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Performance Evaluation Of An Unsignalized Four-Leg Intersection And Traffic Signal Planning Using Ptv Vissim: A Case Study Of Panjalin Intersection, Majalengka

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ABSTRACT

Panjalin Intersection is a strategic four-leg junction connecting the Cirebon–Bandung national road with the Budur–Paningkiran provincial road in Majalengka Regency. Its unsignalized operation, intensive roadside commercial activity, and increasing peak-hour demand create recurring conflicts and unstable traffic movements. This study evaluates the existing intersection and develops a two-phase traffic-signal alternative using the 2023 Indonesian Road Capacity Guidelines (PKJI 2023) and PTV Vissim microscopic simulation. Primary data consisted of intersection geometry, seven-day classified turning-movement counts, vehicle speeds, and roadside-environment observations. Secondary data included population and road-status information. Under the existing condition, total demand reached 2,604 passenger-car units per hour, while the calculated capacity was 2,747.84 passenger-car units per hour. The resulting degree of saturation was 0.947, exceeding the PKJI design criterion of 0.85; the average intersection delay was 16.946 s/pcu and the upper queue-probability estimate was 71.63%. A two-phase signal plan with a 42-s cycle, 15.38-s green time for Phase 1, and 16.62-s green time for Phase 2 reduced approach degrees of saturation to 0.610–0.681, with an average of 0.649 and an average delay of 14.679 s/pcu. The Vissim scenario comparison also indicated reductions in average queue, maximum queue, stopped vehicles, and average travel time by 46.4%, 44.7%, 51.2%, and 21.7%, respectively. The combined analytical and simulation results show that installing a coordinated two-phase traffic signal is a technically reasonable short-term treatment, provided that signal timing, side friction, and queue development are monitored after implementation.

1. INTRODUCTION

Intersections are critical elements of an urban road network because different traffic streams compete for a limited conflict area. When an intersection is operated without traffic signals, drivers must identify acceptable gaps, negotiate priority, and anticipate movements from several directions. Under low and moderate demand, this arrangement may be efficient because vehicles do not wait for a fixed signal. However, once the demand approaches capacity, the same flexibility can generate irregular entry behavior, long queues on minor approaches, excessive delay, and increased exposure to crossing and merging conflicts. The performance of an unsignalized intersection is therefore highly sensitive to traffic composition, turning proportions, approach width, roadside activities, and driver behavior.

Majalengka Regency has experienced continuous development of residential, commercial, educational, and service activities. The expansion of these activities increases trip generation and

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strengthens the role of the Cirebon–Bandung corridor as a regional movement axis. Panjalin Intersection, located in Panjalin Kidul Village, Sumberjaya District, connects the east–west Cirebon–Bandung national road with the north–south Budur–Paningkiran provincial road. The intersection also provides access to local commercial areas. During peak periods, vehicles from the four approaches enter the conflict area with no formal signal allocation. Roadside parking, passenger loading and unloading, pedestrian movement, and access to adjacent businesses further reduce the effective space available for traffic.

The 2023 Indonesian Road Capacity Guidelines provide the national analytical framework for estimating capacity and operational performance for road segments and intersections [1]. For an unsignalized intersection, the principal performance indicator is the degree of saturation, defined as the ratio of demand to capacity. PKJI recommends maintaining the degree of saturation below 0.85 for planning and design evaluation. Delay and queue probability complement this indicator by describing the operational consequences perceived by road users. For signalized intersections, PKJI evaluates effective approach width, saturation flow, phase arrangement, lost time, cycle length, green allocation, capacity, queue length, stopped-vehicle ratio, and delay.

Indonesian traffic regulation recognizes the use of traffic-control devices at locations where traffic movements must be organized to improve order and safety [2]. Signalization is not automatically the best treatment for every junction, because an inappropriate cycle or phase arrangement can increase delay during low-demand periods. The decision should be based on demand, capacity, conflict patterns, geometry, safety considerations, environmental effects, and implementation cost. At a heavily loaded four-leg junction, however, signal control can create clearly separated right-of-way intervals, reduce simultaneous conflicts, and provide a predictable sequence of movements.

Microscopic simulation is useful for complementing deterministic capacity analysis. PTV Vissim represents individual vehicles and their interactions with links, connectors, priority rules, signal controllers, and other road users [3]. It allows planners to compare an existing network with alternative traffic-management scenarios before physical construction. Previous Indonesian studies have used Vissim to evaluate unsignalized intersections, signal timing, widening alternatives, and traffic-management schemes. Mufhidin and Chaniago [4] demonstrated its usefulness for evaluating unsignalized intersections and adjacent road sections. Hadi and Khairurrasyid [5] applied Vissim to a four-leg unsignalized intersection in East Lombok and reported that queue and delay indicators can identify time-dependent operational problems. Putri et al. [6] showed that combining PKJI 2023 with Vissim supports the selection of geometric and signal alternatives for a congested urban intersection.

