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Traffic Congestion Modeling and Simulation in Front of the University of North Sumatra (USU) Campus Using an Agent-Based Modeling Approach

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ABSTRACT

Traffic congestion around the entrance of the University of North Sumatra (USU) campus represents a major issue influenced by several factors, including the presence of street vendors, illegal vehicle parking, public transport (angkot) that frequently stops without proper order, and the movement of both vehicles and pedestrians crossing the road. This research aims to construct and simulate the traffic situation in that area using an Agent-Based Modeling (ABM) approach, which was manually developed through the Python programming language. Each type of vehicle motorcycle, car, public transport, and pedicab is modeled as an individual agent that exhibits specific behaviors such as varying speed, stopping probability, and pause duration, based on observational data obtained from CCTV recordings of the Medan City Transportation Agency's ATCS system. The simulation covers two main traffic directions, namely Jalan Setia Budi and Jalan Jamin Ginting, and evaluates several intervention scenarios such as adding designated bus stops, organizing street vendors, and managing pedestrian crossings. The outcomes demonstrate that applying a combination of these interventions increases the average vehicle speed by approximately 15-20% compared to the initial condition, implying that the proper management of roadside activities and environmental control significantly reduce traffic congestion. The ABM method proves capable of realistically illustrating traffic dynamics and can serve as a valuable analytical tool for evaluating transportation policies within campus zones and other urban areas.

Keywords: *Agent-Based Modeling; traffic congestion; simulation; ATC*S

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1. INTRODUCTION

Traffic congestion poses a critical challenge in rapidly developing cities, particularly in high-activity zones such as university areas. Beyond causing significant time delays, it leads to increased fuel consumption, higher vehicle emissions, and reduced quality of life. These issues demand precise analytical approaches capable of simulating complex traffic patterns and evaluating effective mitigation strategies.

A clear example of such congestion occurs at the entrance of the University of North Sumatra (USU) campus in Medan. Direct observation of CCTV footage from the Medan City Transportation Agency's Area Traffic Control System (ATCS) in October 2025 revealed severe traffic degradation during peak hours. Quantitative data highlights the urgency: on the route toward Setia Budi, the average speed dropped dramatically by 66.5%, from 41.2 km/h to just 13.8 km/h. Similarly, on the Jamin Ginting route, speeds decreased by 45.3%, from 27.8 km/h to 15.2 km/h. The overall average speed across both routes was merely 14.5 km/h a 58% decrease resulting in a Level of Service (LOS) classified as E according to PKJI 2023 standards (Hutahaean & Lubis, 2025).

This severe congestion arises from multiple interacting factors: street vendors narrowing effective road width, illegal parking accumulating at up to 15 points during peak hours, public transportation stopping randomly with a 90% stopping rate, and intense, unregulated pedestrian and turning-vehicle movements. These elements create a complex environment where localized disruptions cascade into systemic congestion.

Agent-Based Modeling (ABM) offers an ideal framework for analyzing such scenarios, as it simulates individual vehicle behaviors and their dynamic interactions. Previous studies confirm ABM's effectiveness: Afdal et al. (2025) achieved an 18% speed improvement through signal optimization in Medan, while Febriany and Radam (2024) found that street vendor activities reduced speeds by 25% in Banjarmasin. Wu et al. (2024) further demonstrated that heterogeneous driving behaviors significantly exacerbate congestion. However, most existing research focuses on isolated factors, leaving a critical gap in studies that integrate the multiple, co-occurring disturbances typical of Indonesian campus areas.

To address this gap, this study develops a customized ABM simulation using Python to model traffic in front of the USU campus. The model incorporates four vehicle agent types motorcycles, cars, public transport (angkot), and pedicabs (becak)with behavioral parameters directly calibrated from ATCS observations. It focuses on two critical corridors, Jalan Setia Budi and Jalan Jamin Ginting, during morning and afternoon peak hours.

This research is guided by three specific questions:

1. How do individual and combined roadside disturbances affect average vehicle speed and traffic flow efficiency?
2. To what extent can targeted interventions vendor relocation, illegal parking control, designated angkot stops, and regulated pedestrian crossings improve traffic performance?
3. How accurately can the ABM approach represent real-world traffic dynamics in a campus zone, and can it serve as a reliable tool for transportation policy evaluation?

Through simulating various intervention scenarios, this research quantifies potential improvements in traffic performance and provides evidence-based recommendations for local authorities. Furthermore, it demonstrates the viability of custom-built ABM as a practical analytical tool for transportation planning in similar Indonesian urban contexts.

2. LITERATURE REVIEW

2.1. Urban Congestion (concept and causal factors)

As per the Ministry of Transportation (2023), traffic congestion refers to a state where vehicle movement surpasses roadway limits, leading to reduced speeds and extended lines of cars. On the other hand, Anggi Hutahaean and Kamluddin Lubis (2025) state that congestion arises when roadway performance falls below level D according to the updated Pedoman Kapasitas Jalan Indonesia (PKJI) 2023 guidelines, marked by typical vehicle speeds dropping to less than 30 % of free-flow levels.

Within busy zones like universities, malls, or medical facilities, congestion frequently stems from peripheral hindrances including roadside vendor operations, unauthorized parking, and public transport halting haphazardly. (Martínez & Young, 2022) This issue worsens due to the interplay of walkers and motor vehicles, which reciprocally affect traffic movement. Moreover, unruly actions by road users, especially during passenger exchanges, play a key role in amplifying traffic jams (Purnama et al., 2024).

Latest studies indicate that congestion in academic zones results from more than just vehicle counts, but also time-based travel trends, featuring heightened activity during specific periods (rush times). This mirrors the scenario outside the University of North Sumatra (USU) campus, experiencing severe congestion at peak hours from the blend of personal cars, public transit, and student foot traffic.

2.2. Concept and Application of Agent-Based Modeling (ABM) in Traffic

Agent-Based Modeling(ABM) is a computer-based modeling approach that represents complex systems through the interaction of individuals or agents that have their own behavior and decision rules. In the context of transportation, each vehicle is considered an agent capable of making independent decisions such as accelerating, decelerating, stopping, or avoiding obstacles on the road. This approach differs from traditional macroscopic models because it is able to describe the micro-behavior of individuals in a traffic system (Doraki et al., 2024).

Modern research confirms that ABM is effective for analyzing urban congestion because it is able to represent variations in road user behavior and heterogeneous environmental conditions

(Bastarianto et al., 2023). Through ABM, researchers can observe the impact of small policy changes, such as regulating vendors or building bus stops, on overall traffic performance. This approach is also suitable for use in local contexts such as in front of the USU campus, where field conditions reflect the complex interactions between various types of vehicles, vendors, and pedestrians.

Furthermore, ABM provides high flexibility for virtual policy experiments without disrupting real traffic. For example, ABM models can be used to assess the impact of adding bus stops or relocating vendors on changes in average vehicle speed. This allows researchers to conduct what-if scenario analyses to determine the most effective strategies for reducing traffic congestion (Li et al., 2024).

