OPTIMIZATION OF HUMAN INTERACTIONS IN THE COLLEGE CAMPUS MODEL VIA SIMIO INTEGRATION

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This Thesis was prepared under the direction of the candidate's Thesis Committee Chair, Dr. Radu Babiceanu, Department of Electrical Engineering and Computer Science, and has been approved by the members of the Thesis Committee. It was submitted to the Office of the Senior Vice President for Academic Affairs and Provost and was accepted in the partial fulfillment of the requirements for the Degree of Master of Science in Systems Engineering.

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ABSTRACT

College campuses are a significant part of life in some cities. Many students each year attend university, pursuing additional knowledge from faculty members. Both staff and faculty members rely on these students to have successful jobs and to ensure the university functions. Yet recently, more and more students are attending, leading to overcrowding, lower admission rates, and difficulty getting into good programs. Previous work exists on qualitative student affairs and quantitative retention data, yet little on using simulations to model this problem.

This work aimed to (a) Determine the ability to successfully model human interactions/people flow on a college campus, (b) Identify optimization strategies through simulation, and (c) Verify the applicability/practicality of the identified solutions. The simulation consists of two different focus levels. The first is a high-level Skeleton Model, which shows a birds-eye view of the campus and the movement of people/vehicles in a day. Second is a Deep Dive Model of the campus, which identifies more moving parts and student/worker interactions. Once the models were generated, they were analyzed, optimized, and shown to university stakeholders for feedback on the results. As an outcome, a more optimized campus model was obtained for ERAU-DB.

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I. INTRODUCTION

The college campus is home to various students, faculty, and staff members. The campus is home to scholarly inquiry, research, cultural/social events, classes, and athletics. Students often spend at least four years here pursuing new knowledge, faculty come to share their experiences and teach, and staff members ensure successful university operations. The college campus has many moving pieces, each being a part of the institution, with varying goals and objectives. A sample of this is in the image taken during a campus activities fair, shown in Figure 1.1.

Figure 1.1: The Embry-Riddle Aeronautical University, Daytona Beach (ERAU-DB) College Campus [1]

Over time, college campuses across the world have changed, and the design has been modernized. Gone are the days of computers taking up classrooms or buildings; now, there is a reliance on laptops in many Science, Technology, Engineering and Mathematics (STEM) courses. Student/faculty interaction has changed into a more intimate setting versus a list of hundreds of students in a class, and the student body has evolved, most recently with the SARS-CoV-2 outbreak beginning in March 2020, but over time as well from new generations entering college and others teaching courses. This evolution and development have also led to interesting new problems on the campus, one of which is discussed throughout this thesis.

I.I BACKGROUND

Colleges have seen expansion over the last 63 years due to more accessible education opportunities and government support (such as the G.I. Bill and the Free Application for Federal Student Aid (FAFSA)) [2] and [3]. This results in more students attending the university, more faculty teaching, and more staff members, ensuring the school operates smoothly. Yet expansion is not always positive. Many financial, physical, and ethical questions need acknowledgment before expansion. This study focuses on Embry-Riddle Aeronautical University, Daytona Beach (ERAU-DB) and the impact of its expansion over the last 58 years. ERAU-DB is home to 7,938 students [4], 378 faculty, and 1,114 staff and university administration (UA) members [5]. Founded in 1926, Embry-Riddle Aeronautical University (ERAU) moved from Miami to Daytona Beach (DB) in 1965 [6]. From there, several new buildings have been built, a few demolished, and others renovated. Figure 1.2 shows the layout of the ERAU-DB campus as of 2022.

Figure 1.2: ERAU-DB Campus Map View, Attention Drawn to the Student Union Center (SUC) [7]

ERAU-DB has a footprint of approximately 350 acres, with an open design to the campus and 33 buildings included. The model generated includes only the residential campus shown in Figure 1.2, satellite buildings are not included. The residential campus has 12 academic buildings, seven residence halls, 12 campus resources, two athletic buildings, and 13 athletic fields/complexes. More information on building classification and modeling is found below in Table 1.1.

Table 1.1: Grouping of different modeled buildings and athletic sites around the ERAU-DB campus, used throughout the modeling and simulations

Grouping	Bldg. Name
Academics	Advanced Flight Sim Center
	Aviation Maintenance Sciences (AMS) Hangar
	Capt. Willie Miller Instructional Center (IC)
	College of Arts and Sciences (COAS)
	College of Aviation (COA)
	David B. O'Maley College of Business (COB)
	Emil Buehler Aviation Maintenance Science (AMS)
	Engineering Special Projects & Labs (M Building)
	Fleet Maintenance Hangar
	Flight Operations Center
	Lehman Building - College of Engineering
	Modular Building 4
Residence Halls	Apollo Hall
	Doolittle Hall
	New Residence Hall 1
	New Residence Hall 2
	New Residence Hall 3
	Student Village (Adams, Wood, Tallman Commons)
	Student Village (O'Connor & Stimpson Halls)
Campus Resources	Campus Safety
	Center for Faith & Spirituality
	Corsair Hall
	Eagle Alumni Center
	Enrollment Operations (S Building)
	Jim W. Henderson Administration & Welcome Center
	Mori Hosseini Student Union
	Postal Services & Language Institute (Tomcat Annex)
	ROTC Athletic & Facilities Storage Building
	ROTC Center
	Wellness Center - Counselling
	Wellness Center - Health & Disability Services

Athletics	Artificial Turf Softball Field
	Clyde Morris Multipurpose Field
	Crotty Tennis Complex
	Eagle Fitness Complex
	ICI Center
	Multipurpose Artificial Turf Field
	Richard Petty Multipurpose East Field
	Richard Petty Multipurpose West Field
	Sliwa Stadium
	Soccer - Ticket Concession
	Soccer Field
	Softball Field
	Tine Davis Fitness Center
	Track & Field
	Track & Field Concession

Optimization is a challenge faced in everyday situations. A system only needs to perform its intended function(s) to be considered complete. Good systems work well, and optimized systems work efficiently. This thesis changes a design problem into an optimization problem and thus tackles it using systems thinking, modeling, and optimization strategies. To assist in narrowing the scope of this work, the flow of people is the optimization target of interest.

I.II SIMULATION METHOD

For analyzing the movement of people, vehicles, and workers on the ERAU-DB campus, a software package Simio (SImulation Modeling framework based on Intelligent Objects) is used [8]. Simio provides the ability to "make better decisions, conduct Real-Time Risk Analysis (RTRA), solve complex problems" and is "agile and responsive" [8]. For consistency, data between July 2021 and June 2022 is used. Simio allows the campus architecture to be modeled in the software and enables users to evaluate different congestion and choke points around the university.

This study consists of a three-stage approach. In the first phase, a general campus model will be created, known as a skeleton model, with basic/limited functionality. This model enables the software and theory to be validated and verified to ensure it is correct. The second phase is a four-prong campus survey to collect information about campus usage and congestion. This survey includes collecting information on the Student Union Center (SUC) as shown below in Figure 1.3 and the College of Engineering (COE) shown in Figure 1.4

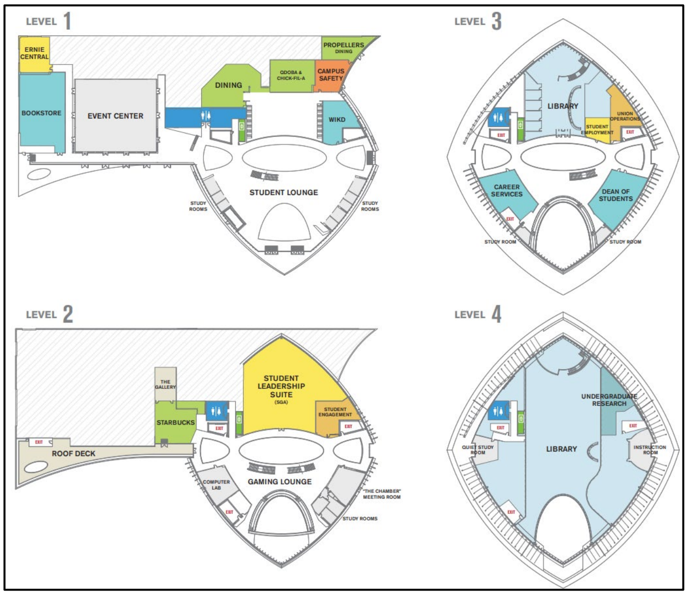


Figure 1.3: Breakdown of Student Union Floors [9]

Figure 1.4: College of Engineering [10].

The final stage in the approach is the creation of a campus detailed model. This shows how modeling theory has application to the campus overall. Additionally, it shows the implementation of the software compared to the survey data.

Within the model, people are represented as entities/tokens. This provides an easy way to view individual and group behavior. The flow of these entities becomes the optimization target which includes items such as entity travel time, average entity time in system, and entity queue times. By using entities and these time-dependent quantities, quantitative analysis can occur. Numerical metrics can be set as targets for goal setting via design and flow optimizations to determine where optimization of the campus should occur.

I.III IMPORTANCE OF RESEARCH

Innovative framework, expansion, and sustainability are critical for successful enterprises and organizations [11]. With the expansion of student enrollment [12] and the desire for competitiveness, ERAU-DB's expansion was inevitable. Yet the lack of sustainability can pose a serious issue and lead to businesses failing to operate. In ecology, one of the terms used for this is carrying capacity, which is "the maximum number of individuals that a habitat or area can support indefinitely, the limit usually being determined by the available food supply" [13]. Numerically, this is solved with the use of Equation 1 below, known as the Verhulst model [14], where *dN/dt* is the rate of population change, ρ is the maximum population growth rate, *N* is the population size, and *K* is the population carrying capacity.

$$\frac{dN}{dt} = \rho N \left(1 - \frac{N}{K}\right) \tag{1}$$

K was calculated by taking the total number of dorm spots available, minus the spots occupied by Resident Advisors, Resident Life Coordinators, and Resident Graduate Assistants. This is shown below in Table 1.2.

Table 1.2: ERAU-DB Dorms, Res Life Staff Numbers, and Updated Capacities

	Dorm Cap.	**RA/RLC/GA Estimation**	**Real Cap.**
Adams	312	8	304
Apollo	261	6	255
Chanute	129	6	123
Doolittle	357	8	349
New Hall 1	661	21	640
New Hall 2	618	21	597
New Hall 3	451	12	439

O'Connor	434	8	426
Stimpson	110	8	102
Wood	166	8	158

Data on the housing quantities versus the number of first-year students is mapped below from August 2018 until August 2022, with a carrying capacity curve for comparison. Figures are generated based on the paper from Ambrosoli [15], and correlations identified when possible. Note that correlations of less than 0.9 were treated as no notable correlation.

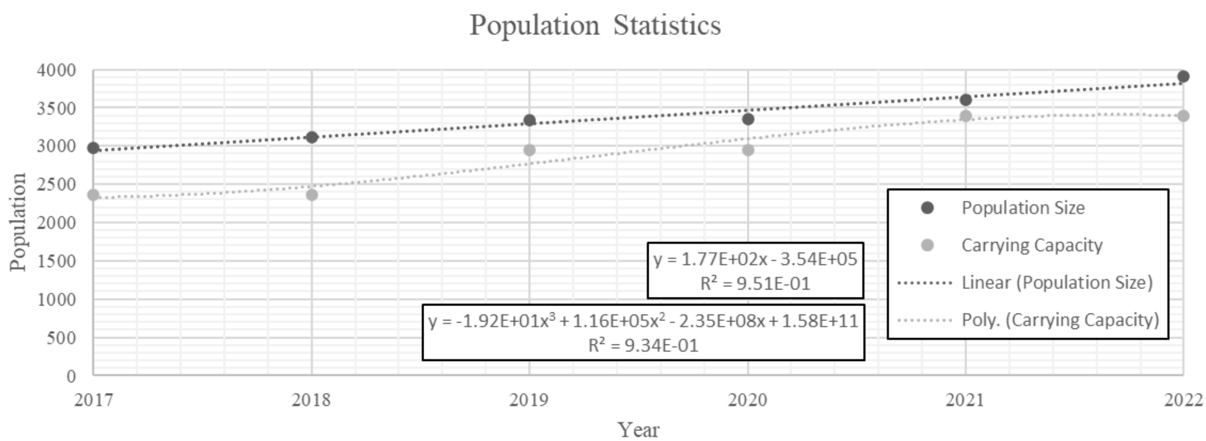


Figure 1.5: ERAU-DB Population Statistics from 2017 to 2022 [15]

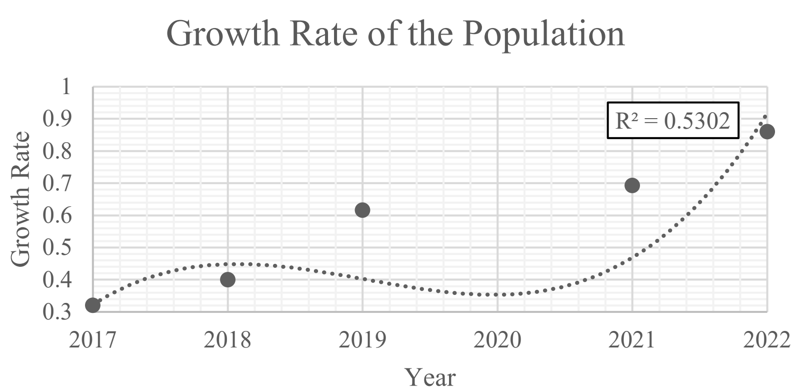


Figure 1.6: ERAU-DB Growth Rate of the Population from 2017 to 2022 [15]

As shown in Figures 1.5 and 1.6, ERAU-DB is quickly heading towards its' carrying capacity limit with no evidence of slowing down the growth observed in recent years. As such, a new strategy needs to be employed on the campus to ensure that carrying capacity is not breached and that the campus continues functioning as intended while bringing in more students in this highperforming modern-day STEM culture. Optimizing performance is one way to achieve this goal for the university without implementation of large-scale or challenging changes, or the slowdown of student admissions.

Optimization strategies employed on the ERAU-DB campus can then be applied at other universities, which may be experiencing the same or similar issues on their campuses. This thesis aims to set up a framework independent of the site it is applied to by using common components and structures of the college campus model, ensuring it remains modular and applicable to several locations rather than just at ERAU-DB. The framework may be applied to a campus model, enabling the university to make quick changes and transitions without excessive downtime or loss of potential student body.

I.IV SCOPE OF THESIS

This thesis consists of a full report of the work performed during the Master of Science in Systems Engineering program and is divided into six chapters. Each of the following chapters is detailed below.

Chapter two of the thesis details the review of relevant literature on simulation, campus design, optimization, and modeling. Relevant theories are covered in this section as well.

The third chapter of the thesis covers the methodology, the ideas employed, and the process followed and executed during this project. This chapter also details the skeleton model, the campus survey, and the detailed model. Lastly, this chapter covers Verification and Validation (V&V) and optimization strategies.

Chapter four provides the results of the thesis work. This chapter highlights the data collected from the campus survey and the raw results obtained from the simulations and designs.

The fifth chapter of the thesis provides a discussion and analysis of the results. The details on model efficacy, modularity, and feasibility to apply to other buildings and campuses are covered here.

The final chapter of the thesis covers the suggested future work, as well as providing a conclusion to the work included herein. This chapter is followed by the references and appendices, where the survey questions are.

II. LITERATURE REVIEW

Universities have been around since 859 AD with the establishment of the University of Al-Karaouine [16]. Designs and layouts have sometimes changed, but core concepts can often still be tied back to the original style of these institutions. Over time, the student body has changed and evolved, with different generations and types of student demographics also being present. Often though, universities are treated more in a "how it has been" versus a "how it could be" lens.

II.I RELEVANT EQUATIONS

The equations presented are divided into two groups, those important to campus fundamentals and those for simulation modeling and understanding. Campus fundamentals include tracked rates (i.e., acceptance, retention, graduation), campus size, demographics, and population numbers. Simulation equations include those for server processing, simulation results, and model entity behavior.

II.I.I CAMPUS FUNDAMENTALS

Campus fundamentals are the core statistical and mathematical principles that guide a university toward its missions and goals. These include physical metrics, such as utilized area and buildings; quantitative metrics, such as graduation rates and age and qualitative metrics, such as race.

The campus area is the first component covered in this section. The campus area has two parts; area available and area utilized. For calculating the area available, maps from [17] were used, and it was estimated with the use of Equation 2 below, where A_{Av} is the area available, L_{Map} is the mapped length, and W_{Map} is the mapped width.

$$A_{Av} = L_{Map} \times W_{Map} \tag{2}$$

The area utilized is calculated next as it requires the area available to be considered. It is calculated using Equation 3 below, where A_{Bi} is the occupied area taken up by a building or field defined in Table 1.1.

$$A_{Utl} = \sum_{i=1}^{46} A_{B_i} \tag{3}$$

The area used by each building was found using the standard area equation for a rectangle, where L_B is the length of the building, and W_B is the width of the building, following the approximation of each structure to be rectangular in shape following the grid pattern from [17].

$$A_B = L_B * W_B \tag{4}$$

Once this has been found for all 46 buildings and fields, an approximation for the area remaining can be calculated using Equation 5 below.

$$A_{Rem} = A_{Av} - A_{Utl} \tag{5}$$

The next series of equations defined in this section deal with trackable rates of student performance. Note that this section only applies to the number of students on campus. Staff members, administrators, and faculty do not get admitted to the school, nor graduate (unless they take classes, in which case they are counted as students), thus they will not be added in here. These include acceptance, retention, and graduation rates. For acceptance rate, this defines the number of students admitted to the university compared to the number of students who applied. It is shown below in Equation 6.

$$\%_{Accept} = \frac{NumAdmit}{NumApply} * 100 \tag{6}$$

While the acceptance rate deals only with the incoming class, the retention rate can be applied to any class year-to-year or to a group over all the years at the university. For the year-to-year analysis, Equation 7 is utilized.

$$\%_{Ret} = \frac{NumEnrolled_{y+1}}{NumEntrolled_y} \quad (7)$$

This year-to-year retention can be applied over multiple periods to track the retention of a class of students for more than one cycle. For instance, a two-year retention period would have $NumEnrolled_{y+2}$ in the numerator and $NumEnrolled_y$ in the denominator.

Retention until graduation is the graduation rate. The graduation rate is often seen as a four-year retention period for undergraduate students, but some will graduate before four years, and others will graduate after four years. The four-year graduation equation for this is found below in Equation 8.

$$\%_{Grad} = \frac{NumGrad_y}{NumAdmitted_{y-4}} \quad (8)$$

Demographic data is often of interest to different programs, grants, and experts in the higher education space. Diversity, Equity, and Inclusion (DEI) are becoming more discussed in the field of higher education and becoming more crucial to campuses as they look to expand and grow [18]. In this section, the entire campus population is of interest, not just the students. The first demographic discussed is the percentage breakdown of different ethnicities on the campus. This demographic is calculated with the use of Equation 9.

$$\%_{ethnicity} = \frac{NumEthnicity_y}{Population_y} \quad (9)$$

ERAU-DB declares nine ethnicities that it tracks for demographics [19]. This allows Equation 9 to be rewritten as Equation 10, where an index gives the ethnicity percentages for each ethnicity at ERAU-DB.

$$\%_{ethnicity_i} = \frac{NumEthnicity_i}{\sum_{i=1}^{9} NumEthnicity_i} \quad (10)$$

The next demographic tracked is the percentage breakdown of gender on the ERAU-DB campus. For this metric, ERAU-DB only declares male and female as the two options. Thus, it can be written as Equation 11 below.

$$\%_{gender} = \frac{NumGender_y}{Population_y} \tag{11}$$

The last demographic that will be covered here is age. While the traditional college student tends to be less than 24 years old [20], nontraditional students will likely fall outside of this range yet still influence campus design, development, and optimization. As per ERAU-DB's current practices, Human Resources (HR) defines seven different age ranges, which will be used in this study. These age range groupings are under 20, 21-30, 31-40, 41-50, 51-60, 61-64, and 65 and older [21]. The calculation for age can be represented as Equation 12.

$$\%_{age_i} = \frac{NumAge_i}{\sum_{i=1}^{7} NumAge_i} \tag{12}$$

Campus employees are another crucial component of the campus model. These employees are divided into three categories, Staff, UA, and Faculty. Staff members and UA are typically 12-month employees (i.e., on-campus year-round), whereas Faculty are sometimes on a nine-month contract (i.e., only in the Fall and Spring semesters, between August and May). As such, Equation 13 is utilized to determine the number of employees on the campus during a given period.

$$\%_{NumEmploy_i} = \frac{NumContract_i}{\sum_{i=1}^{12} NumContract_i} \tag{13}$$

The next metric measured for campus employees is the percentage breakdown of each type. Since there are three types of employees on the ERAU-DB campus, Equation 14 can be used to determine the percentage makeup of each.

$$\%_{EmployType_i} = \frac{NumType_i}{\sum_{i=1}^{3} NumType_i} \tag{14}$$

Campus housing is often a discussion topic for new students when identifying which campus to consider for their time as a student in academia [22]. Different metrics contribute to how housing looks on the ERAU-DB campus. The first metric is housing capacity. Given that there are ten dorms on the campus, capacity can be found as shown below in Equation 15.

$$HousingCap = \sum_{i=1}^{10} DormCap_i \tag{15}$$

The next metric for housing is the utilization of each dorm. This comprises of a few different variables. The first is looking at spatial utilization through the building footprint. With the estimation of square footage from [17], and the number of beds per dorm from [23], a percentage is generated for each dorm, shown in Equation 16 below.

$$\%_{DormEff} = \frac{DormBeds}{DormSqFt} * 100 \tag{16}$$

The next metric to track in the dorms is the utilization of available beds. This includes ensuring that the beds that were assignable are assigned, done with Equation 17.

$$\%_{DormUtl} = \frac{DormAssign}{DormBeds} * 100 \tag{17}$$

While this metric is not a pure efficiency metric, this is something important for campuses to consider as vacant beds mean fewer students, yet over-assigning beds mean students may not have housing on campus.

The final housing metric to track is the involvement of Resident Advisors (RAs) in dorms, done as a ratio of the number of RAs and housing professional staff (Resident Life Coordinators and Graduate Residential Advisors) to students in the dorm rooms. Equation 18 is applied for this.

$$HousingStudRat = \frac{HousingProfStaff}{AssignedStud} \tag{18}$$

Campus parking has been criticized by many universities as talks on sustainability increase [24]. Varying guidance exists on how parking should look on campus, who should have a vehicle on campus, how students get to and from the university, and the installation of parking garages and mass parking systems. For metrics, this includes analyzing the amount of parking space available, measured against the number of parking passes issued. ERAU-DB has 27 parking lots and a parking garage, each assigned one or more colors and divided into six categories: general, commuter student yellow, resident student green, resident student red, resident student purple/white, and employee blue [25]. Only vehicles with matching-colored parking passes can park in those lots.

The usage of each lot also needs to be measured, done using Equation 19 for each of the lots on the ERAU-DB campus.

$$AssignedSpotRat = \frac{ColoredPassIssued}{ColoredPassCap} \tag{19}$$

These fundamental, campus-specific equations drive the academic focus of this study and are not restricted to any one campus. While metrics will change (e.g., more parking lots, different demographics tracked), these are core equations measured at any university and modified to track the various metrics of interest for their university setting.

II.I.II SIMULATION EQUATIONS

Simulation equations drive the simulation, optimization, and systems engineering portion of the campus modeling and optimization problem. They consist of different parameters tracked throughout a simulation and output metrics that show the efficiency of the modeled system. A server is one of the major components of the simulation model. A server is an object that receives an entity, performs a process (or processes) on it, and then releases it. The primary simulation elements covered here, from [8], are the basic server properties, the output results from the server, and the output results of the model entities being tracked in this study (i.e., people).

