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Research Paper

The Analytical Hierarchy Process-Based Geometric Feasibility And Safety Optimization In Road Intersection Planning

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Abstract
Intersection planning within a constrained road corridor has to be defensible on three counts at once: conformity with geometric standards, adequacy of traffic performance, and the priority accorded to road safety. This paper proposes an Analytical Hierarchy Process (AHP)-based framework in which geometric feasibility acts as the first filter and safety optimization as the dominant decision criterion, and applies it to the redevelopment of the Paringin Intersection in Balangan Regency, South Kalimantan, Indonesia. The scheme prepared for that intersection is a roundabout whose central island measures only 5 metres in diameter. That figure is a quarter of the smallest dimension permitted by Circular Letter No. 14/SE/Db/2024 of the Directorate General of Highways and Minister of Transportation Regulation No. PM 96/2015, both of which require 20 to 27 metres, while the right-of-way available on site is roughly 15 metres and therefore rules out widening through land acquisition. The intersection is nonetheless a node on a primary arterial national road crossed daily by semi-trailer trucks longer than 12 metres serving the mining and plantation sectors. The framework runs along three tracks: a conformity test of the planned dimensions against geometric standards; a traffic performance analysis following the Indonesian Highway Capacity Guidelines (PKJI 2023) for both the existing roundabout and a signalized alternative; and multi-criteria weighting using AHP supported by Expert Choice v.11. Primary data comprise a classified traffic count covering one complete weekly cycle (1–7 June 2026), field geometric measurements, and pairwise questionnaires completed by seven expert respondents together with a simple-scale survey of sixteen road users. All six dimensional parameters of the planned roundabout fall below the required minima, and its input variables lie outside the calibration range of the PKJI 2023 weaving capacity equation, so its performance cannot be modelled at all. Peak-hour flows range from 1,200.5 to 1,657.2 pcu/hour with an annual average daily traffic of 19,388 vehicles/day. The existing roundabout returns a maximum degree of saturation of 0.71, whereas a four-phase signalized intersection operating on an 80-second cycle returns 0.65 with an average delay of 32.6 sec/pcu, equivalent to level of service D. AHP weighting places Safety and OHSE at 41.1 per cent, Regulatory Compliance at 28.9 per cent, Traffic Performance at 15.6 per cent, and Economic and Land Feasibility at 14.3 per cent, with a consistency ratio of 0.045, producing global weights of 82.2 per cent for the signalized intersection against 17.8 per cent for the roundabout. The 5-metre roundabout therefore cannot be retained, and a four-phase signalized intersection is recommended as the treatment. The framework itself is transferable to other intersections where spatial limitation, rather than capacity, is the binding constraint.

Keywords: *Analytical Hierarchy Process; geometric feasibility; intersection performance; road safety; signalized intersection*

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I. INTRODUCTION

1.1 Background

An intersection is both the most decisive and the most hazardous element of a road network. It is the point at which streams arriving from several directions must occupy the same space, so the capacity of an entire corridor, the safety of its users, and the efficiency of every trip ultimately depend on how that single point is controlled. At an unsignalized four-arm intersection there are thirty-two points at which vehicle paths meet, comprising crossing, merging, and diverging movements. The two treatments commonly applied deal with those points in fundamentally different ways. A roundabout converts crossing movements into weaving movements by obliging every vehicle to circulate in one direction around a central island, whereas traffic signals eliminate the primary conflicts altogether by separating the release of each stream in time.

The choice between the two is never unconstrained. A roundabout functions only where there is enough room for the design vehicle to complete its weaving manoeuvre. Where that room does not exist, the physical form of a roundabout is still built but its control mechanism never operates — a situation more dangerous than an intersection with no control at all, because other road users have already adjusted their behaviour to priority rules that cannot in practice be enforced.

A problem of exactly this kind is found at the Paringin Intersection in Balangan Regency, South Kalimantan Province. The intersection is a node on a primary arterial national road linking the town centre, Paringin Market, the bus terminal, and residential districts, and it is crossed every day by semi-trailer trucks more than 12 metres long carrying mining and plantation output. The area redevelopment plan prepared by the design consultant proposes a roundabout with a central island 5 metres in diameter. That figure is a quarter of the smallest dimension permitted by Circular Letter No. 14/SE/Db/2024 and Regulation PM 96/2015, namely 20 to 27 metres for a simple roundabout. At the same time, the right-of-way available on site is only about 15 metres and is hemmed in by market buildings and government offices, so enlarging the diameter through land acquisition is not a realistic option. Spatial limitation therefore acts as an absolute boundary rather than a technical constraint open to compromise.