Other studies emphasize that analytical and simulation results should be interpreted together rather than treated as interchangeable. Jalus et al. [7] showed that modifying signal cycles and intergreen sequences can substantially reduce queue length and delay in a Vissim model. Ado et al. [8] applied simulation to assess signalized-intersection performance and develop improvement alternatives. Theodora et al. [9] noted that PKJI is deterministic, whereas Vissim is stochastic and explicitly represents vehicle interactions; consequently, the two methods may produce different delay and queue estimates. Pedo et al. [10] similarly used PKJI 2023 and calibrated Vissim simulation to formulate traffic-management recommendations. These studies support a combined workflow in which PKJI establishes the design basis and simulation tests operational behavior under the proposed arrangement.

The draft field investigation at Panjalin Intersection identified four practical questions. First, does the existing unsignalized intersection still provide adequate capacity during the observed peak hour? Second, what phase arrangement and signal timing are suitable for the existing geometry and directional demand? Third, how does the proposed signal plan perform according to PKJI 2023? Fourth, does the microscopic simulation indicate an operational improvement when the unsignalized and signalized scenarios are compared using common performance measures?

This research addresses those questions by integrating a seven-day traffic survey, PKJI 2023 calculations, and PTV Vissim Student Version modelling. The study contributes a site-specific evaluation for a strategic junction in Majalengka and demonstrates a practical procedure that can be adopted by local road agencies and civil-engineering practitioners. The novelty lies in the direct comparison of the existing unsignalized condition with a two-phase APILL plan using both national capacity procedures and microscopic simulation outputs. The results are intended to support preliminary decision-making; final implementation should be accompanied by detailed engineering design, field verification, and post-installation monitoring.

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2. METHOD

2.1 Study location and intersection characteristics

The study was conducted at Panjalin Intersection in Panjalin Kidul Village, Sumberjaya District, Majalengka Regency, West Java. The junction is formed by four two-way approaches. The east and west approaches are parts of the Cirebon–Bandung national road and have a total roadway width of approximately 12 m, or about 6 m per directional carriageway at the intersection. The north approach is Budur Road and the south approach is Paningkiran Road; both are provincial roads with a total width of approximately 8 m, or about 4 m per directional carriageway. Sidewalks of approximately 1.2 m are present along parts of the approaches.

The surrounding land use is predominantly commercial. Shops, food outlets, informal stopping activity, pedestrians, and vehicles entering or leaving roadside properties produce high side friction. The draft recorded a 2025 population of 1,369,569 for Majalengka Regency, placing the study area in the PKJI city-size category used in the capacity calculations. The physical layout is slightly skewed rather than perfectly orthogonal, which affects turning paths and the location of potential conflict points.

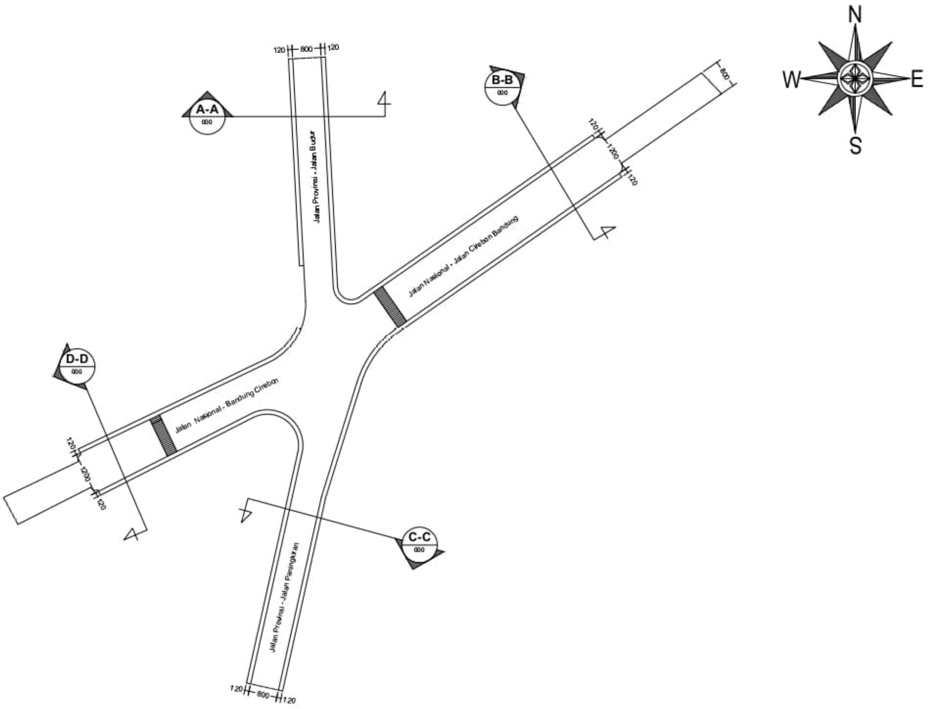

Figure 1. Geometric layout and road orientation at Panjalin Intersection (field drawing, 2025).

North approach (Budur Road) East approach (Cirebon-Bandung Road)

South approach (Paningkiran Road) West approach (Bandung-Cirebon Road)

Figure 2. Field conditions on the four approaches of Panjalin Intersection.

Table 1. Main geometric and environmental characteristics of the study intersection.

