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Enhancing Student Learning through Simulation-Based Analysis of Campus Dining Operations: A Case Study

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Abstract

Engineering education increasingly emphasizes experiential and project-based learning approaches that connect theoretical concepts with real-world applications. Simulation-based learning has emerged as a particularly effective strategy for developing systems thinking, analytical reasoning, and proficiency with modern engineering tools. This paper presents an undergraduate independent study project in which a student developed and analyzed a discrete-event simulation model of an on-campus dining operation using AnyLogic software. The project was intentionally designed to serve as a high-impact educational experience while addressing a realistic service system problem familiar to students. The student constructed a baseline simulation model representing existing dining operations, including mobile and kiosk-based ordering, shared queues, and manual order customization. Performance measures such as throughput, average waiting time, and queue length were used to identify a bottleneck caused by synchronous customization at the pickup counter. Guided by simulation output and systems analysis, the student then designed and evaluated a "what-if" experimental scenario featuring proactive mobile order fulfillment and segregated customer flows. Comparative simulation results demonstrated substantial reductions in waiting time and queue length without changes to staffing or capacity. From an educational perspective, the project supported multiple learning outcomes aligned with ABET criteria, including problem formulation, use of modern engineering tools, data-driven decision making, and professional communication. Assessment based on modeling artifacts and faculty feedback indicated significant growth in systems thinking, experimental design skills, and confidence in independent analysis. This work contributes evidence that simulation-based independent studies, when grounded in authentic campus systems, can effectively enhance undergraduate engineering education by integrating technical modeling with experiential learning and reflective practice.

1. Introduction

Engineering education is increasingly emphasizing experiential learning approaches that connect theoretical knowledge with practical application. Simulation-based learning has been widely recognized as an effective pedagogical strategy in higher education, as it enables students to engage with complex systems in a risk-free environment, visualize system dynamics, and apply analytical reasoning to real-world problems. Research in higher education indicates that games and simulations support cognitive, behavioral, and affective learning outcomes by placing learners in interactive and exploratory contexts that extend beyond traditional lecture-based formats [1].

Within Industrial and Systems Engineering (ISE) programs, discrete-event simulation (DES) has emerged as a powerful tool for modeling and analyzing stochastic systems. DES enables students to explicitly represent system components, processes, and variability, thereby fostering a deeper understanding of queueing behavior, resource constraints, and performance trade-offs. Prior studies have demonstrated that integrating simulation into engineering curricula enhances problem-solving skills and exposes students to computational modeling practices that reflect professional engineering tasks. For example, ASEE conference research has examined immersive, simulation-based learning modules in undergraduate courses and reported positive impacts on experiential learning, student motivation, and self-assessed learning outcomes when compared with traditional assignments [2, 3].

Despite its demonstrated pedagogical value, simulation remains under-integrated in many undergraduate engineering programs, and ongoing research continues to examine how simulation-based projects align with learning theories and competency development. Recent literature highlights a shift from physical experimentation toward digital and immersive simulated environments in engineering education and calls for more structured integration and rigorous assessment of simulation-based instructional interventions [4].

Campus service systems, such as dining operations, provide a compelling context for experiential simulation projects. These systems are familiar to students and inherently complex, involving interacting components such as arrival processes, multiple ordering modalities, service time variability, and shared resource constraints. As a result, they are well suited for discrete-event simulation analysis. Modeling such systems requires students to define system boundaries, collect or estimate input data, implement performance measures, and interpret results to support data-driven recommendations, all of which reflect authentic engineering problem-solving practice.

This paper presents an undergraduate independent study project in which a student developed and analyzed a discrete-event simulation model of an on-campus dining facility using AnyLogic software. The project was designed both to evaluate operational performance and to serve as a high-impact educational experience emphasizing self-directed learning, systems modeling, and experimental analysis. After constructing a baseline model of existing operations that included mobile and kiosk-based ordering, shared queues, and service interactions, the student used performance measures such as throughput, waiting time, and queue length to identify system bottlenecks. A redesigned experimental scenario that decoupled mobile and kiosk customer flows and implemented proactive mobile order fulfillment was then evaluated through comparative simulation experiments.

The primary contribution of this work is twofold. From a technical perspective, the study demonstrates how discrete-event simulation can be used to evaluate operational improvements in a service system prior to physical implementation. From an educational perspective, the paper illustrates how an undergraduate, project-based simulation experience can enhance student learning by integrating modeling, analysis, and professional communication. By situating simulation instruction within an authentic campus environment, this work provides evidence supporting the use of independent, simulation-based projects as an effective pedagogical strategy in engineering education.