The server has nine default states in Simio. These include starved, processing, blocked, failed, off shift, failed processing, off shift processing, setup, and off shift setup. Starved is the first state discussed. This state is defined as "A condition where a process cannot be supported by available resources…can occur due to the lack of resources or the existence of multiple processes that are competing for the same resources" [26]. For tracking, the metric of interest is the percentage of time spent in the starved state done in Equation 20.

$$\%_{time_{starv}} = \frac{TimeInStarv}{TimeElap} \tag{20}$$

Processing is the next metric tracked during the simulation for the server elements. Processing is the "operation or set of operations performed that can include collection, retention, logging, generation, transformation, use, disclosure, transfer, and disposal" [27]. This processing is coded into the simulation and is a user-defined function executed based on the coded logic inside of Simio. Once again, the percentage of time spent in the processing state is tracked using Equation 21.

$$\%_{time_{proc}} = \frac{TimeInProc}{TimeElap} \tag{21}$$

Blocked is when "the server has completed processing, but the entity cannot release the server" [28]. This can be if there is another server after that is not yet vacant, if other paths are all blocked, and so on. The percentage of time spent in the blocked state is another metric tracked during a simulation, done with Equation 22.

$$\%_{time_{block}} = \frac{TimeInBlock}{TimeElap} \tag{22}$$

Failed is a server state where “the resource (server) is failed and not allocated to any tasks” [28]. This can be due to a part failure in the case of machinery, and this study will be treated as any time when the server should be able to be used but cannot be used by people. The percentage time of this is tracked using Equation 23.

$$\%_{time_{fail}} = \frac{TimeInFail}{TimeElap} \tag{23}$$

Offshift is when the server uses a schedule and is not scheduled during a time and thus not assigned to any tasks at that time [28]. For this study, offshift will occur in the case of food when workers are not staffed and buildings during closure dates. The time tracked for this property is done in Equation 24.

$$\%_{time_{offsh}} = \frac{TimeInOffSh}{TimeElap} \tag{24}$$

Failed processing is a server state where the server is in the failed state but is still processing different entities. This state will not be seen often in this study but can occur when servers are being utilized, despite being in a state where they have already failed. The percentage of time tracked for this is in Equation 25.

$$\%_{time_{failproc}} = \frac{TimeInFailProc}{TimeElap} \tag{25}$$

Off shift processing is the server state in which the server is scheduled to be off shift, yet it is still processing entities as the behavior is to finish the entity being processed before going off shift [29]. This state will occur during the off hours for ERAU-DB and is mainly driven by students. The time spent in this state is measured using Equation 26 below.

$$\%_{time_{offshproc}} = \frac{TimeInOffShProc}{TimeElap} \tag{26}$$

Setup is the time required for a server to become functional by physical construction, loading the necessary data files and information, and preparing the correct spaces. Mainly seen with food prep, cleaning, and room arrangements for the campus. The time spent in this state is measured once again in Equation 27.

$$\%_{time_{set}} = \frac{TimeInSet}{TimeElap} \tag{27}$$

Off shift setup is the final server state and is when "the server is offshift, but the OffShift Rule is 'Finish Work Already Started' and thus the setup task is being finished while offshift" [30]. Used for construction time, additional unscheduled prep time, and overtime fixes as needed. Equation 28 is used to track the time spent in this state.

$$\%_{time_{offshset}} = \frac{TimeInOffShSet}{TimeElap} \tag{28}$$

Once a simulation is run and finished, results are generated. In the case of Simio, a pivot grid is the default way to view results, which contain many numerical properties tracked based on the objects added into the simulation. In the case of the server, there are seven properties of interest in this study: scheduled utilization, time processing, time-starved, number in station, time in station, uptime, and downtime. The scheduled utilization is the first metric discussed. It is defined as "the average capacity utilized divided by the average capacity scheduled" [31]. The first metric is determining the total scheduled utilization time using Equation 29.

$$TotSchUtl = \sum_{i=1}^{n} \frac{AvgCapUtl}{AvgCapSch} \tag{29}$$

The other key metric for this result is determining the percentage of time when this occurs, done as a ratio shown in Equation 30 below.

$$SchUtlRat = \frac{TotSchUtl}{TimeElap} \tag{30}$$

Time processing is the next metric to track during the results. This metric is the total amount of time that was spent in the processing state across all server elements. This is a more important metric as it shows the efficiency of a server based on the amount of time it is processing rather than existing in an idle state, defined mathematically in Equation 31.

$$TotTimeProc = \sum_{i=1}^{n} TimeProc \tag{31}$$

Once again, a ratio can be generated to identify the processing time measured against the simulation time, shown earlier in Equation 25.

Time starved is the next result tracked. This metric is the length of time for determining how long the server is idle [32] and is defined mathematically in Equation 32.

$$TotTimeStarv = \sum_{i=1}^{n} TimeStarv \tag{32}$$

The number in station is the metric which deals with the number of entities a server takes in during a given period and then converting that to an average capacity and total sum. It is helpful to see if all servers/stations are taking in the same number of entities, where entities prefer to go, and so on. Mathematically it is defined in Equation 33.

$$TotNumInStat = \sum_{i=1}^{n} NumInStat \tag{33}$$

Ratios are defined here for each of the stations and the usage of each, resulting in Equation 34 below.

$$NumInStatRat = \frac{NumInStat}{TotNumInStat} \tag{34}$$

Time in station is the duration an entity spends at a station during the simulation which can consist of queued, processing, exiting, etc. This is useful for determining if a station is clearing entities efficiently and if it performs as expected. The equation for this is shown below in Equation 35.

$$TotTimeInStat = \sum_{i=1}^{n} TimeInStat \quad (35)$$

For this optimization study, the interest becomes the ratio of stations that clear entities in the expected time against those that do not, shown in Equation 36.

$$StatClrRat = \frac{TimeInStat_{Exp}}{TimeInStat_{Act}} \quad (36)$$

Uptime is a more commonly used term, inside and outside of simulation, and deals with "the percentage of time that a system is operational and accessible to users" [33]. Uptime is calculated as a sum of properties previously defined, shown in Equation 37 below.

$$Uptime = TotTimeProc + \sum_{i=1}^{n} FailProc + \sum_{i=1}^{n} OffShProc \quad (37)$$

A ratio is used here to determine the percentage of time the server spends in the uptime state, as shown in Equation 38.

$$UptimeRat = \frac{Uptime}{ElapTime} \quad (38)$$

Downtime is the last property from the server results of interest during this study. Downtime is the "time during which production is stopped, especially during setup or when making repairs" [34]. It again consists of a few different previously defined metrics and is defined in Equation 39.

$$Downtime = \sum_{i=1}^{n} TimeStarv + \sum_{i=1}^{n} TimeBlock + \sum_{i=1}^{n} TimeFail + \sum_{i=1}^{n} OffSh + \sum_{i=1}^{n} Set + \sum_{i=1}^{n} OffShSet \quad (39)$$

The final ratio in this section is the downtime ratio. Similar to the uptime ratio, this is useful for determining the time the server spends in the downtime state and is represented by Equation 40.

$$DownTimeRat = \frac{Downtime}{ElapTime} \tag{40}$$

While servers are a significant object in simulation for tracking various statistical properties of interest to stakeholders, the entities are another essential piece to successful simulations. In the case of Simio, the metric tracked here is the time in system of the entities. This is "the time in queue plus the time in service…overall from arrival to exit" [28], defined below in Equation 41.

$$TIS = \sum_{i=1}^{n} EntityTime \tag{41}$$

Simulations are a way to enable testing, modeling, and execution of ideas in a cheaper and often faster way than physical changes. They give a way to analyze the current state of a system and then highlight changes made to improve the performance and direct the system closer to existing in an optimized state.

II.II SIMUATION METHOD

The simulation employed in this study stems from best practices applied to the Simio simulation environment. The focus is on the ERAU-DB campus, yet the core principles come from the fundamentals of simulation theory applied to this situation. This section will first cover the fundamental theories in this study, followed by the models generated, the objectives, the systems engineering documentation created, and the key stakeholders involved throughout and ensuring the accuracy of the simulation.

SIMULATION THEORY

Modeling and simulation enable users to see a problem from new lenses, as well as test implementations and potential solutions to a problem for a fraction of the cost of physically testing the same ideas [35]. While we model to understand, simulation techniques have a procedure that is intended to be followed. For this study, the procedure that will be used for the simulation is similar to the circular problem-solving process in engineering design from [36] with its six steps. Along with these basic steps, other major parts of simulation involve documentation, optimization, and iteration. These parts are covered more heavily in Chapter 3.

At the core of this study is systems engineering, and by extension systems thinking. Systems thinking is defined as "a holistic way to investigate factors and interactions that could contribute to a possible outcome" [37]. This framework enables problems to be considered from multiple angles, ultimately leading to a multi-prong solving approach and a more complete solution. In this study, systems thinking was used to identify the problem, and is actively used during modeling and simulation to find the elements which are key players. These elements are the ones that are the most troublesome or problematic in the goals this study aims to achieve.

Lastly for the simulation theory, verification and validation are two steps which need to take place. Verification is defined as "the confirmation, through objective evidence, that the system requirements have been fulfilled" [38] whereas validation is defined as "the confirmation, through objective evidence, that the developed system effectively achieves its intended purpose and meets user needs" [38]. In summary, it can be viewed as 'was the system built right' and 'was the right system built'. The verification process helps to ensure that the model generated matches the expected behavior of campus partners, and validation checks that the model generated is built correctly, and the outputs captured meet the needs of the university stakeholders involved in the project.

MODELS

The first campus model created, the skeleton model, is designed to be a high-level overview of how simulation can fit various settings and models globally. This model provides a bird's eye view of the campus and a way to see the movement of people from one location to another and how long they spend at each location. Storyboarding and templates are elements of designing a good simulation and often encouraged as best practices to be followed [39].

The detailed model shows the application potential of the simulation, alongside the ability to for application in a much more detailed setting. Further, this model is targeted at the student stakeholders, as it directly impacts many of the actions and activities, they will take part in during a day-to-day setting on the campus. Model tuning is used to narrow variability in simulation and create a cleaner final output from the simulation even with small datasets via few-shot learning algorithms [40]. For this study, model tuning will be used to ensure the framework created is sustainable, modular, and can be applied across multiple different campuses and solving different problems in higher education.

SURVEYS

The campus surveys help to drive the simulation data. Over a series of four qualitative surveys, student perceptions on the campus will be gathered. This will provide a foundation for the initial simulation data, and act as a starting point for loading the necessary information. These surveys include questions on the campus dining, queue times, location usage, living location, etc.

While the surveys provide a baseline for the simulation to start from, the simulation will still be the resulting product that leads to suggestions for implementation. From a timeline perspective, the survey data is the "today" value and the simulation data will be the "tomorrow" value, showing how changes that we choose to implement will impact the results of the model as a whole.

OBJECTIVES

Several core objectives drive the design, implementation, and execution of this study. All these objectives are rooted in ERAU-DB and based on issues previously identified and aligning with those in the strategic plans [41]. The first main objective of this study is to determine the current attitudes on the campus layout and existing structure. This is based on the implementation mapping methodology step 1: "conduct an implementation needs assessment and identify program adopters and implementers" [42]. Once the perspectives on the current campus layout are determined, goals are set for optimization, and targets are made for areas where the flow needs improvement.

This leads to the second objective of this study, improving the flow on the ERAU-DB college campus. Different elements of the campus can be focused on during optimization, as it is easier to make small changes across the board rather than one or two significant local changes [42]. Once the simulation has identified different flow objectives and targets, these will be cross-checked with the stakeholders to determine how the suggested changes meet or miss their expectations and needs.

The third and final objective of this study is to look at the understanding generated by the simulation against what the stakeholders expected and the long-range impacts the output of the study will have on the ERAU-DB campus. The simulation aims to improve the quality of life on the campus by shortening waiting times, creating sustainable systems, and understanding the processes and procedures already in place. As such, the simulation needs to handle different queuing systems and their metrics, be run over long periods (10+ years) against growth curves to test sustainability and integrate existing documents and controls from the university. Once metrics are confirmed by the stakeholders, plans for implementing the suggested change(s) can begin.

DOCUMENTATION

This study consists of several stages in which documentation is paramount in highlighting the work conducted and the results determined. This documentation consists of creating a simulation functional specification document, a systems requirement specification document, and a statement of the simulation project.

The simulation functional specification document "defines what the system should do and what functions and facilities are to be provided within the system" [43]. This document helps to outline the expectations and performance of the system, document stakeholder expectations, and define the scope of the system being developed. Once this document is underway, a system requirement specification document is created.

In systems engineering, requirements drive the design of a good system. These are the agreed-upon understanding between the customers/stakeholders and the developers/engineers who design the system. Formally, a system requirement specification document is "a detailed overview of the software parameters and goals…the project's target audience and its user interface, hardware and software requirements…how the client, team and audience see the product and its functionality" [44]. This documentation allows the system to be certified with the stakeholders and the statement of the simulation project created.

Commonly seen in best practices for simulation from [28], the statement of simulation project is a comprehensive project document consisting of the objective of the study, determining model scope and detail level, experiment design, and others [45]. This document provides a comprehensive look at the simulation to be done along the objectives, requirements, stakeholders, and needed data to successfully the simulation. The terminal documentation for this project consists of a conference/journal paper and a poster presentation aimed at disseminating the work in systems engineering and academic settings, respectively.

STAKEHOLDERS

Stakeholders are individuals who, while not directly on the development team, drive the direction the project will go in and how it should perform. This can be done financially or through requirement checking, interviews, and defining the project goals, objectives, and scope. This study involved stakeholders who will be directly impacted by the results, as well as those who will be the ones that need to ensure the recommendations made are implemented.

Students are one of the main stakeholders in this study. Students are at the core of the academic institution and often must deal with most of the fallout of academic processes and policies [46]. In this study, they have been essential to understanding the nature of the problems faced on the campus in day-to-day activities, where they feel more influence and assistance are needed on the campus, and how the issues encountered on the campus impact their abilities to perform well academically.

Faculty and staff are the other influential stakeholders in this study who drive the focus areas of interest and will be impacted by the results. These stakeholders deal with policies concerning accreditation, student success, teaching, and others [47]. As such, they drive the focus areas dealing with more of the classroom facing and location side. They also influence how the campus conducts research and high-profile events, another important metric for college campuses in recent years [48].

University Administration (UA) plays a unique role as a stakeholder in which they get to drive some of the topics, discussions, and focus areas, but they are also the group responsible for ensuring the recommendations from the study are implemented and maintained. They drive some discussions on pieces such as accreditation and student admission but also look at the bigger picture for items on longevity and feasibility of implementing changes on the campus such as those for scholarly activity [49]. As such, they have a more substantial role than other stakeholders since their involvement has two pieces to it.

Systems engineers are the final stakeholder group discussed here. After all, this project comes from the scope of a systems thinking applied simulation and optimization project. These stakeholders assist in the design of the project, ensuring the project is within scope, that best practices are applied, and that the project is correct for what is being requested [50]. This group is the least involved from the study performance standpoint but is essential for the proper design of the study and ensuring that the best practices of systems engineering and systems thinking are followed.

II.III GAP IN LITERATURE

This study aims to expand the current literature on college campus design and layout. Further, this study will enhance systems engineering applications in the higher education realm and show how the fundamentals of systems engineering can be applied to more problems observed in day-to-day settings. This study focuses on tying the bridge between higher education and systems engineering, simulation theories, and campus models.

As a systems engineer, keeping in mind the entire product lifecycle is always important [51]. This study enables this by allowing for multiyear (and multiclass) simulations to take place, showing how the "product" (i.e., student success metrics) change over time and where they are negatively and positively impacted. The study from Hossain found the influence of systems thinking in existing literature in terms of current and emerging trends evolving over time, as well as looking at content analysis for prominent publication statistics [52]. This thesis aims to tackle similar concepts and as such improve the understanding of different systems thinking applications and expansion of possible literature resources.

With the notable recent advances in technology fields such as artificial intelligence, digital twins, and others, simulation is key to success going forward. In their study on the future impacts of simulation, Mittal found that synthetic emergence can allow for better ease of creating modeling and simulation harnesses so a system can be tested and analyzed before going into production [53]. Being rooted in simulation theories and techniques, this study will continue to advance the path of what is possible with simulation and expand on the available documentation, resources, and ideas that are available to other modelers, engineers, and scientists. This thesis aims to create tools and a framework that can be applied at other universities and implemented across the board with other issues faced in higher education.

Being based on a university and the challenges faced, this study fits into the higher education realm, especially in terms of retention and recruitment. By analyzing the capacity of the campus and the use of the space currently available, a bigger picture can be gained for how many new students can be brought it, and how the carrying capacity of the campus shifts over time. Likewise, analyzing the functions currently used on the campus, and optimizing those which have led to issues, can increase student retention, and enable more students to remain at ERAU-DB. Caballero found the influence of various factors and frameworks on student retention in their study on the different factors and strategies for student retention [54]. From the results of Caballero's study, this thesis will expand the literature by incorporating different frameworks and metrics in the simulation, specifically expanding from Tinto's Student Integration Model, and showcasing how this tool can be added in to predict student belongingness and be an aid to retention models.

This study acknowledges some DEI goals, primarily those concerning the equitable access to resources on campus. Through the optimization and implementation of a simulation on the ERAU-DB campus, there is an ability to highlight resources that are either over or under accessed by students. While demographics are mainly looked at from a number lens and less so for study success, the demographic ratios can be applied to the data found from resource usage, and gaps can be determined for where more resources are needed, or where more awareness and attention needs to be brought forth for student awareness. A similar study by Chankseliani and McCowan found that the United Nations Sustainable Development Goals for universities can be used to help begin to form equal access to tertiary education [55]. This study aims to add to this by creating frameworks and integrating metrics for the Sustainable Development Goals inside of the simulation for ease of tracking and future planning of expected growth patterns.

III. METHODOLOGY

This thesis consists of different models being built, simulations being run, and optimization occurring alongside Verification and Validation (V&V). Many internal stakeholders were involved, and external partners determined how effective the results would be for their campuses. This section of the thesis details the research approach taken, complete information about the construction of each of the models, the implementation of V&V, and the optimization approach applied.

III.I RESEARCH APPROACH

Throughout this thesis, various models were generated, and V&V occurred. Initially, the Skeleton Model was created. This model is a framework that was used to ensure that the input data was sufficient to obtain results and that there were no syntax errors which would cause the model to crash. The Skeleton Model is shown in Figure 3.1 below.

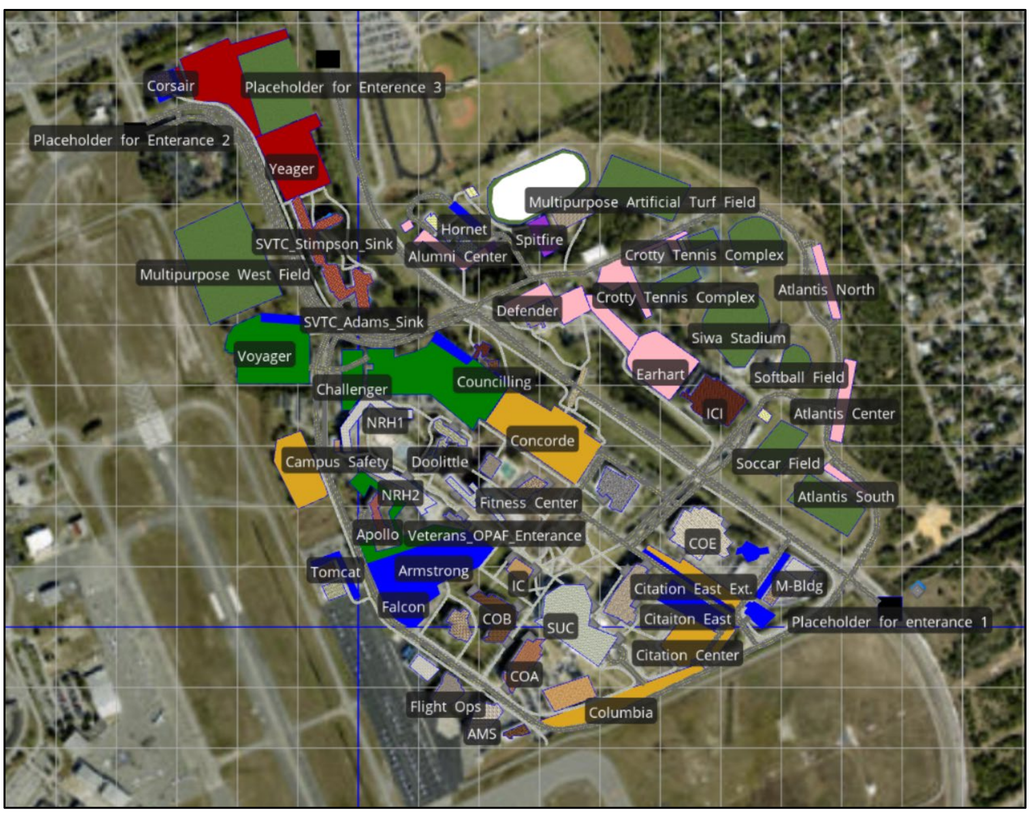


Figure 3.1: Skeleton Model as Seen Inside of the Simio Environment

Once the Skeleton Model was generated, a Detailed Model was designed. This Detailed Model provides more accuracy to the model and allows the simulation to appear cleaner. At this stage, deeper functionality is added in, and the model is again run to ensure results are obtainable and there are no errors which would result in the simulation crashing. The Detailed Model is shown in Figure 3.2 below.

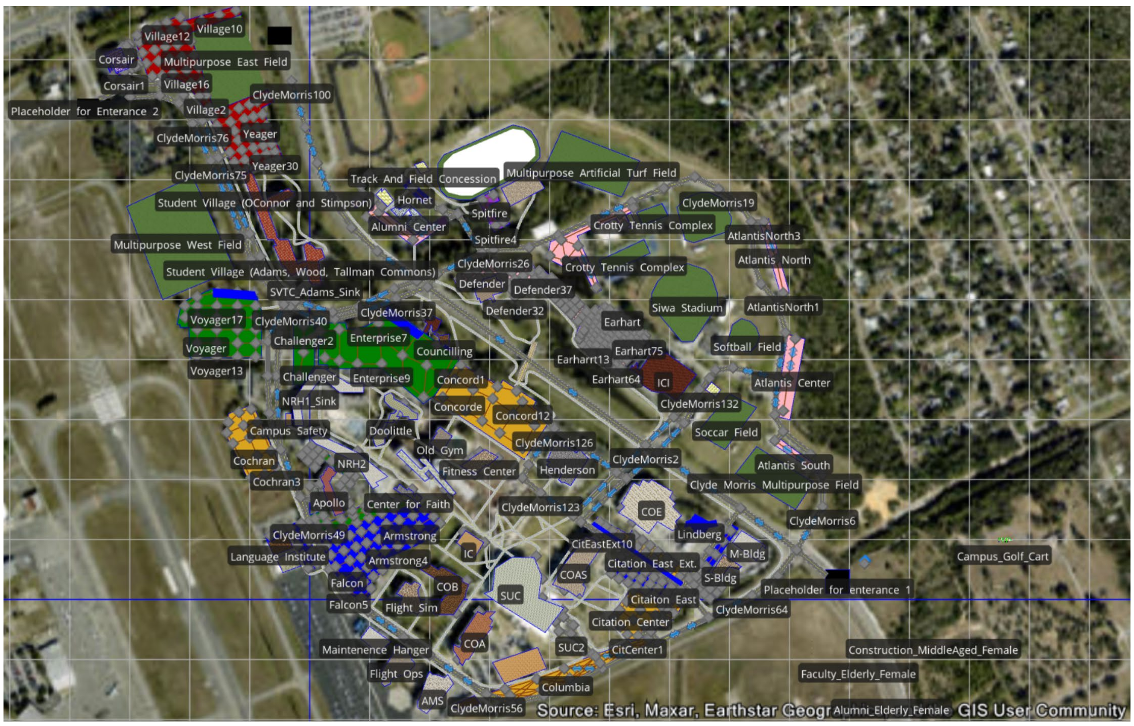


Figure 3.2: Detailed Model as Seen in the Simio Environment

Throughout model design and testing, V&V was performed. This V&V involved consulting campus partners to get their insights on the different designs and problems (including surveys and feedback forms), consulting System Engineering experts to ensure that the frameworks and methodologies applied during the thesis are in line with best practices, and lastly disseminating the work to external engineering partners and colleagues to gain their feedback on how the framework developed needs to be edited for application at their host institutions.

The other major item occurring during this thesis is optimization, the core focus. During the model testing, baselines were generated on the first five trials. After these trials occurred, twenty experiments were set up. In Simio, an experiment is defined by the scenarios, the replications, the controls, and the responses [56]. These experiments were designed with the intent to optimize the flow of people, that is, decreasing the time they wait or idle during simulation tests. Optimization, however, comes at a change of costs, meaning that the differences found need to be significant. For determining statistical significance, confidence intervals were used where response intervals not containing zero are shown to be statistically significant. Once 70% of experiments which showed optimization were found, the trial was considered successful, and the simulation moved on to the next trial. In a case where 20 experiments were run and less than 50% of experiments showed optimization, the trial was considered unsuccessful, and the simulation moved onto the next trial. Once all models were run, all statistically significant changes were recorded and documented to be proposed to university leadership teams.