Agent-Based Modeling (ABM) serves as a computational technique for simulating intricate systems via the engagements of distinct entities or agents, each equipped with personal actions and choice guidelines. In transport scenarios, every car acts as an agent with autonomy to choose actions like speeding up, slowing down, halting, or dodging road barriers. Unlike conventional large-scale models, this method excels at capturing the minute actions of participants within a traffic network (Doraki et al., 2024).

Current studies affirm that ABM proves valuable for examining city jams, as it captures diverse driver habits and varied surroundings. (Bastarianto et al., 2023) Using ABM, experts can evaluate how minor adjustments, including vendor oversight or new bus shelters, affect total traffic efficiency. It's particularly apt for specific settings like the USU campus area, where real-world dynamics involve intricate ties among different vehicle types, sellers, and walkers.

Plus, ABM offers great adaptability for simulated policy trials without interfering with actual roads. For instance, ABM simulations help gauge how introducing bus stops or shifting vendor spots influences shifts in typical vehicle velocities. This enables analysts to run hypothetical tests to pinpoint optimal methods for easing traffic blockages (Li et al., 2024).

2.3. The Influence of Street Vendors (PKL) on Traffic Performance

The activities of street vendors (PKL) on the roadside significantly impact traffic flow. According to Febriany and Radam (2024), the presence of street vendors reduces the effective width of vehicle lanes and increases the potential for conflict between vehicles and pedestrians. The study found that on Jalan Jendral Sudirman, Banjarmasin, average vehicle speed decreased by up to 25% in segments with active vendors.

Similar research by Martínez et al. (2022) showed that the presence of street vendors in densely trafficked areas slows down traffic flow, especially during rush hour. Meanwhile, Purnama (2024) emphasized that an effective solution is not simply eviction, but through organizing and empowering street vendors so that their activities continue without disrupting traffic flow. In the context of the USU campus, the street vendors' activity pattern on the left side of the road narrows the lane and causes slowdowns, especially in the direction of Setia Budi.

The ABM approach offers advantages in modeling this street vendor phenomenon, as vehicle agents can be programmed to slow down or change position when approaching a street vendor area. This allows for realistic simulations that mimic the effects of road narrowing on traffic dynamics (Bastarianto et al., 2023).

2.4. The Impact of Public Transportation Stops and the Existence of Bus Stops on Traffic Flow

Public transportation, particularly angkots, has a major influence on urban traffic patterns, especially in busy areas. The habit of these vehicles stopping randomly to pick up or drop off passengers often cuts down on the road's effective capacity, as noted by Rahman and Santoso in 2021. Their research indicates that setting up designated bus stops could cut traffic disruptions by as much as 30%.

Additionally, a study by Damsara & Saidi (2023) supports the idea that well-designed bus stops with optimal spacing and proper placement away from intersections can significantly improve overall traffic flow. Their research found that maintaining an ideal distance between stops approximately 0.27 km for local routes and 1 km for rapid routes enhances operational efficiency and reduces unnecessary stoppages along the road. When official stops are established at strategic points, public transport vehicles like angkots can halt more systematically, preventing them from scattering randomly and disrupting traffic. In agent-based modeling (ABM) simulations, this condition can be represented by reducing the dwell time of angkot agents while keeping the total number of stops consistent, reflecting the benefits of a more organized stop system.

This approach applies directly to the situation near the USU campus, where installing bus stops at key locations could lessen the negative effects of angkot stops on other road users. Plus, we can use the custom Python-based ABM model from this study to simulate and quantify improvements in average vehicle speeds and travel times.

2.5. The Role of the ATCS (Area Traffic Control System) in Monitoring and Validating Traffic Data

The Area Traffic Control System, or ATCS, represents a comprehensive traffic management setup that relies on sensors, cameras, and communication networks. It's employed by the Department of Transportation to track real-time road conditions. According to Hidayat and Sari in 2022, leveraging ATCS data brings major benefits to transportation studies, as it enables gathering precise real-world information without interfering with ongoing traffic. In our research, we utilized ATCS footage from the area near the USU campus as the main data source to determine hourly vehicle counts, average speeds, and halting behaviors in the morning and evening hours.

Moreover, ATCS functions as a key tool for verifying simulation outcomes. By aligning the ABM model's results with genuine ATCS data, experts can evaluate how well the simulation mirrors real-world scenarios, ultimately boosting the model's precision and trustworthiness for suggesting local traffic policies

3. METHOD

3.1. Research Approach

This research employs an Agent-Based Modeling (ABM) simulation approach to examine traffic congestion dynamics in front of the University of North Sumatra (USU) campus. ABM was selected for its capability to represent individual vehicle behaviors and their dynamic interactions within a complex roadway system. Unlike macroscopic traffic models that treat vehicles as aggregate flows, ABM simulates each vehicle as an autonomous agent with distinct behavioral characteristics, enabling detailed analysis of how localized disturbances affect overall traffic performance.

The ABM framework was developed using Python programming language, providing flexibility to customize agent behaviors and environmental parameters specific to observed field conditions. The model operates on a discrete-time step basis, simulating vehicle movements and interactions over a one-hour period for each scenario.

3.2. Data Sources and Collection

Traffic data were obtained through systematic observation of live CCTV footage from the Medan City Transportation Agency's Area Traffic Control System (ATCS) during October 2025. Data collection focused on two peak traffic periods: morning rush hour (07:00–08:00 WIB) and afternoon rush hour (17:00–18:00 WIB). Observations were conducted over multiple weekdays to ensure data representativeness and minimize day-to-day variability.

The observation process systematically recorded the following parameters for each vehicle type:

1. **Vehicle Volume:** Total count of motorcycles, cars, public transportation (angkot), and pedicabs passing through defined observation points per hour. For the Jamin Ginting route, vehicles were further categorized by movement direction (straight or crossing).
2. **Average Speed:** Vehicle speeds were estimated by measuring the time required to traverse a 50-meter road segment clearly marked on CCTV footage. For each vehicle type, a minimum of 30 individual measurements were recorded and averaged to obtain representative speed values under prevailing traffic conditions.
3. **Stopping Behavior:** The proportion of vehicles exhibiting stopping behavior was calculated by dividing the number of complete stops (defined as halts lasting more than 2 seconds) by the total number of observed vehicles. This metric captures the impact of passenger boarding/alighting, traffic signals, and congestion-induced stops.
4. **Dwell Time:** For vehicles that stopped, the duration of each stop was measured from the moment of complete halt until movement resumption. Average dwell times were calculated

separately for each vehicle type, recognizing that angkots typically exhibit longer stops due to passenger exchanges.

5. **Environmental Conditions:** Physical roadway characteristics including effective lane width (measured by identifying road markings and obstacles visible on CCTV), number and location of street vendor stalls, illegal parking points, and areas with high pedestrian crossing activity were systematically documented through visual assessment of the footage.

