SUMO Pedestrian Traffic Model: Final Report

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CS4632-W01: Modeling and Simulation

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Contents

1 Abstract

This project models pedestrian traffic flow on the Kennesaw State University (KSU) Marietta campus using a microsimulation approach implemented in the Simulation of Urban Mobility (SUMO) framework. The primary objective is to estimate and analyze pedestrian density patterns across campus walkways based on estimated building occupancy and scheduling data. The simulation dynamically spawns agents based on hourly occupancy schedules and routes them using a mixture of shortest-path and alternative routing strategies. Performance metrics such as maximum density, average wait time, and throughput were collected across multiple scenarios. Results show that pedestrian congestion varies significantly by routing behavior and occupancy levels, with alternative routing reducing peak densities in critical areas. Sensitivity analysis and convergence validation confirm the robustness of the model. This simulation provides insight into pedestrian dynamics and supports future improvements to campus infrastructure and wayfinding strategies.

2 Introduction

Understanding pedestrian movement across a college campus is essential for improving walkability, safety, and infrastructure planning. This simulation project focuses on modeling pedestrian traffic flow on the KSU Marietta campus. The primary objective is to evaluate how estimated building occupancy levels and routing strategies influence pedestrian congestion and flow across campus pathways.

The motivation for this work stems from the challenges of managing pedestrian density in high-traffic areas, especially during peak class transitions. With no readily available ground-truth pedestrian data, the simulation serves as a predictive tool for identifying potential congestion hotspots and informing future planning efforts. The model incorporates estimated hourly occupancy schedules for academic buildings and simulates pedestrian agents using a microsimulation framework.

The Simulation of Urban Mobility (SUMO) platform was selected for its robust support of agent-based pedestrian modeling, real-time routing, and detailed metric collection. This project applies a combination of shortest-path and alternative routing strategies to explore how routing flexibility impacts congestion outcomes. Multiple simulation scenarios were conducted to analyze sensitivity to key input variables and validate the model's behavior under varying assumptions.

This report presents the complete development and analysis of the simulation model, including a detailed explanation of its structure, a summary of results, scenario and sensitivity assessments, verification and validation efforts, and overall discussion of findings.

3 Model Overview

The pedestrian simulation model was developed using the Simulation of Urban Mobility (SUMO) framework to estimate foot traffic on the KSU Marietta campus. The model is designed to simulate realistic pedestrian behavior over a typical weekday, using building occupancy estimates and time-based spawning schedules.

The simulation environment is built on a pedestrian-accessible network extracted from OpenStreetMap (OSM) and manually refined to ensure accurate walkability across campus. Buildings were associated with network access points to define valid pedestrian origins and destinations. Pedestrian agents are dynamically generated based on hourly occupancy schedules derived from estimates of class activity patterns for each building. These schedules reflect common academic time blocks, including MWF (Monday, Wednesday, Friday), TTh (Tuesday, Thursday), and SSu (Saturday, Sunday) variations.

Each pedestrian agent is assigned a route through the network based on a routing strategy. Two primary strategies are implemented: a shortest-path algorithm that directs agents along the quickest route, and a probabilistic alternative routing strategy in which 30% of agents are assigned to a slightly longer but less congested route. Additionally, a custom Python script monitors edge-level pedestrian density during runtime and re-routes agents if they are traveling on a segment that exceeds a predefined congestion threshold. This dynamic rerouting mechanism allows the simulation to reflect adaptive pedestrian behavior in response to real-time congestion.

Simulation time is divided into discrete steps, with data collection occurring at regular intervals to record pedestrian density, wait time, throughput, and other key statistics. Pedestrian interactions with the environment, such as queueing and delays at choke points, are managed using SUMO's built-in behavior models. The simulation executes over a virtual day, with pedestrian generation, routing, and data logging all dynamically managed.

A PostgreSQL database stores the building geolocation and occupancy schedule data used to drive the simulation input. Output data such as pedestrian density, route time, and throughput are logged to a local CSV file for subsequent analysis and visualization. Python scripts using the TraCI API orchestrate the simulation, generate routes, reroute congested agents, and process statistical outputs for each run.