2. Educational Context and Learning Objectives

This study was conducted as part of an undergraduate independent study supervised by two faculty members in the Industrial and Systems Engineering discipline. Independent studies offer a flexible instructional format that allows motivated students to engage in open-ended, project-based learning beyond the constraints of traditional course structures. In this case, the independent study was intentionally designed to immerse the student in the full engineering problem-solving cycle, including system observation, problem formulation, model development, experimentation, and interpretation of results. This independent study replaced a 3-credit undergraduate technical elective course requirement and was conducted for a standard letter grade credit over a single semester that was consistent with institutional norms. Both supervising faculty have extensive experience mentoring undergraduate and graduate students on undergraduate research, capstone industrial projects, and thesis work across multiple domains of Industrial and Systems Engineering.

The project focused on applying discrete-event simulation to a real-world service system, specifically an on-campus dining facility, using AnyLogic software. Unlike typical classroom-based simulation assignments that often provide predefined process flows and parameter values, this independent study required the student to define system boundaries, identify key processes and resources, collect or estimate input data, and translate operational logic into a functional simulation model. The open-ended nature of the project encouraged iterative learning, self-reflection, and increasing autonomy, closely mirroring professional engineering practice.

From an educational standpoint, the project was structured to support multiple learning dimensions, including technical skill development, systems thinking, and professional competencies. Regular meetings between the student and faculty supervisors were used to guide progress, provide formative feedback, and reinforce connections between theoretical concepts such as queueing behavior, bottlenecks, and flow synchronization and observed system performance. The student was also required to document modeling assumptions, justify design decisions, and communicate findings in a scholarly format, further strengthening professional communication skills.

The specific learning objectives for the student participating in this independent study were as follows:

a. Develop proficiency in discrete-event simulation modeling by constructing a complete system model in AnyLogic that accurately represents a real-world service operation.
b. Apply systems thinking principles to decompose a complex operational process into interconnected components, including arrivals, service mechanisms, resource constraints, and exit conditions.
c. Identify and analyze system bottlenecks using quantitative performance measures such as throughput, waiting time, and queue length.
d. Design and evaluate alternative system configurations through structured what-if simulation experiments and comparative analysis.
e. Interpret simulation results to support data-driven decision making, including assessing trade-offs and operational implications of proposed changes.
f. Communicate technical and educational outcomes effectively through written documentation suitable for a conference publication.

Objective (a) aligns with ABET Outcome 1 (solving complex engineering problems) and Outcome 2 (engineering design), as the student translated a real-world dining operation into a functional analytical model using modern engineering tools. Objective (b) supports ABET Outcome 1 by emphasizing problem formulation, system decomposition, and understanding interdependencies within service operations. Objective (c) corresponds to ABET Outcome 6 (experimentation and data analysis), requiring interpretation of throughput, waiting time, and queue metrics to diagnose system constraints. Objective (d) reinforces ABET Outcomes 2 and 6, as the student developed and assessed a redesigned system using controlled comparative analysis. Objective (e) supports ABET Outcomes 1 and 6 by requiring engineering judgment to evaluate trade-offs and operational implications. Finally, objective (f) aligns with ABET Outcome 3 (effective communication), demonstrated through preparation of a professional, conference-style technical report.

Collectively, these objectives integrate modeling, experimentation, design evaluation, and professional communication within an authentic service system context, highlighting the value of simulation-based independent study in supporting ABET-aligned undergraduate learning.

3. System Description: Campus Dining Operations

The system under study is an on-campus dining facility that serves undergraduate students during peak meal periods. The rationale to model a familiar on-campus dining operation is to reduce the cognitive efforts associated with complex system comprehension, allowing the student to focus on abstraction, logic development and experimental reasoning. While modeling unfamiliar systems may better reflect complex industry environments, familiar systems can be particularly effective in independent study contexts by accelerating engagement and enabling deeper analytical exploration by undergraduate students. The facility operates as a mixed-service system in which customers place food orders using either a mobile application or in-store self-service kiosks. The dining operation consists of multiple interconnected processes, including order entry, food preparation, pickup, and post-service dining behavior. These characteristics make the system well suited for discrete-event simulation and systems analysis. Data for simulation modeling was captured using time and motion analysis techniques including work sampling, direct time studies, and methods analysis tools.

3.1 Customer Arrival and Ordering Modalities

Students arrive at the dining facility according to a time-varying arrival process representative of a typical lunch period. Upon arrival, each student entity is routed to one of two primary ordering channels based on the selected ordering method.