Data reliability was ensured through multiple observation sessions conducted on different days, with consistency checks performed by comparing traffic patterns across similar time periods. This observation methodology aligns with established traffic survey protocols adapted for CCTV-based data collection.

3.3. Model Design and Agent

3.3.1 Simulation Environment

The simulation environment represents two critical 300-meter road segments in front of USU campus:

1. **Route 1 (Toward Setia Budi):** Characterized by single-direction flow with significant roadside obstacles including street vendors and illegal parking
2. **Route 2 (Toward Jamin Ginting):** Features more complex traffic patterns with both straight-moving and crossing vehicles, along with roadside disturbances

The road segments are modeled with variable effective lane widths that change based on the presence and density of roadside obstacles. Baseline lane width is 6 meters under unobstructed conditions, but reduces to 4 meters (Setia Budi) or 3.5 meters (Jamin Ginting) during peak congestion when vendors and illegal parking occupy roadside space.

3.3.2 Agent Types and Behavioral Parameters

Four distinct agent types were implemented, each representing a vehicle category with unique behavioral characteristics derived from ATCS observations:

1. **Motorcycles:** Most numerous and flexible agents with higher baseline speeds and lower stopping probabilities. Can navigate partially obstructed lanes more effectively than larger vehicles.
2. **Cars:** Moderate speeds with intermediate stopping probabilities. More constrained by lane narrowing and require greater following distances.
3. **Public Transportation (Angkot):** Characterized by high stopping probabilities (approximately 90%) and longer dwell times (15-20 seconds) due to frequent passenger boarding and alighting activities. Exhibit the slowest speeds among motorized vehicles.
4. **Pedicabs (Becak):** Slowest vehicle type with moderate stopping probabilities. Often park at roadside locations, contributing to lane obstruction.

Each agent type is assigned behavioral parameters including baseline speed, stopping probability, and average dwell time based on observed data from Tables 1 and 2. These parameters vary between morning and afternoon periods to reflect changing traffic conditions.

3.3.3 Agent Movement and Interaction Mechanisms

Agent movement is governed by several interacting mechanisms that simulate realistic traffic behavior:

1. **Speed Adjustment:** Vehicle speeds are dynamically adjusted based on effective lane width. As roadside obstacles narrow the available lane, vehicle speeds decrease proportionally. The relationship assumes that a 6-meter lane width represents optimal flow conditions, with speed reductions occurring as width decreases.
2. **Stopping Behavior:** Each agent makes probabilistic stopping decisions based on its stopping probability parameter. When a stop occurs, the agent remains stationary for a duration sampled from its dwell time distribution. Stopping probability increases in the presence of roadside obstacles, as parking and vendor activities create additional conflict points.
3. **Inter-Agent Interactions:** Agents respond to surrounding traffic conditions. When faster vehicles encounter slower vehicles ahead (particularly angkots or pedicabs), they must decelerate or temporarily stop. This interaction creates cascading slowdown effects typical of congested conditions.

4. **Environmental Response:** Agents adjust their behavior when encountering street vendor zones, illegal parking areas, or high-density sections. These adjustments include speed reductions and increased stopping probabilities, simulating driver caution and forced lane changes.

Travel time for each agent is calculated by tracking its movement through the 300-meter route segment, accounting for variable speeds, stops, and interactions with other agents and environmental obstacles.

3.4. Model Calibration and validation

3.4.1 Calibration Process

Model calibration was performed to ensure simulated traffic behavior accurately reflects observed field conditions. Initial agent parameters (speeds, stopping probabilities, dwell times) were set to observed mean values from ATCS data. The model was then run iteratively, with parameters adjusted within ±10% of observed values to minimize discrepancies between simulated and observed traffic metrics. The calibration focused on matching average vehicle speeds and travel times for baseline scenarios, ensuring that the model reproduces the dramatic speed differences observed between morning (relatively free-flowing) and afternoon (severely congested) conditions.

3.4.2 Validation Process

Model validation was conducted by comparing simulation outputs with empirical baseline data from ATCS observations. Two primary validation metrics were employed:

1. **Average Speed Validation:** Simulated average speeds for each vehicle type were compared against observed speeds using percentage error calculations.
2. **Travel Time Validation:** Mean travel times for the 300-meter route segments were compared between simulation and field measurements.

Validation was performed separately for each route and time period, yielding the following accuracy:

Table 1. Validation Results for Average Speed and Travel Time

Route	Period	Speed Error (%)	Travel Time Error (%)
Setia Budi	Morning	4.2	5.1
Setia Budi	Afternoon	6.3	7.2
Jamin Ginting	Morning	5.1	6.0
Jamin Ginting	Afternoon	7.8	8.5

All validation errors remained below 10%, indicating strong agreement between simulated and observed traffic conditions. The slightly higher errors during afternoon periods reflect the increased complexity and behavioral variability characteristic of peak congestion. These validation results confirm the model's reliability for comparative scenario analysis.

3.4.3 Model Limitations

Several simplifications were necessary for model tractability:

1. Weather conditions and special events are not explicitly modeled
2. Pedestrian movements are represented implicitly through stopping probability adjustments rather than as independent agents
3. Traffic signal timing at intersections is simplified
4. Individual driver variability within each vehicle type is aggregated to mean behavioral parameters

These limitations are considered acceptable given the model's intended use for evaluating relative effectiveness of intervention strategies rather than absolute traffic forecasting.

3.5. Simulation Scenarios and Interventions

The intervention scenarios were selected based on key congestion factors identified from ATCS CCTV observations, including roadside obstacles, angkot stopping behavior, and crossing vehicle conflicts, which were found to be the primary contributors to traffic delays in the study area.

Multiple intervention scenarios were designed to evaluate traffic management strategies. Each simulation ran for a one-hour period with vehicles entering according to observed hourly volumes.

Each scenario was executed multiple times to account for stochastic variability in agent behaviors, with the results averaged across runs.

3.5.1 Setia Budi Route Scenarios

1. **Baseline Morning:** Represents relatively smooth conditions with 6-meter lane width and minimal roadside obstacles (1–2 parking/vendor points).
2. **Baseline Afternoon:** Represents congested conditions with lane width reduced to 4 meters due to approximately 15 parking/vendor points occupying roadside space.
3. **Intervention 1 - Designated Bus Stops (Morning):** Evaluates the impact of establishing official angkot stops, reducing passenger boarding/alighting time by 40% while maintaining the same stopping frequency.
4. **Intervention 2 - Light Intervention (Afternoon):** Tests partial regulation where approximately half of street vendors and illegal parking are removed, increasing lane width to 5 meters and reducing angkot dwell times by 30%.
5. **Intervention 3 - Full Intervention (Afternoon):** Simulates complete removal of all roadside obstacles, restoring full 6-meter lane width, combined with regulated angkot stops that reduce dwell times by 50%.