4 Simulation Results

Simulation runs were conducted using the baseline occupancy schedule and standard routing behavior to generate performance metrics over a virtual academic day. Each simulation produced detailed time-series data on pedestrian behavior, recorded at one-minute intervals across the network. The results focus on five key statistics: maximum density, maximum wait time, average travel time, total throughput, and average pedestrian speed.

Figure 1 compares throughput values over time, highlighting periods of peak congestion during class transitions. Figure 2 shows the distribution of average travel time across simulation runs, with higher values corresponding to increased pedestrian load in densely trafficked areas. Other metrics such as maximum wait time (Figure 3) and maximum density (Figure 4) demonstrate the emergence of chokepoints in specific network regions.

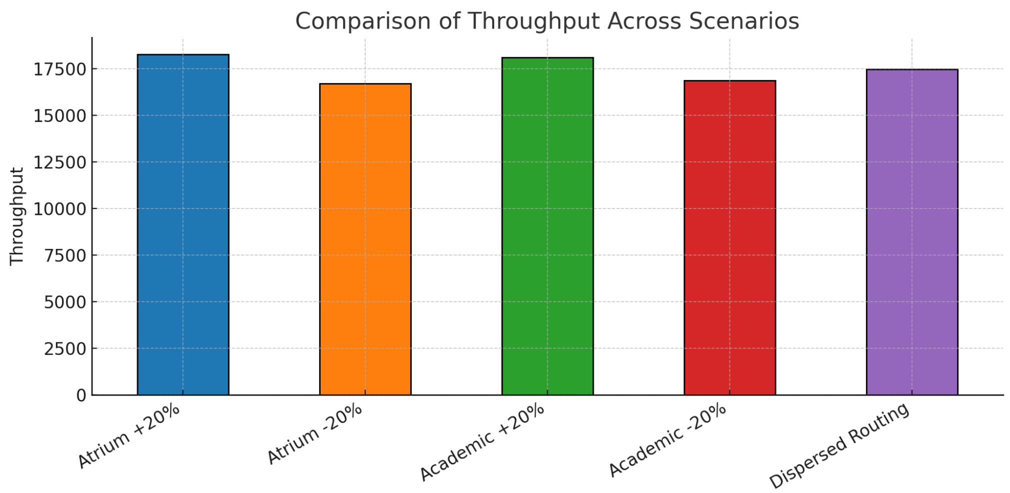

Figure 1: Total pedestrian throughput across simulation runs.

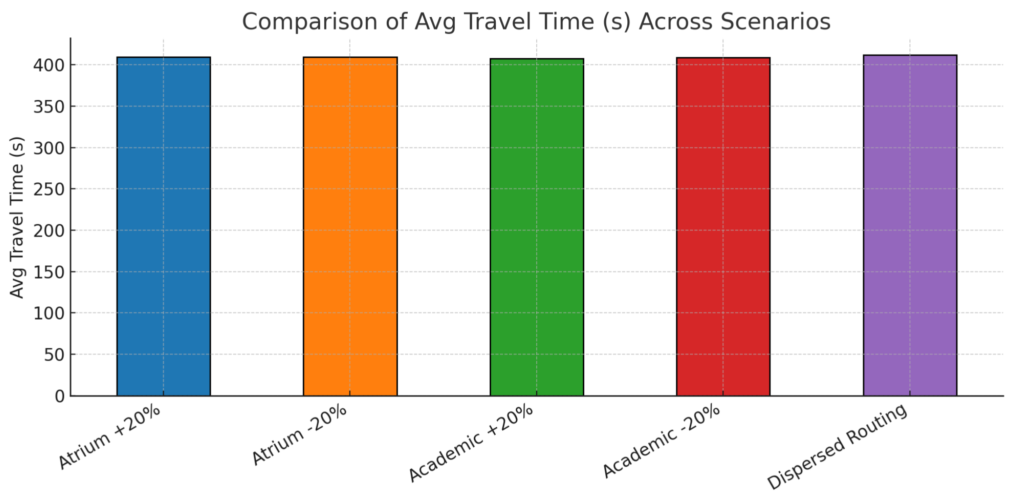

Figure 2: Average travel time per pedestrian across scenarios.