Three questions of different orders arise from this situation, and no single method can answer all of them: first, whether the planned 5-metre roundabout may be built at all under the standards in force; second, whether the chosen treatment is capable of serving the traffic it will carry; and third, which of the available alternatives is optimal once safety, regulatory compliance, operational performance, and land constraints are weighed together.

1.2 Related Work and Research Gap

Several studies published over the past five years underpin the framework adopted here. Christine et al. (2025) applied Circular Letter No. 14/SE/Db/2024 to the design of the Soekarno Hatta–Ibrahim Adjie intersection in Bandung and reduced the degree of saturation from above 1.0 to 0.76, confirming the standing of that circular as a binding geometric design reference. Juwita et al. (2024) evaluated the performance of a signalized intersection along the Sultan Agung–Ki Maja corridor using PKJI 2023 and obtained a degree of saturation of 0.910 across all approaches, demonstrating the application of the latest capacity guidelines to an urban case. Derry (2025) showed empirically that installing traffic signals at the unsignalized Betro T-junction lowered the degree of saturation from 0.91 to 0.75 with a capacity of 3,520 pcu/hour. In the decision-making domain, Yuliani (2020) and Susanto (2023) used AHP supported by Expert Choice to set priorities for road infrastructure treatment, while Gandung (2022) mapped the framework of authority for managing traffic facilities on national roads. The methodological basis for the weighting follows Saaty (1993), and Anugerah (2019) cautions that an AHP resting solely on respondent perception, without measured data behind it, risks producing a weakly grounded decision. Beyond the Indonesian literature, international evidence supplies the safety rationale that underpins the weighting adopted here. Elvik (2017), synthesising crash studies across several countries, reports substantial reductions in fatal and serious injury crashes where a roundabout is built to standard geometry, while Gross et al. (2013) find that the safety benefit of converting a signalized intersection to a roundabout is conditional on adequate deflection and circulating space — precisely the condition that is absent at the site examined here. The weighting procedure itself follows the current formulation of the method set out by Saaty (2008).

On closer reading, these studies tend to run along separate tracks. Geometric studies stop at checking dimensions, performance studies stop at a degree-of-saturation figure, and AHP studies stop at a ranking of alternatives without tying respondent judgement back to technical measurement. Few studies treat conformity with dimensional standards as a decision criterion in its own right and then combine it with performance analysis and multi-criteria weighting in a single sequence in which each track feeds the next — still fewer for a national-road intersection subject to an extreme right-of-way constraint. It is this gap that the present paper addresses.

1.3 Objectives and Contribution

Accordingly, this paper sets out to examine the conformity of the planned 5-metre roundabout against the minimum parameters prescribed by regulation; to compute the traffic performance of the existing condition and of a signalized alternative following PKJI 2023; and to establish the optimal treatment through multi-criteria weighting with AHP, which is then translated into a conceptual design.

The contribution is at once methodological and practical. Methodologically, the paper offers a three-track framework that positions the standard-conformity test not as an appendix to the report but as an initial filter that simultaneously supplies objective input to the weighting stage. Practically, the results can be used directly as academic input to a design review before the detailed engineering document is finalised.

II. METHODOLOGY

2.1 Study Location and Research Design

The study was carried out at the Paringin Intersection in Balangan Regency, South Kalimantan Province. The intersection is an irregular four-arm junction comprising the Tanjung (A), Halong (B), Barabai (C), and Amuntai (D) approaches. The surrounding area is dominated by commercial and government functions: Paringin Market, with intense loading and unloading activity, lies to the north, while Sanggam Hall and the municipal tennis courts lie to the south. On-street parking and street-vendor activity make side friction high. The existing layout and geometric dimensions are shown inFigure 1.

