial Engineering	45	26	47	51	63
Manufacturing Engineering	13	14	8	14	18
Materials Engineering	45	30	32	53	38
Mechanical Engineering	190	165	149	209	184
Software Engineering	12	29	34	19	44
Total CENG First-Time Freshmen	**1,101**	**1,126**	**913**	**1,287**	**1,143**

Appendix B: Two Year Course Plan for the IME Department

IME Department Course Offerings - 2013 - 2014
As of Feb 20, 2013

Course #	IE Req	MfgE Req	Fall 2128	Winter 2132	Spring 2134
101	X	X	X		
140	X	X	X		
141	X	X	X	X	X
142		X	X	X	X
143			X	X	X
144	X	X	X	X	X
156	X		X	X	X
223	X	X	X	X	X
239	X			X	X
301	X		X	X	
303	X		X	X	
312	X		X	X	X
314	X	X	X	X	X
319	X		X	X	X
326	X		X	X	X
327		X	X		
330		X	X		
335		X		X	X
342		X		X	
356		X		X	X
400			X	X	X
401			X	X	
405	X		X	X	
408					X
409			X		
410	X		X	X	~~X~~
411					
416			X		
417	X	X	X	X	X
418		X		X	

Course #	IE Req	MfgE Req	Fall 2128	Winter 2132	Spring 2134
420	X		X	X	X
427					X
428					
429	X		X	X	X
430	X	X	X	X	X
437					
441/442			X	X	X
443	X		X	X	X
450		X			X
457					
458				X	
470					X
481/482	X	X	X	X	X
500			X	X	X
503			X		
507				X	X
510			X		
511					
520			X		
541					X
542					X
543				X	
544			X		
545			X		
556					X
570/457					
577				X	
580					X
596					
599			X	X	X

Appendix C: Course Offerings from 2013-2014 Cutout

IME Course Offerings Worksheet for 2013/...

"Two Year Course Plan"

Course #	IE Reqd	MfgE Reqd	Grad Required	Other Major?	Lec/Sem	Lab	Act	wtu's	Fall 2013 (2138)	How many sections?	Lecture Capacity?	Lab Capacity	Total WTU's	Wtr 2014 (2142)	How many sections?	Lecture Capacity?	Lab Capacity	Total WTU's	Spr 2014 (2144)	How many sections?	Lecture Capacity?	Lab Capacity	Total WTU's	Fall 2014 (214...	How ...	
Introduction to IME 90 Seats/year									Karen																	
101	X	X			0	1		2	1	2	0	45	4											1	2	
Graphics Comm & Modeling 90 seats/year									Rob																	
140	X	X			1	1		3	1	3	90	30	7											1	3	9
Mfg Process: Net Shape 252 seats/yr									Martin																	
141	X	X			0	1		2	1	5		24	10	1	4		24	8	1	4		24	8	1	5	
Mfg Process: Materials Joining 268 seats/yr									Kevin = 8, Dave = 1					Kevin = 8, Dave = 1					Kevin = 8, Dave = 1							
142		X		ME	1	1		3	1	4	96	24	9	1	4	96	24	9	1	4	96	24	9	1	4	9
Mfg Process: Material Removal 199 seats/yr									Dave = 3, Eric = 4					Paul = 4, Dave = 1, Eric = 2					Paul = 4, Eric = 4							
143				ME	1	1		3	1	3	72	24	7	1	3	72	24	7	1	3	72	24	7	1	3	7
Introduction to Design & Mfg 259 seats/yr									Rod = 10, Dave = 4, Unknown = 4					Rod = 10, Dave = 8 give to Dave					Rod = 10, Dave = 4							
144	X	X		Mate	2	2		6	1	4	96	24	18	1	4	96	24	18	1	3	72	24	14	1	4	9
Basic Electronics Mfg 417 seats/yr									Gary = 5, Rob = 8					Gary = 5, Rob = 8					Gary = 4, Rob = 9							
156	X			CPE EE	1	1		3	1	6	144	24	13	1	6	144	24	13	1	6	144	24	13	1	6	14
157	X	X			2	2		6	*No longer offered, MfgE students can take IME 156 instead, pl...*																	
200																										
Process Improvement Fund									Karen																	
223	X	X			3	1		5	1	2	60	30	7	1	1	30	30	5	1	1	30	30	5	1	2	60

Need to select 8 tech elects to offer each year.