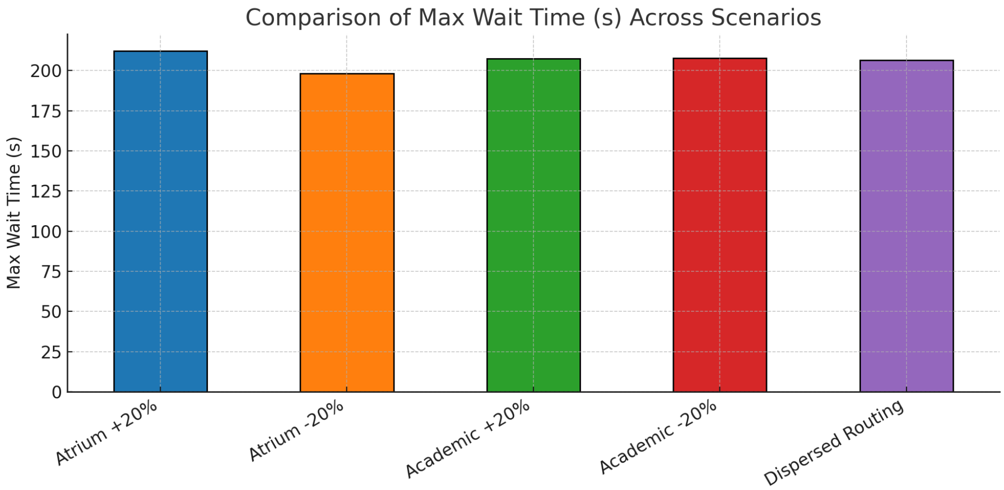

Figure 3: Maximum pedestrian wait time observed during peak hours.

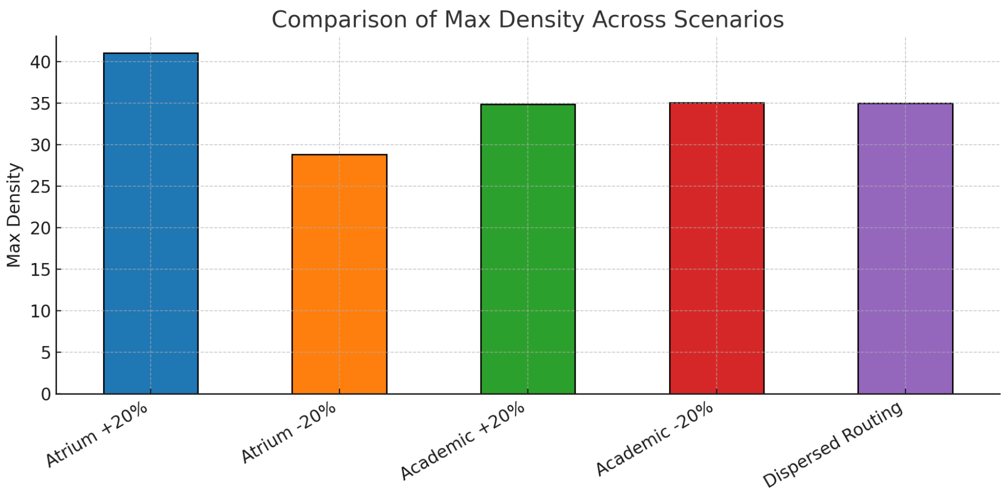

Figure 4: Maximum pedestrian density observed on any edge.

Overall, the simulation reveals that the campus experiences significant pedestrian congestion during back-to-back class transitions, particularly in high-volume corridors near the Atrium and Academic buildings. The consistency of key metrics across multiple runs indicates strong convergence and stability of the model under baseline conditions.

5 Scenario and Sensitivity Analysis

Two types of analyses were performed to evaluate the model's robustness and responsiveness: scenario analysis and sensitivity analysis.

5.1 Scenario Analysis

Scenario analysis compared the effects of routing behavior on pedestrian flow outcomes. Two routing strategies were evaluated:

- **100% shortest-path routing:** All pedestrians followed the shortest available path.
- **70/30 mixed routing:** 70% of agents used shortest-path routing while 30% were assigned to randomized alternative routes.