III.II SKELETON MODEL

The Skeleton Model is the first model that is created during the thesis. This is the high-level framework model of the ERAU-DB campus that the model is based on. This section covers the input data required to build and run the model, the construction process for the model, the output data that the model can yield, and the intended impact and implications this model has on both this project and future work.

The Skeleton Model requires the least input data of all the models generated during this study. For this model, the only input data required comprised of building locations, sidewalk locations, entity types, and building entrances. Building and sidewalk info has been previously defined in Table 1.1 and Figure 1.2. Entity types are newly defined and shown below in Table 3.1.

Table 3.1: Identification of the 18 Entities Modeled During This Thesis with Their Unique Identifiers and Other Pertinent Information

Entity Number	Classification	Ethnicity	Gender
1	Student	American Indian/Alaskan Native	Male
2		Asian	
3		Black/African American	
4		Hispanic/Latino	
5		Native Hawaiian/Pacific Islander	
6		Nonresidential Alien (International)	
7		Race/Ethnicity Unknown	
8		Two or more races	
9		White	
10		American Indian/Alaskan Native	Female
11		Asian	
12		Black/African American	
13		Hispanic/Latino	
14		Native Hawaiian/Pacific Islander	
15		Nonresidential Alien (International)	
16		Race/Ethnicity Unknown	
17		Two or more races	
18		White	

Apart from this info on the physical model components, the behavior of the entities needed to be defined as well. Each entity assumed similar walk speeds defined as 1.31 meters per second inside of Simio. This is based on the average human walking speed of approximately three miles per hour from [57]. In addition, all entities were assumed to have predefined times in the servers of each building. These processing times are defined in Table 3.2 below.

Table 3.2: List of Locations Used by Students and Their Time Spent There in a Typical Week

Location	Average Time Spent (Mins)	Standard Deviation
COE	583.52	665.29
COA	500.29	559.05
SU	732.65	732.65
IC	170	44.72
COAS	814.48	691.86
COB	489.55	500.8
Admissions	840	0
Fitness Center	452.79	399.93
ROTC	780	500.2
Dorms	4500.9	2654.65
Quad	342	459.15
Flight Ops	60	0

M Building	532.5	425.52
Bldg. 508	300	0
ICI	750	150

This model does not account for travel to campus but does have the entities beginning at their respective locations. For instance, only student entities can begin in the dorms, where other entities begin at campus entrance/exit points. This model also does not account for shifts, so it is only analyzing the movement behavior and flow of entities and not their predictive behaviors.

The first step in constructing the Skeleton Model is identifying the location to build in. Since Simio has ArcGIS integration with it for mapping, the first step is to input the location of ERAU-DB into Simio. This yielded the image shown in Figure 3.3 below.

Figure 3.3: ERAU-DB Campus as Shown in the Simio Environment. The Blue Lines and Their Intersection Show the Location Manually Inputted and the Map Generated

Next for the Skeleton Model creation, the buildings needed to be added in. These were drawn as polygons with preset materials being used to color code and differentiate between them. The resulting model is shown below in Figure 3.4.

Figure 3.4: ERAU-DB Campus as Shown in the Simio Environment with Preliminary Buildings Added in (Based on the Available Campus Map)

Adding the parking lots and athletic fields to it was the next step in developing the Skeleton Model. It should be noted that these don't impact the Skeleton Model since parking is not a function added in yet, but for planning and location setting they were added in at this stage. The resulting model update is shown below in Figure 3.5.

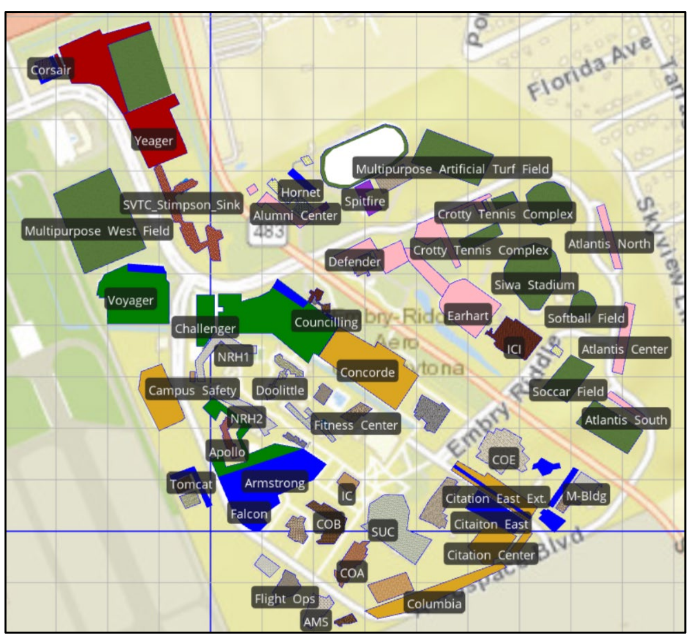


Figure 3.5: ERAU-DB Campus as Shown in the Simio Environment with Preliminary Parking Lots and Athletic Fields Added in (Based on the Available Campus Map)

The other significant building part of this model is adding in the sidewalks and roadways. As per the figures shown in Chapter 1 for the campus map, these sidewalks were adapted for the digital model and added in as closely as possible to preserve model accuracy. The resulting model is shown below in Figure 3.6.

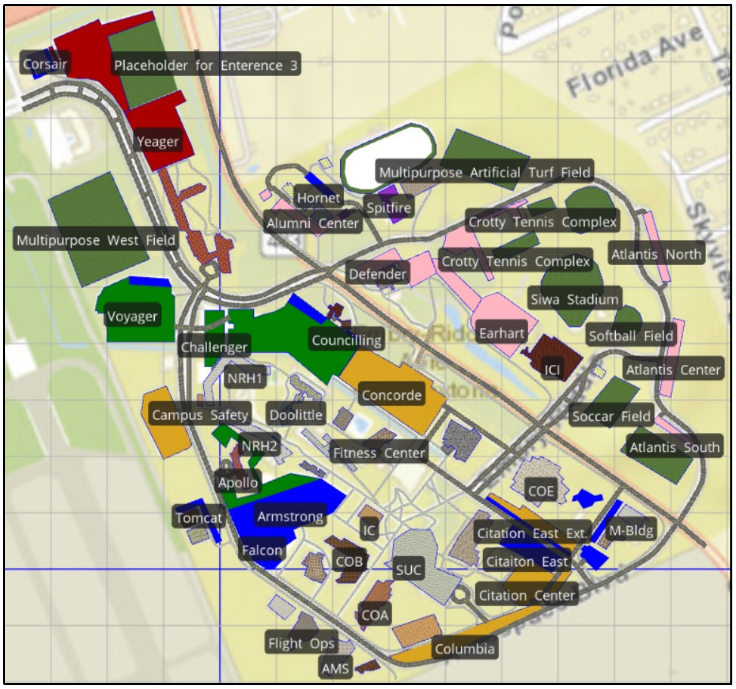


Figure 3.6: ERAU-DB Campus as Shown in the Simio Environment with Preliminary Roads and Sidewalks Added in (Based on the Available Campus Map)

The final construction component of this model consisted of adding campus entrance/exit points and building entrance/exit points. This resulted in the updated model shown below in Figure 3.7.

Figure 3.7: ERAU-DB Campus as Shown in the Simio Environment with Preliminary Campus and Building Entrance/Exit Added in (Based on the Available Campus Map)

To complete the Skeleton Model, the entities defined in Table 3.1 needed to be added in. This is shown in the model as seen in Figure 3.8.

Figure 3.8: ERAU-DB Campus as Shown in the Simio Environment with Preliminary Entities Added in (Based on the Available Campus Map)

The Skeleton Model only reports basic output metrics as not all functionality has yet been added in. The model reports statistics such as time in system, time in station, and number generated, but will not be able to identify optimization strategies for queue times or people interactions. The complete data set from the Skeleton Model can be found in Ch 4.

The Skeleton Model is created largely to determine if the initial construction is logically sound with correct syntax. This model helps to determine if additional construction or input data is needed. It also shows if the movement and behavior patterns of the entities match what is expected. Lastly, it helps to determine where additional measurement points are needed before developing the detailed model.

III.III DETAILED MODEL

The Detailed Model is another campus-wide model, yet this model encompasses all campus-wide functions and roles inside of it. Unlike the Skeleton Model, the Detailed Model adds in all walkways with proper walking functionality, additional entry points to building, and more detailed logic flow for the various entities. This model is designed to be a bird's eye digital twin of the ERAU-DB campus, and as such has the more accurate behavior for how entities move and interact inside of the system.

This model aims to capture typical movement of entities on the ERAU-DB campus and can highlight long queue times, typical congestion patterns, and the expected movement of entities during different times on the campus. This model will help generate average times in the system for various stations and locations, average waiting times, and analyze points where more stations need to be added in. More detailed result data can be found in Chapter 4.

This section once again covers the input data required to build and run the model, the construction process for the model, the output data that the model can yield, and the intended impact and implications this model has.

The Detailed Model begins to include different arrival and departure times of the various entities. While residential students (those who live in the dorms) do not leave campus, non-residential students, faculty, staff, UA, and contractors all leave and return to campus at various times and thus need to have arrival and departure times considered in the model. While specific arrival and departure times for exact roles cannot be distributed, class schedules follow the time blocks shown below in Table 3.3.

Table 3.3: Identification of the Different Class Blocks Offered at ERAU-DB. Note That All Times Are Listed Assuming a Three-Credit Hour Class, Either Three Days a Week or Two Days a Week

Block	Monday/Wednesday/Friday	Tuesday/Thursday
1	0800-0850	0815-0930
2	0900-0950	0945-1100
3	1000-1050	1115-1230
4	1100-1150	1245-1400
5	1200-1250	1415-1530
6	1300-1350	1545-1600
7	1400-1450	1615-1730
8	1500-1550	1745-1900
9	1600-1650	1915-2030
10	1700-1750	-
11	1800-1850	-
12	1900-1950	-

The Detailed Model also uses satellite imagery from [58] to ensure that the sidewalks, building entrances, and entity walking paths are accurate. Figure 3.9 below shows an example of how satellite imagery is used for the model construction.

Figure 3.9: ERAU-DB Campus as Shown in the Simio Environment with Satellite Imagery Enabled

Starting from the completed Skeleton Model, the first thing that needed to be added in to obtain the Detailed Model is to define all the sidewalks/walkways as necessary movement sites for the entities. This is done by first creating node grids on the paths, and then defining them as paths inside of Simio. An example of doing this in Simio is shown in Figure 3.10 below.

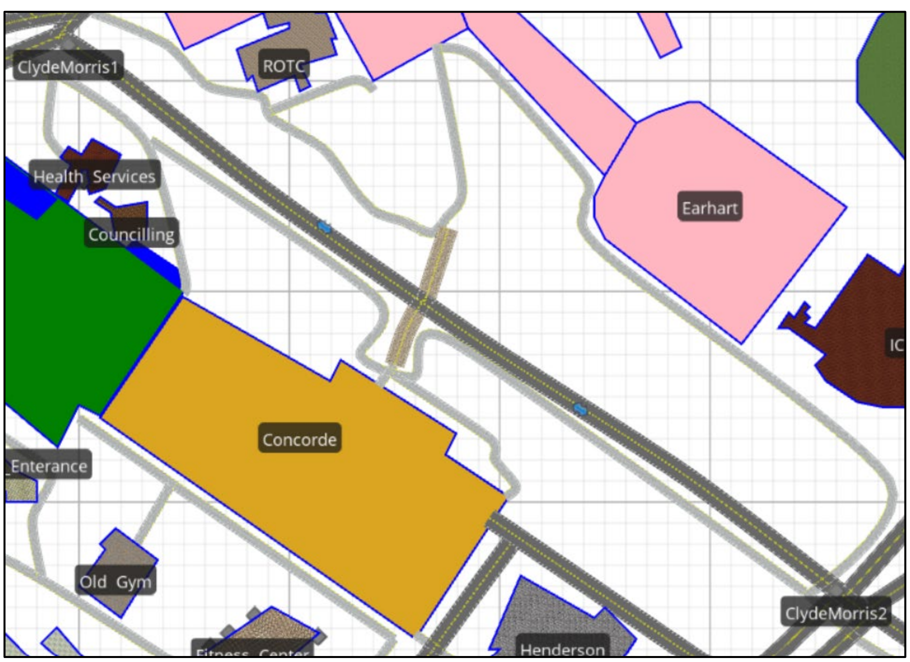
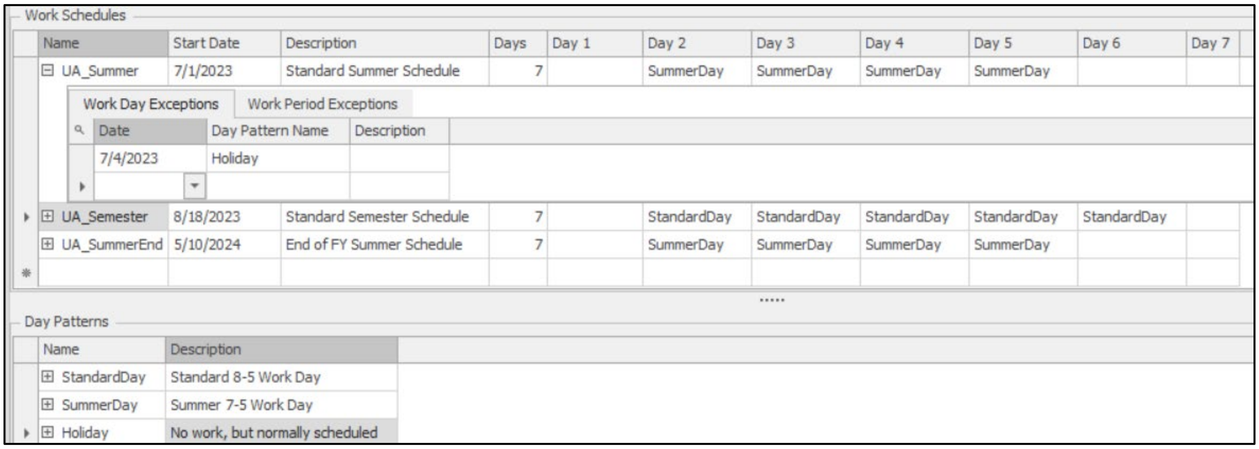


Figure 3.10: Example of Adding Paths into the Detailed Model in the Simio Environment

Entity shifts need to be added next. This is done for students assuming five classes (three Monday/Wednesday/Friday, two Tuesday/Thursday), faculty assuming three classes, staff/UA/contractors all being normal 8 a.m. to 5 p.m. employees. An example of this in Simio is shown below in Figure 3.11.


Work Schedules

Name	Start Date	Description	Days	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
UA_Summer	7/1/2023	Standard Summer Schedule	7		SummerDay	SummerDay	SummerDay	SummerDay		
UA_Semester	8/18/2023	Standard Semester Schedule	7		StandardDay	StandardDay	StandardDay	StandardDay	StandardDay	
UA_SummerEnd	5/10/2024	End of FY Summer Schedule	7		SummerDay	SummerDay	SummerDay	SummerDay		

Work Day Exceptions | Work Period Exceptions

Date	Day Pattern Name	Description
7/4/2023	Holiday	

Day Patterns

Name	Description
StandardDay	Standard 8-5 Work Day
SummerDay	Summer 7-5 Work Day
Holiday	No work, but normally scheduled

Figure 3.11: Example of Shift Schedules for UA Employees with a Holiday Exception Shown in the Simio Environment

The final part of the detailed model is adding vehicles for the campus. These vehicles include commuter student vehicles, residential student vehicles, faculty/staff vehicles, and campus services vehicles. An example of vehicle integration in Simio is shown below in Figure 3.12 with system properties defined in Table 3.4. Note that the campus has a speed limit of 10 mph.

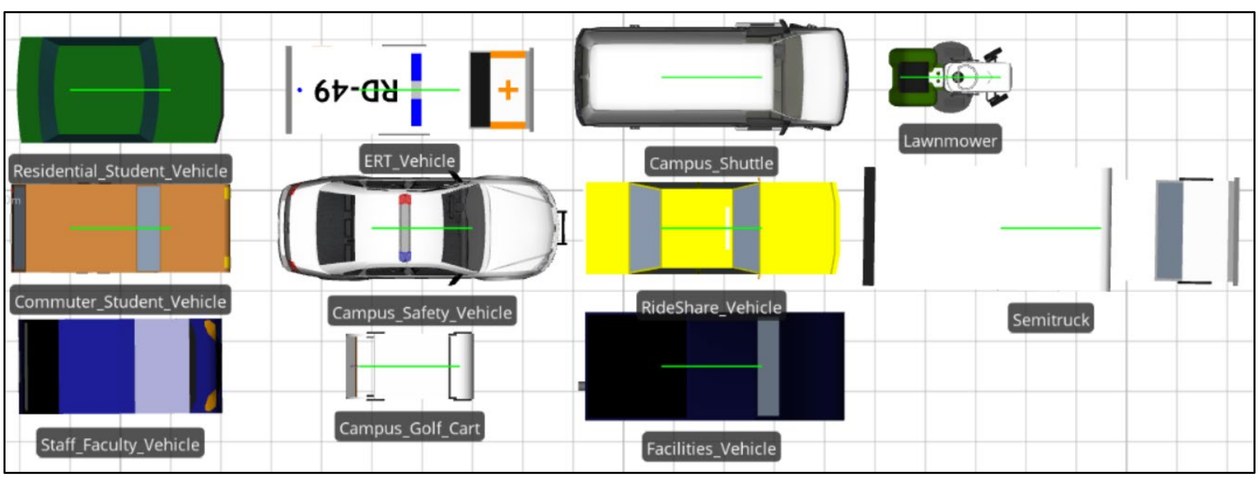


Figure 3.12: Set of Vehicles Used in the Simio Detailed Model Shown in the Simio Environment

Table 3.4: System Vehicle Properties Used in the Simio Detailed Model

Name	Number in System	Speed (mph)	User
Residential Student Vehicle	<= 1,869		Student
Commuter Student Vehicle	1,621		Student
Staff Faculty Vehicle	1,683		Staff/Faculty/UA
ERT Vehicle	3		Student
Campus Safety Vehicle	20		Staff
Campus Golf Cart	30	10	Student/Staff/UA
Campus Shuttle	5		Student/Staff/UA
Ride Share Vehicle	40		Student/Staff/Faculty/UA
Facilities Vehicle	20		Staff
Lawnmower	3		Staff
Semitruck	5		External

Once all these properties have been added in, the Detailed Model is completed. It was seen previously in Figure 3.2.

This model requires the most updating and tracking of all the models being created during this thesis. This model is designed to be a digital twin of the entire campus and as such, needs to be updated whenever there is an addition, removal, or change to the design and layout of the campus. This model will be able to have functionality built in to predict new behavior of building construction or demolition, incoming student classes, and other typical problems that are encountered on the ERAU-DB campus. Additionally, this digital twin approach could be implemented at other universities, where they can use similar methodologies to design bird's eye views of their campus for planning and the expectations around bringing new students into their institutions.

III.IV STUDENT UNION CENTER

The Student Union Center (SUC) is a campus building where the flow of people is not only measured, but also the interactions between individuals begins to be measured. For this building, the impact of the four floors of the SUC will be analyzed, along with the different functions and features on each floor. The surrounding area outside the SUC will also be analyzed to accurately capture where people flow in from and out to (i.e., sources and sinks).

The SUC requires some different information to be entered in, one of which involves the operating hours of the various dining locations on campus. Table 3.5 below lists the different SUC dining options and their hours of operation.

Table 3.5: List of Dining Locations and Their Hours of Operation in the SUC from [59]

Location	**Mon-Thu**	**Fri**	**Sat**	**Sun**
Refueling Station	0715-2100	0715-1900	1100-1900	1100-1900
Propellers	0800-1530	0800-1530	-	-
Starbucks	0600-2200	0600-1800	1300-1800	1300-2200
Qdoba Mexican Eats	0730-1900	0730-1900	-	1000-1900
Chick-fil-A	0730-2100	0730-1800	1100-1800	-

Along with the hours of operation for campus dining, the typical building operation schedule is needed for this model. It is shown below in Table 3.6.

Table 3.6: Hours of Operation for the SUC Staffing Types During a Semester from [60]

Staffing Type	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Union Ops	0600-2100	0600-2100	0600-2100	0600-2100	0600-2100	0600-2100	0600-2100

The rooms available in the building are another input condition required to develop a proper model. These rooms are shown below in Table 3.7.

Table 3.7: Rooms Modeled in the SUC Model from [61]

Room Name	**Room Number**
Study Room	SU 101
Study Room	SU 102
Study Room	SU 103
Study Room	SU 104
Study Room	SU 105
Study Room	SU 106
Study Room	SU 107
Study Room	SU 108
Event Center: A	SU 165A
Event Center: B	SU 165B

Event Center: C	SU 165C
Event Center: D	SU 165D
Event Center: E	SU 165E
Event Center: F	SU 165F
Video Gaming Lounge	SU 202
Study Room	SU 206
Study Room	SU 207
Study Room	SU 208
The Chamber	SU 210
Conference Room	SU 232
SGA Conference Room	SU 237
Conference Room	SU 301
Conference Room	SU 317
Conference Room	SU 331
Study Room (Hunt Library)	SU 347
Study Room (Hunt Library)	SU 348
Study Room (Hunt Library)	SU 349
Study Room (Hunt Library)	SU 350
Study Room (Hunt Library)	SU 351
Conference Room	SU 428
Conference Room	SU 435

The final input condition for the SUC model is the number of people who are on the different floors throughout the day. This is shown below in Table 3.8.

Table 3.8: Average Occupancy of the SUC During Each Day of the Week from [62]

Day of the Week	Time	Average Occupancy	Standard Deviation
Sunday	Twilight	18.45	22.6
	Morning	10.73	13.62
	Afternoon	80.63	62.9
	Evening	62.12	59.03
Monday	Twilight	20.16	31.99
	Morning	75.36	108.37
	Afternoon	204.68	143.39
	Evening	94.04	89.33
Tuesday	Twilight	20.81	40.76
	Morning	89.48	111.68
	Afternoon	220.21	155.85
	Evening	102.75	87.29
Wednesday	Twilight	19.79	30.21
	Morning	81.42	108.68
	Afternoon	201.24	143.19

	Evening	93.41	80.39
Thursday	Twilight	18.96	30.21
	Morning	82.58	96.56
	Afternoon	195.89	133.34
	Evening	104.59	84.88
Friday	Twilight	18.4	24.81
	Morning	80.93	118.53
	Afternoon	203.02	149.78
	Evening	78.58	74.71
Saturday	Twilight	21.43	32.33
	Morning	18.79	42.45
	Afternoon	76.28	70.71
	Evening	61.01	59.84

The SUC model will be able to report queue times from the various functions provided within as well as analyze typical behavior for number of people in the building at different times, highlight peak and lull periods, and show where additional functionality would be beneficial.

The SUC model will help with validating some of the student feedback gained during this project as well as analyzing the typical flow of individuals within the building. This analysis can also help to highlight some of the typical areas of congestion and issues faced by different groups of people on the campus.

III.V VERIFICATION AND VALIDATION

Throughout all creation processes, V&V will be occurring. These processes will be followed to align with best practices in systems engineering and utilize campus stakeholders and subject matter experts to ensure that the models created are accurate. Table 3.9 below shows a checklist series of prompts for verification of the system.