3.5.2 Jamin Ginting Route Scenarios

1. **Baseline Morning/Afternoon:** Observed field conditions with varying congestion levels and roadside obstacle densities.
2. **Intervention A – Remove Parking and Street Vendors:** All illegal parking and vendor stalls removed, restoring normal lane capacity.
3. **Intervention B – Regulate Public Transportation:** Angkots restricted to designated stops with enforced discipline, reducing random stopping behavior by 50% and dwell times by 40%.
4. **Intervention C – Crossing Management:** Traffic control measures implemented to reduce crossing vehicle conflicts, decreasing stopping frequency for crossing vehicles by 40% and improving their movement efficiency.
5. **Intervention Combined (A+B+C):** All three interventions applied simultaneously to assess synergistic effects on overall traffic performance.

3.6. Performance Metrics

For each scenario, the following performance metrics were computed and compared:

1. **Average Travel Time:** Mean time required for vehicles to traverse the 300-meter segment, calculated separately for each vehicle type.
2. **Average Speed:** Effective speed achieved under each scenario condition.
3. **Speed Improvement:** Percentage increase in average speed relative to baseline conditions, indicating intervention effectiveness.
4. **Flow Efficiency:** Ratio of achieved speed to theoretical free-flow speed, providing a normalized measure of congestion relief.

Results were analyzed to quantify the relative effectiveness of each intervention strategy and identify the most promising approaches for congestion mitigation in the USU campus area.

4. RESULTS AND DISCUSSION

4.1 *General Description of Location and Traffic Conditions*

This study was conducted on two main roads in front of the University of Sumatera Utara (USU), namely the road leading to Setia Budi Street and the road leading to Jamin Ginting Street. The congestion characteristics of both roads were observed using direct field data and live ATCS CCTV footage, allowing real-time observation of vehicle movements, side obstacles, and public transport behavior.

On the road leading to Setia Budi Street, congestion is mainly caused by lane narrowing due to street vendors and illegal parking. The effective lane width, which is normally around 6 meters, can decrease to approximately ±4 meters at several constrained points, especially in the afternoon when the number of side obstacles reaches ±15 points. This local narrowing limits vehicle maneuverability and easily triggers queues during peak hours.

On the road leading to Jamin Ginting Street, congestion is influenced more by movement conflicts, particularly vehicles that cross before the traffic light toward Pajus and Lapangan Merdeka. These crossing movements slow down the main flow because vehicles must wait for a safe gap. In addition, public transport (angkot) frequently stops abruptly near the intersection. Side obstacles are also present, with 2-3 points in the morning and increasing to ±13 points in the afternoon, reducing the effective lane width from 5-5.5 meters to approximately ±3.5 meters.

These differences in physical conditions and movement patterns form the basis for applying Agent-Based Modeling (ABM), where each vehicle is represented as an agent capable of stopping, slowing down, crossing, or being disrupted according to the real patterns captured from field observations and ATCS CCTV footage.

4.2 *Field Observation Data*

Field observations were conducted during two peak periods morning (07:00-08:00) and afternoon (17:00-18:00) using direct field monitoring and live ATCS CCTV footage. These data were used to obtain accurate information on traffic volumes, average speeds, stopping behavior, and roadside obstacles, and became the basis for designing intervention scenarios in the model.

4.2.1 Road Toward Setia Budi

In the morning, traffic flow remained smooth with only 1-2 roadside obstacles, and the effective lane width was still around 6 meters. Vehicle speeds were relatively high, with motorcycles at 42.5 km/h and cars at 35 km/h, reflecting minimal disturbances.

In the afternoon, the number of street vendors and illegally parked vehicles increased to ±15 points, narrowing the effective lane at several segments to approximately ±4 meters. As a result, traffic speeds dropped sharply: motorcycles to 15 km/h, cars to 11 km/h, and public transport to 9 km/h. These conditions guided the formulation of scenarios involving regulated angkot stops (bus stops) and reductions in roadside obstacles (partial and full).

Table 2. Traffic Observation Data Towards Setia Budi

Periode	Jenis Kendaraan	Jumlah per Jam	Kecepatan Rata-rata (km/jam)	Proporsi Berhenti	Rata-rata Waktu Berhenti (detik)	Lebar Jalur Efektif (m)	Jumlah Parkir/Pedagang
Pagi (07:00–08:00)	Motor	3.068	42,5	0,1	2	6	1–2
	Mobil	712	35	0,1	4	6	1–2
	Angkot	60	30	0,9	15	6	1–2
	Becak	32	15	0,15	5	6	1–2
Sore (17:00–18:00)	Motor	3.660	15	0,2	4	4	±15
	Mobil	936	11	0,3	6	4	±15
	Angkot	64	9	0,9	20	4	±15
	Becak	40	8	0,2	10	4	±15

4.2.2 Road Toward Jamin Ginting

In the morning, straight-moving vehicles maintained stable speeds (motorcycles 32.5 km/h), while vehicles crossing before the traffic light moved slower (motorcycles 22.5 km/h) because they needed to wait for safe gaps. Roadside obstacles were limited (2–3 points).

In the afternoon, roadside obstacles increased to ±13 points, reducing the effective width from 5–5.5 meters to around 3.5 meters. Crossing movements before the traffic light and sudden angkot stops caused significant slowdowns, with crossing cars dropping to 9 km/h. These conditions informed the selection of intervention scenarios: removal of roadside obstacles (A), regulated angkot stops (B), and crossing management (C), along with a combined scenario.

Table 3. Traffic Observation Data Towards Jamin Ginting

Periode	Jenis Pergerakan	Jenis Kendaraan	Jumlah per Jam	Kecepatan Rata-rata (km/jam)	Proporsi Berhenti	Rata-rata Waktu Berhenti (detik)	Lebar Jalur Efektif (m)	Jumlah Parkir/Pedagang
Pagi (07:00–08:00)	Lurus	Motor	1.848	32,5	0,1	3	5,5	2–3
	Menyebrang	Motor	1.002	22,5	0,3	6	5,5	2–3
	Lurus	Mobil	642	27,5	0,15	5	5,5	2–3
	Menyebrang	Mobil	396	17,5	0,5	8	5,5	2–3
	Lurus	Angkot	54	20	0,9	20	5,5	2–3
	Lurus	Becak	18	13	0,3	10	5,5	2–3
Sore (17:00–18:00)	Lurus	Motor	1.592	17,5	0,2	3–4	3,5	±13
	Menyebrang	Motor	224	12,5	0,4	6	3,5	±13
	Lurus	Mobil	580	12,5	0,3	5	3,5	±13
	Menyebrang	Mobil	120	9	0,45	8	3,5	±13
	Lurus	Angkot	48	9	0,9	20	3,5	±13
	Lurus	Becak	28	5	0,3	10	3,5	±13

4.3 *Simulation Results and Analysis*

4.3.1 Directions to Setia Budi Street

a. Morning Period (07.00-08.00 WIB)

In the morning, traffic conditions in the direction of Setia Budi are relatively smooth, with average vehicle speeds remaining high and travel times relatively short. Based on the simulation results in Figure 1, motorbikes have the fastest travel time, which is around 25.63 seconds, while pedicabs are the slowest with a travel time of 72.50 seconds.