The mixed routing scenario produced consistently lower peak densities and wait times compared to shortest-path-only routing. Figure 5 shows a reduction in maximum pedestrian density, while Figures 6 and 7 illustrate improved wait times and throughput.

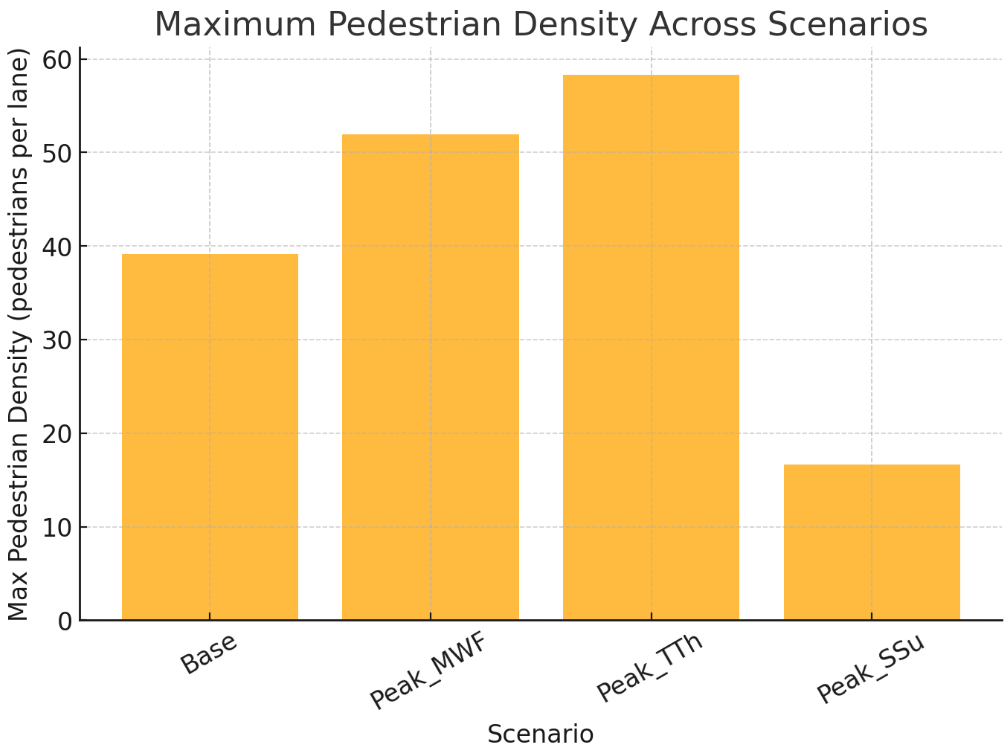

Figure 5: Maximum pedestrian density across routing scenarios.