Table 3.9: Verification Prompts for the Simio Model Developed [63]

ID	Item	Description
1	**Inspecting Model Loading**	Verify that the Model Loaded Correctly
1.1	Inspecting the Campus Layout	
1.2	Inspecting Campus Population Data	
1.3	Inspecting Campus Employment Data	
1.4	Inspecting Campus Vehicle Data	
1.5	Inspecting Campus Queue Data	
2	**Starting Model Running**	Verify the Model Starts Correctly
2.1	Inspect Start Conditions	
2.2	Inspect Process Conditions	
2.3	Inspect Closing Conditions	
2.4	Inspect Exit Conditions	
2.5	Inspect Error Log	
3	**Running Model**	Verify the Model Runs Correctly
3.1	Inspect Node Network	
3.2	Inspect Vehicle Behavior	
3.3	Inspect Worker Behavior	
3.4	Inspect Entity Behavior	
3.5	Inspect Server Behavior	
4	**Model Experimentation**	Verify that Experiments Run Correctly
4.1	Inspect Experiments	
4.2	Inspect Scenarios	
4.3	Inspect Replications	
4.4	Inspect Controls	
4.5	Inspect Reponses	
5	**Loading Data**	Verify that Data Loads Correctly
5.1	Inspect Import File	
5.2	Inspect CSV	
5.3	Inspect Simio Tables	
5.4	Inspect Elements	
5.5	Inspect Properties	
6	**Exporting Results**	Verify that Results Export Correctly
6.1	Inspect Export File	
6.2	Inspect Result Table	
6.3	Inspect Error Log	
6.4	Inspect Experiments	
7	**Closing Model**	Verify that Model Stops Correctly
7.1	Inspect Model Pausing	
7.2	Inspect Model Stopping	
7.3	Inspect Model Stepping	
7.4	Inspect Model Rushing	

7.5	Inspect File Closing	
8	**Model Storing**	Verify that Model Files are Stored Properly
8.1	File Naming Convention	
8.2	Source Files	
8.3	Screenshots	
8.4	Data Files	
9	**Documenting Changes**	Verify that Changes are Properly Documented
9.1	Change Logs	
9.2	Crash Reports	

Similarly, validation will occur during model creation and testing. While this is related to verification, it is a separate process that needs to be carried out and as such will have a separate checklist of items. This checklist is shown below in Table 3.10.

Table 3.10: Validation Prompts for the Simio Model Developed [64]

ID	Item	Description
1	**Qualification**	Validate that User Qualifications Have Been Met
1.1	Student User Qualifications	
1.2	Faculty User Qualifications	
1.3	Staff User Qualifications	
1.4	UA User Qualifications	
1.5	Admin User Qualifications	
1.6	Stakeholder User Qualifications	
2	**User Requirement Specification**	Validate that User Requirements Have Been Met
2.1	Student User Requirements	
2.2	Faculty User Requirements	
2.3	Staff User Requirements	
2.4	UA User Requirements	
2.5	Admin User Requirements	
2.6	Stakeholder User Requirements	
3	**Functional Specifications**	Validate that User Functions Have Been Added
3.1	Student User Functions	
3.2	Faculty User Functions	
3.3	Staff User Functions	
3.4	UA User Functions	
3.5	Admin User Functions	
3.6	Stakeholder User Functions	
4	**Design Specifications**	Validate that User Designs Have Been Added
4.1	Student User Designs	
4.2	Faculty User Designs	
43	Staff User Designs	

4.4	UA User Designs	
4.5	Admin User Designs	
4.6	Stakeholder User Designs	
5	**System Build**	Validate that the System is Accessible by the User
5.1	Student User Accessibility	
5.2	Faculty User Accessibility	
5.3	Staff User Accessibility	
5.4	UA User Accessibility	
5.5	Admin User Accessibility	
5.6	Stakeholder User Accessibility	
6	**Installation Qualification Tests**	Validate that the System is in the Correct Environment for the User
6.1	Student User Installation	
6.2	Faculty User Installation	
6.3	Staff User Installation	
6.4	UA User Installation	
6.5	Admin User Installation	
6.6	Stakeholder User Installation	
7	**Operational Qualification Tests**	Validate that the System Operates Successfully for the User
7.1	Student User Operational Test	
7.2	Faculty User Operational Test	
7.3	Staff User Operational Test	
7.4	UA User Operational Test	
7.5	Admin User Operational Test	
7.6	Stakeholder User Operational Test	
8	**Performance Qualification Tests**	Validate that System Performance Meets Users Demands
8.1	Student User Performance Test	
8.2	Faculty User Performance Test	
8.3	Staff User Performance Test	
8.4	UA User Performance Test	
8.5	Admin User Performance Test	
8.6	Stakeholder User Performance Test	
9	**Reporting**	Validate that the System Reports to the User Correctly
9.1	Student User Reporting	
9.2	Faculty User Reporting	
9.3	Staff User Reporting	
9.4	UA User Reporting	
9.5	Admin User Reporting	
9.6	Stakeholder User Reporting	

Different stakeholders will be involved for each process, as they have different knowledge on the campus and are looking at different components. Table 3.11 below lists each stakeholder involved in V&V, the models they will check, and the level of their involvement.

Table 3.11: List of Stakeholders Involved in V&V with Expected Involvement Levels

Stakeholder	Models Checked	Involvement Level
Students	Detailed Model, SUC Model, COE Model	Medium
Faculty	Detailed Model, COE Model	Low
Staff	Detailed Model	Low
UA	Detailed Model	Low
Administration	Detailed Model, SUC Model, COE Model	Medium
Systems Engineers	Skeleton Model, Detailed Model, SUC Model, COE Model	High

III.VI SURVEY AND OPTIMIZATION

This project is an improvement project. Part of this involves gaining ideas of campus climate and perceptions, and then cross-referencing this data with the models created to being to target optimization strategies.

First, a preliminary survey was delivered to participants to gain a feel for where they are on the campus, their perceptions of it, and so on. This survey enabled participants to express info on several campus functions, listed below in Table 3.12 where 50% is neutral agreement, 67% is moderate agreement, and 75% is high agreement. All survey questions can be found in Appendix A. This survey was conducted as a Quality Improvement Initiative and thus Institutional Review Board approval was not required.

Table 3.12: Intended Optimization Targets and Required Sample Sizes for Neutral, Moderate, and High Agreement of Improvement

Optimization Target	Sample Size (People)
Housing	[106,141,158]
Parking	[172,229,257]
Dining	[183,244,275]
Fitness Center	[142,189,213]
Faith/Spirituality	[32,42,47]
Classes/Scheduling	[248,331,372]
Campus Transportation	[44,58,65]

A qualitative interview followed this survey for participants who completed the preliminary survey and expressed interest in an additional discussion. This interview narrowed down the original questions into a thirty-minute question and answer session and targeted getting specific info on a few categories in. Seventy-seven people took part in the interview with the categories discussed being listed below in Table 3.13.

Table 3.13: Intended Two Round Delphi Categories and Required Sample Sizes for Neutral, Moderate, and High Agreement of Improvement

Delphi Category	**Sample Size (People)**
Housing	[12,16,18]
Parking	[17,22,25]
Dining	[15,19,22]
Fitness Center	[18,23,26]
Campus Software	[18,23,26]
Campus Transportation	[15,20,23]

Once the data from both the survey and the interview was collected, optimization strategies could begin to be designed. An example of the method used to design optimization strategies is shown below in Figure 3.13.

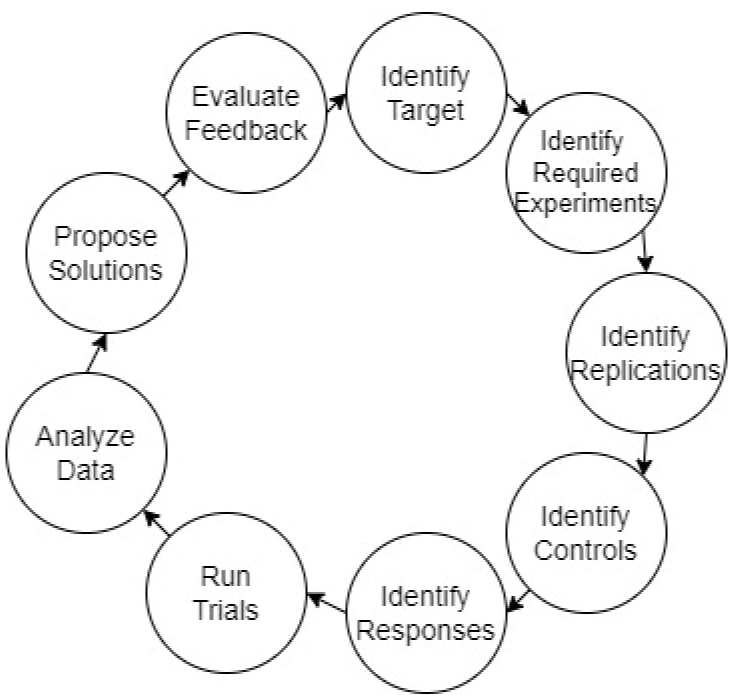


Figure 3.13: Sequence of Events Followed During Optimization

Once all the optimization strategies are developed, they can be implemented into various models. The optimization package OptQuest was used for this, and experiments were designed inside of Simio to assist in setting and achieving target values. An example of these experiments is shown below in Figure 3.14.

	Scenario			Replications		Responses	Constraints
	☑	Name	Status	Required	Completed	Response1	Constraint1
	☑	Scenario1	Idle	10	0 of 10		
	☑	Scenario2	Idle	8	0 of 8		
▸	☑	Scenario3	Idle	15	0 of 15		
*	■						

Figure 3.14: Experiment Example as Shown in the Simio Environment

III.VII METHODOLOGY FLOWCHART

To help highlight the different major tasks which are completed during this thesis along with the ones which occur concurrently or independently, a flowchart diagram is utilized. This diagram is found below in Figure 3.15.

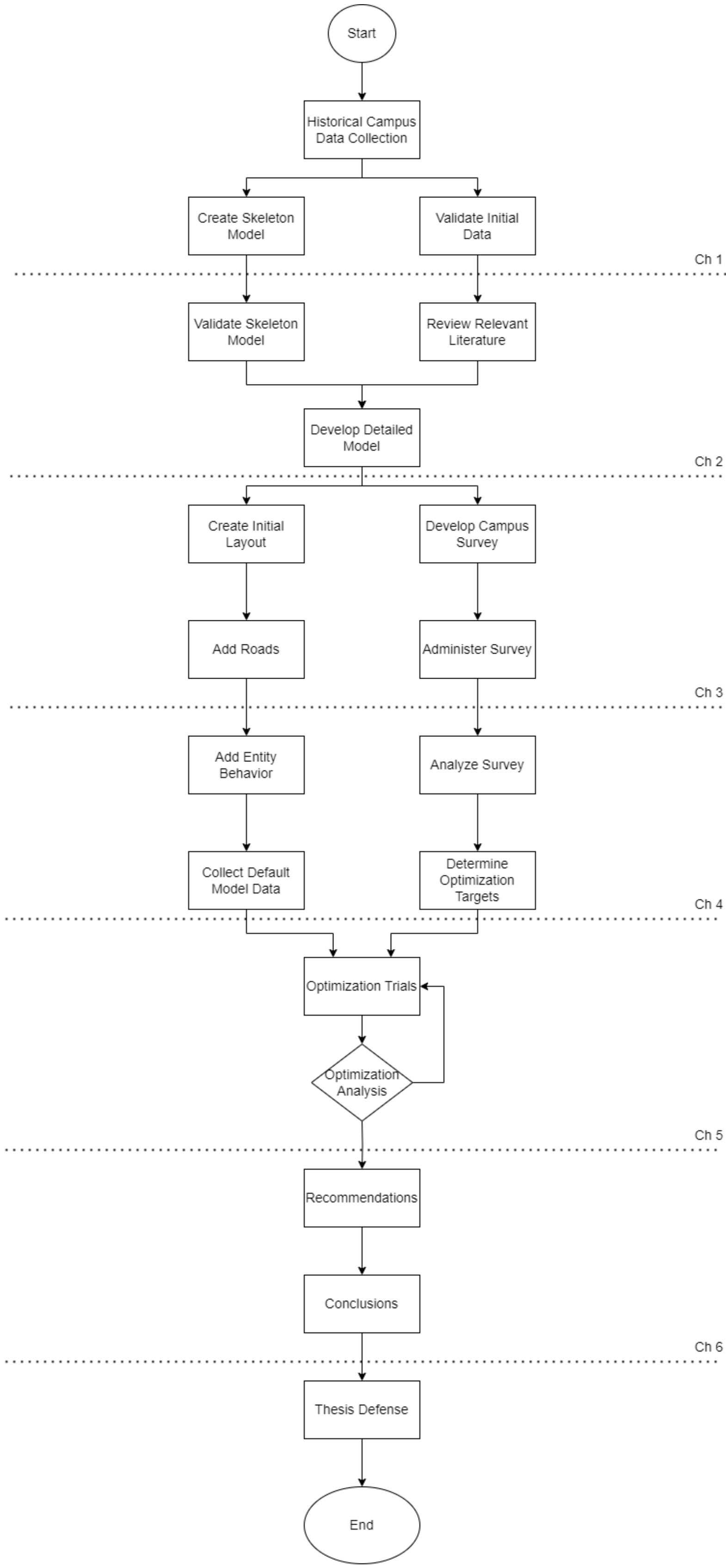


Figure 3.15: Flowchart of Steps for the Theis Methodology

IV. RESULTS

As this thesis was completed over multiple stages, each part is organized into an independent results section below, and then cross-sorted in and analyzed in Chapter 5. Section IV.I deals with the Skeleton Model and initial model development, Section IV.II addresses the Campus Survey and results obtained, and Section IV.III goes through the results obtained from the Detail Model.

IV.I SKELETON MODEL

During the development of the Skeleton Model, the geographical footprint of ERAU-DB was determined. From Simio, the length of campus was determined to be 1,205 m, and the width was 1,180 m. Equation 2 is then applied to find the area of campus to be 1.42x10^6 m^2, which is equal to approximately 350 acres using the conversion of 4047 m^2 to 1 acre. From the footprint calculated, the ratio of area available to people can be calculated by using the total population of ERAU-DB. This is calculated by using Equation 46 below.

$$PopTot = StudentPop + StaffPop + FacultyPop + UAPop \tag{46}$$

From [65], the *StudentPop* is 7,945, the *StaffPop* is 729, the *FacultyPop* is 422, and the *UAPop* is 532. Thus, from Equation 46, there are 9,628 people total at ERAU-DB. Next the ratio of people to area can be calculated using Equation 47.

$$OccupancyRatio = \frac{PopTot}{Area} \tag{47}$$

From the results of Equation 2 and Equation 46, Equation 47 results in a 28.66:1 ratio.

The other item of interest while developing the Skeleton Model is the impact that ERAU-DB has on the local area. From [66], Daytona Beach, FL has a population of 77,958, which means that ERAU-DB is approximately 12.55% of the population, with the assumption that the entire population of ERAU-DB lives in Daytona Beach. Additionally, the approximate size of Daytona

Beach is 68.19 mi^2 (43,641.6 acres) from [67], which means ERAU-DB uses approximately 0.802% of the available area. With these new percentages in mind, Equation 47 can be used once again which results in a 15.65:1 people-to-area ratio to show that ERAU-DB is over the predicted capacity based on land usage of the area alone.

While not directly a part of the Skeleton Model, Campus Housing is another item which can be discussed here. For the Fall 2023 semester, there were 3,499 beds available. ERAU-DB currently requires first and second year students to stay on campus. From [4], in Fall 2023 there were 1,933 first year, traditional students, and in Fall 2022 there were 1,839 first year, traditional students. Using a dropout rate of 18%, this means there were 3,441 students who are required to have campus housing. Additionally, as the dorms are part of the college, there are 106 housing staff members who live in the building, bringing the total number of people staying in the dorms up to 3,547. From the number of students compared against the number of available beds, a ratio of 1.014:1 was found.

ERAU-DB currently has no rules regarding the students who can bring cars to campus. It was reported from [68] that ERAU-DB has 5,200 parking spots available across the various lots. Since faculty/staff/UA typically do not live on campus, it is assumed that they will all be driving to campus. This means that there are 1,683 vehicles coming from them. Further, as third year and up (upperclassmen) students are not able to live on campus, it is assumed that they will have to drive to campus as well, with 2,071 students in this group. There is a shuttle service available to them, however, which transports about 900 students per day in a one-way trip (thus 450 students daily), which brings the total down to 1,621 vehicles from upperclassmen. The sum of these vehicle groupings from upperclassmen and university employees can be considered, and the resulting total vehicles becomes 3,304 and a gap of 1,869 spots. Using the capacity, a ratio of spots to vehicles can be made, which results in 1.57:1. This however operates under the assumption that no on-campus residents have vehicles, which is not the case. As such, there are 3,547 students who have not been captured in this process. By comparing the available spots to the students remaining, only 52.7% of them will be able to have vehicles to avoid a parking problem.

IV.II CAMPUS SURVEY

Beyond the preliminary data collected using the Skeleton Model, a way to capture student perceptions on the ERAU-DB campus was needed. A four-prong survey approach was designed to enable this to take place. The survey was divided into two phases, and each phase has two parts to it. Table 4.1 below shows each phase, the delivery time, and the sample size.

Table 4.1: Survey Phases and Sample Sizes for the Thesis

Survey Phase	Delivery	Sample Size
Phase 1	Summer 2023	44
Phase 1.1	Summer 2023	24
Phase 2	Fall 2023	464
Phase 2.1	Fall 2023	48

To ensure a wide range of experiences were considered, the survey respondents were asked to report the number of semesters they have been at ERAU-DB. The results from this are shown in Table 4.2 below.

Table 4.2: Semesters at ERAU-DB for Survey Phases

Survey Phase	Average Semester	Standard Deviation
Phase 1	6.89	3.02
Phase 2	4.00	3.00
Average	5.45	3.01

Since ERAU-DB consists of four colleges, it was of interest to get responses from students in each of them and determine how it compares to the school's overall major demographics. Table 4.3 below shows the results of this for each phase.

Table 4.3: College at ERAU-DB for Survey Phases

Survey Phase	COE	COAS	COA	COB
Phase 1	67.50%	22.50%	7.50%	2.50%
Phase 2	58.26%	20.55%	12.29%	8.90%
Average	62.88%	21.53%	9.90%	5.70%
Campus Results	38.37%	12.96%	38.36%	6.19%
Variance	+24.51%	+8.57%	-28.46%	-0.49%

One of the items of interest during this study was identifying if there was a specific day of the week that was busier on campus than others. Table 4.4 below shows the results of this.

Table 4.4: Busiest Day at ERAU-DB for Survey Phases

Survey Phase	Phase 1	Phase 2	Average
Monday	47.37%	51.59%	49.48%
Tuesday	7.89%	11.01%	9.45%
Wednesday	42.11%	32.75%	37.43%
Thursday	2.63%	3.19%	2.91%
Friday	0.00%	6.09%	3.05%
Saturday	0.00%	0.87%	0.44%
Sunday	0.00%	0.29%	0.15%

Along with identifying the busiest day on campus, the busiest time was also of interest. This is shown below for both survey phases in Table 4.5 using a 24-hour time style.

Table 4.5: Busiest Time at ERAU-DB for Survey Phases

Survey Phase	Busiest Time	Standard Deviation
Phase 1	1203	85.38
Phase 2	1211	126.12
Average	1207	105.75

The breakdown for where students are spending the most time on campus was also of interest to determine. The results of this for the first phase of the thesis are shown below in Table 4.6.

Table 4.6: Daily Percentage Location Breakdown for the First Thesis Phase

	M	T	W	TH	F	S	SU
SU	27.12%	25.42%	27.12%	25.42%	20.34%	20.34%	20.34%
COAS	23.73%	22.03%	22.03%	22.03%	20.34%	3.39%	3.39%
COE	18.64%	22.03%	22.03%	22.03%	20.34%	5.08%	6.78%
Micaplex	3.39%	3.39%	3.39%	3.39%	3.39%	1.69%	1.69%
Fitness Center	8.47%	8.47%	8.47%	8.47%	8.47%	5.08%	3.39%

COB	1.69%	1.69%	1.69%	3.39%	1.69%	3.39%	1.69%
Quadrangle	1.69%	1.69%	1.69%	1.69%	1.69%	0.00%	0.00%
COA	1.69%	1.69%	1.69%	1.69%	1.69%	0.00%	0.00%
Dorms	13.56%	10.17%	11.86%	13.56%	3.39%	22.03%	22.03%
Honors Lounge	0.00%	1.69%	0.00%	1.69%	0.00%	0.00%	0.00%
Off Campus	0.00%	1.69%	0.00%	0.00%	3.39%	18.64%	18.64%
Center for Faith	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.69%

During the second thesis phase, it was of interest to expand the search and see the typical student usage of different buildings and facilities during a week. Table 4.7 below shows these results.

Table 4.7: Typical Usage Rates for Buildings on the ERAU-DB Campus

Building	Typical Week Usage
A^2	0.15%
Alumni Center	0.10%
Baseball Field	0.20%
Boundless	0.10%
Center for Faith	0.05%
COA	4.57%
COAS	18.07%
COB	10.04%
COE	12.40%
Dorms	11.70%
Flight Ops	0.40%
Flight Sim	0.20%
Fitness Center	9.54%
Honors Center	0.30%
Housing Office	0.05%
IC	7.48%
ICI	0.20%
Lacross Fields	0.05%
M Building	0.50%
Micaplex	0.65%
Quad	2.11%
ROTC	0.80%
S Building	0.10%
Soccer Field	0.05%
Softball Complex	0.05%
SUC	19.83%

Student Veterans Lounge	0.05%
Tennis Courts	0.10%
Tomcat Annex	0.05%
Track	0.05%
Welcome Center	0.05%

This survey consisted of several sections on different functions of campus life. These include campus dining, campus congestion, campus housing, campus software, and campus transportation. This section will detail the results from each of these major sections for each of the survey phases that were administered.

IV.II.1 CAMPUS SURVEY – DINING

Campus dining is analyzed since it is a significant contributor to a student's time at the university. With 12 dining options on campus, ERAU-DB has many options for students to choose from. While residential students are required to have a meal plan, many other students still dine on campus due to the convenience of it, even when they move off campus. Table 4.8 below shows the distribution of students who dine on campus from the survey, and the campus population that percentage corresponds to.

Table 4.8: Results of Dining on Campus for the ERAU-DB Campus

Survey Phase	Dines on Campus	Corresponding Population
Phase 1	73.68%	5,854
Phase 2	77.29%	6,451
Average	75.49%	6,153

Despite having 12 options available for campus dining, the hours of operation, location, and offerings have led students to be more preferential to some dining options over others. Table 4.9 below shows the results from the survey on this.

Table 4.9: Results of Dining Selection for the ERAU-DB Campus

Dining Location	Phase 1	Phase 2	Average	Students Served
Refueling Station	20.7%	19.9%	20.3%	1,249
Propellers	4.5%	6.4%	5.5%	338
Late Night	8.1%	5.7%	6.9%	425
Flightcafe	0.9%	1.4%	1.2%	74

Boundless	10.8%	18.1%	14.5%	892
Simple Servings	0.9%	1.7%	1.3%	80
C-Store	1.8%	1.8%	1.8%	111
Starbucks	13.5%	11.3%	12.4%	763
Qdoba	17.1%	13.6%	15.4%	948
Chick-fil-A	19.8%	18.2%	19.0%	1,169
Legacy Walk Eats	1.8%	1.9%	1.9%	117
The Fuselage	0%	0%	0%	0

Despite a clear preference for some dining locations over others, in the second survey phase students were asked to report which dining locations they are aware of. The results of this are shown below in Table 4.10.

Table 4.10: Knowledge of all Dining Locations at ERAU-DB for Survey Phases

Dining Location	**Phase 2**
Refueling Station	88.0%
Propellers	64.0%
Late Night	52.0%
Flightcafe	24.0%
Boundless	74.0%
Simple Servings	44.0%
C-Store	40.0%
Starbucks	72.0%
Qdoba	74.0%
Chick-fil-A	88.0%
Legacy Walk Eats	38.0%
The Fuselage	6.0%
Average	55.3%

Along with determining which location students are inclined to pick for campus dining, it was of interest to learn about the typical time in which they dine on campus. The results for this are found below in Table 4.11 in a 24-hour format.

Table 4.11: Results of Dining Time for the ERAU-DB Campus

Survey Phase	**Average Dining Time**	**Standard Deviation (mins)**
Phase 1	1437	371.39
Phase 2	1539	429.98
Average	1508	400.69

The primary concern with campus dining is the time it takes to get food. Table 4.12 below shows the reported average waiting time, standard deviation, and the agreement level for Phase 1 and Phase 2.

Table 4.12: Results of Dining Wait Time for the ERAU-DB Campus

Survey Phase	Dining Wait Time (Mins)	Standard Deviation	Level of Agreement	Standard Deviation
Phase 1	15.54	8.85	66.67%	48.15%
Phase 2	16.85	7.87	54.35%	50.36%
Average	16.20	8.36	60.51%	49.26%

While the results of both phases trend towards a positive consensus on the dining time, the significant variance present makes it difficult to narrow down the actual dining time for students. It should be noted that the 8.42% increase in dining time for Phase 2 is correlated to the 5.06% increase in students on the campus, who came in during the Fall 2023 semester.