Need to select 11 (500 level) courses a year

Last updated: 2/20/2013

Appendix D: Course Offering & Capacity Data Cutout

Class Type Enrollment Section

IME 101

Term Code	Term	# of Sections	Enrl Cap	Total # Enrolled
2128	Fall Quarter 2012	2	90	82
2118	Fall Quarter 2011	2	90	76
2108	Fall Quarter 2010	2	70	70
2098	Fall Quarter 2009	2	70	51
2088	Fall Quarter 2008	2	70	70
2078	Fall Quarter 2007	2	60	72
2068	Fall Quarter 2006	2	60	73
2058	Fall Quarter 2005	2	70	69
2048	Fall Quarter 2004	2	70	66
2038	Fall Quarter 2003	2	70	65
2028	Fall Quarter 2002	2	70	55
2018	Fall Quarter 2001	2	60	52
2008	Fall Quarter 2000	2	60	53
0998	Fall Quarter 1999	2	90	50
0988	Fall Quarter 1998	2	0	60
0978	Fall Quarter 1997	2	0	66
0968	Fall Quarter 1996	2	0	85
0958	Fall Quarter 1995	2	0	67
0948	Fall Quarter 1994	2	0	61

Course Enrollments

	# of Students			# of Students Total
Plan	2128	2118	Prior Terms	
AERO Primary BS UG	1			**1**
ASM Primary BS UG		1	1	**2**
Electrical Engineering			1	**1**
Engineering			6	**6**
FNR Primary BS UG		1		**1**
Food Science Minor			1	**1**
GENE Primary BS UG			1	**1**
GRC Primary BS UG			1	**1**
German Minor			1	**1**
IE Primary BS UG	62	47	81	**190**
IT Primary BS UG			5	**5**

Appendix E: Pass & Fail Rates from IME Classes

Course Pass/Fail Analysis for Selected Industrial Engineering Courses From Fall 2010 through Winter 2013

	Total Grades	Average Grade	Fail Rate
Course:			
IME 101	227	3.72	0.4%
IME 140	249	3.48	0.8%
IME 141	1,049	3.91	0.0%
IME 144	543	3.12	1.5%
IME 156	992	3.17	0.5%
IME 223	266	3.19	0.0%
IME 239	162	3.21	0.0%
IME 301	254	3.10	0.0%
IME 303	244	3.61	0.0%
IME 312	169	2.92	1.8%
IME 314	1,131	3.20	0.5%
IME 319	356	3.26	0.3%
IME 326	269	2.80	0.4%
IME 405	215	3.03	0.9%
IME 410	231	2.95	0.0%
IME 417	184	3.59	0.0%
IME 420	209	3.60	0.5%
IME 429	181	3.94	0.0%
IME 430	219	2.99	0.0%
IME 443	182	3.98	0.5%
IME 481	226	3.84	1.5%
IME 482	204	3.81	1.2%

Appendix F: Four Year Persistence Rates

INDUSTRIAL ENGINEERING: FIRST-TIME FRESHMEN PERSISTENCE
Four-Year Persistence Rates

	Fall 2003	Fall 2004	Fall 2005	Fall 2006	Fall 2007	Fall 2008
Original Cohort	42	38	44	45	46	40
No Major Change	26	27	32	38	37	31
Changed TO a Different Major Within the College	6	8	8	3	7	8
Changed TO a Different College	10	3	4	4	2	1
Total Exports	16	11	12	7	9	9
Changed FROM a Different Major Within the College	26	24	20	23	43	20
Changed FROM a Different College	0	0	1	5	5	2
Total Imports	26	24	21	28	48	22
Exclusions (Left for Military Service, or Death)	0	0	0	0	0	0
Adjusted Cohort (Original-Exports+Imports-Exclusions)	52	51	53	66	85	53
Graduated Within Four Years	3	2	0	1	7	3
	5.8%	3.9%	0.0%	1.5%	8.2%	5.7%