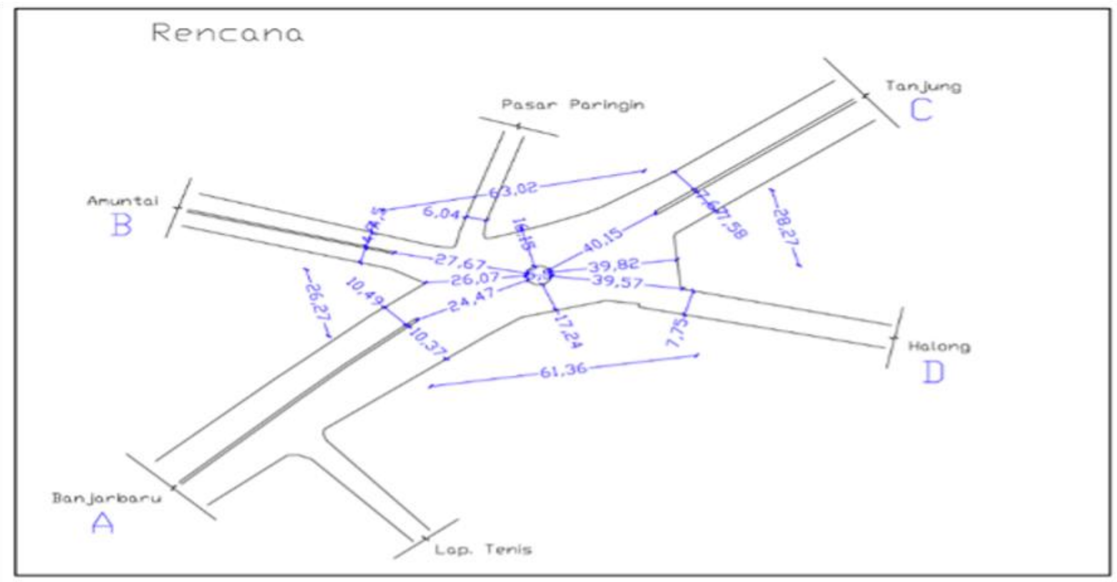

Figure 1. Existing Layout and Geometric Dimensions of the Paringin Intersection

Source: field measurement, 2026 (dimensions in metres; approach labels A–D as used throughout this paper)

The research design is descriptive-evaluative, describing the actual condition of the intersection and then assessing it against the technical standards in force, combined with a quantitative approach through AHP to determine the preferred alternative.

2.2 The Three-Track Analytical Framework

The analysis is organised into three tracks, each answering a different question and each feeding the next, as illustrated in Figure 2. The first track, the geometric standard conformity test, answers whether the scheme may be built. The second, the PKJI 2023 performance analysis, answers whether it can serve the traffic. The third, the AHP, answers which alternative is optimal once every consideration is weighed together.