Along with the time it takes students to get their food, the other significant part of the dining experience is eating the food. The survey first aimed to capture the time students spend in dining facilities after getting their food, with results shown in Table 4.13 below.

Table 4.13: Results of Time in Dining Facilities for the ERAU-DB Campus

Survey Phase	Dining Time (Mins)	Standard Deviation	Level of Agreement	Standard Deviation
Phase 1	19.82	13.64	79.17%	41.49%
Phase 2	23.33	13.87	84.78%	36.32%
Average	21.58	13.76	81.98%	38.91%

It was of interest to also determine if students had an issue finding seating while dining due to the congestion of the ERAU-DB campus. The results of this are shown in Table 4.14 below.

Table 4.14: Results of Seating in Dining Facilities for the ERAU-DB Campus

Survey Phase	Has Seating Problems	Standard Deviation
Phase 1	83.33%	38.07%
Phase 2	71.74%	45.52%
Average	77.54%	41.80%

Lastly, it was of interest to determine if students encountered additional problems with campus dining, namely finding places to eat. The results of this are shown below in Table 4.15.

Table 4.15: Results of Problems Dining in Dining Facilities for the ERAU-DB Campus

Survey Phase	Dining Problems	Standard Deviation
Phase 1	20.83%	41.49%
Phase 2	54.35%	50.36%
Average	37.59%	45.93%

In Fall 2023, the ERAU-DB dining service Sodexo added in new systems for two dining locations. The Refueling Station and Boundless, All You Care to Eat, had a change implemented with their ordering system. During the Phase 1 survey, students were asked to identify if they believe that campus locations need new buzzers added in for ordering. Interestingly for these locations, the data shows that while the Refueling Station was a significant choice for adding buzzers in, Boundless was not one of the top options, and others should have been prioritized first as seen in Table 4.16 below.

Table 4.16: Results of Buzzer Addition for the ERAU-DB Campus

Dining Location	Phase 1
Refueling Station	20%
Propellers	17.5%
Late Night	5.0%
Flightcafe	5.0%
Boundless	7.5%
Simple Servings	2.5%
C-Store	2.5%
Starbucks	15.0%
Qdoba	12.5%
Chick-fil-A	-
Legacy Walk Eats	10.0%
The Fuselage	2.5%

Since a new ordering system was added in, during the Phase 2 survey students were asked to report if they found this new system to be beneficial. The results of this are shown in Table 4.17 below.

Table 4.17: Results of Ordering System Overhaul for the ERAU-DB Campus

Dining Location	Agreement Level
Refueling Station	68.48%
Boundless	59.78%

Mobile ordering is another option that was discussed with students. In Fall 2022, ERAU-DB added Starship Robots to campus to provide a delivery option for campus dining. Another advantage of this service is that students can use the app to order a pickup in the store and skip the line, rather than needing to go through other third-party apps such as Grubhub or DoorDash. The results of student perceptions on mobile ordering are shown below in Table 4.18.

Table 4.18: Results of Mobile Ordering Interest for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	70.83%	46.43%
Phase 2	59.78%	49.01%
Average	65.31%	47.72%

Despite dining being a typical complaint and concern of the student population, much of the data points towards positive reception and good changes being implemented. While future data collection cycles will be needed to see how the dining changes are implemented, it seems that this is not as significant an issue as students make it seem.

IV.II.11 CAMPUS SURVEY - CONGESTION

The congestion of campus resources is the overall focus of this thesis and serves as a major focus throughout the data collection process. Campus parking is unsurprisingly a notable issue for students, staff, and faculty on the ERAU-DB campus. Table 4.19 below shows the percentage of respondents who were identified as having parking problems during their survey phase.

Table 4.19: Results of Parking Issues for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	70.83%	46.43%
Phase 2	67.39%	47.40%
Average	69.11%	46.92%

Along with determining who had parking problems, it was of interest to determine the lot they must park in. Table 4.20 below shows the results of this.

Table 4.20: Results of Parking Issues for the ERAU-DB Campus

Parking Lot	Phase 1	Phase 2	Average
Parking Garage	5.56%	7.89%	6.73%
Atlantis Noth	5.56%	0.00%	2.78%
Atlantis Center	5.56%	2.63%	4.10%
Defender	5.56%	5.26%	5.41%
Earhart	11.11%	13.16%	12.14%
Citation Center	16.67%	5.26%	10.97%
Citation East Ext	16.67%	13.16%	14.92%
Cochran	0.00%	5.26%	2.63%
Concorde	11.11%	15.79%	13.45%
MicaPlex	5.56%	0.00%	2.78%
Enterprise	0.00%	7.89%	3.95%
Mustang	0.00%	5.26%	2.63%
Voyager	5.56%	13.16%	9.36%
Village	5.56%	2.63%	4.10%
Yeager	5.56%	2.63%	4.10%

Interestingly, this does not align with the previously reported parking findings. This is due to students not reporting their parking passes, and likely an unrealistic understanding of the available parking spots from both students and campus safety. While spots have been added off campus, students will not see these as "available" and spots that are then supposed to be vacant for faculty/staff/commuters will be taken by these students. Parking in the incorrect zones causes issues, as well as student vehicles that are parked and not moved from congested areas. Despite this, mathematically there should still be a significant space buffer, so data is not being reported correctly by either students or campus safety.

In the College of Arts and Sciences (COAS) there are three stairwells, but only one is significantly used. This has led to multiple congestion issues, fire code concerns, and sometimes even the full stoppage of movement during the day. However, the survey results have shown that people are aware of the existence of alternative stairwells that they can use. Table 4.21 below shows the results of COAS stairwell usage, and Table 4.22 shows the results of knowing the alternative routes.

Table 4.21: Usage of COAS Stairwells for the ERAU-DB Campus

Survey Phase	Uses Stairwells
Phase 1	87.50%
Phase 2	76.09%
Average	81.80%

Table 4.22: Knowledge of Alternative COAS Routes for the ERAU-DB Campus

Survey Phase	Knows Routes
Phase 1	100.00%
Phase 2	77.14%
Average	88.57%

Despite the significant knowledge on alternative routes existing within COAS, students still choose to use the main staircase and end up unintentionally creating this congestion issue on the campus.

Student mental health and well-being is at the forefront of many conversations in higher education currently, and campus congestion plays an important role in it. If a student is already in a stressed state from exams, homework, etc., and then they have difficulty getting food, finding parking, etc., it not only adds to their stress but causes new levels of detriment to their education [69]. Table 4.23 below shows the results from the student's self-reported levels of stress caused by campus congestion.

Table 4.23: Stress on Students from Campus Congestion for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	66.67%	48.15%
Phase 2	65.22%	48.15%
Average	65.95%	48.15%

In 2022 ERAU-DB opened a new Fitness Center due to the expansion of the student population on the campus. As such, it was of interest to determine the congestion level in the new building. Table 4.24 below highlights the perceptions of crowding in this building.

Table 4.24: Usage of the Fitness Center for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	62.50%	49.45%
Phase 2	52.17%	50.50%
Average	57.34%	49.98%

Along with the usage of the Fitness Center, there was an interest in determining the perceptions of crowding in the facility. The results of this for the survey are shown below in Table 4.25 where 1 is not crowded and 10 is overcrowded.

Table 4.25: Crowding of the Fitness Center for the ERAU-DB Campus

Survey Phase	Average Score	Standard Deviation
Phase 1	6.48	1.94
Phase 2	7.19	2.06
Average	6.84	2.00

Another point of interest was determining the specific equipment item(s) that students have difficulty accessing in the Fitness Center due to the congestion it has. The results of this from the survey are shown below in Table 4.26.

Table 4.26: Congested Equipment of the Fitness Center for the ERAU-DB Campus

Equipment Item	Phase 1	Phase 2	Average
Lifting Machines	15.8%	36.4%	26.1%
Benches	42.1%	21.2%	31.7%
Squat Racks	36.8%	27.3%	32.1%
Free Weights	5.3%	6.1%	5.7%
Treadmills	0%	9.1%	4.6%

The ERAU-DB Center for Faith and Spirituality has been another location which was reported to be congested often. Table 4.27 below shows the results of the population of campus who uses this space for each phase.

Table 4.27: Usage of the Center for Faith and Spirituality for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	15.78%	36.95%
Phase 2	9.61%	29.50%
Average	12.70%	33.23%

Survey respondents here were again asked to report how open/crowded they felt the space was. The results of this are shown below in Table 4.28 where 1 is not crowded and 10 is overcrowded.

Table 4.28: Crowding of the Center for Faith and Spirituality for the ERAU-DB Campus

Survey Phase	Average Score	Standard Deviation
Phase 1	3.67	2.73
Phase 2	4.16	2.17
Average	3.92	2.45

Students previously had reported that there were not many non-class academic spaces they were able to use on the campus. These include study spaces, club spaces, study rooms, conference rooms, etc. The results of this question for both survey phases are shown below in Table 4.29 where 1 is lacking and 10 is plentiful.

Table 4.29: Access to Non-Class Academic Spaces for the ERAU-DB Campus

Survey Phase	Average Score	Standard Deviation
Phase 1	6.26	2.29
Phase 2	6.80	2.24
Average	6.53	2.27

As ERAU-DB has a spaced-out footprint, it was of interest to know how students felt about the distribution of buildings on the campus. Table 4.30 below shows the results of this from the survey where 1 is too close together and 10 is too far apart.

Table 4.30: Spacing of Buildings for the ERAU-DB Campus

Survey Phase	Average Score	Standard Deviation
Phase 1	5.21	1.45
Phase 2	5.68	1.63
Average	5.45	1.54

As some students reported that some buildings are far out of the way on the campus, it was of interest to determine which. The results of this are shown in Table 4.31 below.

Table 4.31: Distant Buildings for the ERAU-DB Campus

Building Name	Phase 1	Phase 2	Average
A^2	0.00%	0.27%	0.14%
Alumni	0.00%	3.23%	1.62%
AMS	0.00%	0.54%	0.27%
Baseball Field	0.00%	0.27%	0.14%
C Store	0.00%	2.70%	1.35%
Center for Faith	0.00%	0.54%	0.27%
Chanute	0.00%	0.27%	0.14%
COA	0.00%	1.89%	0.95%
COAS	0.00%	1.62%	0.81%
COB	0.00%	3.23%	1.62%
COE	19.23%	20.49%	19.86%
DSS	3.85%	0.81%	2.33%
Fitness Center	0.00%	0.54%	0.27%
Flight Line	0.00%	0.81%	0.41%
Flight Ops	0.00%	1.89%	0.95%
Health Services	3.85%	1.62%	2.74%
IC	0.00%	1.35%	0.68%
ICI	7.69%	7.55%	7.62%
ISSS	0.00%	0.27%	0.14%
M Building	3.85%	8.09%	5.97%
Mail Room	0.00%	5.93%	2.97%
MicaPlex	15.38%	3.50%	9.44%
NRH1	0.00%	1.89%	0.95%
NRH2	7.69%	1.35%	4.52%
NRH3	3.85%	1.08%	2.47%
Parking Garage	0.00%	1.62%	0.81%
Print Shop	0.00%	0.81%	0.41%
ROTC	3.85%	5.12%	8.97%
S Building	0.00%	0.27%	0.14%
Sim Building	0.00%	0.27%	0.14%
Sport Field	0.00%	0.27%	0.14%
SUC	0.00%	1.62%	0.81%
SVTC	30.77%	16.98%	23.88%
Tennis Courts	0.00%	0.27%	0.14%
Tomcat Annex	0.00%	0.81%	0.41%
Track	0.00%	0.27%	0.14%

The last part of the survey dealing with the congestion of campus resources focused on the Student Village Tallman Commons (SVTC). While this is primarily a series of dorms for on-campus students, there are also classes, offices, and some open rooms available that many students do not take advantage of. Table 4.32 below shows some of the difficulties students face with using this space.

Table 4.32: Interest in Using SVTC for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	37.50%	49.45%
Phase 2	34.78%	48.15%
Average	36.14%	48.80%

IV.II.1II CAMPUS SURVEY - HOUSING

With campus dorms often being a major discussion point for campus congestion, there was interest in looking at how many students have (or currently do) live on the campus in the dorms. Table 4.33 below shows the survey results for both phases on this.

Table 4.33: Currently or Previously Lived in the Dorms for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	91.67%	28.23%
Phase 2	86.96%	34.05%
Average	89.32%	31.14%

As the dorms vary in their design, age, and capacity, it was of interest to determine which dorm the survey respondents did/do live in. The results of this are shown in Table 4.34 below.

Table 4.34: Dorm Stayed In for the ERAU-DB Campus

Dorm	Phase 1	Phase 2	Average	Campus Percent	Variance
Apollo	0.00%	3.88%	1.94%	7.52%	-5.58%
Wood	0.00%	6.47%	3.24%	4.66%	-1.42%
Adams	0.00%	11.21%	5.61%	8.96%	-3.35%
Doolittle	35.71%	5.60%	20.66%	10.29%	+10.37%
Chanute	0.00%	1.29%	0.65%	3.63%	-2.98%
Stimpson	0.00%	1.29%	0.65%	3.01%	-2.36%
O'Connor	14.29%	5.17%	9.73%	12.56%	-2.83%
New Res Hall 1	14.29%	25.43%	19.86%	18.86%	+1.00%
New Res Hall 2	14.29%	36.64%	25.47%	17.60%	+7.87%
New Res Hall 3	21.43%	3.02%	12.23%	12.94%	-0.71%

Since the lack of space and the location of the dorms are typical complaints from students, it was of interest to determine if they feel the space is overcrowded or not. Table 4.35 below shows the results of this from both survey phases where 1 is crowded and 10 is not crowded.

Table 4.35: Level of Crowding in the Dorms for the ERAU-DB Campus

Survey Phase	Average Rating	Standard Deviation
Phase 1	5.73	1.74
Phase 2	6.20	2.30
Average	5.97	2.02

One of the primary complaints about the housing situation at ERAU-DB is on the communication between the housing department and the students living in the dorms. Table 4.36 below shows the results of student's contact method preferences.

Table 4.36: Preferred Housing Contact Method for the ERAU-DB Campus

Contact Method	Phase 1	Phase 2	Average
Door Posting	13.9%	10.0%	12.0%
Email	47.2%	58.0%	52.6%
Text	11.1%	16.0%	13.6%
GroupMe	8.3%	2.0%	5.2%
Phone Call	5.6%	4.0%	4.8%
Discord	8.3%	2.0%	5.2%
Slack	5.6%	0%	2.8%
Hall Meeting	0%	2.0%	1.0%
Social Media	0%	6.0%	3.0%

<u>IV.II.1V CAMPUS SURVEY - SOFTWARE</u>

Along with the physical elements of campus, ERAU-DB has two software packages that are aimed at assisting students during their time at the university. One of these software packages is called SchedulER and deals with helping students find open rooms they can reserve for studying, meetings, hangouts, etc. Despite this software being actively supported by the school, not all the students use it. Table 4.37 below shows the results from the survey.

Table 4.37: Usage Level of SchedulER for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	66.67%	48.15%
Phase 2	45.65%	50.36%
Average	56.16%	49.26%

Along with room scheduling, ERAU-DB pushes a software package for the student groups on campus, the RSOs. This software is known as CampusGroups and has functionality inside of it for communication, budgeting, and forms for campus communication. While the administration continues to push this software, many students do not use it or do not see the value in using it. Table 4.38 below shows the results from the survey.

Table 4.38: Usage Level of CampusGroups for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	50.00%	51.08%
Phase 2	73.91%	44.40%
Average	61.96%	47.74%

IV.II.V CAMPUS SURVEY – TRANSPORTATION

In the local area surrounding ERAU-DB there is minimal available public transportation. The local area has a bus system, but many students do not feel comfortable taking it. During the survey Phase 1, there was the suggestion to add a bus system specific to ERAU-DB. Table 4.39 below shows the student interest in adding this system.

Table 4.39: Interest in a Bus System for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	65.79%	36.95%
Phase 2	56.11%	42.56%
Average	60.95%	39.76%

One of the main factors when a new system is added in is the cost of the item's addition. The results for ERAU-DB from the survey on paying for the bus system via a pass are shown below in Table 4.40.

Table 4.40: Paying to Use Bus System for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	68.18%	47.67%
Phase 2	26.09%	44.40%
Average	47.14%	46.04%

Despite a high agreement level in Phase 1, there was not a strong correlation between respondents on the cost of the bus pass. Table 4.41 below shows some of the recommended price ranges for the bus pass for a semester and their frequency for each survey phase.

Table 4.41: Bus Pay Range Frequency for the ERAU-DB Campus

Pay Range	Phase 1 Frequency	Phase 2 Frequency	Average
0	37.50%	75.56%	56.53%
1-20	0.00%	6.67%	3.34%
21-40	4.17%	4.44%	8.61%
41-60	12.50%	6.67%	9.59%
61-80	16.67%	4.44%	10.56%
81-100	0.00%	0.00%	0.00%
101<	29.17%	2.22%	15.70%

Along with determining the cost for the bus system, it was of interest to determine how often the bus system should loop during the day. The results of this are shown below in Table 4.42.

Table 4.42: Average Bus Loop Time for the ERAU-DB Campus

Survey Phase	Average Time (Minutes)	Standard Deviation
Phase 1	42.75	22.90
Phase 2	25.25	13.60
Average	34.00	18.25

The days of the week the bus runs were also of interest to determine as it has direct impacts on both student usage and operating costs. The results of this are shown below in Table 4.43.

Table 4.43: Daily Usage Agreeance for the ERAU-DB Campus

Survey Phase	Phase 1	Phase 2	Average
Monday	100.00%	93.18%	96.59%
Tuesday	92.86%	90.91%	91.88%
Wednesday	100.00%	90.91%	95.45%
Thursday	100.00%	94.45%	97.73%
Friday	100.00%	100.00%	100.00%
Saturday	92.86%	54.55%	73.70%
Sunday	71.43%	54.55%	62.99%

Determining the start and end times for the bus system was also of interest during this study. The results of this are shown below in Table 4.44.

Table 4.44: Average Bus Start and End Times for the ERAU-DB Campus

Survey Phase	Start Time	Standard Deviation (Min)	End Time	Standard Deviation (Min)
Phase 1	0851	299.34	1859	199.19
Phase 2	0733	299.19	2012	705.43
Average	0809	299.27	1936	452.31

While ERAU-DB does not yet have any type of bus system in place, several of the apartment complexes do have a shuttle service provided by the Student Government Association

(SGA) available to them. As such, it was of interest to know how many students in the survey were utilizing this service. The results of this are shown below in Table 4.45.

Table 4.45: Utilizes the Campus Shuttle System for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	18.42%	39.29%
Phase 2	16.59%	37.24%
Average	17.51%	38.27%

While 17.5% is not an insignificant part of campus, it was of interest to determine if expanding this shuttle service would be of benefit to the ERAU-DB campus. Table 4.46 below shows the percentage of students who live at an apartment complex that does not currently have a transportation service to campus and they would use it if added.

Table 4.46: Desires for Expansion of the Campus Shuttle System for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	22.37%	38.02%
Phase 2	10.70%	28.93%
Average	16.54%	33.48%

Another possible expansion of the SGA shuttle service is to use it to provide transportation from the main campus to the satellite facilities of ERAU-DB. These include the MicaPlex, the Eagle Flight Research Center, the Worldwide Headquarters, etc. The results of this from the survey are shown below in Table 4.47.

Table 4.47: Satellite Facility Expansion of the SGA Shuttle System for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	21.05%	41.32%
Phase 2	11.35%	31.76%
Average	16.20%	36.54%

It was also suggested that the SGA shuttle service could be expanded internally to campus, to provide transportation from one building to another internally to ERAU-DB. The results of this from the survey are shown below in Table 4.48.

Table 4.48: Internal Building Expansion of the SGA Shuttle System for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	56.58%	42.19%
Phase 2	45.85%	40.70%
Average	51.22%	41.45%

Rather than adding a new system into the campus, it was also of interest to determine if students would respond well to developing a car-pool system for the area instead. The results of this are shown below in Table 4.49.

Table 4.49: Interest in a Car-Pool App for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	40.79%	43.27%
Phase 2	35.26%	41.12%
Average	38.03%	42.20%

On the ERAU-DB campus, it is not uncommon to see students using skateboards and longboards to go between classes, meetings, dorms, etc. Unfortunately, with the campus congestion, there have been people who have gotten hit and injured due to longboard riders running into them on the sidewalks. One of the suggestions during this project was to add bike and skateboard lanes on the sidewalks. The results of this are shown in Table 4.50 below.

Table 4.50: Adding in Bike/Skateboard Lanes for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	83.33%	38.07%
Phase 2	65.22%	48.15%
Average	74.28%	43.11%

Along with adding lanes in, it was of interest to learn if there should be specific times of the day when they are not allowed to be used, like the University of Wisconsin at Eau Claire's system. The results of this are shown below in Table 4.51.

Table 4.51: Bike/Skateboard Block Out Times for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	39.47%	49.54%
Phase 2	26.42%	44.14%
Average	32.95%	46.84%

If these lanes are to be added, they are only helpful in fixing the problem if they are followed or enforced. For purposes of this study, only abiding by them is considered. During both survey phases, participants were asked if they would abide by these lanes if they were added in. The results of this are shown below in Table 4.52.

Table 4.52: Abiding by Bike/Skateboard Lanes for the ERAU-DB Campus

Survey Phase	Agreement Level	Standard Deviation
Phase 1	37.50%	49.45%
Phase 2	86.96%	34.05%
Average	62.23%	41.75%

IV.III DETAILED MODEL

For the Detailed Model, there were a series of source elements that were created. Their names and distributions are found in Table 4.53 below.

Table 4.53: Names and Distributions of Source Elements in the Detailed Model

Source		
Name	**Cap**	**Category**
Adams	312	Dorms
Apollo	261	
Chanute	129	
Doolittle	357	
NRH1	661	
NRH2	618	
NRH3	451	
O'Connor	434	
Stimpson	110	
Wood	166	
Off Campus 1	2971	Non-Residential
Off Campus 2	2972	

Next, a series of sink elements were created in the model to enable the complete flow of entities throughout the simulation. The names of each sink are listed in Table 4.54 below.

Table 4.54: Names of Sink Elements in the Detailed Model

Sink	
Name	**Category**
Adams	Dorms
Apollo	
Chanute	
Doolittle	
NRH1	
NRH2	
NRH3	
O'Connor	
Stimpson	
Wood	
Off Campus 1	Non-Residential
Off Campus 2	

The other major element to be added into the model was servers. This enables the completion of the standard source-server-sink loop in simulation models. The servers modeled, their processing time, variance, and corresponding minimum and maximum values are shown below in Table 4.55.

Table 4.55: List of Servers in the Detailed Model with Their Processing Time, Variance, and Corresponding Min/Max Values

Server					
Name	**Processing Time (Min)**	**Variance (Min)**	**Min. (Min)**	**Max. (Min)**	**Category**
Adams	643	379	264	1022	Dorms
Apollo	643	379	264	1022	
Chanute	643	379	264	1022	
Doolittle	643	379	264	1022	
NRH1	643	379	264	1022	
NRH2	643	379	264	1022	
NRH3	643	379	264	1022	
O'Connor	643	379	264	1022	
Stimpson	643	379	264	1022	
Wood	643	379	264	1022	
COE	83	95	0	178	Academic Building
COAS	116	99	17	215	
IC	24	6	18	30	

COB	70	72	0	142	
COA	71	80	0	151	
Flight Ops	9	0	9	9	
M Building	76	61	15	137	
Bldg. 508	43	0	43	43	
Fitness Center	65	57	8	122	Athletics
ICI	107	21	86	128	
ROTC	111	71	40	182	
SU	105	105	0	210	Recreational
Quad	49	66	0	115	
Henderson	120	0	120	120	Administrative

Next, the mix of the different entity types were added in. From Table 3.1, the percentage breakdown of different entity types is known. As such, mix percentages can be created. Table 4.56 below shows the mix percentages for students.

Table 4.56: Mix Percentages for Students in the Detailed Model

Student Mix				
Ethnicity	**Male**	**%Tot**	**Female**	**%Tot**
American Indian/Alaskan Native	14	0.18	4	0.05
Asian	284	3.57	94	1.18
Black/African American	285	3.59	95	1.20
Hispanic/Latino	849	10.69	283	3.56
Native Hawaiian/Pacific Islander	9	0.11	3	0.04
Nonresidential Alien (International)	784	9.87	261	3.29
Race/Ethnicity Unknown	118	1.49	39	0.49
Two or more races	276	3.47	92	1.16
White	3336	41.99	1112	14.00

This same logic can be applied for faculty, staff, and UA to complete the campus population mix, and is shown below in Table 4.57.