Appendix G: Screenshot of Service Time Input

	Number of Sections offered Annually	Capacity	Number of Students per Year
IME101	2	45	90
IME140	3	30	90
IME141	13	24	312
IME144	11	24	264
IME156	18	24	432
IME223	3	30	90
IME239	2	45	90
IME314	13.5	30	405
IME301	3	30	90
IME303	3	30	90
IME319	3	40	120
IME326	3	35	105
IME312	3	30	90
IME405	3	30	90
IME430	3	40	120
IME420	3	30	90
IME481	2	30	60
IME410	3	30	90
IME443	3	30	90
IME429	3	24	72
IME417	3	40	120
IME482	2	30	60

INSTRUCTIONS
1.) Insert Number of Sections Offered Annually
2.) Insert Capacity for each Class
3.) The spreadsheet calculates the Actual IE capacity
4.) Inputs into the model are stored on Service_Time_Entities Spreadsheet

Appendix H: Screenshot of Results Spreadsheet Output

	A	B	C	D	E
1			Minutes to Graduate	Years to Graduate	4 year Grad rate: Finish or Not
2				0	-4
3				0	-4
4				0	-4
5				0	-4
6				0	-4
7				0	-4
8				0	-4
9				0	-4
10				0	-4
11				0	-4
12				0	-4
13				0	-4
14				0	-4
15				0	-4
16				0	-4
17				0	-4
18				0	-4

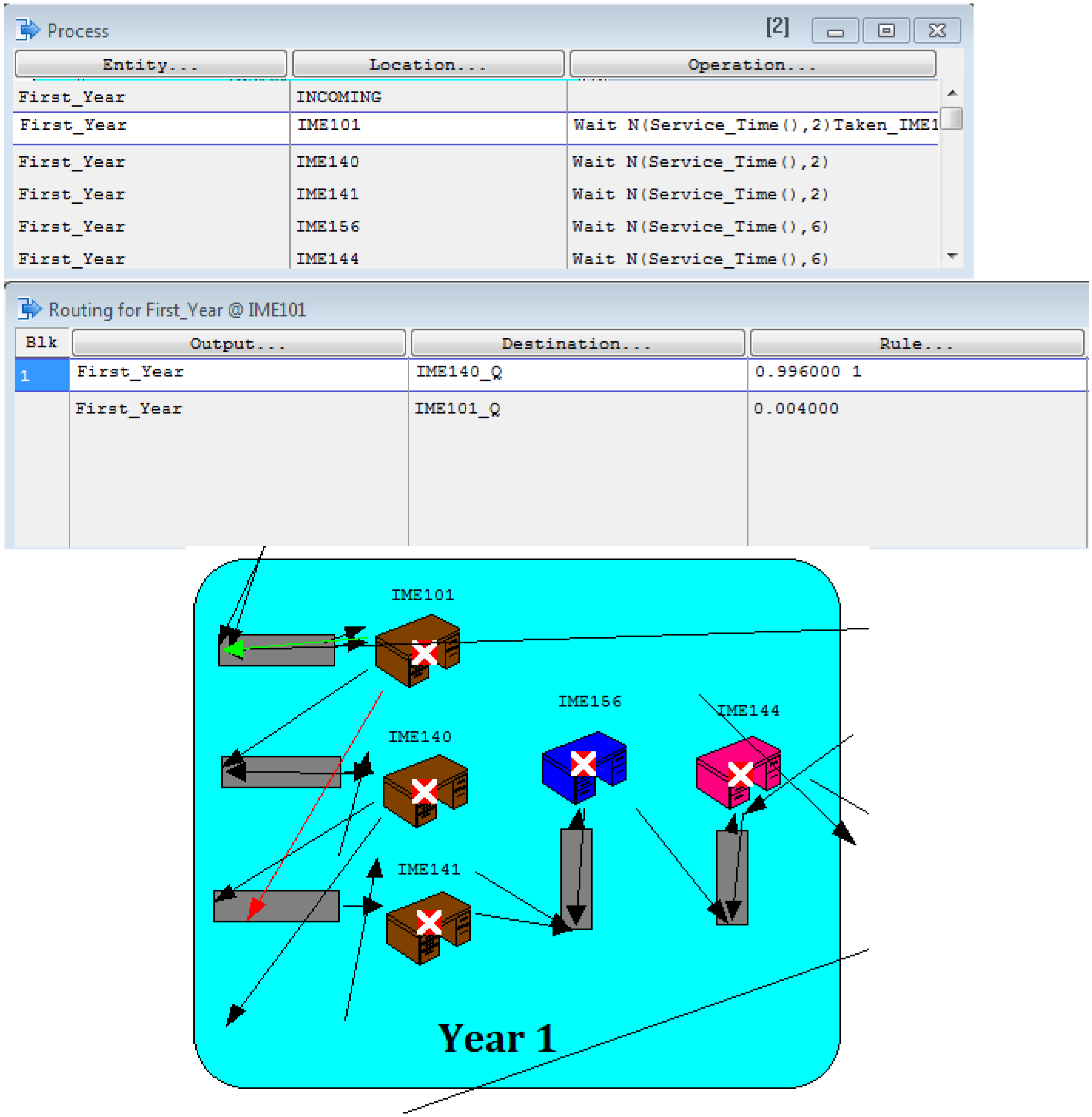
Student Type	Average Time to Graduation (in years)	
First_Year		0
New_Student		0
Second_Year_TRANSFER		0
Within_CalPoly_Transfer		0