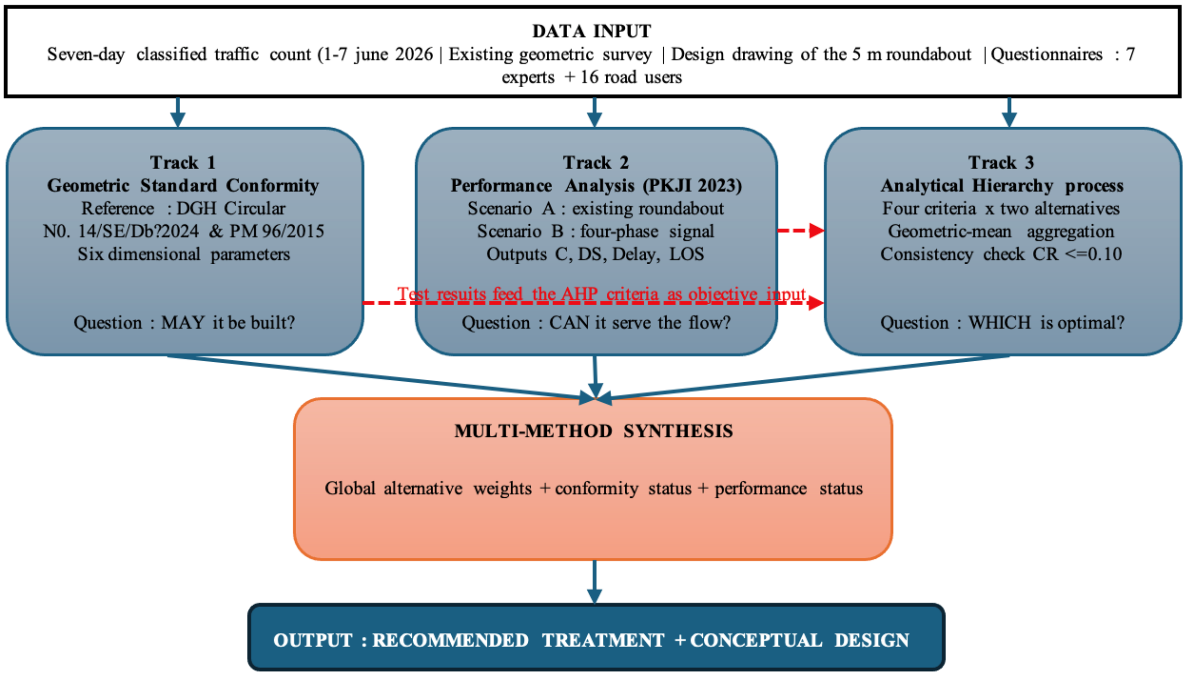

Figure 2. Three-Track Analytical Framework Adopted in This Study
Source: authors, 2026

One point about the sequence deserves emphasis. Results from the first and second tracks are used as objective input to the criteria assessed in the third, yet at the weighting stage both alternatives are still treated as equals. In this way the conclusion regarding the roundabout is not fixed in advance and then justified after the fact; it emerges consistently from three tracks reasoning in different ways. The arrangement also responds directly to the criticism raised by Anugerah (2019) concerning the use of AHP based on perception alone.

2.3 Data and Collection Techniques

Primary data are of three kinds. The first is a classified traffic count conducted on seven consecutive days, from 1 to 7 June 2026, over six observation periods each day (07.00–08.00, 08.00–09.00, 12.00–13.00, 13.00–14.00, 15.00–16.00, and 16.00–17.00 local time) on all four approaches. A full weekly cycle was chosen so that weekday, Friday, and weekend characteristics were all captured, allowing the peak hour to be established from data rather than assumption. The second is a field geometric survey covering approach widths, weaving section widths and lengths, and island dimensions. The third is a pairwise-comparison questionnaire on the Saaty 1–9 scale distributed to seven expert respondents from the Regency Public Works and Transportation Agencies, selected purposively on the basis of expertise and experience, together with a simple-scale questionnaire administered to sixteen road users in the vicinity through face-to-face interview. Every questionnaire was returned fully completed.
Secondary data comprise the consultant's area design drawings, Circular Letter No. 14/SE/Db/2024, Regulation PM 96/2015, PKJI 2023, and Law No. 22 of 2009 on Road Traffic and Transport.

2.4 Track 1: Geometric Standard Conformity Test

The planned dimensions are compared against the six minimum parameters prescribed by regulation, namely central island diameter, circulating radius, weaving section width, weaving section length, entry design speed, and the ability to accommodate the weaving manoeuvre of heavy vehicles longer than 12 metres. The assessment is binary — conforming or not conforming, with no weighting between parameters — so that the outcome does not depend on the authors' judgement.

2.5 Track 2: Performance Analysis Following PKJI 2023

Performance is computed for two scenarios: Scenario A, the existing roundabout, and Scenario B, a four-phase signalized intersection. The choice of the existing roundabout rather than the planned 5-metre roundabout as the point of comparison rests on a methodological consideration set out in Section 3.3.

a. Weaving section capacity

The capacity of a weaving section is computed using the empirical PKJI 2023 equation:

$$C = 135 \times Ww^{1.3} \times (1 + We/Ww)^{1.5} \times (1 - pw/3)^{0.5} \times (1 + Ww/Lw)^{-1.8} \times FUK \times FRSU$$

where Ww is the weaving width (m), We the average entry width (m), Lw the weaving length (m), pw the ratio of weaving flow to total flow, FUK the city-size adjustment factor, and FRSU the adjustment factor for road environment type, side friction, and non-motorised vehicles. Because the equation is empirical it is valid only within its calibration range: Ww between 10 and 25 metres, Lw not less than 21 metres, a Ww/Lw ratio between 0.12 and 0.63, and We not less than 9 metres. Outside that range the computed result cannot be defended. Performance is then judged through the degree of saturation DS = q/C, delay, and queue probability, against a threshold of DS $\leq$ 0.85.