Students using the mobile application pre-select menu items prior to arriving at the facility. In the current operational configuration, however, mobile orders are not released to the kitchen until the student physically arrives and scans a QR code located at the restaurant entrance. This interaction is modeled as a delay representing the time required to locate and scan the QR code. The completion of this delay triggers downstream kitchen processing.

Students who do not use the mobile application place their orders using in-store self-service kiosks. The kiosk interaction is modeled as a separate delay that captures the time required for menu browsing, item selection, and order confirmation using the touch-screen interface. After completion of the ordering process, both mobile and kiosk orders initiate food preparation and converge into a shared fulfillment process.

3.2 Food Preparation and Pickup Process

Following completion of the ordering stage, all customer entities enter a common queue that represents the kitchen production buffer. This queue models the sequencing of orders awaiting preparation and customization. A key feature of the system is the order customization stage, during which students verbally specify topping or modification preferences to service staff. This interaction introduces a synchronous dependency between the customer and staff resources and contributes to variability in service time.

Once food preparation and customization are completed, orders are transferred to students at the pickup counter. This pickup point represents the primary service completion event in the system and marks the transition from operational processing to post-service behavior.

3.3 Post-Service Dining Behavior

After receiving their orders, students follow one of several exit paths based on dining preference. Some students remain on site and occupy seating in one of two dining areas within the facility. These options are modeled as downstream delays representing food consumption time in the Haus dining or Markee dining areas. Other students choose to leave the facility immediately with their meals, representing a takeout option. This path bypasses the dining areas and directs entities directly to system exit.

3.4 System Scope and Performance Measures

The modeled system focuses on customer flow and service performance during a representative two-hour operating window. Staffing levels and kitchen capacity are assumed to remain constant throughout the simulation run. Key performance measures used to evaluate system behavior include customer throughput, average waiting time, and average queue length. These metrics provide quantitative insight into system congestion and service efficiency and serve as the basis for subsequent bottleneck identification and experimental scenario evaluation.

4. Baseline Simulation Model Development

The baseline simulation model was developed using AnyLogic as a discrete-event representation of the existing campus dining operation, as shown in Figure 1. The primary objective of the baseline model was to replicate current system behavior accurately so that inefficiencies and bottlenecks could be identified prior to testing alternative system designs. Figure 1 presents the complete logical process flow implemented in the simulation environment, while Figure 2 displays the corresponding 3D animation used to visualize entity movement, queue formation, and resource utilization within the dining facility.

4.1 Model Structure and Entity Flow

Customer entities enter the system through a Source block, which represents student arrivals during a peak operating period. A SelectOutput block probabilistically routes entities into one of two ordering channels based on observed ordering behavior: mobile application ordering or in-store kiosk ordering.

For mobile application users, entities enter a queue_mobile block followed by a delay_mobile block. This delay represents the time required to locate and scan the QR code at the facility entrance, which triggers the release of the mobile order to the kitchen. For kiosk users, entities are routed to a queue_instore block followed by a delay_instore block, which captures the time spent interacting with the kiosk interface to browse the menu and complete the transaction. Although mobile users place orders prior to arrival, the baseline model reflects the operational constraint that food preparation does not begin until physical arrival and QR-code scanning occur. As a result, both mobile and kiosk entities converge into a shared fulfillment process.

4.2 Unified Queue and Service Process

After completing the ordering delays, all entities enter a common Queue block that represents the kitchen production buffer. This shared queue models the sequencing of orders awaiting preparation and service. To support performance measurement, TimeMeasureStart and TimeMeasureEnd blocks are positioned immediately before and after the queueing and service stages, enabling direct calculation of customer waiting times.

Following the queue, entities pass through two sequential delay blocks. The delay_waiting block represents general food preparation time, while the delay_topping block captures the manual order customization stage during which students verbally specify toppings or modifications to service staff. This customization stage introduces a synchronous interaction between customers and staff and was later identified as a primary contributor to system congestion.