Approach	Road / direction	Road status	Approx. width	Environment
East	Cirebon–Bandung Road	National road	12 m total; 6 m approach	Commercial; high side friction
West	Bandung–Cirebon Road	National road	12 m total; 6 m approach	Commercial; high side friction
North	Budur Road	Provincial road	8 m total; 4 m approach	Commercial; high side friction
South	Paningkiran Road	Provincial road	8 m total; 4 m approach	Commercial; high side friction

2.2 Data collection

Primary data were collected through direct field observation. The geometric survey measured the width of each entry and exit, shoulder or sidewalk space, median condition, and the location of roadside activities that could reduce effective approach width. A speed survey was carried out by observing representative motorcycles, passenger cars, medium vehicles, and heavy vehicles on each approach. Environmental observation focused on parking, stopping public transport, pedestrian activity, informal trading, and access movements near the intersection.

Classified turning-movement counts were conducted for seven consecutive days, from Monday to Sunday. Counts were made in three one-hour periods: 06:30–07:30, 11:30–12:30, and 16:00–17:00 local time. On Friday, the midday survey was shifted to 10:30–11:30. Eight surveyors were assigned to four counting stations, with two surveyors on each approach. The first surveyor recorded selected turning movements and the second recorded the remaining movements, allowing left-turn, through, and right-turn volumes to be reconstructed by approach and vehicle type.

Observed vehicles were classified as passenger cars, medium vehicles, heavy vehicles, motorcycles, and non-motorized vehicles. For the unsignalized PKJI analysis, the draft used passenger-car-equivalent values of 1.0 for passenger cars, 1.3 for medium vehicles, and 0.5 for motorcycles. For the opposed signalized approaches, the motorcycle equivalent was adjusted to 0.4 in accordance with the procedure adopted in the draft. Non-motorized vehicles were considered in the side-friction assessment rather than

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added directly to the motorized flow. The peak-hour dataset was selected from the seven-day observation as the most demanding hour for operational evaluation.

Secondary data comprised population information, road classification, and road-network maps from the relevant local agencies. These data were used to determine the city-size correction factor and to describe the institutional status of the national and provincial road approaches. The study did not change the road classification or assume new lanes beyond the existing geometric envelope.

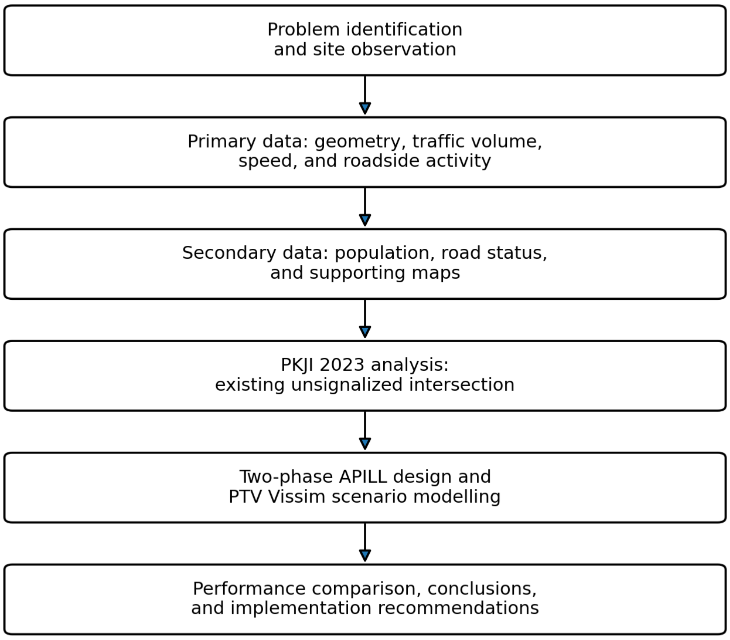

Figure 3. Research and analysis workflow.

2.3 PKJI 2023 analysis of the existing unsignalized intersection

The unsignalized-intersection analysis followed the PKJI 2023 sequence [1]. Directional vehicle counts were converted to passenger-car units per hour (pcu/h). Total major-road flow, minor-road flow, left-turn flow, right-turn flow, and through flow were calculated. The ratios of minor-road flow, left-turn flow, right-turn flow, and non-motorized vehicles were then used to determine the relevant correction factors.

The intersection was classified as type 422: four arms, two lanes on the major road, and two lanes on the minor road. Its basic capacity was 2,900 pcu/h. The adjusted capacity was calculated from the basic capacity and correction factors for average approach width, major-road median, city size, side friction, left-turn ratio, right-turn ratio, and minor-road flow ratio. The average approach width was 5 m. The major road had no median. The environment was commercial with high side friction. The performance measures were the degree of saturation, intersection delay, and queue probability. The study applied the PKJI design criterion that a degree of saturation above 0.85 indicates that the existing arrangement requires improvement.

$$C = C^{0} \times F^{LP} \times F^{M} \times F^{UK} \times F^{HS} \times F^{BKi} \times F^{BKa} \times F^{Rmi}$$

Equation (1). Adjusted capacity of an unsignalized intersection according to PKJI 2023.

2.4 Development of the signalized-intersection alternative

The proposed APILL arrangement was designed as a two-phase fixed-time system. Phase 1 serves the east–west movements on the Cirebon–Bandung corridor, while Phase 2 serves the north–south movements on Budur and Paningkiran Roads. A two-phase system was selected as the initial alternative because it minimizes the number of phase changes and generally preserves more effective green time than a three- or four-phase arrangement, provided that opposing right-turn movements can remain under opposed operation. The analysis therefore treated all approaches as opposed type O approaches.