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==================== PERIODE PAGI ====================

Baseline (Pagi - Cukup Lancar)
Motor    | Waktu Tempuh Rata-rata: 25.63 s | Kecepatan Rata-rata: 42.50 km/jam
Mobil    | Waktu Tempuh Rata-rata: 31.54 s | Kecepatan Rata-rata: 35.00 km/jam
Angkot   | Waktu Tempuh Rata-rata: 49.95 s | Kecepatan Rata-rata: 30.00 km/jam
Becak    | Waktu Tempuh Rata-rata: 72.50 s | Kecepatan Rata-rata: 15.00 km/jam

Penambahan Halte (Pagi - 1 Halte)
Motor    | Waktu Tempuh Rata-rata: 24.44 s | Kecepatan Rata-rata: 44.62 km/jam
Mobil    | Waktu Tempuh Rata-rata: 29.67 s | Kecepatan Rata-rata: 36.75 km/jam
Angkot   | Waktu Tempuh Rata-rata: 42.03 s | Kecepatan Rata-rata: 31.50 km/jam
Becak    | Waktu Tempuh Rata-rata: 69.47 s | Kecepatan Rata-rata: 15.75 km/jam
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Figure 1. Simulation results of the direction to Jalan Setia Budi-Morning Period (Baseline and Additional Bus Stops)

The following results show that the addition of official stops or bus stops in the intervention scenario resulted in a slight improvement in travel times for all vehicle types, with a 5% increase in speed per vehicle, due to more regular passenger boarding and alighting. Overall, vehicle flow tended to be stable in the morning, and traffic congestion remained relatively low. Factors such as public transportation (angkot) stopping haphazardly did not significantly impact travel times because vehicle volume remained under control.

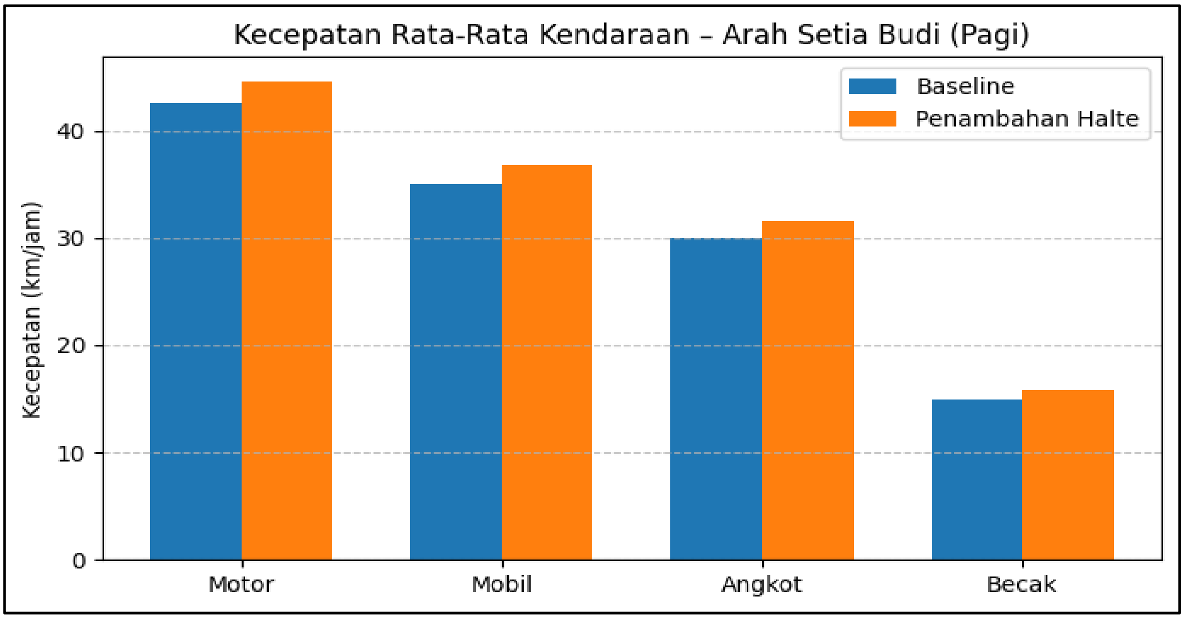

Figure 2. Setia Budi (Morning): Shows comparison of baseline and additional stops

b. Afternoon Period (17.00-18.00 WIB)

Different conditions are seen in the afternoon, during this period, the number of vehicles increases and the activity of street vendors (PKL) and illegal parking on the side of the road increases to ± 15 points, causing a narrowing of the effective lane width from 6 meters to 4 meters and speeds decrease drastically compared to the morning.

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===================== PERIODE SORE =====================

Baseline (Sore - Kondisi Macet)
Motor    | Waktu Tempuh Rata-rata: 109.20 s | Kecepatan Rata-rata: 15.00 km/jam
Mobil    | Waktu Tempuh Rata-rata: 149.01 s | Kecepatan Rata-rata: 11.00 km/jam
Angkot   | Waktu Tempuh Rata-rata: 199.00 s | Kecepatan Rata-rata: 9.00 km/jam
Becak    | Waktu Tempuh Rata-rata: 205.10 s | Kecepatan Rata-rata: 8.00 km/jam

Intervensi Ringan (Sore - Sebagian Pedagang Tertib & 1 Halte)
Motor    | Waktu Tempuh Rata-rata: 99.10 s | Kecepatan Rata-rata: 16.50 km/jam
Mobil    | Waktu Tempuh Rata-rata: 135.80 s | Kecepatan Rata-rata: 12.10 km/jam
Angkot   | Waktu Tempuh Rata-rata: 176.80 s | Kecepatan Rata-rata: 9.90 km/jam
Becak    | Waktu Tempuh Rata-rata: 185.99 s | Kecepatan Rata-rata: 8.80 km/jam