Table 4.57: Mix Percentages for Faculty/Staff/UA in the Detailed Model

Staff/Faculty/UA Mix					
Classification	**Age**	**Male**	**%Tot**	**Female**	**%Tot**
Staff	Young	68	12.41	68	12.41
	Middle Aged	137	25	137	25
	Elderly	68	12.41	68	12.41
Faculty	Young	47	12.37	47	12.37
	Middle Aged	95	25	95	25
	Elderly	47	12.37	47	12.37
UA	Young	71	12.48	71	12.48
	Middle Aged	142	24.96	142	24.96
	Elderly	71	12.48	71	12.48

The last calculation needed prior to running the Detailed Model is the capacity of each entity, which is the maximum number in the system. This is shown below in Table 4.58.

Table 4.58: Population of Each Entity in the Detailed Model

Classification	Ethnicity	Gender	Average Summer Population	Fall Population	Spring Population
Student	American Indian/Alaskan Native	Male	1	14	12
Student	Asian	Male	36	284	267
Student	Black/African American	Male	35	285	257
Student	Hispanic/Latino	Male	89	849	778
Student	Native Hawaiian/Pacific Islander	Male	1	9	9
Student	Nonresidential Alien (International)	Male	141	784	738
Student	Race/Ethnicity Unknown	Male	13	118	102
Student	Two or more races	Male	30	276	266
Student	White	Male	340	3336	3111
Student	American Indian/Alaskan Native	Female	0	4	4
Student	Asian	Female	10	94	89
Student	Black/African American	Female	10	95	85
Student	Hispanic/Latino	Female	25	283	259
Student	Native Hawaiian/Pacific Islander	Female	0	3	3
Student	Nonresidential Alien (International)	Female	41	261	246
Student	Race/Ethnicity Unknown	Female	4	39	34
Student	Two or more races	Female	8	92	88
Student	White	Female	98	1112	1037

Once this data was loaded into the Detailed Model, the first trials could begin. These were conducted as an 8-hour trial, a 24-hour trial, a 72-hour trial, and a 168-hr trial. The results for each trial can be found in Tables 4.59-4.62 below.

Table 4.59: Server Results from the 8-Hour Campus Simulation in the Detailed Model

Server	Time Processing	Percent Util	Entities Processed	Percent Usage
508	5.690	71.13%	45	0.62%
Apollo	7.999	99.99%	53	0.73%
Chanute	7.999	99.99%	35	0.48%
COA	6.785	84.81%	13	0.18%
COAS	6.666	83.33%	36	0.49%
COB	5.385	67.32%	18	0.25%
COE	7.045	88.07%	94	1.29%
Doolittle	7.997	99.97%	86	1.18%
Fitness	7.375	92.19%	55	0.76%
FlightOps	0.767	9.58%	6	0.08%
Henderson	4.707	58.83%	5	0.07%
IC	6.503	81.29%	39	0.54%
ICI	4.700	58.75%	10	0.14%
MBldg	6.384	79.81%	45	0.62%
NRH1	7.999	99.99%	113	1.55%
NRH2	7.999	99.98%	108	1.48%
NRH3	7.998	99.98%	112	1.54%
Quad	6.192	77.41%	7	0.10%
ROTC	6.236	77.94%	9	0.12%
SUC	5.713	71.41%	22	0.30%
SVTC_Adams	7.999	99.98%	54	0.74%
SVTC_Oconnor	7.999	99.99%	70	0.96%
SVTC_Stimpson	7.998	99.98%	32	0.44%
SVTC_Wood	7.999	99.99%	46	0.63%

Table 4.60: Server Results from the 24-Hour Campus Simulation in the Detailed Model

Server	Time Processing	Percent Util	Entities Processed	Percent Usage
508	21.690	90.38%	358	4.7%
Apollo	23.999	100.00%	449	5.9%
Chanute	23.999	100.00%	179	2.4%
COA	22.785	94.94%	241	3.2%
COAS	22.666	94.44%	799	10.6%
COB	21.385	89.11%	268	3.5%
COE	23.045	96.02%	1038	13.7%
Doolittle	23.997	99.99%	497	6.6%

Fitness	23.375	97.40%	649	8.6%
FlightOps	4.929	20.54%	35	0.5%
Henderson	20.707	86.28%	155	2.0%
IC	22.497	93.74%	260	3.4%
ICI	20.700	86.25%	430	5.7%
MBldg	22.384	93.27%	462	6.1%
NRH1	23.999	100.00%	857	11.3%
NRH2	23.999	99.99%	837	11.1%
NRH3	23.998	99.99%	663	8.8%
Quad	22.192	92.47%	101	1.3%
ROTC	22.236	92.65%	200	2.6%
SUC	21.713	90.47%	656	8.7%
SVTC_Adams	23.999	99.99%	522	6.9%
SVTC_Oconnor	23.999	100.00%	659	8.7%
SVTC_Stimpson	23.998	99.99%	202	2.7%
SVTC_Wood	23.999	100.00%	290	3.8%

Table 4.61: Server Results from the 72-Hour Campus Simulation in the Detailed Model

Server	Time Processing	Percent Util	Entities Processed	Percent Usage
508	69.644	96.73%	807	10.4%
Apollo	71.999	100.00%	1602	20.6%
Chanute	71.999	100.00%	369	4.8%
COA	70.785	98.31%	1453	18.7%
COAS	70.666	98.15%	3678	47.3%
COB	69.385	96.37%	973	12.5%
COE	71.045	98.67%	3483	44.8%
Doolittle	71.996	100.00%	983	12.7%
Fitness	71.375	99.13%	1883	24.2%
FlightOps	20.402	28.34%	157	2.0%
Henderson	68.707	95.43%	584	7.5%
IC	69.888	97.07%	946	12.2%
ICI	68.700	95.42%	2348	30.2%
MBldg	70.384	97.76%	962	12.4%
NRH1	71.999	100.00%	1332	17.1%
NRH2	71.999	100.00%	1500	19.3%
NRH3	71.998	100.00%	1796	23.1%
Quad	68.559	95.22%	382	4.9%
ROTC	70.236	97.55%	762	9.8%
SUC	69.713	96.82%	3503	45.1%
SVTC_Adams	71.999	100.00%	1342	17.3%
SVTC_Oconnor	71.999	100.00%	1473	19.0%
SVTC_Stimpson	71.998	100.00%	700	9.0%

SVTC_Wood	71.999	100.00%	1053	13.6%

Table 4.62: Server Results from the 168-Hour Campus Simulation in the Detailed Model

Server	Time Processing	Percent Util	Entities Processed	Percent Usage
508	165.640	98.60%	1592	19.5%
Apollo	167.999	100.00%	3936	48.2%
Chanute	167.999	100.00%	771	9.4%
COA	166.785	99.28%	4621	56.6%
COAS	166.666	99.21%	8860	108.6%
COB	165.385	98.44%	2440	29.9%
COE	167.045	99.43%	7731	94.8%
Doolittle	167.997	100.00%	1619	19.8%
Fitness	167.375	99.63%	4397	53.9%
FlightOps	57.429	34.18%	479	5.9%
Henderson	164.707	98.04%	1300	15.9%
IC	165.823	98.70%	2204	27.0%
ICI	164.700	98.04%	5330	65.3%
MBldg	166.384	99.04%	1785	21.9%
NRH1	167.999	100.00%	1921	23.5%
NRH2	167.999	100.00%	2080	25.5%
NRH3	167.998	100.00%	5335	65.4%
Quad	164.294	97.79%	878	10.8%
ROTC	166.236	98.95%	1485	18.2%
SUC	165.713	98.64%	8832	108.2%
SVTC_Adams	167.999	100.00%	2463	30.2%
SVTC_Oconnor	167.999	100.00%	2564	31.4%
SVTC_Stimpson	167.998	100.00%	1695	20.8%
SVTC_Wood	167.999	100.00%	2358	28.9%

Now that data has been collected from the ERAU-DB student population and from Simio via the Detailed Model, analysis of both data sets collected and a comparative analysis of the level of agreement between the qualitative and quantitative data can occur.

V. DISCUSSION

As results have been generated from qualitative and quantitative data sources for this thesis, a discussion on them can now occur. This chapter consists of three subsections. Section V.I discusses the model's efficacy and how the data compares to the expected outputs, growth curves, etc. Section V.II analyzes the student perception data against the model to see where the level of agreement falls for the different optimization targets of interest. Lastly, section V.III discusses optimization strategies from the model data and a comparative analysis of the quantitative and qualitative data collected up to this point.

V.I MODEL EFFICACY

From the simulations performed in the detailed model, the campus congestion became more apparent over time. For instance, over longer simulation trials, more students were present. Figure 5.1 below shows the growth of students in the model via entities over the simulation run duration.

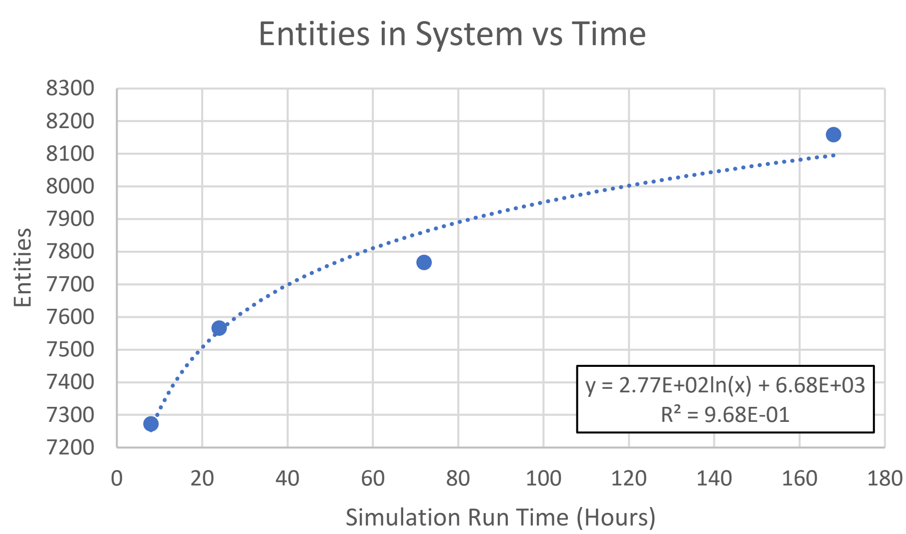


Figure 5.1: Maximum Entities Present in the System vs Simulation Duration

Additionally, the congestion of buildings increased over the simulation run time. Building congestion was most prevalent in the COAS, COE, and SUC locations. Graphically, the congestion level of these buildings as the simulation time increases is shown below in Figure 5.2 where 100% is when the theoretical maximum population of a building is reached, over 100% means that a building is serving more students than it was designed to support.

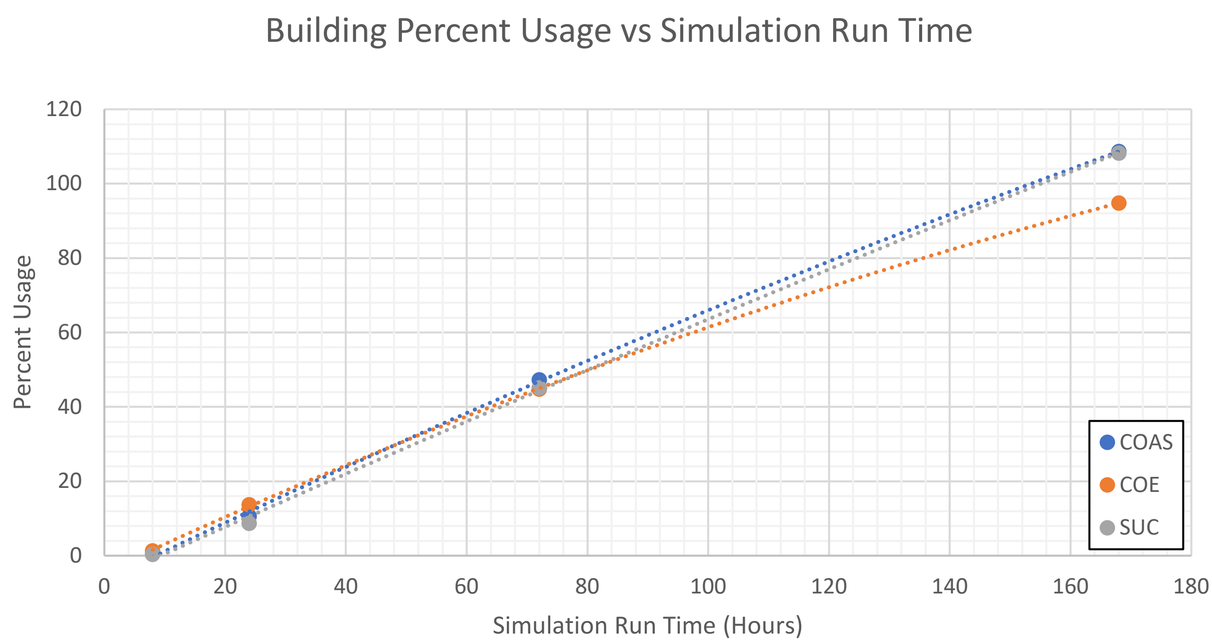


Figure 5.2: Percent Usage of the COAS, COE, and SUC vs Simulation Run Time

Excel was used for trend line fitting and the results of this are shown below:

$$COAS: y = -0.0006x^2 + 0.784x - 6.6051, R^2 = 0.9996$$

$$COE: y = -0.001x^2 + 0.757x - 4.3779, R^2 = 0.9999$$

$$SUC: y = -0.0003x^2 + 0.7304x - 6.7947, R^2 = 0.9992$$

The utilization of buildings was more dramatic over time and, in some cases, remained near 100% for all trials. For the dorms, for instance, maximum utilization was nearly always present and is shown below in Figure 5.3.

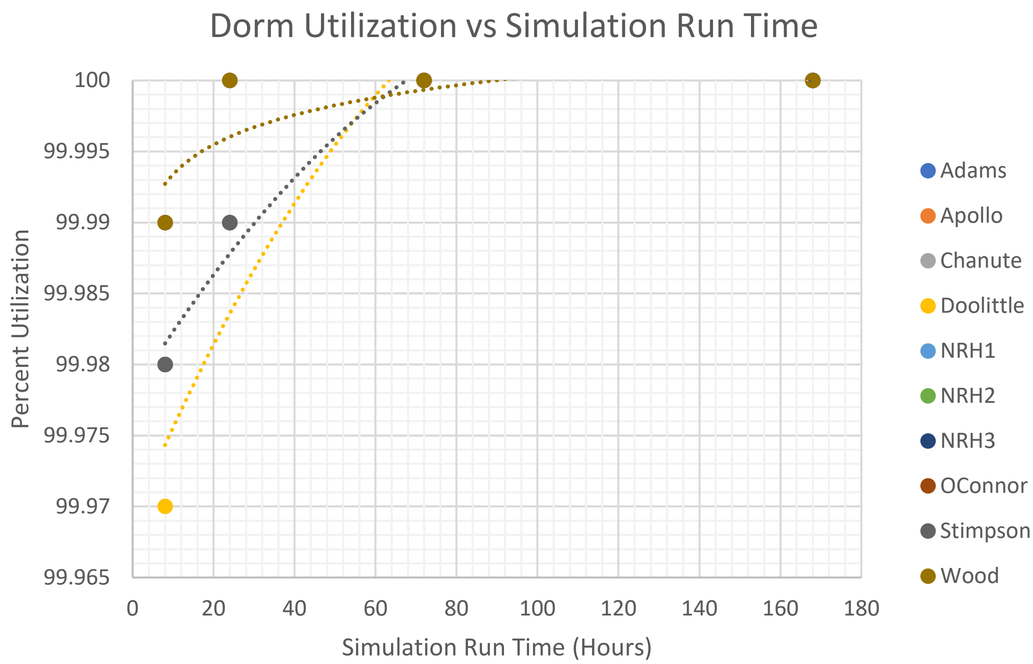


Figure 5.3: Dorm Utilization Percentages vs the Simulation Run Time. Note: Many Series Have Overlap

It was also of interest to determine any possible correlation between the utilization of buildings over time and the population of students (entities) who used the buildings in the model. The utilization statistics are shown below in Table 5.1.

Table 5.1: Usage Rates Per Utilization Rates for Each Building Modeled in the Detailed Model Simulation.

Location	Average Util Per Hour	Average Usage Per Hour	Usage per Util
508	14.59%	0.53%	3.67%
Apollo	18.65%	0.91%	4.89%
Chanute	18.65%	0.28%	1.51%
COA	16.51%	0.75%	4.55%
COAS	16.30%	1.81%	11.08%
COB	14.05%	0.53%	3.78%
COE	16.97%	1.92%	11.31%
Doolittle	18.65%	0.72%	3.84%
Fitness	17.55%	1.11%	6.32%
FlightOps	2.65%	0.09%	3.49%
Henderson	12.86%	0.29%	2.28%
IC	16.00%	0.54%	3.38%
ICI	12.85%	1.06%	8.27%
MBldg	15.81%	0.63%	4.01%

NRH1	18.65%	1.04%	5.60%
NRH2	18.65%	1.07%	5.72%
NRH3	18.65%	1.27%	6.80%
Quad	15.43%	0.20%	1.30%
ROTC	15.55%	0.37%	2.38%
SUC	14.63%	1.67%	11.42%
SVTC_Adams	18.65%	0.80%	4.29%
SVTC_Oconnor	18.65%	0.93%	5.01%
SVTC_Stimpson	18.65%	0.42%	2.23%
SVTC_Wood	18.65%	0.60%	3.21%

The usage rates vary dramatically, with the smallest rates often being for housing options and the largest being for the SUC, COAS, and COE, all identified as possible overcrowding concern locations.

The last element of interest was determining when other buildings on campus would reach maximum capacity. From curve fitting in Excel, it was determined that the buildings exhibit a linear growth trend over time. This curve can then be calculated for the buildings by using Equation 48 below.

$$\%Usage = UsageGrowthRate * SimTime + InitialGrowthRate \tag{48}$$

For this equation, the *UsageGrowthRate* can be found from the simulation outputs, and the *SimTime* is the elapsed simulation value when a value is calculated. The *InitialGrowthRate* is found with the use of the Excel solver.

This can also be done graphically, as shown in Figure 5.4 below.

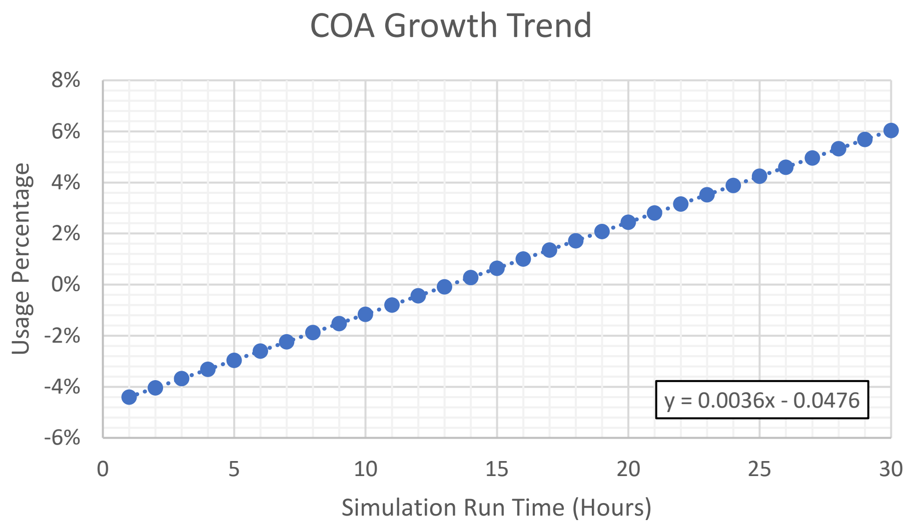


Figure 5.4: COA Growth Rate Determined Graphically

It was of interest to determine the time at which each campus building would eclipse 100% usage since that is when congestion begins to occur. The results of this analysis for each of the campus buildings are compiled and shown in Table 5.2 below.

Table 5.2: List of Campus Locations Modeled and the Time at Which 100% Usage is Predicted

Location	Eqn	Time at 100% Usage (Hours)
508	0.0011*x+0.0117	898.45
Apollo	0.003*x-0.0124	337.47
Chanute	0.0005*x+0.0063	1987.40
COA	0.0036*x-0.0476	291.00
COAS	0.0068*x-0.044	153.53
COB	0.0018*x-0.0099	561.06
COE	0.0058*x-0.0059	173.43
Doolittle	0.0011*x+0.0274	884.18
Fitness	0.0033*x-0.0027	303.85
FlightOps	0.0004*x-0.0038	2509.50
Henderson	0.001*x-0.0029	1002.90
IC	0.0017*x-0.0043	590.76
ICI	0.0041*x-0.0262	250.29
MBldg	0.0012*x+0.018	818.33
NRH1	0.0012*x+0.0539	788.42
NRH2	0.0013*x+0.0537	727.92
NRH3	0.004*x-0.022	255.50
Quad	0.0007*x-0.0023	1431.86
ROTC	0.0011*x+0.0011	908.09

SUC	0.0068*x-0.0579	155.57
SVTC_Adams	0.0018*x+0.018	545.56
SVTC_Oconnor	0.0018*x+0.0287	539.61
SVTC_Stimpson	0.0013*x-0.0039	772.23
SVTC_Wood	0.0018*x-0.0024	556.89

As can be seen, the earliest that building capacity is reached is 153.53 hours, and the longest is 2509.50 hours. This is the expected length of time a building can continually be used prior to being over capacity. Surprisingly, some dorms (specifically the SVTC, excluding Stimpson) hit capacity before some academic buildings did (e.g., COB). While for SVTC Adams and Wood, this is likely due to the inclusion of non-dorm spaces used by the students (such as program support and dining), it is still an item not anticipated in initial model predictions.

Since permanent sustained linear growth is unrealistic for the campus model (as people are finite), a logarithmic equation was also generated. The logarithmic model for COA is shown below in Equation 49.

$$\%Usage = Multiplier * \ln(SimTime) - InitialGrowthRate \quad (49)$$

In this equation, the *Multiplier* value was determined through the rate of growth changes observed in the various simulation trials. Like the linear model, this can also be solved graphically, shown below in Figure 5.5

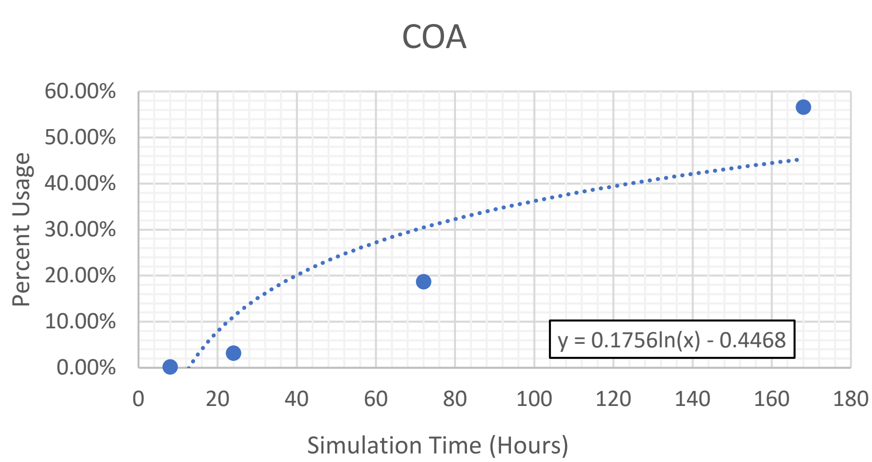


Figure 5.5: COA Building Percent Usage Over Simulation Time

With this new curve fitting applied, the steady-state value for each utilization of each building was of interest to determine. This was calculated with the results shown below in Table 5.3.