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All-red time was estimated for each phase by considering the clearance distance, vehicle length, and assumed approach and departure speeds. The calculated all-red times were 1.209 s for Phase 1 and 1.388 s for Phase 2. A yellow interval of 3 s per phase produced a total lost time of 9.59 s per cycle. Effective approach widths were 6 m for the east and west approaches and 4 m for the north and south approaches. Basic saturation flows were derived from the PKJI opposed-approach graphs and then adjusted for city size, side friction, grade, and parking effects.

The critical flow ratios were 0.262 for Phase 1 and 0.276 for Phase 2, giving a total critical flow ratio of 0.538. The calculated cycle length was rounded to 42 s. Effective green times were allocated in proportion to the phase flow ratios, resulting in 15.38 s for Phase 1 and 16.62 s for Phase 2. The remaining cycle time consisted of yellow and all-red intervals. Approach capacities were computed from adjusted saturation flow multiplied by the green-to-cycle ratio. Performance measures included approach degree of saturation, queue length, stopped-vehicle ratio, and delay.

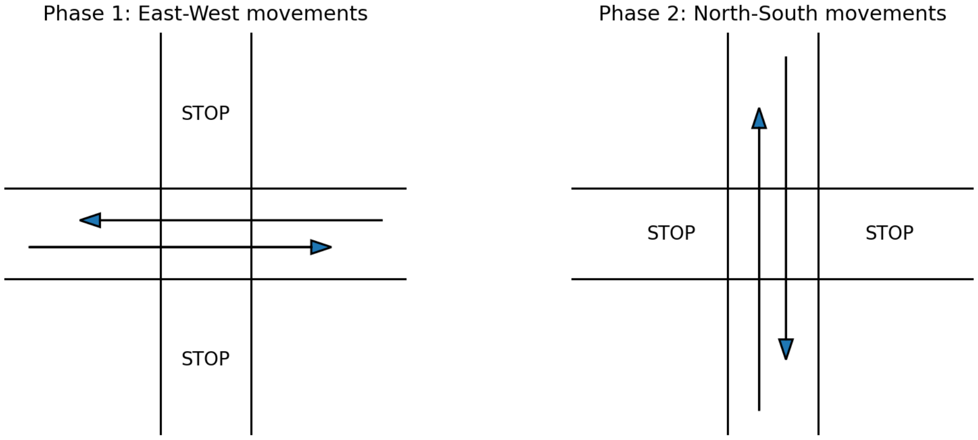

Figure 4. Proposed two-phase movement plan for Panjalin Intersection.

2.5 PTV Vissim model and scenario comparison

The microscopic model was developed in PTV Vissim Student Version, which is intended for academic traffic-simulation applications [11]. The network was constructed from the measured geometry using links and connectors for the four approaches and all permitted turning movements. Directional traffic inputs were assigned from the observed peak-hour flows. Vehicle classes and desired-speed inputs reflected the field classification and speed observations. Route decisions distributed vehicles to left-turn, through, and right-turn movements in accordance with the observed turning proportions.

Two scenarios were modelled. Scenario 1 represented the existing unsignalized intersection using priority and conflict-area settings. Scenario 2 introduced the fixed-time two-phase signal controller derived from the PKJI design. Queue counters, node evaluation, and vehicle travel-time measurements were used to obtain average queue length (QLEN), maximum queue length (QLENMAX), stopped vehicles (QSTOPS), and average travel time (TRAVTM). The draft simulation summary reported two model runs and descriptive statistics. Because the Student Version and the available draft output did not provide a complete calibration report, the simulation results were used primarily for relative scenario comparison rather than as a replacement for the PKJI design calculation.

This interpretation follows the approach used in previous studies: deterministic capacity procedures define the planning threshold and signal timing, while microscopic simulation provides additional information about vehicle interactions, spatial queue development, and the relative response of the network to an alternative design [6], [9], [10]. The percentage change for each Vissim indicator was calculated as the difference between the existing and signalized scenarios divided by the existing value.

3. RESULTS AND DISCUSSION

3.1 Peak-hour traffic demand and movement pattern

The selected peak-hour demand was dominated by motorcycles. In the unsignalized analysis, motorcycles represented approximately 73.37% of the motorized traffic count, passenger cars 10.48%, and medium vehicles 15.85%. The high motorcycle proportion is operationally important because motorcycles can occupy lateral gaps, form multiple queues within a nominal lane, and enter the conflict area with behavior that is not fully represented by lane-based capacity concepts. The commercial roadside environment also creates frequent disturbances near the entries.

After conversion to passenger-car units for the signalized analysis, the east approach carried 704 pcu/h, the west approach 627 pcu/h, the south approach 416 pcu/h, and the north approach 434 pcu/h. The left-turn ratios were 0.38, 0.18, 0.23, and 0.43 for the east, west, south, and north approaches, respectively. The corresponding right-turn ratios were 0.07, 0.17, 0.40, and 0.14. The south approach therefore had the highest right-turn proportion, while the north approach had the highest left-turn proportion. These differences are important for opposed signal operation because turning vehicles can interfere with opposing through traffic.