b. Signalized intersection capacity

For Scenario B the computation follows Forms SA-1 to SA-5. Base and adjusted saturation flows are obtained as:

$$S_0 = 600 \times We \quad \text{and} \quad S = S_0 \times FHS \times FUK \times FG \times FP \times FBKi \times FBKa$$

The flow ratio of each approach, RQ/S = q/S, is summed to give the intersection flow ratio (IFR), after which the optimum cycle time is set using the Webster equation c = (1.5 × LT + 5)/(1 − IFR), where LT is the total lost time. Approach capacity is then computed as C = S × g/c, the degree of saturation as DS = q/C, and average delay as the sum of traffic delay and geometric delay:

$$TD = c \times [0.5 \times (1 - GR)^2 / (1 - GR \times DS)] + NQ1 \times 3600/C \;; \quad D = TD + GD$$

Level of service is assigned from average delay in accordance with PKJI 2023, in which the band from 25.1 to 40.0 sec/pcu corresponds to level of service D, a condition still regarded as tolerable for an urban intersection during the peak hour.

> ***Cara membaca:*** *two indicators recur throughout the results. The degree of saturation expresses how much of the available capacity is being used; a value of 0.65 means that 65 per cent is taken up and 35 per cent remains in reserve. Delay expresses the average waiting time per vehicle and is the basis on which level of service is assigned.*

2.6 Track 3: Analytical Hierarchy Process

The decision hierarchy comprises one goal, four criteria, and two alternatives, as shown in Figure 3. The criteria are Safety and OHSE, Regulatory Compliance, Traffic Performance, and Economic and Land Feasibility. The Regulatory Compliance criterion measures the extent to which an alternative conforms to Circular Letter No. 14/SE/Db/2024, Regulation PM 96/2015, and Law No. 22 of 2009. The two alternatives compared are the 5-metre roundabout as planned and a four-phase signalized intersection.

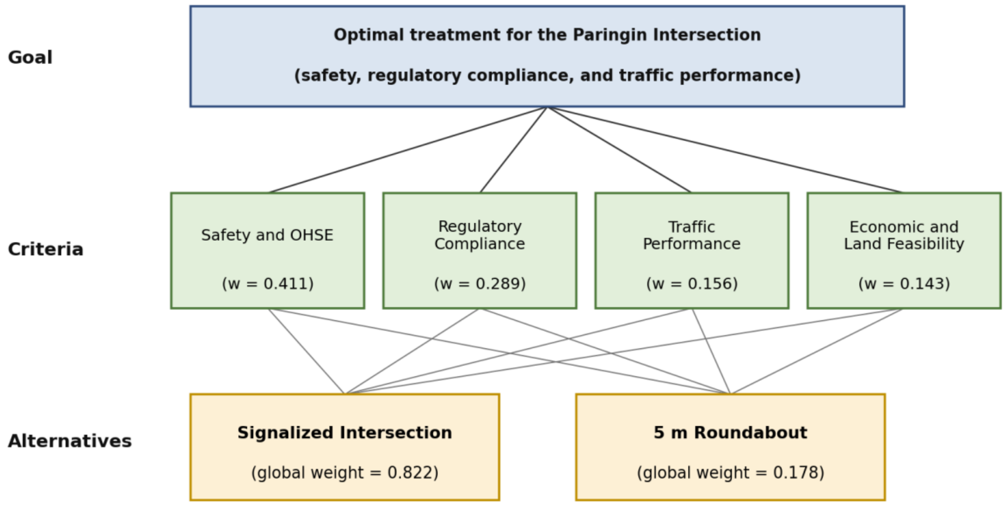

Figure 3. Decision Hierarchy for Selecting the Treatment of the Paringin Intersection
Source: authors, 2026

The judgements of the seven expert respondents were aggregated using the geometric mean so that extreme scores would not dominate the outcome, then arranged as a pairwise comparison matrix in which the lower triangle is the reciprocal of the upper. Priority weights were derived by column normalisation and row averaging — the eigenvector approach — and tested for consistency through the consistency index CI = (λmax − n)/(n − 1) and the consistency ratio CR = CI/RI, subject to CR $\leq$ 0.10 (Saaty, 1993). All manual computations were verified using Expert Choice version 11. Responses from the sixteen road users were analysed descriptively as a cross-check on the expert assessment and were not part of the weighting itself.