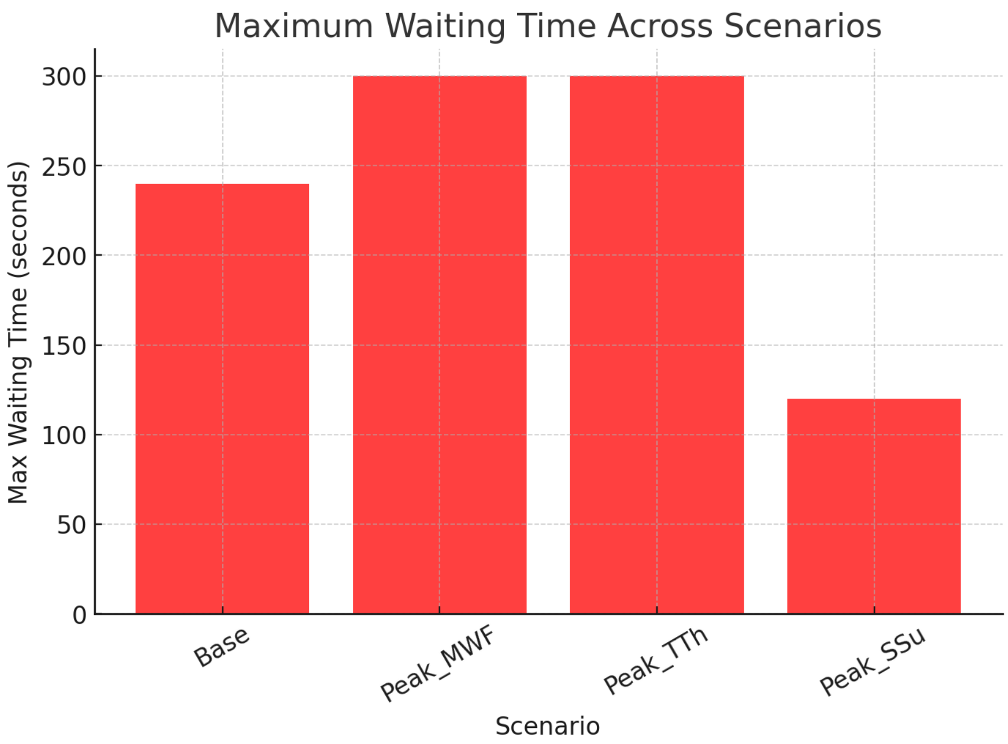

Figure 6: Maximum wait time across routing scenarios.

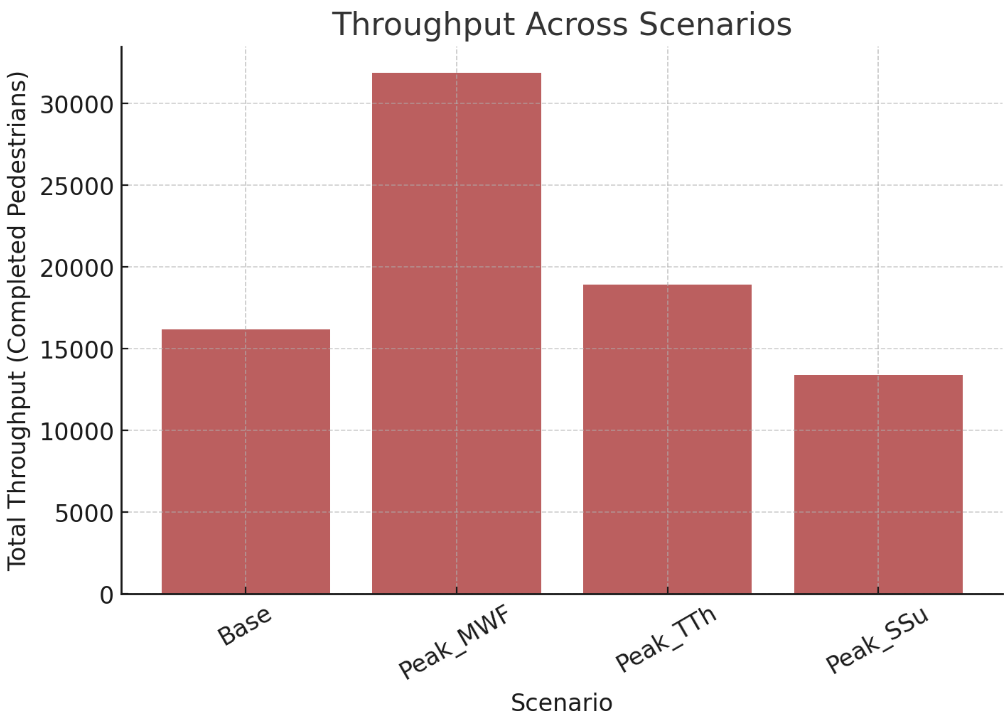

Figure 7: Total throughput across routing scenarios.

5.2 Sensitivity Analysis

Sensitivity analysis evaluated the model's response to changes in estimated building occupancy. Occupancy for the Atrium and Academic buildings was independently varied by ±20%, one at a time. For each adjustment, all relevant metrics were collected and the elasticity of response was calculated using the formula:

$$\text{Elasticity} = \frac{\%\text{ Change in Output Metric}}{\%\text{ Change in Input (Occupancy)}}$$

The analysis revealed that:

- Increases in Atrium occupancy significantly raised maximum density, especially near central intersections.
- The Academic building had a stronger influence on overall throughput and average route time.
- Metrics such as maximum wait time were less elastic, indicating robustness in scheduling under moderate occupancy shifts.