Table 2. Peak-hour flow and turning ratios used in the signalized-intersection analysis.

Approach	Flow (pcu/h)	Left-turn ratio	Right-turn ratio	Effective width
East	704	0.38	0.07	6 m
West	627	0.18	0.17	6 m
South	416	0.23	0.40	4 m
North	434	0.43	0.14	4 m

3.2 Existing unsignalized-intersection performance

The total entering flow for the unsignalized calculation was 2,604 pcu/h. The major-road flow was 1,492 pcu/h and the minor-road flow was 1,111 pcu/h. The total left-turn, through, and right-turn flows were 605, 1,217, and 782 pcu/h, respectively. These values indicate substantial cross and turning demand rather than a simple major-road-dominant pattern. The minor-road flow ratio and the high right-turn volume increase the number of interactions inside the conflict area.

The adjusted capacity was 2,747.84 pcu/h. Dividing demand by capacity produced a degree of saturation of 0.947. This value is 11.4% higher than the PKJI planning threshold of 0.85. A junction operating at this level has little residual capacity to absorb short-term fluctuations, non-uniform arrivals, or temporary blockages caused by roadside activity. The calculated average delay was 16.946 s/pcu and the upper queue-probability estimate was 71.63%. The draft classified the operational condition as level of service E, reflecting unstable operation and significant interference.

The result confirms the field observation that the lack of formal right-of-way allocation is no longer appropriate during the peak hour. Even though the numerical capacity is slightly higher than the mean entering flow, the small margin between demand and capacity means that ordinary variability can generate queues. The value also explains why congestion becomes more visible on weekends, holidays, and periods when roadside stopping activity increases.

Table 3. PKJI 2023 performance of the existing unsignalized intersection.

Indicator	Result	Interpretation
Total entering flow	2,604 pcu/h	High peak-hour demand
Adjusted capacity	2,747.84 pcu/h	Limited residual capacity
Degree of saturation	0.947	Above the 0.85 design criterion
Average delay	16.946 s/pcu	Substantial operational delay
Upper queue probability	71.63%	High likelihood of queue formation
Reported service level	E	Unstable / constrained operation

3.3 Signal timing and approach capacity

The calculated two-phase cycle of 42 s is within the PKJI recommended range for a two-phase signal. Phase 1 received 15.38 s of effective green and Phase 2 received 16.62 s. The green ratios were approximately 0.371 and 0.399. The short cycle limits red time and is suitable for a compact intersection with moderate approach lengths. However, practical implementation should verify that the all-red intervals are sufficient for the actual skewed geometry and that pedestrian crossing needs are accommodated.

Approach capacities were 1,034 pcu/h for the east, 1,027 pcu/h for the west, 665 pcu/h for the south, and 637 pcu/h for the north. The resulting degrees of saturation ranged from 0.610 to 0.681. The east and north approaches had the highest values, 0.680 and 0.681, respectively, but all approaches remained below

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the 0.85 criterion. The average approach degree of saturation was 0.649. This reduction from 0.947 indicates that temporal separation of movements can use the available intersection space more effectively despite the lost time associated with the signal.

Calculated queue lengths ranged from 18.42 to 22.06 m. The east approach had the longest calculated queue, followed by the north approach. These queues can generally be stored within the approach area shown in the field drawing, but the result should be checked against the location of driveways, roadside parking, and pedestrian crossings. The average signalized-intersection delay was 14.679 s/pcu. Delay values by approach were relatively balanced, ranging from 13.864 to 15.787 s. Balanced delay is a desirable feature because it indicates that the green allocation does not excessively disadvantage one approach.

Table 4. Two-phase signal timing and approach performance according to PKJI 2023.

Parameter	East	West	South	North
Flow (pcu/h)	704	627	416	434
Adjusted saturation flow (pcu/h)	2,689	2,715	1,590	1,572
Capacity (pcu/h)	1,034	1,027	665	637
Degree of saturation	0.680	0.610	0.625	0.681
Calculated queue length (m)	22.06	18.42	18.75	21.06
Delay (s/pcu)	15.094	13.864	14.050	15.787

Table 5. Principal parameters of the proposed signal controller.

Parameter	Phase 1	Phase 2	Intersection total / note
Served movement	East–West	North–South	Two-phase fixed-time control
Critical flow ratio	0.262	0.276	0.538
All-red time	1.209 s	1.388 s	Yellow time = 3 s/phase
Effective green	15.38 s	16.62 s	Cycle length = 42 s
Green ratio	0.371	0.399	Total lost time = 9.59 s

3.4 PTV Vissim scenario results

The Vissim summary showed that the signalized scenario reduced all four reported comparison indicators. Average queue length decreased from 2.8 to 1.5 in the reported simulation units, equivalent to a 46.4% reduction. Maximum queue length decreased from 7.6 to 4.2, or 44.7%. The number of stopped vehicles decreased from 82 to 40, corresponding to a 51.2% reduction. Average travel time decreased from 2.3 to 1.8 in the reported travel-time units, or 21.7%.