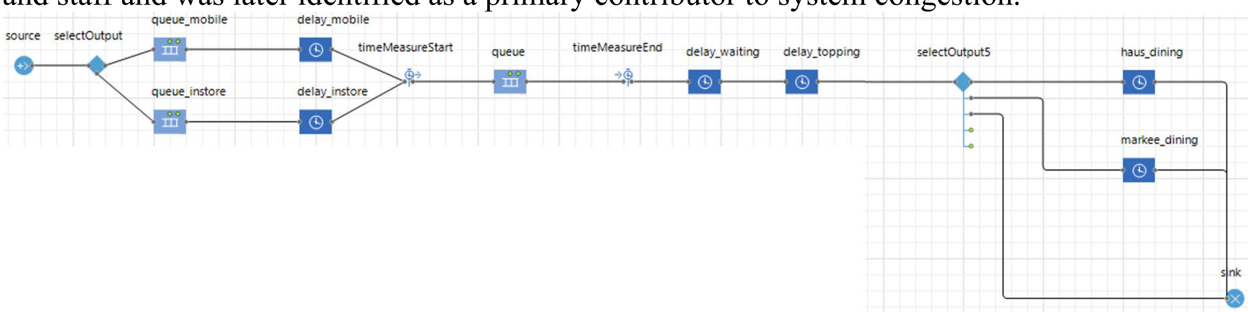

Figure 1. Baseline discrete-event simulation model of the campus dining operation developed in AnyLogic.

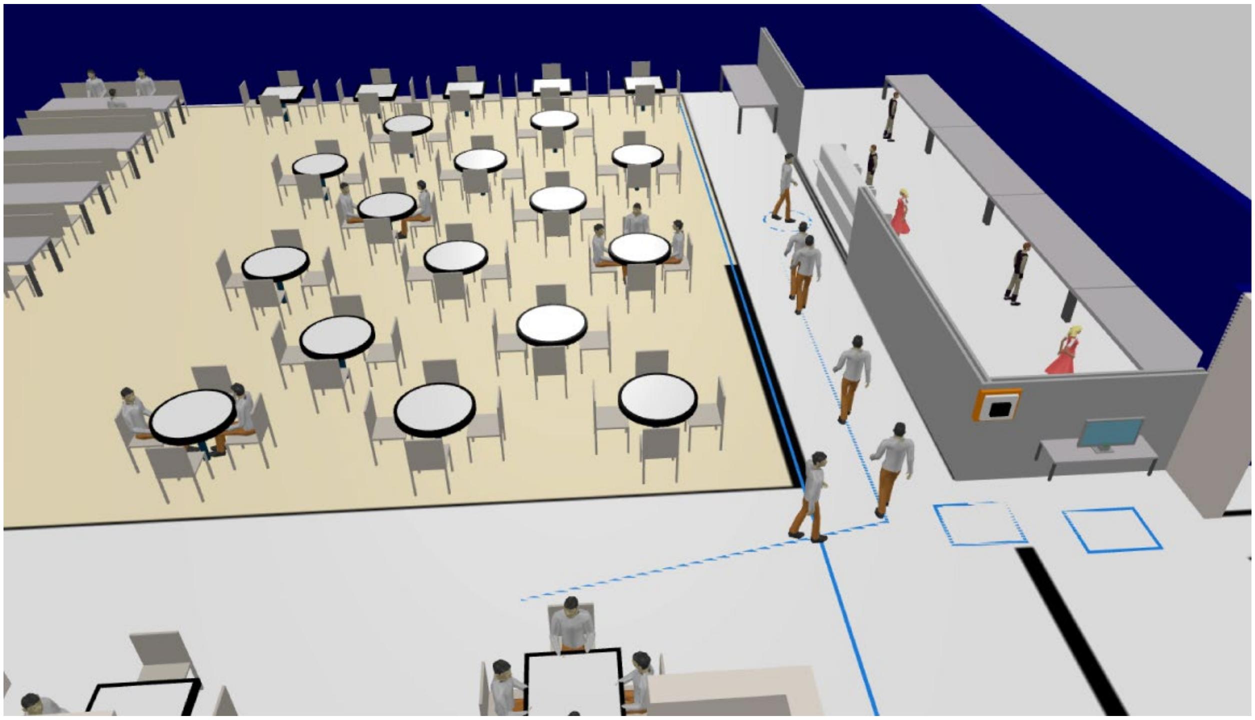
Figure 2: Animated 3D environment of the campus dining simulation in AnyLogic.

4.3 Post-Service Routing and System Exit

Upon completion of service, entities are routed through a SelectOutput block that directs them to one of three exit paths based on dining preference. Students who choose to dine on site are routed to either the haus_dining or markee_dining blocks, which are modeled as delays representing meal consumption time in the respective dining areas. Students who opt for takeout bypass the dining areas and proceed directly to the Sink block, which marks system exit and records final performance statistics.

4.4 Model Assumptions and Performance Measures

The baseline model assumes constant staffing levels and uninterrupted kitchen operation throughout the simulation run. Service times and delays are modeled using deterministic or stochastic distributions based on observational estimates and reasonable operational assumptions. The simulation is executed for a two-hour operating window to represent peak demand conditions.