Intervensi Penuh (Sore - Semua Tertib & 1 Halte)
Motor    | Waktu Tempuh Rata-rata: 90.92 s | Kecepatan Rata-rata: 18.00 km/jam
Mobil    | Waktu Tempuh Rata-rata: 124.11 s | Kecepatan Rata-rata: 13.20 km/jam
Angkot   | Waktu Tempuh Rata-rata: 158.70 s | Kecepatan Rata-rata: 10.80 km/jam
Becak    | Waktu Tempuh Rata-rata: 170.65 s | Kecepatan Rata-rata: 9.60 km/jam
```

Figure 3. Simulation results of the direction towards Jalan Setia Budi-Afternoon Period (Baseline, Light Intervention, and Full Intervention)

The following figure explains that implementing light interventions such as regulating some vendors and establishing one bus stop for public transportation resulted in a 10% increase in speed per vehicle. Meanwhile, with full intervention, where the lane is cleared of illegal parking and street vendors, meaning the road returns to its original width of 6 meters and all public transportation stops orderly at the bus stops, the average speed per vehicle increases by up to 20% compared to the baseline.

The most noticeable improvements occurred in public transportation (angkot) and cars, as these two types of vehicles are most affected by lane narrowing and inter-vehicle interactions during peak traffic conditions. Overall, these results indicate that bus stop arrangements and curbside activity controls are highly effective in reducing travel times and improving traffic flow in the afternoon.

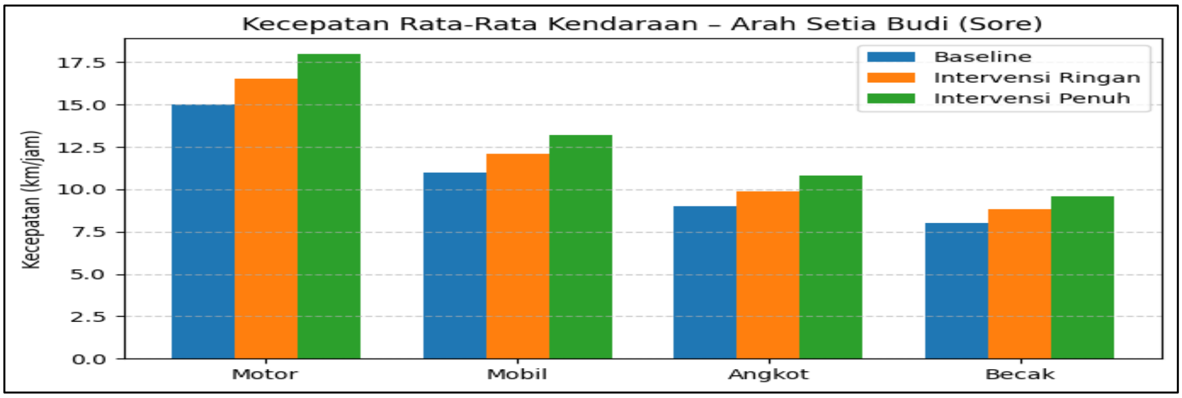

Figure 4. Setia Budi (Evening): Demonstrates improvement in speed between baseline, light intervention and full intervention.

4.3.2 Directions to Jalan Jamin Ginting

a. Morning Period (07.00-08.00 WIB)

In the morning, simulation results showed that traffic conditions in the direction of Jamin Ginting were still relatively smooth but dense, with average vehicle speeds varying depending on the direction and type of vehicle. Vehicles traveling straight showed fairly high speeds, namely motorcycles around 32.5 km/h and cars 27.5 km/h, indicating a still stable flow in the main lane, only occasionally stopping because of a public transportation in front of it dropping off passengers or a vehicle in front wanting to cross, causing a slight obstruction. However, vehicles crossing to another road section had a slower speed because they had to change direction and interact with the flow of vehicles from the other direction. Under these conditions, the speed of motorcycles crossing dropped to around 22.5 km/h, and cars crossing to 17.5 km/h, reflecting the slowdown due to natural queues while waiting for a safe space to pass.

Public transportation vehicles (angkot) have the lowest speed, only around 20 km/h, because they often stop on the shoulder of the road without a clear stopping point. A similar situation occurs for becaks, with an average speed of 13 km/h. Obstacles from street vendors and illegal parking are still limited in the morning, so their impact on speed reduction is not significant.

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===================== PERIODE PAGI =====================

=== Baseline ===
Motor    (Lurus       ) | Waktu Tempuh: 43.67    s | Kecepatan: 32.5 km/jam
Motor    (Menyeberang ) | Waktu Tempuh: 150.6    s | Kecepatan: 22.5 km/jam
Mobil    (Lurus       ) | Waktu Tempuh: 74.17    s | Kecepatan: 27.5 km/jam
Mobil    (Menyeberang ) | Waktu Tempuh: 574.0    s | Kecepatan: 17.5 km/jam
Angkot   (Lurus       ) | Waktu Tempuh: 7895.0   s | Kecepatan: 20 km/jam
Becak    (Lurus       ) | Waktu Tempuh: 344.0    s | Kecepatan: 13 km/jam

=== Intervensi A - Hapus Parkir/PKL ===
Motor    (Lurus       ) | Waktu Tempuh: 42.17    s | Kecepatan: 35.75 km/jam
Motor    (Menyeberang ) | Waktu Tempuh: 170.0    s | Kecepatan: 24.75 km/jam
Mobil    (Lurus       ) | Waktu Tempuh: 69.33    s | Kecepatan: 30.25 km/jam
Mobil    (Menyeberang ) | Waktu Tempuh: 566.33   s | Kecepatan: 19.25 km/jam
Angkot   (Lurus       ) | Waktu Tempuh: 7790.0   s | Kecepatan: 22.0 km/jam
Becak    (Lurus       ) | Waktu Tempuh: 366.0    s | Kecepatan: 14.3 km/jam

=== Intervensi B - Tertib Angkot ===
Motor    (Lurus       ) | Waktu Tempuh: 46.83    s | Kecepatan: 32.5 km/jam
Motor    (Menyeberang ) | Waktu Tempuh: 146.4    s | Kecepatan: 22.5 km/jam
Mobil    (Lurus       ) | Waktu Tempuh: 74.17    s | Kecepatan: 27.5 km/jam
Mobil    (Menyeberang ) | Waktu Tempuh: 515.33   s | Kecepatan: 17.5 km/jam
Angkot   (Lurus       ) | Waktu Tempuh: 515.0    s | Kecepatan: 23.0 km/jam
Becak    (Lurus       ) | Waktu Tempuh: 434.0    s | Kecepatan: 13 km/jam

=== Intervensi C - Atur Menyeberang ===
Motor    (Lurus       ) | Waktu Tempuh: 44.5     s | Kecepatan: 32.5 km/jam
Motor    (Menyeberang ) | Waktu Tempuh: 99.8     s | Kecepatan: 24.75 km/jam
Mobil    (Lurus       ) | Waktu Tempuh: 75.0     s | Kecepatan: 27.5 km/jam
Mobil    (Menyeberang ) | Waktu Tempuh: 235.67   s | Kecepatan: 19.25 km/jam
Angkot   (Lurus       ) | Waktu Tempuh: 11535.0  s | Kecepatan: 20 km/jam
Becak    (Lurus       ) | Waktu Tempuh: 504.0    s | Kecepatan: 13 km/jam

=== Gabungan (A+B+C) ===
Motor    (Lurus       ) | Waktu Tempuh: 33.93    s | Kecepatan: 37.38 km/jam
Motor    (Menyeberang ) | Waktu Tempuh: 91.92    s | Kecepatan: 25.87 km/jam
Mobil    (Lurus       ) | Waktu Tempuh: 45.0     s | Kecepatan: 31.62 km/jam
Mobil    (Menyeberang ) | Waktu Tempuh: 250.27   s | Kecepatan: 20.12 km/jam
Angkot   (Lurus       ) | Waktu Tempuh: 1215.0   s | Kecepatan: 23.0 km/jam
Becak    (Lurus       ) | Waktu Tempuh: 241.0    s | Kecepatan: 14.95 km/jam
```