Table 5.3: Fitted Equations and Corresponding Usage Times for the Detailed Model

Location	Eqn	Time at 100% Usage (Hours)
508	0.0601*LN(X)-0.132	1.51E+08
Apollo	0.1503*LN(X)-0.3621	8.62E+03
Chanute	0.0281*LN(X)-0.0605	2.45E+16
COA	0.1756*LN(X)-0.4468	3.78E+03
COAS	0.3455*LN(X)-0.8488	2.11E+02
COB	0.0936*LN(X)-0.2276	4.95E+05
COE	0.2989*LN(X)-0.7086	3.04E+02
Doolittle	0.0602*LN(X)-0.12	1.20E+07
Fitness	0.1677*LN(X)-0.396	4.13E+03
FlightOps	0.018*LN(X)-0.0448	1.60E+25
Henderson	0.0509*LN(X)-0.1227	3.79E+09
IC	0.0844*LN(X)-0.2015	1.52E+06
ICI	0.211*LN(X)-0.5198	1.34E+03
MBldg	0.0677*LN(X)-0.1456	2.23E+07
NRH1	0.0702*LN(X)-0.1233	9.09E+07
NRH2	0.0786*LN(X)-0.1446	2.11E+06
NRH3	0.1958*LN(X)-0.4705	1.82E+03
Quad	0.0341*LN(X)-0.0822	5.94E+13
ROTC	0.0592*LN(X)-0.1399	2.31E+08
SUC	0.3443*LN(X)-0.8559	2.20E+02
SVTC_Adams	0.0954*LN(X)-0.2117	3.26E+05
SVTC_Oconnor	0.0984*LN(X)-0.2105	2.19E+05
SVTC_Stimpson	0.0644*LN(X)-0.1538	6.03E+07
SVTC_Wood	0.0906*LN(X)-0.2148	6.68E+05

As can be seen, the quickest time capacity is reached is 211 hours, and the longest is 1.6E+25 hours. From this, it was evident that while this curve fitting still does not perfectly fit the data, it provides a more accurate picture of the usage of significant campus buildings, such as those for academics, and is more representative of expected behavior.

Along with the analysis conducted through the simulation and the plots above, it was of interest to compare the student perceptions against the data suggested by the model to determine where the overlap of both were positive (they agreed), both were negative (disagreement), or neutral (no trend).

V.II STUDENT PERCEPTION

From the data collected during the survey rounds on campus, it was determined that the busiest perceived day on campus is Monday (38.6%). For the simulation, this is the period between 0 hours and 24 hours. As such, there was not agreement here. The simulation reported the second-highest average growth rate (0.248%/hr) for the 24-hour trial, but the highest was during the 72-hour trial (0.254%/hr). As such, the simulation claims Wednesday is the busiest day on campus, with 24.9% of respondents agreeing. Ultimately, there is still some overlap in the data here, but not complete agreement.

Some campus locations were reported to be busier than others from the campus surveys conducted. Specifically, the three busiest were the SUC (19.6%), the COAS (17.9%), and the COE (13.6%). In the simulations run, the three busiest buildings for the liner model were COAS, SUC, and COE, and in the logarithmic model, the three were COAS, SUC, and COE. As can be seen, there was agreement here with the busiest buildings, but in a slightly different order. While the simulation predicts that COAS is busier than the SUC (108.6% vs 108.2%), the comparison is close enough that seeing them at the top two aligns with the qualitative data collected. Seeing COE further down in the qual data (-4.3%) also aligns well with the reported simulation data of 94.8%, which is a -13.4% difference from the SUC. Again, here there is a good agreement between the busiest buildings, but also variances of these crowding levels, which is expected model behavior.

Similar to the building crowding levels, some buildings were more used than others. The survey respondents reported that the dorms were overwhelmingly the most utilized buildings for them (4500.9 mins compared to 840 mins for the highest utilized non dorm building). From the simulations, the dorms were the most utilized buildings on the campus. Again, there is a high level of agreement, but this should be expected as dorms will be the most used building (i.e., students sleeping, eating, studying), so it is of interest to dig deeper into this question. With dorms omitted, the qualitative data reports that the most used buildings are Henderson, COAS, and ROTC. From the simulation data, the most used buildings are the Fitness Center, COE, and COA. Here, there is a low level of agreement between the two data sets but only fractions of a percent difference in the simulation data (99.63%, 99.43%, 99.28%). As such, this should be further investigated to determine variances.

This thesis intends to be of interest to the author and the ERAU-DB campus at large. As such, it was of interest to determine the level of interest in seeing the results of the data collected. During the survey, 5.77% of participants were interested in seeing the finished thesis, 15.4% were interested in seeing published paper(s) from the work, and 53.8% were interested in receiving both documents.

Lastly, it was of interest to see how well the survey data agreed with the simulation data. From the category comparison completed, it shows that there is roughly 85% agreement between qualitative and quantitative data collected. This agreement level can be explored further with additional Delphi groups and surveys, but for time, this thesis is just a full comparison here.

V.III OPTIMIZATION

From the data collected and the analysis performed in sections V.I and V.II, it is apparent that there is room for improvement on the ERAU-DB campus. While many concerns are raised on campus regarding problems noticed by the campus population, some are more jarring and troublesome than others.

One significant issue acknowledged throughout this thesis is the overcrowding of the COAS building. In both curve fitting models, and across all trials, COAS was the quickest to reach capacity, in the linear model by 1.3% and in the logarithmic model by 4.1%. The COAS building is used on the campus for classes, labs, and study spaces and is home to nine academic departments. As such, high foot traffic is expected in this building. One of the significant congestion points in the building is the main staircase, yet 77.5% of survey respondents reported they were aware of alternative routes they could use. It is recommended that signage be added to identify additional stair options and that during orientation tours they be pointed out. Further, it is recommended to faculty who teach in COAS to point out the nearest side stairwell to their students in the event of an emergency evacuation.

The other building with continuously reported overcrowding is the SUC. This building is not academic but serves as a campus hub for events, speakers, dining, Greek life, campus organizations, campus safety, the bookstore, etc. As such, high levels of foot traffic are expected. First looking at the dining system, a wait time of 17 minutes was reported during the campus survey collection. This time is a bit higher than what is generally considered reasonable, with an average reported national dining time of 5.68 minutes in fast-food restaurants [70]. As such, it is recommended to look more at the effectiveness of different dining options on campus and encourage wider usage of all possible options. It is also encouraged to look at the rearrangement of the dining location spaces on the campus, specifically tables for solo diners. One possibility for this is to look at using outer walls for single dining spaces, such as stools with a wall-mounted counter, and to expand the use of the buzzer system to additional campus dining locations such as the Refueling Station (20%), Propellers (17.5%), and Starbucks (15%). Both will help make solo dining in the SUC easier and would be expected to help cut down the queue and usage time of the space.

Campus parking is arguably the most complained about item across the ERAU-DB campus that was investigated during this study. Yet, according to the simulations run and the campus data provided, there should not be any problems finding a parking spot. Quantitatively, there is a 35.9% surplus of parking spots on the campus during peak hours. Yet 69.11% of students have reported numerous issues identifying parking spots they can use, and many reported needing to park illegally to make it to their classes/obligations on time. This is an interesting observation as the quantitative and qualitative data here do not agree. While some of the complaints likely come from the closest parking lots not being available, there are still inconsistencies in the data that should be further investigated. It is recommended to do a more thorough investigation of the identification and usage of parking spots on the campus, an audit of campus vehicles (and passes distributed) and provide a better outline of when spaces can and cannot be used and by whom.

Lastly, the overcrowding of campus housing has been mentioned a few times throughout this study as a possible area of concern. For the last two years (2022-2023, 2023-2024), the ERAU-DB campus dorms have been at or above 100% capacity which means there are more than two beds in a two person room. Yet, during both years and in multiple preceding years, campus enrollments have climbed. While it is possible to make another dorm to accommodate more students, this also takes time and capital, which may not necessarily be allocated to such a project. The campus currently requires students in their first two years to remain on campus and permits some upperclassmen to apply to live there. This change required here is likely policy in nature. From the simulation, the dorms had a maximum utilization of 100% and a minimum utilization of 99.97%. As such, there need to be policy changes made to prevent this usage from exceeding its possible capacity. One option would be to reduce campus housing to only include first and second-year students, saving a few percentage points of usage. Additionally, the campus could give the option to second-year students to opt out of housing, yet this runs the risk of further overcrowding the local Daytona Beach area, which is struggling to keep up with the school. The ERAU-DB housing problem ends in a situation with no great outcome, but it is recommended to continue to investigate options here for further work and development both on campus and locally.

As has been shown throughout this thesis, there are several areas where the ERAU-DB campus needs to be optimized and further investigated. Long queue times, uncertainty of housing options, difficulty getting to campus, and problems dining all contribute to higher stress levels, reported by 65.95% of respondents. No issue has one unique solution, nor can it be implemented overnight. These all require some combination of policy, capital, and user buy-in to be successful. It is recommended that the ERAU-DB campus looks into creating a campus optimization task force, consisting of essential VIPs, students, faculty, staff, and external partners, intending to make strides in the positive direction of these items over the next several years. A target date of 2030 for the implementation of these recommended optimizations and improvements is within reason, and further work on this topic is expected to lead to additional quality-of-life improvements on the campus.

VI. CONCLUSION

VI.I SIGNIFICANT FINDINGS

From January 2023 to March 2024, a quantitative methods study on optimizing the ERAU-DB campus was performed. This study consisted of the five preceding chapters, two simulation models, and a four-prong survey administered to 580 respondents. Throughout the thesis, some changes were made to the work conducted, and it became of interest to identify student perceptions on campus for areas of improvement and optimization and to combine this with the simulations.

The development of this thesis was guided by the central hypothesis that ***a digital twin simulation model can be created to aid in the identification of campus congestion***. The goal of this was to be able to accomplish the following:

1. Analyze the understanding generated by the simulation against expectations.
2. Improve the flow on the ERAU-DB college campus.
3. Determine the real-time attitudes on the campus layout and existing structure.

For the first item, a raw comparison of data was performed first. This comparison looked at whether the data reported by the simulation model and the surveys agreed. Overall, there was a high level of agreement on the items where historical data was actively available and a low level of agreement on the items where this data was less available. Table 6.1 below lists some of the major sections addressed in the survey and the simulation and their projected level of agreement, broken into congestion (both reporting high utilization) and usage (both reporting high usage).

Table 6.1: Comparison of the Various Campus Congestion Items and the Level of Agreement Between the Survey and Simulation Results

Campus Congestion Item	**Level of Agreement**
Housing	High (Congestion), Medium (Usage)
Parking	High (Congestion), Low (Usage)
Dining	High (Congestion), High (Usage)
Fitness Center	Medium (Congestion), High (Usage)

On the second item, it was of interest to see how well the simulation predicts and highlights campus congestion points. For this, the model performed better than expected in terms of the pedestrian and vehicle network systems. In Simio, when you have overcrowding at a node, it creates a deadlock. As such, the model would report the exact spots (and times) where deadlocking is happening. An example of this is shown in Figure 6.1 below, with the timestamp shown in Figure 6.2.

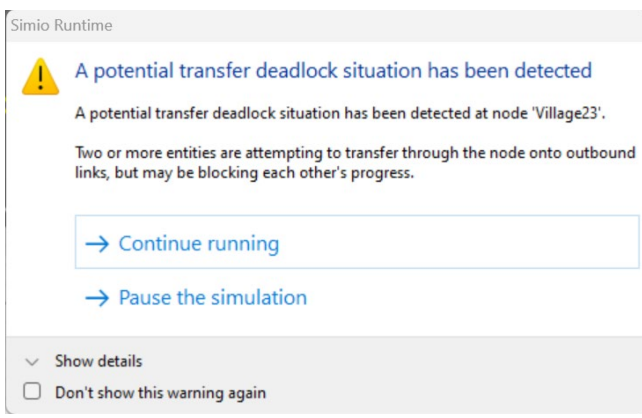


Figure 6.1: Deadlock Warning as Shown in the Simio Environment

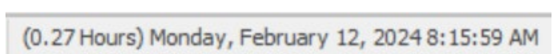


Figure 6.2: Time Date Format Provided by Simio for When the Warning Occurred

From the results of this, high usage and high congestion zones on the networks were able to be identified.

The third item is one that will not necessarily be able to be fully answered at this moment but acts as the reflection and need for the reasoning behind doing this thesis. The digital twin was partially successful in incorporating and analyzing qualitative survey data to determine campus usage points and congestion areas and was successful in identifying areas of the network system where congestion occurs. As such, it would be expected that there will be some beneficial changes to the campus model if these suggestions are implemented, but time is needed to see the results of these new implementations.

VI.II RECOMMENDATIONS FOR ERAU-DB

As this thesis provides suggestions for improving the optimization of the ERAU-DB campus (and reducing congestion), some of the suggestions will be reiterated here. The three major areas addressed in the survey and the simulation are dining, parking, and housing.

For campus dining, more data is needed for where congestion occurs, but it was clear from the thesis that students have locations they prefer to dine at. Part of this is due to not being aware of locations, but part is likely due to dietary choices and preferences. While this is not something that the campus cannot necessarily cater to everyone, it is something that should be further investigated to determine why students do and don't dine at specific locations.

For campus parking, more data is needed to create clarity between the survey data and simulation data. Here, there was low agreement between the two, and no real solutions were able to be found as a result. It is encouraged that more data is collected on the number of parking passes in circulation, the lots used (and the time of day of this usage), and the student complaints to see where the major issues are.

Lastly, there are significant concerns with the ability to continue housing more students on the campus. On a positive note, both the survey and the simulation data pointed to some of the problems students face with campus housing, but unfortunately, this means it is necessary to address. It is recommended that surveys be administered to determine who has (and who is lacking) housing, both on and off campus, and determine where the need for campus housing expands from and goes. These surveys will provide the campus with a better understanding of the needs of the students for housing and where the efforts need to be first.

VI.III FUTURE WORK

While some of the preliminary data has proven useful and accurate, there is more work to improve model efficacy and usefulness for the ERAU-DB campus. These items include further model development, creating an Optimization Task Force, and implementing (and tracking) these changes.

While the two models developed are helpful and provide essential input data for future more detailed models, creating more advanced models is a natural place to continue the study. By developing a detailed model of each campus building, a better idea of the networks, supply lines, and staffing of each can be generated. These models will then show the true usage of different buildings and how students can best utilize them.

As mentioned in Chapter 5, the development of an Optimization Task Force is recommended. By creating this group of people who can be focused on the implementation and evaluation of the suggestions provided in this thesis, there will be a higher chance of sustaining this work. Short- and long-term goals will need to be established by the task force to encourage and promote growth and development on the campus.

Lastly, the suggestions provided by this thesis should be implemented and evaluated in future studies. While the groundwork has been laid through the survey and the simulation, without implementing and evaluating it, the campus is not in a better position than it originally was. Now that the data is available and the suggestions are known, they should be implemented in both short- and long-term durations to see the impact they have on the campus. Further, they should be evaluated using mixed methods to ensure that the changes are benefiting the campus, and not causing any new issues or not having a significant impact.

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IX. APPENDIX

IX.I Phase 1 Campus Survey Questions

Campus Layout Survey

Greetings,

Thanks for your interest in completing the survey on the current ERAU Campus Layout.

This survey is being administered as part of Benjamin E. Chaback's Thesis in Systems Engineering surrounding campus design and optimization.

The goal of this survey is to gain a baseline for the current climate and feelings on the layout of campus and possible areas of improvement.

Throughout the survey, please keep in mind the focus here is mainly on administrative and policy changes, and less on physical changes.

If you have any questions about how the data will be collected, disseminated, or used, please contact Ben at chabackb@erau.edu

Thank you for your time on this!

This survey is estimated to take around 15 minutes to complete.

* Required

Informed Consent

Please answer the following question on your willingness to participate in this study.

1. ***Optimization of Human Interactions in the College Campus Model Via Simio Integration***

Purpose of this Research: I am asking you to take part in a research project for the purpose of determining the average time spent on campus, the campus resources used, and the impact of campus queues on the quality of your education. During this study, you will be asked to complete a brief online survey about your experiences on the ERAU-DB campus and how they have affected your time at the university. The completion of the survey will take approximately twelve minutes.

Risks or Discomforts: The risks of participating in this study are no greater than what is experienced in daily life.

Benefits: Your assistance during this survey can contribute to a better understanding of campus resources used by students and the impact of them on quality of education with intent for expansion.

Confidentiality of Records: Your individual information will be protected in all data resulting from this study. Your responses to this survey will be anonymous. No personal information will be collected other than basic demographic descriptors. The online survey system will not save IP address or any other identifying information. In order to protect the anonymity of your responses, I will keep your responses in a password-protected file on a password-protected computer. No one other than the researcher will have access to any of the responses.

Compensation: There is no compensation offered for taking part in this study.

Contact: If you have any questions or would like additional information about this study, please contact Benjamin E. Chaback, chabackb@erau.edu, or the faculty member overseeing this project, Dr. Radu Babiceanu, babicear@erau.edu.

Voluntary Participation: Your participation in this study is completely voluntary. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Should you wish to discontinue the research at any time, no information collected will be used.

CONSENT: By checking AGREE below, I certify that I understand the information on this form, I am a student, staff, and/or faculty member at ERAU-DB, and voluntarily agree to participate in the study.

If you do **not** wish to participate in the study, simply close the browser or check DISAGREE which will direct you out of the study. Please print a copy of this form for your records.

A copy of this form can also be requested from Benjamin E. Chaback, chabackb@erau.edu. *

◯ AGREE

◯ DISAGREE

General Demographics1

Please answer the following questions about your classification at ERAU

2. How many semesters have you been at ERAU? (Enter the number, including your current semester) *

The value must be a number

3. What college are you in? *

- ◯ COE
- ◯ COAS
- ◯ COA
- ◯ COB
- ◯ Multiple (Dual major in different colleges)

General Day to Day

Please see the questions below concerning your time spent on campus in a typical week.

4. Where do you spend the most time on campus on an average Monday? *

- ☐ COE
- ☐ COAS
- ☐ COB
- ☐ COA
- ☐ Student Union Center
- ☐ Micaplex
- ☐ Dorms
- ☐ Gym
- ☐ Quad
- ☐ Not on Campus
- ☐ Other

5. Where do you spend the most time on campus on an average Tuesday? *

- [ ] COE
- [ ] COAS
- [ ] COB
- [ ] COA
- [ ] Student Union Center
- [ ] Micaplex
- [ ] Dorms
- [ ] Gym
- [ ] Quad
- [ ] Not on Campus
- [ ] Other

6. Where do you spend the most time on campus on an average Wednesday? *

- ☐ COE
- ☐ COAS
- ☐ COB
- ☐ COA
- ☐ Student Union Center
- ☐ Micaplex
- ☐ Dorms
- ☐ Gym
- ☐ Quad
- ☐ Not on Campus
- ☐ Other

7. Where do you spend the most time on campus on an average Thursday? *

- [ ] COE
- [ ] COAS
- [ ] COB
- [ ] COA
- [ ] Student Union Center
- [ ] Micaplex
- [ ] Dorms
- [ ] Gym
- [ ] Quad
- [ ] Not on Campus
- [ ] Other

8. Where do you spend the most time on campus on an average Friday? *

- [ ] COE
- [ ] COAS
- [ ] COB
- [ ] COA
- [ ] Student Union Center
- [ ] Micaplex
- [ ] Dorms
- [ ] Gym
- [ ] Quad
- [ ] Not on Campus
- [ ] Other

9. Where do you spend the most time on campus on an average Saturday? *

- [ ] COE
- [ ] COAS
- [ ] COB
- [ ] COA
- [ ] Student Union Center
- [ ] Micaplex
- [ ] Dorms
- [ ] Gym
- [ ] Quad
- [ ] Not on Campus
- [ ] Other

10. Where do you spend the most time on campus on an average Sunday? *

- [ ] COE
- [ ] COAS
- [ ] COB
- [ ] COA
- [ ] Student Union Center
- [ ] Micaplex
- [ ] Dorms
- [ ] Gym
- [ ] Quad
- [ ] Not on Campus
- [ ] Other

11. Which day seems the busiest on campus? *

- ◯ Monday
- ◯ Tuesday
- ◯ Wednesday
- ◯ Thursday
- ◯ Friday
- ◯ Saturday
- ◯ Sunday

12. What time seems the busiest on campus? *

- ◯ 9am
- ◯ 10am
- ◯ 11am
- ◯ 12pm (noon)
- ◯ 1pm
- ◯ 2pm
- ◯ 3pm
- ◯ 4pm
- ◯ 5pm
- ◯ 6pm
- ◯ 7pm
- ◯ 8pm

Campus Dining

Please see the questions below concerning your time spent on campus for dining.

13. Do you dine on campus? *

- ◯ Yes
- ◯ No

14. When do you typically dine? Choose all that are applicable. *

- ☐ 7 am
- ☐ 8 am
- ☐ 9 am
- ☐ 10 am
- ☐ 11 am
- ☐ 12 pm (noon)
- ☐ 1 pm
- ☐ 2 pm
- ☐ 3 pm
- ☐ 4 pm
- ☐ 5 pm
- ☐ 6 pm
- ☐ 7 pm
- ☐ 8 pm
- ☐ 9 pm
- ☐ 10 pm
- ☐ 11 pm
- ☐ 12 am (midnight)
- ☐ Other

15. Where do you typically dine? *

- [ ] Boundless
- [ ] Refueling Station
- [ ] Chick-fil-A
- [ ] Qdoba
- [ ] Starbucks
- [ ] Propellors
- [ ] Legacy Walk Eats
- [ ] Flight Cafe
- [ ] Late Night
- [ ] Simple Servings
- [ ] Late Night C-Store
- [ ] The Fuselage

16. How long is your typical wait? *

- ◯ None
- ◯ 5 mins
- ◯ 10 mins
- ◯ 15 mins
- ◯ 20 mins
- ◯ 25 mins
- ◯ 30 mins
- ◯ 35 mins
- ◯ 40 mins
- ◯ 45 mins
- ◯ >45 mins

17. How long do you spend in dining facilities after the line? *

- ○ None
- ○ 5 mins
- ○ 10 mins
- ○ 15 mins
- ○ 20 mins
- ○ 25 mins
- ○ 30 mins
- ○ 35 mins
- ○ 40 mins
- ○ 45 mins
- ○ >45 mins

18. Please select 2 *

- ○ 5
- ○ 3
- ○ 1
- ○ 4
- ○ 2

Campus Redesign and Optimization

Please see the questions below concerning your opinions on campus design and layout.

19. What is a spot on/function of campus that needs to be optimized/streamlined? *

20. What ways would you change this to make it more optimized? *

21. What impact do you believe this would have on the quality of your education? *

Campus Housing

Please see the questions below concerning your involvement with campus housing.

22. Do you live on or off campus? *

- ◯ On Campus (Including Chanute)
- ◯ Off Campus

23. What dorm do you live in? *

- ◯ Apollo
- ◯ Wood
- ◯ Adams
- ◯ Doolittle
- ◯ Chanute
- ◯ Stimpson
- ◯ O'Connor
- ◯ New Res Hall 1
- ◯ New Res Hall 2
- ◯ New Res Hall 3

24. On a scale of 1 to 10 (1 being crowded, 10 being open), how crowded/open do you feel the space is? *

1	2	3	4	5	6	7	8	9	10

25. What would you change, if anything, to improve the space? *

Campus Services

Please see the questions below concerning your usage of campus services.

26. Do you utilize the Center for Faith and Spirituality? *

- ◯ Yes
- ◯ No

27. On a scale of 1 to 10 (where 1 is not crowded, and 10 is overcrowded), how crowded do you feel the space is? *

1	2	3	4	5	6	7	8	9	10

28. What would you change, if anything, to improve the space? *

29. On a scale of 1 to 10 (where 1 is lacking, 10 is plentiful) how do you feel about your access level to non class academic spaces on campus? E.g., college specific study spaces, club spaces, study rooms, conference rooms, etc. *

1	2	3	4	5	6	7	8	9	10

30. What would you change, if anything, to improve the access to the spaces? *

31. Do you utilize the ERAU Fitness Center? *

- Yes
- No

32. On a scale of 1 to 10 (where 1 is not crowded, and 10 is overcrowded), how crowded do you feel the space is? *

1	2	3	4	5	6	7	8	9	10

33. What would you change, if anything, to improve the space? *

Campus Design

Please see the questions below concerning your opinions on the campus layout.

34. On a scale of 1 to 10 (where 1 is too close together, and 10 is too far apart) how do you feel about the distribution of buildings on campus? *

1	2	3	4	5	6	7	8	9	10

35. Which buildings, if any, are far out of your way? *

36. Does this discourage you from using them? Why or why not? *

Campus Walkways/Transportation

Please see the questions below concerning your usage of campus walkways and transportation.