Key performance measures collected from the baseline model include the total number of customers served, average customer waiting time, and average queue length. These metrics provide a quantitative foundation for evaluating system performance and guide subsequent bottleneck identification and experimental model development.

4.5 Model Validation

To ensure the credibility and analytical rigor of the simulation study, model validation procedures were conducted prior to experimentation and comparative analysis. Validation focused on assessing whether the baseline model reasonably represented observed dining hall operations representing structural and behavioral realism.

Validation included:

- *Face validation:* The modeled process flow was compared against direct observations of the dining operation to ensure alignment with actual arrival patterns, service sequencing, and staffing configurations. In addition, the 3D animation shown in Figure 2 was used to visually examine entity movement, queue formation, and resource interactions, allowing for real-time comparison between simulated behavior and observed system operations.
- *Performance measure comparison:* Simulated throughput, average waiting time, and average queue length were compared with observed operational estimates during peak lunch periods. Across these key performance indicators, model outputs fell within realistic operational ranges, supporting the model's behavioral validity.
- *Bottleneck consistency*: The simulation identified congestion at the food preparation stages, consistent with observed peak-hour crowding patterns.
- *Sensitivity analysis:* Variations in arrival rates and service times produced proportional and intuitive changes in queue lengths and waiting times, indicating stable and logical system behavior.

Collectively, these validation steps provide reasonable assurance that the baseline simulation model is both technically correct and behaviorally representative of the real dining system. Consequently, the model was deemed suitable for structured experimentation and comparative analysis of alternative operational configurations.

4.6 Educational Significance

From an educational perspective, constructing the baseline model required the student to translate a real-world process into formal simulation logic, identify appropriate abstraction levels, and implement performance measurement mechanisms. This baseline model served as a critical learning artifact and enabled meaningful comparison with alternative system configurations explored in later sections.

5. Bottleneck Identification and Experimental Design

The baseline simulation model was used to evaluate system performance and identify operational constraints within the campus dining facility. Performance metrics, including customer throughput, average waiting time, and average queue length, were analyzed to determine where congestion occurred and how delays propagated through the system. This analysis provided the foundation for designing targeted simulation experiments to evaluate potential process improvements.

5.1 Bottleneck Identification

Results from the baseline simulation indicated that the primary source of congestion occurred during the order customization stage, represented by the delay_topping block. This stage requires direct interaction between the customer and service staff, as students verbally specify toppings or modifications at the pickup counter. Regardless of whether a customer initially ordered through the mobile application or an in-store kiosk, all entities were required to pass through this same physical interaction point.

The shared queue configuration forced mobile application users, who had already completed most of the ordering process digitally, to wait behind kiosk customers in the same physical service line. Analysis of queue lengths and waiting times revealed that this design inflated system dwell time for mobile users and increased congestion at the service counter. From a systems perspective, the bottleneck was not caused by insufficient arrival control or preparation capacity but by a process design that coupled customization and pickup into a single service stage.

This bottleneck identification process represented a key learning milestone for the student, as it required interpretation of simulation outputs, tracing delay accumulation through the system, and distinguishing between resource capacity limitations and structural process constraints.

5.2 Experimental Design Rationale

Based on the bottleneck analysis, a what-if simulation experiment was designed to evaluate a structural redesign of the system rather than incremental capacity adjustments. The proposed intervention aimed to transition the operation from a reactive fulfillment strategy, in which food preparation and customization begin only after customer arrival, to a proactive fulfillment strategy, in which mobile orders are prepared in advance.

Two guiding hypotheses informed the experimental design. First, eliminating synchronous customization at the pickup counter for mobile orders would reduce overall system congestion. Second, segregating mobile and kiosk customer flows would decrease waiting times for both customer groups by reducing effective arrival rates at the shared service counter.
To test these hypotheses prior to physical implementation, the student developed a modified simulation model that reconfigured ordering, customization, and pickup logic while preserving the same arrival rates and operating conditions used in the baseline scenario.

5.3 Experimental Factors and Performance Measures

The experimental design focused on structural changes to process flow rather than changes to demand or staffing levels. Key experimental factors included the timing of order release to the kitchen, the location of order customization, and the separation of customer queues. All other model parameters, including arrival patterns and preparation times, were held constant to ensure a fair comparison with the baseline model.

Performance measures used to evaluate the experimental scenario included customer throughput, average waiting time, and average queue length for both mobile and kiosk customers. These metrics enabled direct comparison between the baseline and experimental models and allowed quantification of the operational impact of the proposed system redesign.