Student Type	Four Year Graduation Rate	
First_Year		5
New_Student		5
Second_Year_TRANSFER		5
Within_CalPoly_Transfer		5

INSTRUCTIONS

1.) Run Data_File.xslm
2.) Sort data from A to Z using Microsoft Excel
3.) Copy and Paste the cells into Results.xslx
4.) Graduation metrics are shown in the light green box

Appendix I: Screenshot of Processing from Promodel



Appendix J: Minitab File Screenshot Used for 2-Sample T-Tests

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6
	1 - Freshman	1 - CC Transfer	1 - Within Transfer	2 - Freshman	2 - CC Transfer	2 - Within Transfer
1	3.68639	3.82489	4.09556	4.21000	4.37044	4.74133
2	3.75428	3.84150	4.11144	4.28250	4.42200	4.77944
3	3.78511	3.97183	4.18250	4.28511	4.44328	4.78172
4	3.80589	4.04183	4.19522	4.30289	4.45261	4.78850
5	3.82611	4.10078	4.21928	4.30617	4.52311	4.81922
6	3.85039	3.90839	4.24633	4.31217	4.49189	4.82761
7	3.85178	3.91567	4.27300	4.31522	4.50244	4.84122
8	3.85650	3.98294	4.28117	4.33761	4.55511	4.84617
9	3.85828	4.27722	4.28906	4.36600	4.91889	4.86483
10	3.88350	4.30150	4.30978	4.36633	4.80700	4.87256
11	3.90822	3.97483	4.31300	4.36844	4.41611	4.88094
12	3.93961	3.97972	4.35550	4.37761	4.49706	4.89328
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

	C7	C8	C9	C10	C11	C12
	3-Freshman	3- CC Transfer	3 - Within Transfer	4 - Freshman	4 - CC Transfer	4 - Within Transfer
1	3.69833	3.84428	3.97622	3.69833	3.84428	3.97622
2	3.70594	3.87372	4.03400	3.70594	3.87372	4.03400
3	3.78489	3.88856	4.05067	3.78489	3.88856	4.05067
4	3.80156	3.95411	4.09872	3.80156	3.95411	4.09872
5	3.82083	3.97428	4.13267	3.82083	3.97428	4.13267
6	3.82111	3.84006	4.17244	3.82111	3.84006	4.17244
7	3.82533	3.91961	4.21144	3.82533	3.91961	4.21144
8	3.82700	3.94889	4.21728	3.82700	3.94889	4.21728
9	3.82728	4.09067	4.22417	3.82728	4.09067	4.22417
10	3.84389	4.16206	4.22472	3.84389	4.16206	4.22472
11	3.84689	3.79983	4.22511	3.84689	3.79983	4.22511
12	3.85006	3.94428	4.23522	3.85006	3.94428	4.23522
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]