The largest proportional improvement occurred in the number of stopped vehicles. At first glance, a traffic signal might be expected to increase stopping because red intervals deliberately halt vehicles. In this model, however, the unsignalized condition created repeated stop-and-go interactions as vehicles searched for gaps and yielded within the conflict area. The signalized scenario organized these interactions into clear movement intervals, reducing the number of unproductive stops and the spread of queue formation.

The reduction in maximum queue is especially important for the study location. Long queues on the national-road approaches can block access to roadside businesses and can propagate toward adjacent road sections. On the provincial approaches, queues can interfere with the narrower 4-m entries. The simulated improvement is consistent with the PKJI result that all signalized approaches operate below the saturation threshold. Nevertheless, Vissim outputs should be interpreted as scenario indicators because the draft did not include a complete calibration and validation table such as GEH statistics, travel-time error, or queue-length error. Future work should document these measures before using the model for final controller programming.

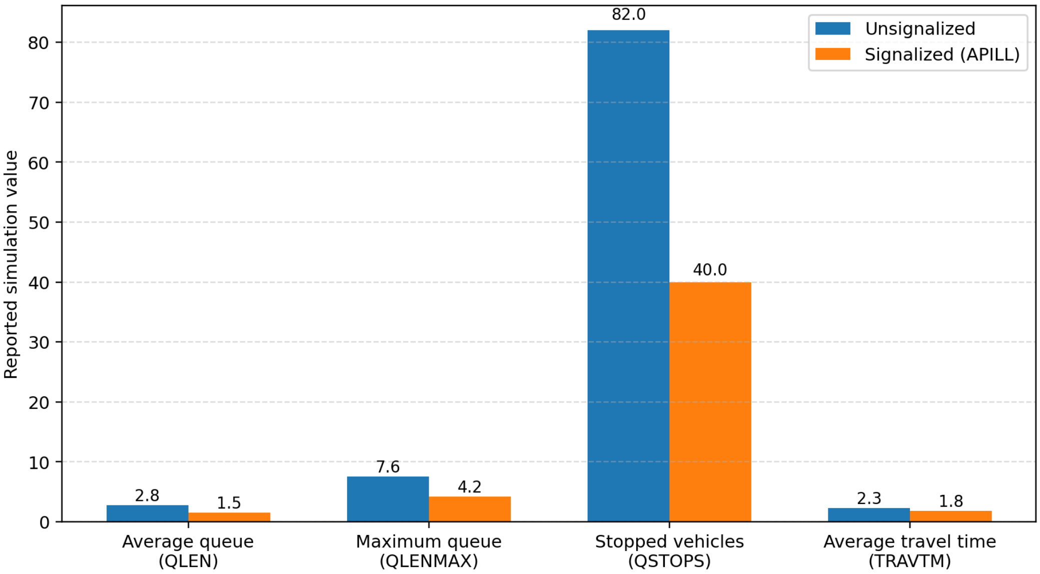

Figure 5. Comparison of the reported PTV Vissim performance indicators for the existing and signalized scenarios.

Table 6. Relative change in PTV Vissim performance indicators.

Indicator	Unsignalized	Signalized	Change
Average queue (QLEN)	2.8	1.5	−46.4%
Maximum queue (QLENMAX)	7.6	4.2	−44.7%
Stopped vehicles (QSTOPS)	82	40	−51.2%
Average travel time (TRAVTM)	2.3	1.8	−21.7%

3.5 Comparison with previous studies

The direction of improvement obtained in this study is consistent with earlier intersection-simulation research. Hadi and Khairurrasyid [5] found that queue length and delay were effective indicators for evaluating an unsignalized four-leg intersection in a commercial area. Mufhidin and Chaniago [4] similarly demonstrated that Vissim can identify operational differences between intersection and road-section conditions that are difficult to describe using only aggregate volume-to-capacity ratios. The Panjalin case extends this approach by explicitly designing a PKJI-based signal alternative and comparing it with the existing priority operation.

Jalus et al. [7] reported that changes in cycle time and intergreen sequence reduced average queues and delay at a signalized intersection. The Panjalin design reaches the same general conclusion, although the treatment begins from an unsignalized condition. Ado et al. [8] and Putri et al. [6] also emphasize that the best alternative depends on local demand, approach geometry, and turning proportions. The results should therefore not be generalized as evidence that every congested unsignalized junction must be signalized. Instead, they demonstrate that signalization is appropriate at this site because the existing degree of saturation is above the national planning threshold and the two-phase alternative distributes capacity adequately among the approaches.

The difference between deterministic and microscopic results should also be recognized. PKJI calculates capacity and delay from standardized relationships and average traffic conditions, while Vissim models individual arrivals and interactions. Theodora et al. [9] observed that the two methods can produce different queue and delay values even after model validation. In the Panjalin study, PKJI provides the defensible design criterion—degree of saturation below 0.85—whereas Vissim illustrates the relative reduction in queues, stops, and travel time. Using both methods produces a more complete decision basis than relying on either method alone.

Table 7. Relationship between the Panjalin findings and selected previous studies.