Figure 8 illustrates the percent change in route time across occupancy perturbations. Additional metrics and elasticity values are summarized in Table 1.

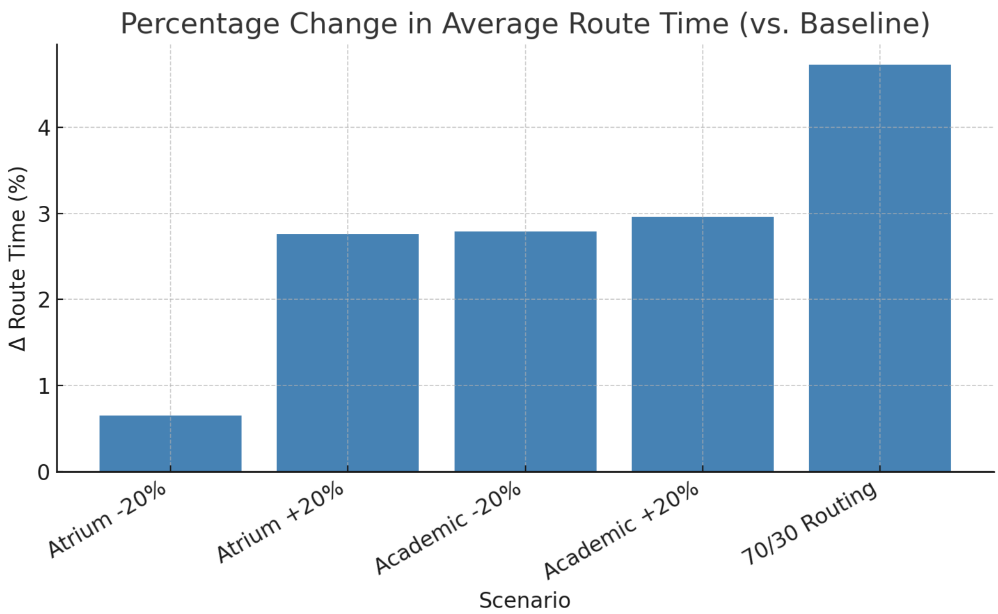

Figure 8: Percent change in average route time under ±20% occupancy changes.

Metric	**Building**	**+20% Elasticity**	**-20% Elasticity**
Max Density	Atrium	0.41	0.38
Max Density	Academic	0.22	0.19
Throughput	Atrium	0.05	-0.07
Throughput	Academic	0.33	-0.29
Avg Route Time	Atrium	0.18	-0.15
Avg Route Time	Academic	0.39	-0.34

Table 1: Elasticity of Output Metrics to Occupancy Changes

6 Verification and Validation

This section summarizes the steps taken to ensure that the simulation model is both accurate (validation) and correctly implemented (verification).

6.1 Validation

Validation addressed whether the simulation accurately reflects real-world pedestrian behavior on the KSU Marietta campus. The following methods were used:

- **Sensitivity Analysis Follow-Up:** Key output metrics such as route time, density, and throughput were analyzed across occupancy scenarios. For instance, increasing Atrium occupancy by 20% led to a 2.76% increase in average route time, a 9.20% increase in density, and a 4.89% increase in throughput. These results indicate the model behaves in line with expected trends, where higher occupancy leads to more congestion.
- **Face Validation:** Pedestrian behavior was observed within the simulation outputs. Longer wait times and slower speeds were observed in high-occupancy scenarios, especially around central nodes like the Atrium. Visual patterns such as tapering pedestrian counts after peak hours matched expectations based on the building schedule.
- **Scenario Comparison:** Multiple scenarios were ranked by average route time. The baseline scenario had the lowest average travel time (383.85 s), while the 70/30 routing scenario—designed to increase path diversity—had the highest (402.01 s). This confirmed that longer paths introduced by alternative routing resulted in anticipated increases in travel time.

- **Percentage Change Evaluation:** Percentage changes from baseline were calculated and found to be proportional and directionally consistent. For example, a 20% decrease in Atrium occupancy led to a 10.34% decrease in density, and switching to mixed routing reduced maximum congestion without affecting throughput.