Figure 5. Simulation results of the direction towards Jalan Jamin Ginting-Afternoon Period (Baseline, Interventions A, B, C, and Combined)

In the following outputs after the interventions were implemented, there was an increase in speed across all vehicle types. The intervention of eliminating illegal parking and vendors increased the speed of each vehicle by 10%. Meanwhile, regulating public transportation (angkot) increased the speed of public transportation to 23 km/h and made the flow of vehicles more stable. Regulating the flow of crossings was also effective in increasing vehicle speeds to 25-26 km/h. The most significant increase was seen in the combined intervention (A+B+C), with the average speed of motorcycles reaching 37.38 km/h, cars 31.62 km/h, and public transportation 23 km/h, indicating an increase in vehicle flow efficiency of around 15% compared to the initial condition. The combination of eliminating side obstacles (street vendors and illegal parking), regulating public transportation stopping points, and regulating the flow of crossings proved to have a synergistic effect on improving the smoothness of the flow. These three factors complement each other: eliminating street vendors expands lane capacity, regulating public transportation reduces delays due to sudden stops, and regulating the flow of crossings maintains the stability of vehicle speeds. This explains why the combined scenario produced the greatest improvement compared to the single interventions.

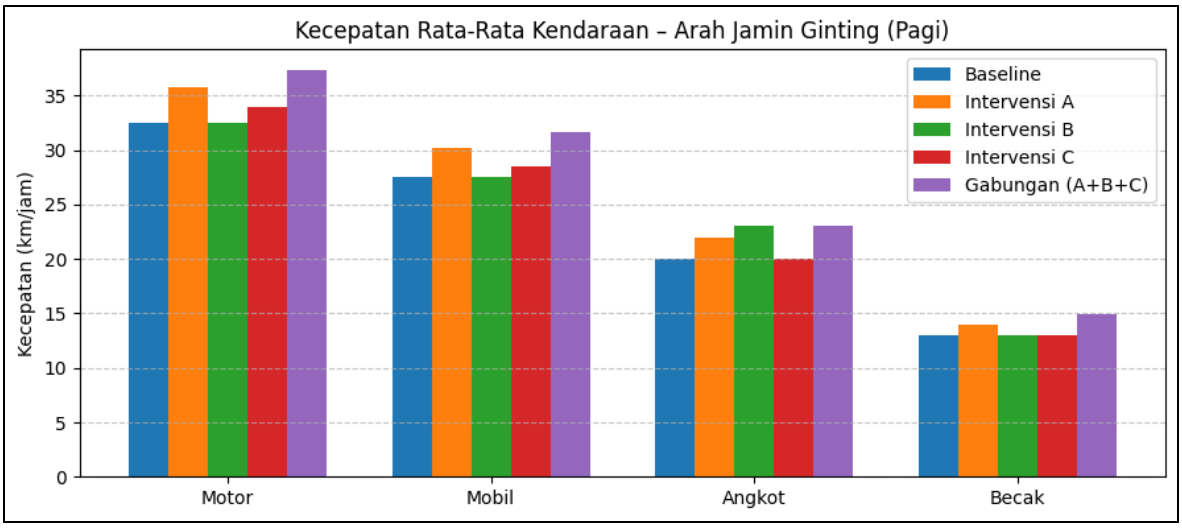

Figure 6. Jamin Ginting (Morning): Shows the difference in speed between baseline, interventions A, B, C and Combined

b. Afternoon Period (17.00-18.00 WIB)

Traffic conditions in the afternoon experience a sharp decline in performance compared to the morning. ATCS observations show that motorcycle speeds drop to around 17-18 km/h, cars to 12-14 km/h, and angkot to about 9 km/h. This decrease is caused by a significant rise in traffic volume, increased pedestrian and student activity, and the growth of roadside obstacles from only 2-3 points in the morning to approximately 13 points in the afternoonwhich narrows the effective lane width to around 3.5 meters.

The main disturbances include random stopping by angkot, lane narrowing due to street vendors and illegal parking, and crossing vehicles near the Pajus intersection. These factors create frequent conflict points, forcing vehicles to slow down, queue, and wait for safe gaps. In the ABM simulation, these conditions are represented by higher stopping probabilities and reduced maneuvering space, resulting in baseline speeds that closely match field observations. This alignment confirms that the afternoon congestion pattern is driven by the combined effects of lane narrowing, irregular stopping behavior, and intersection conflicts.

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==================== PERIODE SORE ====================

=== Baseline ===
Motor   (Lurus        ) | Waktu Tempuh: 128.13   s | Kecepatan: 17.5 km/jam
Motor   (Menyeberang  ) | Waktu Tempuh: 429.0    s | Kecepatan: 12.5 km/jam
Mobil   (Lurus        ) | Waktu Tempuh: 267.0    s | Kecepatan: 12.5 km/jam
Mobil   (Menyeberang  ) | Waktu Tempuh: 904.0    s | Kecepatan: 9 km/jam
Angkot  (Lurus        ) | Waktu Tempuh: 19360.0  s | Kecepatan: 9 km/jam
Becak   (Lurus        ) | Waktu Tempuh: 1246.0   s | Kecepatan: 5 km/jam

=== Intervensi A - Hapus Parkir/PKL ===
Motor   (Lurus        ) | Waktu Tempuh: 118.6    s | Kecepatan: 19.25 km/jam
Motor   (Menyeberang  ) | Waktu Tempuh: 430.0    s | Kecepatan: 13.75 km/jam
Mobil   (Lurus        ) | Waktu Tempuh: 228.0    s | Kecepatan: 13.75 km/jam
Mobil   (Menyeberang  ) | Waktu Tempuh: 918.0    s | Kecepatan: 9.9 km/jam
Angkot  (Lurus        ) | Waktu Tempuh: 22690.0  s | Kecepatan: 9.9 km/jam
Becak   (Lurus        ) | Waktu Tempuh: 1077.0   s | Kecepatan: 5.5 km/jam

=== Intervensi B - Tertib Angkot ===
Motor   (Lurus        ) | Waktu Tempuh: 127.6    s | Kecepatan: 17.5 km/jam
Motor   (Menyeberang  ) | Waktu Tempuh: 435.0    s | Kecepatan: 12.5 km/jam
Mobil   (Lurus        ) | Waktu Tempuh: 274.0    s | Kecepatan: 12.5 km/jam
Mobil   (Menyeberang  ) | Waktu Tempuh: 960.0    s | Kecepatan: 9 km/jam
Angkot  (Lurus        ) | Waktu Tempuh: 1197.0   s | Kecepatan: 10.35 km/jam
Becak   (Lurus        ) | Waktu Tempuh: 966.0    s | Kecepatan: 5 km/jam