6. Experimental Simulation Model: Proactive Mobile Fulfillment

To evaluate the potential benefits of addressing the identified bottleneck, an experimental simulation model, shown in Figure 3, was developed to support proactive mobile order fulfillment and customer flow segregation. The experimental model retained the same system scope, arrival patterns, and operating conditions as the baseline scenario to enable direct performance comparison. Key structural changes were introduced to decouple mobile and kiosk customer flows and eliminate synchronous service interactions for mobile orders at the pickup counter.

6.1 Model Logic Modifications

The primary modification in the experimental model involved changing the timing of order release to the kitchen for mobile application users. In contrast to the baseline model, in which mobile orders were triggered only after physical arrival and QR-code scanning, the experimental model initiates food preparation immediately upon order submission through the mobile application. As a result, kitchen processing for mobile orders occurs in parallel with the student's travel time to the dining facility.

In addition, the order customization process was relocated from the physical service counter to the digital ordering interface. By requiring mobile users to specify all toppings and preferences at the time of order placement, the delay_topping stage was removed from the physical pickup process for mobile entities. This modification eliminated the need for direct verbal interaction between mobile customers and service staff during pickup.

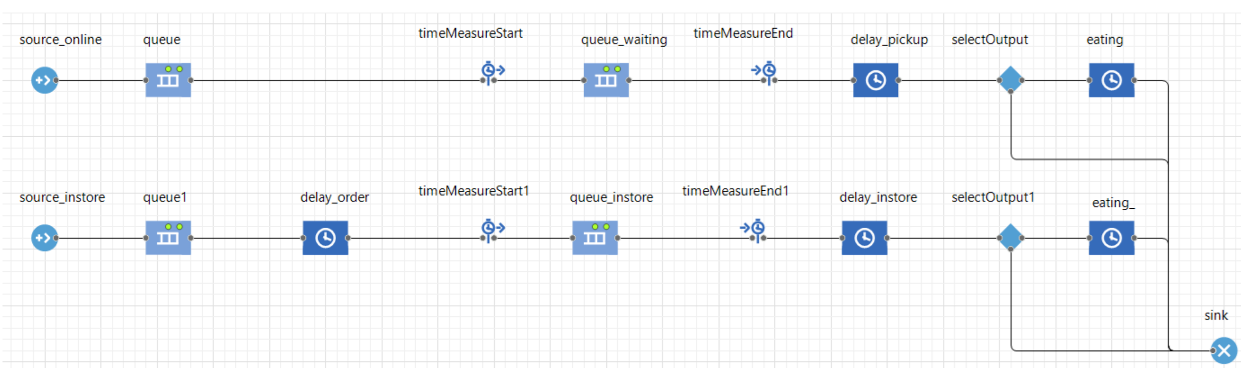

Figure 3. Discrete-event simulation model of the campus dining operation with proactive mobile order fulfillment and segregated customer flows.

6.2 Separation of Mobile and Kiosk Customer Flows

To further reduce congestion, the experimental model segregates mobile and kiosk customers after order entry. Kiosk customers continue to follow the baseline logic, entering the shared queue and undergoing manual service at the primary pickup counter. Mobile customers bypass the shared queue entirely.

A dedicated Online Delivery Station was introduced as a separate pickup point for completed mobile orders. Upon arrival at the facility, mobile entities proceed directly to this station for order retrieval. Pickup at the delivery station is modeled as instantaneous, provided that kitchen preparation has been completed. If the order is not yet ready, the entity remains in a holding state until preparation finishes.

6.3 Experimental Assumptions and Control Variables

All experimental changes were implemented while holding constant key system parameters, including customer arrival rates, preparation time distributions, and staffing levels. This controlled experimental setup ensured that observed performance differences between the baseline and experimental scenarios could be attributed to the structural redesign rather than external factors.

The experimental model was executed for the same two-hour operating window as the baseline scenario. Performance measures collected included customer throughput, average waiting time, and average queue length, reported separately for mobile and kiosk customers.

6.4 Educational Significance

From an educational perspective, development of the experimental model required the student to move beyond descriptive modeling toward prescriptive system design. The student formulated hypotheses, implemented controlled model modifications, and evaluated outcomes using comparative performance metrics. This process reinforced learning objectives related to experimental design, systems thinking, and data-driven decision making.

7. Simulation Results and Comparative Analysis

The baseline and experimental simulation models were executed under identical operating conditions to enable direct comparison of system performance. Each scenario was simulated for a two-hour operating window representative of a peak dining period. Key performance measures included the total number of customers served, average waiting time, and average queue length. Results are presented for the baseline scenario at the system level and for the experimental scenario by ordering method.