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Study	Method	Main relevance to the present study
Mufhidin and Chaniago [4]	Vissim; unsignalized intersection and road section	Supports microscopic evaluation of queue and travel performance
Hadi and Khairurrasyid [5]	Vissim; four-leg unsignalized intersection	Confirms the importance of commercial side friction and time-dependent queues
Putri et al. [6]	MKJI, PKJI 2023, and Vissim	Demonstrates integrated analytical and simulation-based alternative selection
Jalus et al. [7]	Vissim; signal-cycle improvement	Shows that cycle and intergreen adjustment can reduce queue and delay
Theodora et al. [9]	PKJI 2023 and validated Vissim	Explains differences between deterministic and stochastic outputs
Pedo et al. [10]	PKJI 2023 and calibrated Vissim	Uses combined analysis to formulate traffic-management recommendations

3.6 Engineering implications and implementation requirements

The proposed two-phase APILL should be treated as a preliminary engineering design. Before installation, the road authority should repeat the turning-movement survey to confirm that the selected peak hour remains representative. Surveys should include weekday and weekend conditions, school and market peaks, and holiday traffic. The signal-controller plan should then be checked for minimum green time, pedestrian clearance, intergreen safety, and coordination with any nearby traffic-control devices.

Roadside management is essential. Signalization alone cannot fully improve performance if parking, passenger loading, or informal commercial activity occupies the approach area. No-parking and no-stopping controls should be introduced within an appropriate distance from the stop line. Clearly visible lane arrows, stop lines, pedestrian crossings, warning signs, and approach markings should be installed. Where feasible, access points near the intersection should be consolidated or managed to reduce turning conflicts.

The high motorcycle share requires particular attention to stop-line design and driver behavior. A motorcycle waiting area may be considered if it can be designed safely and consistently with national guidance. Enforcement and public education should accompany signal activation because early non-compliance can undermine the intended phase separation. The operating agency should also prepare a transition plan for the first weeks of operation, including field personnel during the initial adjustment period.

After implementation, performance should be monitored at regular intervals. Recommended indicators include hourly approach volume, maximum queue length, average delay, red-light compliance, crash and near-miss records, and roadside stopping activity. Signal timing should be reviewed whenever one or more approaches approach a degree of saturation of 0.85. If demand becomes strongly time-dependent, the fixed-time plan can be expanded into time-of-day plans or an actuated/adaptive controller. Such an upgrade should use detector data and should be evaluated through a newly calibrated simulation model.

The study has several limitations. The available draft summarizes the field and simulation results but does not provide raw turning-count spreadsheets, complete Vissim parameter settings, or formal calibration statistics. The Student Version may also restrict network size and some advanced functions. The analysis represents the observed peak hour and does not include traffic growth, crash-cost analysis, pedestrian demand modelling, or life-cycle economic evaluation. These limitations do not invalidate the identified capacity problem, but they define the additional work needed before detailed design and procurement.

3.7 Demand-growth sensitivity

The previous results describe the observed peak hour and should not be interpreted as a long-term traffic forecast. Nevertheless, a simple demand-sensitivity test is useful for understanding how much operational reserve remains in each scenario. The test holds geometry, traffic composition, turning proportions, saturation flow, side friction, and signal timing constant, while increasing all approach flows by the same percentage. Under those assumptions, the degree of saturation changes in direct proportion to demand. This is not a substitute for a formal traffic forecast, because actual growth may differ by approach and may be accompanied by changes in land use, vehicle composition, or roadside activity.

For the unsignalized condition, the current degree of saturation is already 0.947. A uniform 5% increase in traffic would raise it to approximately 0.994, leaving almost no theoretical reserve. A 10% increase would raise it to 1.042, and a 15% increase would raise it to 1.089. Once the value exceeds 1.0,

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the average demand is greater than the calculated capacity, so residual queues are expected to accumulate from one analysis period to the next. This sensitivity result reinforces the conclusion that retaining the existing priority operation would provide poor resilience even under modest demand growth.

The proposed signal plan has substantially more reserve. With a 10% uniform increase, the highest approach degree of saturation would be approximately 0.749. With a 20% increase, the east and north approaches would reach approximately 0.816 and 0.817, respectively, while the west and south approaches would remain below 0.76. A 25% uniform increase would bring the highest approach close to the 0.85 design criterion. In other words, under the simplifying assumptions of this sensitivity test, the proposed fixed-time plan provides an approximate demand reserve of 24–25% before the critical approach reaches the planning threshold.

This reserve should not be treated as a guaranteed service life. The actual rate at which capacity is consumed will depend on directional growth, changes in turning movements, parking and access activity, motorcycle behavior, signal compliance, and the effectiveness of roadside management. For example, growth concentrated on the north approach would exhaust the available reserve sooner than uniform growth. Conversely, strict removal of parking near the stop line and improved lane discipline could preserve or increase effective capacity. The practical value of the sensitivity test is therefore to identify the approaches that should receive priority in future monitoring: east and north are the most critical, followed by south and west.

Table 8. Sensitivity of degree of saturation to uniform demand growth (capacity and signal timing held constant).