=== Intervensi C - Atur Menyeberang ===
Motor   (Lurus        ) | Waktu Tempuh: 128.67   s | Kecepatan: 17.5 km/jam
Motor   (Menyeberang  ) | Waktu Tempuh: 268.0    s | Kecepatan: 13.75 km/jam
Mobil   (Lurus        ) | Waktu Tempuh: 283.0    s | Kecepatan: 12.5 km/jam
Mobil   (Menyeberang  ) | Waktu Tempuh: 414.0    s | Kecepatan: 9.9 km/jam
Angkot  (Lurus        ) | Waktu Tempuh: 20280.0  s | Kecepatan: 9 km/jam
Becak   (Lurus        ) | Waktu Tempuh: 1026.0   s | Kecepatan: 5 km/jam

=== Gabungan (A+B+C) ===
Motor   (Lurus        ) | Waktu Tempuh: 87.49    s | Kecepatan: 20.12 km/jam
Motor   (Menyeberang  ) | Waktu Tempuh: 232.0    s | Kecepatan: 14.37 km/jam
Mobil   (Lurus        ) | Waktu Tempuh: 144.0    s | Kecepatan: 14.37 km/jam
Mobil   (Menyeberang  ) | Waktu Tempuh: 495.4    s | Kecepatan: 10.35 km/jam
Angkot  (Lurus        ) | Waktu Tempuh: 3385.0   s | Kecepatan: 10.35 km/jam
Becak   (Lurus        ) | Waktu Tempuh: 572.0    s | Kecepatan: 5.75 km/jam
```

Figure 7. Simulation results of the direction towards Jalan Jamin Ginting – Afternoon Period (Baseline, Interventions A, B, C, and Combined)

The simulation results show that under baseline conditions, the average speed of motorcycles was only around 17.5 km/h, cars 12.5 km/h, public transportation 9 km/h, and pedicabs 5 km/h, depicting a traffic jam with unstable vehicle speeds. After the intervention of eliminating illegal parking and vendors (A), the average speed increased by around 13.25%, and reached 19.25 km/h for motorcycles and 13.75 km/h for cars. The intervention of public transportation regulation (B) also had a significant impact, with an increase in public transportation speed to 10.35 km/h.

The most optimal results were achieved with the combined intervention (A+B+C). The average speed of motorcycles increased to 20.12 km/h, cars to 14.37 km/h, and public transportation to 10.35 km/h, indicating an increase of up to 15-20% compared to the baseline. This increase indicates that the main cause of congestion on this route is not only vehicle volume, but also flow conflicts when vehicles cross to other sections and roadside activities that disrupt the effective capacity of the road.

Overall, the simulation results show that the removal of side barriers and the regulation of public transportation (angkot) had the greatest impact on increasing average vehicle speed. Speed is a more representative indicator than travel time because it reflects the smoothness of traffic flow and the efficiency of road use. With the implementation of these combined interventions, afternoon traffic flow became more stable and congestion was reduced.

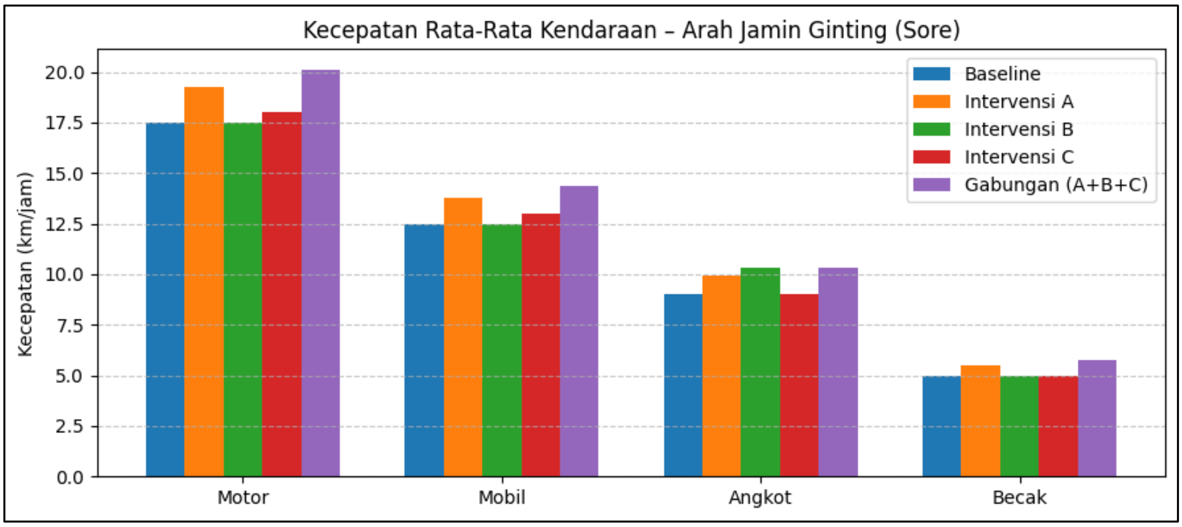

Figure 8. Jamin Ginting (Afternoon): Shows the difference in speed between baseline, interventions A, B, C and Combined

5. CONCLUSION

This study successfully modeled and simulated traffic conditions in front of the USU campus using a Python-based Agent-Based Modeling (ABM) approach. The model demonstrated strong alignment with field observations, with validation errors for average speed and travel time maintained below 10%, indicating high reliability.

The simulation results show that traffic congestion on the Setia Budi corridor is primarily caused by lane narrowing due to street vendors and illegal parking. In the afternoon peak hour, the effective lane width decreases from 6 meters to approximately 4 meters, causing motorcycle speeds to fall from 42.5 km/h to 15 km/h and car speeds from 35 km/h to around 11 km/h. Implementing light interventions such as partial vendor regulation and enforcing a single bus stop improves average vehicle speed by about 10%. When full intervention is applied, restoring lane width and enforcing structured angkot stopping behavior, the average speed increases by up to 20% compared to baseline conditions.

On the Jamin Ginting corridor, congestion is driven by three major factors: random stopping by angkot, illegal parking and roadside vendors that reduce the lane width to 3.5 meters, and conflict with crossing vehicles before the Pajus intersection. The combined intervention scenario removing roadside obstacles, regulating public transportation stops, and managing crossing movements produces the most significant improvements, increasing average speeds for motorcycles from 17.5 to 20.1 km/h, for cars from 12.5 to 14.3 km/h, and for angkot from 9.0 to 10.3 km/h, representing an overall 15-20% improvement in flow efficiency.

Based on these findings, several concrete policy recommendations can be proposed. First, the establishment and enforcement of official bus stops are essential to reduce random angkot stopping and shorten dwell times. Second, structured management of street vendors and the elimination of illegal parking are necessary to restore effective lane width during peak hours. Third, improved control of crossing movements either through physical barriers, designated crossing phases, or traffic wardens can reduce intersection conflicts that significantly disrupt flow on Jamin Ginting.

Overall, this study demonstrates that managing roadside activities and regulating public transport operations have an immediate and measurable impact on improving traffic performance. The ABM approach proves highly effective for evaluating such intervention strategies and can serve as a practical decision-support tool for urban traffic management in campus corridors and similar high-density urban areas.

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