7.1 Baseline Scenario Results

The baseline simulation resulted in 172 customers served during the two-hour operating window. The average customer waiting time was 2.5 minutes, and the average queue length at the shared service counter was 4.24 customers. These results indicate moderate congestion during peak operation and reflect the impact of a shared queue in which both mobile and kiosk customers compete for the same service resources.

Further analysis showed that mobile customers experienced meaningful waiting times despite placing orders in advance. This outcome highlights inefficiencies associated with requiring mobile users to join a physical service line and supports the identification of synchronous order customization as a primary contributor to system delay.

7.2 Experimental Scenario Results: Proactive Mobile Fulfillment

The experimental simulation produced substantially different performance outcomes through customer flow segregation and proactive fulfillment of mobile orders.
For mobile application customers, the model served 108 customers with an average waiting time of 0 minutes and an average queue length of 0. These results indicate that mobile orders were consistently prepared and staged prior to customer arrival, effectively eliminating in-system waiting for this group.

For in-store kiosk customers, the model served 35 customers during the same operating window. The average waiting time for kiosk customers was reduced to 0.162 minutes, and the average queue length was 0.052 customers. Although kiosk customers continued to follow the baseline service logic, their performance improved due to reduced congestion at the primary service counter.

7.3 Comparative Analysis

Comparison of the baseline and experimental scenarios demonstrates the significant impact of structural process redesign on system performance. The proactive fulfillment model eliminated waiting for mobile customers while simultaneously reducing congestion for kiosk customers. These improvements were achieved without increasing staffing levels or service capacity, highlighting the effectiveness of process reconfiguration.
From a systems perspective, the results show that decoupling customer flows and shifting work from physical service interaction to digital interfaces reduces synchronous dependencies and improves efficiency. The reduction in effective arrival rate at the primary service counter aligns with queueing theory principles and results in shorter queues and lower waiting times.

7.4 Educational Insights

For the student, this comparative analysis reinforced learning outcomes related to experimental design and performance evaluation. The clear contrast between baseline and experimental results provided evidence of how modeling assumptions and system structure influence outcomes. By interpreting quantitative results and linking them to system logic, the student developed a deeper understanding of bottleneck behavior, flow variability, and proactive system design in service operations.

8. Student Learning Assessment

Student learning was assessed using a combination of artifact-based evaluation and formative faculty feedback. Given the independent study format and single-student participation, the assessment approach emphasized depth of learning and demonstrated competency rather than statistical generalizability. Formal reflective artifacts were not collected as part of this credit-bearing independent study as metacognitive data analysis was beyond the scope of this work.

This approach is consistent with recommended practices for evaluating experiential and project-based learning in engineering education.

Three primary artifacts were evaluated:

(a) The completed discrete-event simulation model developed in AnyLogic,
(b) The simulation experimentation and performance analysis results, and
(c) The final written technical report documenting assumptions, system logic, experimental design, and findings.

A consolidated three-level analytic rubric (3 = Advanced, 2 = Competent, 1 = Emerging) shown in Table 1 was used to assess performance across modeling, analytical reasoning, and technical communication dimensions. The rubric criteria were directly aligned with the stated learning objectives of developing systems thinking, applying discrete-event simulation methods, designing controlled experiments, and communicating data-driven insights.

Table 1: Student learning assessment rubric

Dimension	Criteria	3 – Advanced	2 – Competent	1 – Emerging
Simulation Model Development	System Representation	Accurately captures process flow, resources, queues, and assumptions with clear justification	Represents core processes with minor simplifications	Incomplete or inaccurate representation of system structure
	Use of Simulation Constructs	Correct and effective use of blocks, parameters, and stochastic logic	Generally appropriate use with minor technical issues	Misuse or limited understanding of constructs
	Logical Transparency	Clear, traceable, and reproducible model structure	Mostly clear logic with minor ambiguities	Disorganized or difficult-to-follow logic
Experimental Design & Analysis	Experimental Validity	Well-controlled comparison; bottleneck clearly identified; variables appropriately managed	Logical comparison with minor methodological limitations	Weak experimental control or unclear comparison
	Performance Metrics & Interpretation	Insightful interpretation of throughput, waiting time, and queue length with strong data-to-conclusion linkage	Accurate reporting with reasonable interpretation	Superficial or incorrect interpretation of results

	Analytical Reasoning	Demonstrates strong systems thinking and understanding of process dynamics	Demonstrates basic cause–effect reasoning	Limited connection between system structure and outcomes
Technical Communication	Model Documentation	Clearly explains assumptions, logic, and experimental design	Generally clear with minor gaps	Incomplete or unclear documentation
	Discussion & Implications	Insightfully links findings to operational improvement	Accurate but limited discussion of implications	Minimal or unclear discussion of implications
	Professional Writing Quality	Well-structured, precise, and professional	Adequate organization with minor clarity issues	Significant clarity or structural weaknesses

Formative assessment occurred through weekly supervisory meetings over the course of 16-week semester, during which the student presented incremental model updates and justified modeling decisions. Although supervisory meetings were not recorded or coded, feedback followed a consistent formative structure in strengthening the student's systems thinking, clarifying assumptions, and improving experimental rigor.