37. Do you use the campus shuttles to go to/from campus? *

- ◯ Yes
- ◯ No

38. Do you currently need a shuttle from/to your apartment complex? (I.e., none already present and you would utilize it if added). *

- ◯ Yes
- ◯ No
- ◯ Maybe

39. Do you need a shuttle to go to satellite campus facilities? (E.g., Micaplex, EFRC, WW HQ, etc.). *

- ◯ Yes
- ◯ No

40. Do you believe there should be shuttles to get to different locations on campus? *

- ◯ Yes
- ◯ No
- ◯ Maybe

41. Would you use a car-pool app for the campus? *

- ◯ Yes
- ◯ No
- ◯ Maybe

42. Would you use an ERAU bus transit system? *

- ◯ Yes
- ◯ No
- ◯ Maybe

43. Do you feel the sidewalks on campus are useful? *

- Yes
- No

44. Do you feel there should be designated skateboard/bike/vehicle lanes? *

- Yes
- No

45. Do you think there should be times when skateboards/bikes/vehicles should not be used on campus sidewalks? *

- Yes
- No

46. What time frame should they NOT be used during? *

Feedback and Follow Up

I want to hear from you! If you would like to be contacted about the study, the status of it, or to discuss ideas further, please complete the info below. It will not be attached to your responses given.

47. What is your name?

48. What is the best way to contact you?

- [ ] Email
- [ ] Phone
- [ ] Discord
- [ ] Other

49. Please list your contact info below as applicable.

IX.II Phase 1 Focus Group Survey Questions

Campus Layout Survey - Additional Discussion

Please see the questions below to assist with the data collection from the survey follow up chats.

All data added in and coded by Benjamin E. Chaback.

* Required

* This form will record your name, please fill your name.

1. What is today's date? *

2. What time is it? *

3. How is the meeting being conducted? *

- ◯ Teams
- ◯ Discord
- ◯ Zoom
- ◯ Phone Call
- ◯ Other

4. What is the interviewees pseudonym? *

5. The average waiting time for food is about 15 mins on campus. Does this meet your expectations? *

- ◯ 1
- ◯ 0

6. Why or why not? *

7. The average time spent in a dining hall after getting food is about 20 mins. Does this meet your expectations? *

◯ 1

◯ 0

8. Why or why not? *

9. One of the common remarks when it comes to campus layout and optimization is the state of the parking situation. Is this something that impacts you? *

◯ 1

◯ 0

10. If so, where do you generally have to park? *

11. Do you see ways this could be remedied? *

12. The COAS stairwells are another point of typical congestion on campus. Do you use them? *

◯ 1

◯ 0

13. If so, are you aware that there are two additional stairwells available for students? *

◯ 1

◯ 0

14. How do you think we can better inform students of three stairwell options, and not just the main one? *

15. Dining seating has come up a few times when speaking with different folks. Do you ever have an issue finding seating in the SU? *

◯ 1

◯ 0

16. If so, where do you think additional seating would be helpful to add? *

17. Campus dining is another point of scrutiny during this study. Do you often have a problem finding places to dine on campus? *

◯ 1

◯ 0

18. What do you think would help with some of the problems you face with campus dining? *

19. Do you know all of the dining options on campus? *

- ○ 1
- ○ 0

20. Chick Fil A added buzzers in to help the student ordering process on campus for dining. Do you think these should be added at other campus dining locations? *

- ○ 1
- ○ 0

21. If so, which ones? *

- ☐ Boundless
- ☐ Refueling Station
- ☐ Qdoba
- ☐ Starbucks
- ☐ Propellers
- ☐ Legacy Walk Eats
- ☐ Flight Cafe
- ☐ Late Night
- ☐ Simple Servings
- ☐ Late Night C-Store
- ☐ The Fuselage

22. Online/Mobile ordering is a suggestion mentioned often when it comes to campus dining. Do you currently or would you use mobile ordering for campus food? *

◯ 1

◯ 0

23. How do you think it should be best implemented? *

24. Do you often feel stressed by the campus congestion/time it takes for your to wait for campus functions (e.g., parking, dining, etc.)? *

◯ 1

◯ 0

25. Do you now, or have you previously, lived on campus? *

◯ 1

◯ 0

26. If so, what did you think of the dorms? *

27. What would you change in them, if anything? *

28. Housing communication is often a point of contention between students and the housing office. What would be the best way for them to inform you of events, maintenance, housing updated, etc.? *

29. SchedulER is a software used by the school to help in booking rooms. Do you use it? *

- ◯ 1
- ◯ 0

30. What are the limitations of it? *

31. How can it be made more helpful for the students? *

32. CampusGroups is a software that lists the different RSOs on campus and other info about upcoming campus events. Do you use it? *

- ◯ 1
- ◯ 0

33. If no, what would make your more interested in using it? *

34. How can it be changed to be more helpful for students? *

35. Students largely report feeling that the new fitness center is overcrowded. Do you use it? *

◯ 1

◯ 0

36. What equipment do you typically have trouble accessing? *

37. If no, why not? *

38. Some students reported that the Student Village is largely out of their way. Do you foresee using this space it if was more accessible to you? *

◯ 1

◯ 0

39. Why or why not? *

40. A majority of students expressed interest in a campus shuttle service. What locations would you like to see it service? *

41. A majority of students expressed interest in a campus bus system. What locations would you like to see it service? *

42. Would you pay to use it? *

- ◯ 1
- ◯ 0

43. If so, what is reasonable? *

44. How often should it run? *

45. When should it run? *

- [ ] 7 am
- [ ] 8 am
- [ ] 9 am
- [ ] 10 am
- [ ] 11 am
- [ ] 12 pm
- [ ] 1 pm
- [ ] 2 pm
- [ ] 3 pm
- [ ] 4 pm
- [ ] 5 pm
- [ ] 6 pm
- [ ] 7 pm
- [ ] 8 pm
- [ ] 9 pm
- [ ] 10 pm
- [ ] 11 pm
- [ ] 12 am
- [ ] Other

46. What days should it run? *

- [ ] Su
- [ ] M
- [ ] Tu
- [ ] W
- [ ] Th
- [ ] F
- [ ] S

47. A majority of students expressed interest in designated bike/skateboard lanes on the sidewalks. Would you abide by them? *

◯ 1

◯ 0

48. What issues do you foresee with adding them? *

49. How would you like them to be added? *

50. Do you have any additional information on the campus you would like to add? *

51. Thank you for your time. It is expected that this thesis will be completed around March 2024 with results presented at Discovery Day 2024 and publications pending. Would you like to receive the full thesis results, the paper, both, or neither? *

- ◯ Thesis
- ◯ Paper
- ◯ Both
- ◯ Neither

IX.III Phase 2 Campus Survey Questions

Campus Layout Survey - Phase 2

Greetings,

Thanks for your interest in completing the survey on the current ERAU Campus Layout.

This survey is being administered as part of Benjamin E. Chaback's Thesis in Systems Engineering surrounding campus design and optimization.

The goal of this survey is to gain a baseline for the current climate and feelings on the layout of campus and possible areas of improvement.

Throughout the survey, please keep in mind the focus here is mainly on administrative and policy changes, and less on physical changes.

If you have any questions about how the data will be collected, disseminated, or used, please contact Ben at chabackb@erau.edu

Thank you for your time on this!

This survey is estimated to take around 10 minutes to complete.

* Required

Informed Consent

Please answer the following question on your willingness to participate in this study.

1. ***Optimization of Human Interactions in the College Campus Model Via Simio Integration***

Purpose of this Study: I am asking you to take part in a quality improvement iniative for the purpose of determining the average time spent on campus, the campus resources used, and the impact of campus queues on the quality of your education. During this study, you will be asked to complete a brief online survey about your experiences on the ERAU-DB campus and how they have affected your time at the university. The completion of the survey will take approximately twelve minutes.

Risks or Discomforts: The risks of participating in this study are no greater than what is experienced in daily life.

Benefits: Your assistance during this survey can contribute to a better understanding of campus resources used by students and the impact of them on quality of education with intent for expansion.

Confidentiality of Records: Your individual information will be protected in all data resulting from this study. Your responses to this survey will be anonymous. No personal information will be collected other than basic demographic descriptors. The online survey system will not save IP address or any other identifying information. In order to protect the anonymity of your responses, I will keep your responses in a password-protected file on a password-protected computer. No one other than the researcher will have access to any of the responses.

Compensation: There is no compensation offered for taking part in this study.

Contact: If you have any questions or would like additional information about this study, please contact Benjamin E. Chaback, chabackb@erau.edu, or the faculty member overseeing this project, Dr. Radu Babiceanu, babicear@erau.edu.

Voluntary Participation: Your participation in this study is completely voluntary. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Should you wish to discontinue the research at any time, no information collected will be used.

CONSENT: By checking AGREE below, I certify that I understand the information on this form, I am a student, staff, and/or faculty member at ERAU-DB, and voluntarily agree to participate in the study.

If you do **not** wish to participate in the study, simply close the browser or check DISAGREE which will direct you out of the study. Please print a copy of this form for your records.

A copy of this form can also be requested from Benjamin E. Chaback, chabackb@erau.edu. *

◯ AGREE

◯ DISAGREE

General Demographics

Please answer the following questions about your classification at ERAU

2. How many semesters have you been at ERAU? (Enter the number, including your current semester) *

The value must be a number

3. What college are you in? *

- ◯ COE
- ◯ COAS
- ◯ COA
- ◯ COB
- ◯ Multiple (Dual major in different colleges)

General Week

Please see the questions below concerning your time spent on campus in a typical week.

4. Where do you spend time on campus in an average week? *

- [ ] COE
- [ ] COAS
- [ ] COB
- [ ] COA
- [ ] Student Union Center
- [ ] Micaplex
- [ ] Dorms
- [ ] Gym
- [ ] Quad
- [ ] Instructional Center (IC)
- [ ] Other

5. Please provide an hour breakdown approximation for EACH location you selected in an average week (e.g., 4 hours COE, 5 hours COAS, etc.). *

6. Which day seems the busiest on campus? *

- ◯ Monday
- ◯ Tuesday
- ◯ Wednesday
- ◯ Thursday
- ◯ Friday
- ◯ Saturday
- ◯ Sunday
- ◯ Don't Know

7. What time seems the busiest on campus? *

- ◯ 9am
- ◯ 10am
- ◯ 11am
- ◯ 12pm (noon)
- ◯ 1pm
- ◯ 2pm
- ◯ 3pm
- ◯ 4pm
- ◯ 5pm
- ◯ 6pm
- ◯ 7pm
- ◯ 8pm
- ◯ Don't Know
- ◯ Other

Campus Dining

Please see the questions below concerning your time spent on campus for dining.

8. Do you dine on campus? *

- ◯ Yes
- ◯ No

9. When do you typically dine? Choose all that are applicable. *

- ☐ 7 am
- ☐ 8 am
- ☐ 9 am
- ☐ 10 am
- ☐ 11 am
- ☐ 12 pm (noon)
- ☐ 1 pm
- ☐ 2 pm
- ☐ 3 pm
- ☐ 4 pm
- ☐ 5 pm
- ☐ 6 pm
- ☐ 7 pm
- ☐ 8 pm
- ☐ 9 pm
- ☐ 10 pm
- ☐ 11 pm
- ☐ 12 am (midnight)
- ☐ Other

10. Where do you typically dine? *

- [ ] Boundless
- [ ] Refueling Station
- [ ] Chick-fil-A
- [ ] Qdoba
- [ ] Starbucks
- [ ] Propellors
- [ ] Legacy Walk Eats
- [ ] Flight Cafe
- [ ] Late Night
- [ ] Simple Servings
- [ ] Late Night C-Store
- [ ] The Fuselage

11. How long is your typical wait? *

◯ None

◯ 5 mins

◯ 10 mins

◯ 15 mins

◯ 20 mins

◯ 25 mins

◯ 30 mins

◯ 35 mins

◯ 40 mins

◯ 45 mins

◯ >45 mins

12. How long do you spend in dining facilities after the line? *

- None
- 5 mins
- 10 mins
- 15 mins
- 20 mins
- 25 mins
- 30 mins
- 35 mins
- 40 mins
- 45 mins
- >45 mins

13. Please select 2 *

- 3
- 2
- 4
- 1
- 5

Campus Redesign and Optimization

Please see the questions below concerning your opinions on campus design and layout.

14. What is a spot on/function of campus that needs to be optimized/streamlined? *

15. What ways would you change this to make it more optimized? *

Campus Housing

Please see the questions below concerning your involvement with campus housing.

17. Do you live on or off campus? *

◯ On Campus (Including Chanute)

◯ Off Campus

16. What impact do you believe this would have on the quality of your education? *

18. What dorm do you live in? *

- ◯ Apollo
- ◯ Wood
- ◯ Adams
- ◯ Doolittle
- ◯ Chanute
- ◯ Stimpson
- ◯ O'Connor
- ◯ New Res Hall 1
- ◯ New Res Hall 2
- ◯ New Res Hall 3

19. On a scale of 1 to 10 (1 being crowded, 10 being open), how crowded/open do you feel the space is? *

1	2	3	4	5	6	7	8	9	10

20. What would you change, if anything, to improve the space? *

Campus Services

Please see the questions below concerning your usage of campus services.

21. Do you utilize the Center for Faith and Spirituality? *

◯ Yes

◯ No

22. On a scale of 1 to 10 (where 1 is not crowded, and 10 is overcrowded), how crowded do you feel the space is? *

1	2	3	4	5	6	7	8	9	10

23. What would you change, if anything, to improve the space? *

24. On a scale of 1 to 10 (where 1 is lacking, 10 is plentiful) how do you feel about your access level to non class academic spaces on campus? E.g., college specific study spaces, club spaces, study rooms, conference rooms, etc. *

1	2	3	4	5	6	7	8	9	10

25. What would you change, if anything, to improve the access to the spaces? *

26. Do you utilize the ERAU Fitness Center? *

◯ Yes

◯ No

27. On a scale of 1 to 10 (where 1 is not crowded, and 10 is overcrowded), how crowded do you feel the space is? *

1	2	3	4	5	6	7	8	9	10

28. What would you change, if anything, to improve the space? *

Campus Design

Please see the questions below concerning your opinions on the campus layout.

29. On a scale of 1 to 10 (where 1 is too close together, and 10 is too far apart) how do you feel about the distribution of buildings on campus? *

1	2	3	4	5	6	7	8	9	10

30. Which buildings, if any, are far out of your way? *

31. Does this discourage you from using them? Why or why not? *

Campus Walkways/Transportation

Please see the questions below concerning your usage of campus walkways and transportation.

32. Do you use the campus shuttles to go to/from campus? *

◯ Yes

◯ No

33. Do you currently need a shuttle from/to your apartment complex? (I.e., none already present and you would utilize it if added). *

- ◯ Yes
- ◯ No
- ◯ Maybe

34. Do you need a shuttle to go to satellite campus facilities? (E.g., Micaplex, EFRC, WW HQ, etc.). *

- ◯ Yes
- ◯ No

35. Do you believe there should be shuttles to get to different locations on campus? *

- ◯ Yes
- ◯ No
- ◯ Maybe

36. Would you use a car-pool app for the campus? *

- ◯ Yes
- ◯ No
- ◯ Maybe

37. Would you use an ERAU bus transit system? *

- ◯ Yes
- ◯ No
- ◯ Maybe

38. Do you feel the sidewalks on campus are useful? *

- ◯ Yes
- ◯ No

39. Do you feel there should be designated skateboard/bike/vehicle lanes? *

- ◯ Yes
- ◯ No

40. Do you think there should be times when skateboards/bikes/vehicles should not be used on campus sidewalks? *

- ◯ Yes
- ◯ No

41. What time frame should they NOT be used during? *

[ ]

Feedback and Follow Up

I want to hear from you! If you would like to be contacted about the study, the status of it, or to discuss ideas further, please complete the info below. It will not be attached to your responses given.

42. What is your name?

[ ]

43. What is the best way to contact you?

- ☐ Email
- ☐ Phone
- ☐ Discord
- ☐ Other

44. Please list your contact info below as applicable.

[ ]

IX.IV Phase 2 Focus Group Survey Questions

Campus Layout Survey - Additional Discussion: Phase 2

Greetings,

Thanks for expressing interest in completing the additional survey on the current ERAU Campus Layout.

This survey is being administered as part of Benjamin E. Chaback's Thesis in Systems Engineering surrounding campus design and optimization.

The goal of this survey is to gain a baseline for the current climate and feelings on the layout of campus and possible areas of improvement.

Throughout the survey, please keep in mind the focus here is mainly on administrative and policy changes, and less on physical changes.

If you have any questions about how the data will be collected, disseminated, or used, please contact Ben at chabackb@erau.edu.

Thank you for your time on this!

This survey is estimated to take around 20 minutes to complete.

* Required

Informed Consent

Please answer the following question on your willingness to participate in this study.

1. ***Optimization of Human Interactions in the College Campus Model Via Simio Integration***

Purpose of this Study: I am asking you to take part in the second phase of a quality improvement initiative for the purpose of determining the average time spent on campus, the campus resources used, and the impact of campus queues on the quality of your education. During this survey, you will be asked to complete a brief online survey about your experiences on the ERAU-DB campus and how they have affected your time at the university. The completion of the survey will take approximately twenty minutes.

Risks or Discomforts: The risks of participating in this survey are no greater than what is experienced in daily life.

Benefits: Your assistance during this survey can contribute to a better understanding of campus resources used by students and the impact of them on quality of education with intent for expansion.

Confidentiality of Records: Your individual information will be protected in all data resulting from this study. Your responses to this survey will be anonymous. No personal information will be collected other than basic demographic descriptors. The online survey system will not save IP address or any other identifying information. In order to protect the anonymity of your responses, I will keep your responses in a password-protected file on a password-protected computer. No one other than the researcher will have access to any of the responses.

Compensation: There is no compensation offered for taking part in this survey.

Contact: If you have any questions or would like additional information about this survey, please contact Benjamin E. Chaback, chabackb@erau.edu, or the faculty member overseeing this project, Dr. Radu Babiceanu, babicear@erau.edu.

Voluntary Participation: Your participation in this survey is completely voluntary. You may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Should you wish to discontinue the survey at any time, no information collected will be used.

CONSENT: By checking AGREE below, I certify that I understand the information on this form, I am a student, staff, and/or faculty member at ERAU-DB, and voluntarily agree to participate in the survey.

If you do **not** wish to participate in the survey, simply close the browser or check DISAGREE which will direct you out of the survey. Please print a copy of this form for your records.

A copy of this form can also be requested from Benjamin E. Chaback, chabackb@erau.edu. *

◯ AGREE

◯ DISAGREE

Introduction

Please complete the following questions for data encoding.

2. What is today's date? *

3. Would you like to use a pseudonym for attribution to your responses? *

◯ Yes

◯ No

4. What pseudonym would you like to use? *

Campus Dining

Please complete the following questions on campus dining.

5. The average waiting time for food is about 17 mins on campus. Does this meet your expectations? *

◯ Yes

◯ No

6. Why or why not? *

7. The average time spent in a dining hall after getting food is about 22 mins. Does this meet your expectations? *

◯ Yes

◯ No

8. Why or why not? *

9. Campus dining is another point of scrutiny during this study. Do you often have a problem with the dining on campus? *

- ◯ Yes
- ◯ No

10. What do you think would help with some of the problems you face with campus dining? *

11. Dining seating has come up a few times when speaking with different folks. Do you ever have an issue finding seating in the SU? *

- ◯ Yes
- ◯ No

12. Where do you think additional seating would be helpful to add? *

13. Please select each dining option you are familiar with *

- ☐ Refueling Station
- ☐ Propellers
- ☐ Late Night
- ☐ Flightcafe
- ☐ Boundless
- ☐ Simple Servings
- ☐ C-Store
- ☐ Starbucks
- ☐ Qdoba
- ☐ Chick-fil-A
- ☐ Legacy Walk Eats (food truck)
- ☐ The Fuselage

14. Do you think the new ordering system at the Refueling Station has been helpful? *

- ◯ Yes
- ◯ No
- ◯ Unsure

15. What, if anything, would you change with it? *

16. Do you think the new ordering system at the Boundless grill has been helpful? *

- ◯ Yes
- ◯ No
- ◯ Unsure

17. What, if anything, would you change with it? *

18. Online/Mobile ordering is a suggestion mentioned often when it comes to campus dining. Do you currently or would you use mobile ordering for campus food? *

- ◯ Yes
- ◯ No

19. How do you think it should be best implemented or expanded? *

Campus Congestion

Please complete the following questions regarding congestion points on campus.

20. One of the common remarks when it comes to campus layout and optimization is the state of the parking situation. Is this something that impacts you? *

◯ Yes

◯ No

21. Where do you generally have to park? *

22. Do you see ways this could be improved? *

23. The COAS stairwells are another point of typical congestion on campus. Do you use them? *

◯ Yes

◯ No

24. If so, are you aware that there are two additional side stairwells available for students? *

◯ Yes

◯ No

25. How do you think we can better inform students of three stairwell options, and not just the main one? *

26. Do you often feel stressed by the campus congestion/time it takes for you to wait for campus functions (e.g., parking, dining, etc.)? *

◯ Yes

◯ No

27. Students largely report feeling that the new fitness center is overcrowded. Do you use it? *

◯ Yes

◯ No

28. What equipment do you typically have trouble accessing? *

29. Why not? *

30. Some students reported that the Student Village is largely out of their way. Do you foresee using this space it if was more accessible to you? *

◯ Yes

◯ No

31. Why or why not? *

Campus Housing

Please complete the following questions on the campus dorms.

32. Do you now, or have you previously, lived on campus? *

◯ Yes

◯ No

33. What did/do you think of the dorms? *

34. What would you change in them, if anything? *

35. Housing communication is often a point of contention between students and the housing office. What would be the best way for them to inform you of events, maintenance, housing updates, etc.? *

Campus Software

Please complete the following questions on software used at the campus.

36. SchedulER is a software used by the school to help in booking rooms. Do you use it? *

- ◯ Yes
- ◯ No

37. What are the limitations of it? *

38. How can it be made more helpful for the students? *

39. CampusGroups is a software that lists the different RSOs on campus and other info about upcoming campus events. Do you use it? *

- ◯ Yes
- ◯ No

40. How can it be changed to be more helpful for students? *

41. What would make you more interested in using it? *

Campus Transportation

Please answer the following questions on campus transportation.

42. A majority of students expressed interest in a campus shuttle service. What locations would you like to see it service? *

43. Would you pay to use it? *

- ◯ Yes
- ◯ No

44. What is reasonable? *

45. How often should it run? (e.g., every 15 mins, etc.) *

46. What time should the bus begin? (Start time on the hour) *

- ◯ 0000
- ◯ 0100
- ◯ 0200
- ◯ 0300
- ◯ 0400
- ◯ 0500
- ◯ 0600
- ◯ 0700
- ◯ 0800
- ◯ 0900
- ◯ 1000
- ◯ 1100
- ◯ 1200
- ◯ 1300
- ◯ 1400
- ◯ 1500
- ◯ 1600
- ◯ 1700
- ◯ 1800
- ◯ 1900
- ◯ 2000
- ◯ 2100
- ◯ 2200
- ◯ 2300

47. What time should the bus end? (End time on the hour) *

- ◯ 0000
- ◯ 0100
- ◯ 0200
- ◯ 0300
- ◯ 0400
- ◯ 0500
- ◯ 0600
- ◯ 0700
- ◯ 0800
- ◯ 0900
- ◯ 1000
- ◯ 1100
- ◯ 1200
- ◯ 1300
- ◯ 1400
- ◯ 1500
- ◯ 1600
- ◯ 1700
- ◯ 1800
- ◯ 1900
- ◯ 2000
- ◯ 2100
- ◯ 2200
- ◯ 2300

48. What days should it run? *

- [ ] Monday
- [ ] Tuesday
- [ ] Wednesday
- [ ] Thursday
- [ ] Friday
- [ ] Saturday
- [ ] Sunday

49. A majority of students expressed interest in designated bike/skateboard lanes on the sidewalks. Would you abide by them? *

- ◯ Yes
- ◯ No

50. What issues do you foresee with adding them? *

51. Would you like them to be added? *

- ◯ Yes
- ◯ No

52. How would you like them to be added? *

53. Do you have any additional information on the campus you would like to add? *

Closing

Please answer the final question on result dissemination.

54. Thank you for your time. It is expected that this thesis will be completed around March 2024 with results presented at Discovery Day 2024 and publications pending. Would you like to receive the full thesis results, the published paper, both, or neither? *

    - ◯ Thesis
    - ◯ Paper
    - ◯ Both
    - ◯ Neither

55. Please list your email to receive the above document(s). [NOTE: This is NOT tied to your survey responses]. *