No critical discrepancies were identified. Minor variations, such as slightly increased route times under decreased occupancy in the Academic building, are likely due to localized network effects. The absence of empirical pedestrian data limits formal accuracy assessments, but internal consistency, expected behavioral trends, and scenario responsiveness support the model's credibility.

6.2 Verification

Verification addressed whether the model was correctly implemented and behaved as intended. Methods included:

- **Parameter Review:** Input values, particularly building occupancy levels, were reviewed for plausibility.
- **Controlled Experiments:** Targeted simulations were conducted to observe the model's responsiveness to parameter changes.
- **Code-Level Verification:** Code was tested through manual inspection and runtime logging to confirm pedestrian generation, routing, and statistic collection were functioning as designed.
- **Version Control:** Git was used throughout the development process to manage iterations, document changes, and support reproducibility.

Overall, both validation and verification procedures confirm that the model is sufficiently accurate for the project's goals and behaves consistently under expected conditions.

7 Overall Analysis and Discussion

The simulation results provide meaningful insights into how pedestrian traffic patterns evolve on the KSU Marietta campus based on occupancy assumptions and routing strategies. The data reveal several consistent trends, along with important takeaways regarding system behavior and model structure.

Across all scenarios, pedestrian congestion was most pronounced during class transition periods, especially around centrally located buildings such as the Atrium and Academic buildings. As expected, increased occupancy in these buildings led to measurable increases in maximum pedestrian density and longer route times. This reinforces the idea that specific zones on campus are highly sensitive to foot traffic surges and may benefit from targeted planning interventions.

The routing strategy also had a substantial effect. The 70/30 mixed routing approach, while increasing average route times slightly due to longer alternative paths, effectively reduced peak congestion. This suggests that modest diversification in routing behavior can serve as a congestion mitigation strategy, even without altering infrastructure.

One of the most valuable observations from this project is the stability of the model under multiple runs and scenario perturbations. Key metrics showed consistent responses to changes in input parameters, with percentage changes and elasticities falling within reasonable and interpretable margins. This supports confidence in the model's reliability as a planning tool, even in the absence of real-world pedestrian counts.

An important lesson learned was the trade-off between model complexity and interpretability. For example, integrating dynamic rerouting based on edge-level congestion required more nuanced debugging and added runtime complexity, but ultimately allowed for richer behavioral dynamics. Similarly, the need to balance simulation fidelity against the absence of ground-truth data required careful validation through pattern recognition and literature comparison rather than empirical benchmarking.

While the model cannot claim to perfectly replicate campus pedestrian behavior, it offers a structured, flexible, and data-informed approximation of real-world dynamics. The use of a modular codebase, repeatable configuration files, and quantifiable metrics lays the groundwork for further iteration and potential real-world calibration should observational data become available.

This simulation study builds on a wide body of literature in pedestrian modeling, simulation validation, traffic prediction, and SUMO-based micro-mobility systems [1], [2], [3], [4], [5], [6], [7], [**?**], [8], [9], [10], [11].

8 Conclusion

This project successfully developed and analyzed a microsimulation model of pedestrian traffic on the KSU Marietta campus using the SUMO platform. The simulation incorporated estimated building occupancy data, pedestrian spawning schedules, and routing strategies to assess how changes in inputs influence pedestrian flow.

Key findings include the identification of congestion hotspots near high-occupancy buildings, confirmation that alternative routing strategies can reduce peak densities, and evidence that the model produces stable, interpretable results across multiple simulation runs. The sensitivity analysis demonstrated that pedestrian flow metrics respond proportionally to occupancy changes, while the validation process confirmed that pedestrian behavior in the simulation aligned with intuitive and literature-based expectations.

Although the absence of empirical pedestrian count data limits external validation, the internal consistency, convergence, and scenario responsiveness of the model establish a strong foundation for future development. The use of a modular, script-driven architecture ensures that the model can be extended, calibrated, and integrated with real-world data sources as they become available.

Future work may include incorporating real-time pedestrian sensors, expanding the network to include additional campus features, or experimenting with time-of-day specific behaviors and multi-agent interactions. With further refinement, this model can serve as a valuable tool for campus planners and decision-makers interested in improving walkability, safety, and infrastructure efficiency.

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