Demand scenario	Unsignalized	East	West	South	North
Observed peak hour	0.947	0.680	0.610	0.625	0.681
+5% demand	0.994	0.714	0.641	0.656	0.715
+10% demand	1.042	0.748	0.671	0.688	0.749
+15% demand	1.089	0.782	0.702	0.719	0.783
+20% demand	1.136	0.816	0.732	0.750	0.817
+25% demand	1.184	0.850	0.763	0.781	0.851

3.8 Safety, environmental, and institutional considerations

The performance analysis focuses on capacity, delay, and queues, but the decision to signalize an intersection also has safety implications. The existing unsignalized junction exposes vehicles to simultaneous crossing, merging, and turning conflicts. A properly designed signal can reduce these conflicts by assigning right of way in time. The two-phase plan is particularly simple for drivers to understand because each phase serves one road axis. However, signalization can introduce different risks, including rear-end collisions during the transition to red, red-light violations, and conflicts involving permissive right turns. A formal road-safety audit should therefore be conducted at the preliminary-design and pre-opening stages.

The safety audit should verify sight distance to signal heads, the visibility and placement of stop lines, the clearance interval, pedestrian crossing distance, night-time lighting, drainage, pavement condition, and the location of utility poles or signs. The skewed geometry shown in Figure 1 requires special attention because the longest vehicle path through the conflict area may not align with a simple rectangular clearance assumption. Heavy vehicles and slow motorcycles should be considered when checking all-red time. If pedestrian demand is significant, the cycle and phase plan may need a protected pedestrian interval or a longer minimum green time than the purely vehicle-based calculation.

The Vissim output tables in the draft included fields for fuel consumption and emissions, but the final comparison summarized only queue, stops, and travel time. The present article therefore does not claim a quantified environmental benefit. It is reasonable to expect that fewer repeated stops and shorter travel time can reduce unnecessary acceleration and idling, but a fixed signal can also create red-time idling during low-demand periods. An environmental assessment should use a calibrated model, consistent vehicle-emission factors, and comparable simulation periods. Until such an assessment is completed, environmental improvement should be regarded as a potential co-benefit rather than a verified result.

Implementation also requires institutional coordination because the intersection connects a national road and provincial roads within a regency. The road authority responsible for each approach, the local transportation agency, traffic police, utility providers, and nearby property owners should agree on the design, construction sequence, power supply, maintenance responsibility, and enforcement arrangements. Signal equipment should have reliable electrical protection, backup operation, accessible controller cabinets, and a maintenance schedule. The agency should establish a response procedure for lamp failure, detector failure, power interruption, and abnormal queues.

A staged implementation process is recommended. The first stage is detailed design and renewed traffic data collection. The second stage includes geometric preparation, markings, signs, signal poles, and roadside-access control. The third stage is controller commissioning with temporary field supervision. The fourth stage is an evaluation after one month and again after three to six months. Timing adjustments should be based on measured approach queues and saturation, not solely on complaints or visual impressions. This process converts the proposed signal from a static construction project into an actively managed traffic-control system.

Table 9. Recommended implementation and monitoring actions.

Stage	Main action	Minimum evidence / output
1. Verification	Repeat peak-hour counts, speed survey, pedestrian count, and safety review	Updated design traffic, confirmed geometry, safety-audit findings
2. Detailed design	Finalize phase plan, intergreen, signal-head layout, markings, signs, and power supply	Approved drawings, controller schedule, bill of quantities
3. Site preparation	Remove near-stop-line parking, manage access, install markings and signs	Clear approach storage and visible lane assignment
4. Commissioning	Activate signal with field officers and public information	Controller test record and initial compliance observations
5. Post-opening review	Measure queues, delay, saturation, violations, and incidents	One-month and three-to-six-month evaluation reports
6. Future optimization	Introduce time-of-day or actuated control when demand patterns diverge	Revised timing plans supported by detector and survey data

4. CONCLUSION

The existing unsignalized Panjalin Intersection operates above the PKJI 2023 planning threshold during the selected peak hour. Total entering demand was 2,604 pcu/h, adjusted capacity was 2,747.84 pcu/h, and the degree of saturation reached 0.947. The calculated average delay was 16.946 s/pcu and the upper queue-probability estimate was 71.63%. These results confirm that the junction has insufficient operational reserve and is vulnerable to recurring congestion when traffic fluctuates or roadside interference increases.

A two-phase APILL arrangement provides a feasible short-term improvement using the existing approach geometry. The proposed 42-s cycle allocates 15.38 s of effective green to east–west traffic and 16.62 s to north–south traffic. Approach degrees of saturation fall to 0.610–0.681, with an average of 0.649. The average calculated delay becomes 14.679 s/pcu, and approach queues remain approximately 18–22 m. All approaches therefore satisfy the PKJI saturation criterion under the analysed demand.

The microscopic scenario comparison supports the analytical result. Relative to the unsignalized model, the signalized model reduced average queue, maximum queue, stopped vehicles, and average travel time by 46.4%, 44.7%, 51.2%, and 21.7%, respectively. The principal benefit is not merely a reduction in average delay but the organization of conflicting movements into predictable right-of-way intervals.

Accordingly, the installation of a two-phase traffic signal at Panjalin Intersection is recommended for detailed engineering evaluation. Implementation should include clearance-time verification, lane and pedestrian markings, roadside-parking control, public education, and post-installation monitoring. A future study should provide complete Vissim calibration and validation, evaluate pedestrian and safety performance, and test time-of-day or adaptive signal control as traffic demand grows.

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