Based on the rubric evaluation, the student achieved an overall Advanced (Level 3) performance across most criteria. The student demonstrated strong competency in translating a real-world service system into a functional simulation model, designing controlled experiments, interpreting quantitative results, and communicating findings effectively. These outcomes indicate successful attainment of the project's learning objectives and support the effectiveness of simulation-based independent study in enhancing undergraduate engineering education.

9. Implications for Engineering Education

The results of this simulation-based independent study contribute to the growing body of evidence supporting project-based and experiential learning approaches in undergraduate engineering education. Prior research has shown that when students engage in open-ended projects that require the application of simulation tools to authentic systems, they develop stronger technical skills and achieve learning outcomes more effectively than through traditional lecture-based instruction alone. For example, Egilmez, Sormaz, and Gedik reported that a project-based learning approach in teaching simulation improved students' ability to model and apply simulation concepts regardless of their initial academic performance, highlighting the pedagogical value of experiential simulation projects in engineering curricula [5].

The integration of simulation into engineering education aligns closely with constructivist and experiential learning theories, which emphasize learning through active engagement, reflection, and application. In this framework, learners progress through cycles of experience, reflection, conceptualization, and experimentation, a model that has long been advocated in engineering pedagogy and is formalized in theories such as Kolb's experiential learning framework [6, 7]. This alignment suggests that structured simulation projects, such as the one presented in this study, provide meaningful opportunities for students to connect theoretical concepts with practical system behavior, thereby fostering deeper understanding and transferable problem-solving skills.

In addition to technical skill development, the literature indicates that simulation-based learning can positively influence motivational and affective dimensions of student learning. Systematic reviews of simulation- and game-based pedagogies report cognitive, behavioral, and affective gains among students who engage with simulation tools when compared to more passive instructional formats [8–10]. These gains include increased engagement, improved conceptual understanding, and greater confidence in managing complex systems. Similar outcomes were observed in the present study, where the student demonstrated increased confidence, independence, and ownership of the learning process as the project progressed.

The integration of simulation experiences also has important implications for ABET-aligned curriculum design. Simulation-based projects require students to synthesize knowledge across system analysis, the use of modern engineering tools, data-driven decision making, and professional communication. These competencies map directly to ABET student outcomes and are consistent with findings from the broader project-based learning literature, which shows that intentionally designed projects can promote self-efficacy, critical thinking, teamwork, and communication skills in engineering students [11–13].

Taken together, existing research supports positioning authentic, simulation-based independent studies and projects as high-impact educational practices within engineering curricula. Embedding such experiences at multiple points in an academic program, including independent studies, capstone courses, and integrated project modules, can expand student exposure to real-world systems, strengthen discipline-specific competencies, and enhance overall student engagement and learning outcomes.

10. Conclusions and Future Work

This paper demonstrates the dual technical and educational value of an undergraduate independent study project focused on discrete-event simulation of campus dining operations. Technically, the student successfully modeled a complex service system, identified bottlenecks, and evaluated a proactive mobile order fulfillment redesign, resulting in measurable performance improvements. Educationally, the project facilitated experiential learning, systems thinking, professional communication, and confidence in independent analysis. Given the single-participant design, learning gains were evaluated relative to the stated learning objectives and expected competency levels rather than through statistical comparison.

The findings suggest that open-ended simulation projects are effective pedagogical tools for enhancing undergraduate engineering education, particularly when projects are situated in familiar, real-world systems that students can observe directly. The combination of technical modeling and iterative feedback creates a rich learning environment that supports multiple dimensions of student growth.

Future work will expand this framework to include multiple students working on different campus service systems, enabling comparison of learning outcomes across participants. Additionally, pre- and post-project assessment instruments will be implemented to quantify learning gains and better evaluate the impact of simulation-based independent studies on student competency development and student confidence in analytical reasoning. Finally, further investigation into integrating collaborative simulation projects and cross-disciplinary applications could enhance the scalability and relevance of experiential learning in engineering curricula.

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