III. RESULTS AND DISCUSSION

3.1 Flow Characteristics and Determination of the Peak Hour

The seven-day count yields an annual average daily traffic (AADT) of 19,388 vehicles per day. Fluctuation of the total intersection flow across the six observation periods is presented in Table 1 and visualised in Figure 4.

Table 1. Fluctuation of Total Flow at the Paringin Intersection over One Weekly Cycle (pcu/hour)

Period (local time)	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mean
07.00–08.00	1,200.5	1,229.0	1,194.6	1,135.3	882.0	950.2	863.6	1,065.0
08.00–09.00	1,093.3	995.1	958.5	834.6	640.7	722.2	779.4	860.5
12.00–13.00	1,224.8	1,213.6	1,135.8	1,112.6	–	736.3	636.8	1,010.0
13.00–14.00	1,082.7	1,097.3	1,030.8	922.6	402.0	727.6	751.6	859.2
15.00–16.00	856.2	920.9	804.7	779.2	588.4	670.5	722.5	763.2
16.00–17.00	1,023.4	1,657.2	1,279.4	1,362.3	772.0	1,032.4	1,010.3	1,162.4
AADT from the seven-day survey = 19,388 vehicles/day								

Source: traffic volume survey, 1–7 June 2026

> ***Cara membaca:*** *the figures are flows for the whole intersection converted into passenger car units (pcu) using the equivalence factors for unsignalized intersections, namely 1.0 for light vehicles, 1.3 for heavy vehicles, 0.2 for motorcycles, and 1.0 for non-motorised vehicles. The Tuesday afternoon composition of 684 light vehicles, 92 heavy vehicles, 4,178 motorcycles, and 18 non-motorised vehicles thus gives 684 + 119.6 + 835.6 + 18 = 1,657.2 pcu/hour.*

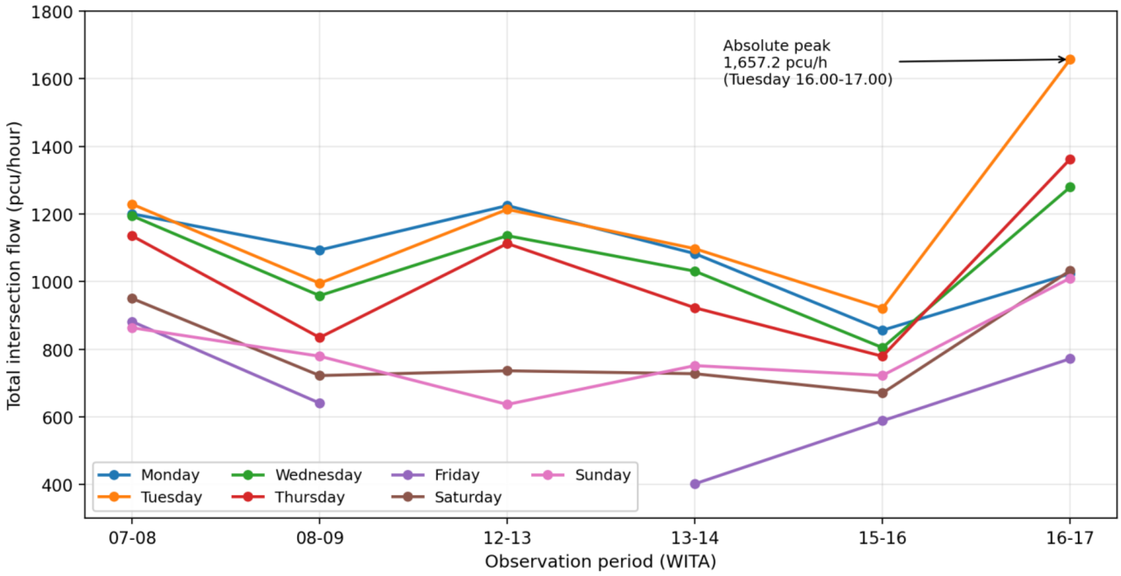

Figure 4. Fluctuation of Total Flow at the Paringin Intersection over Seven Days
Source: analysis of survey data, 2026

Two characteristics stand out. First, the range of fluctuation is very wide, from 402.0 pcu/hour on Friday midday to 1,657.2 pcu/hour on Tuesday afternoon, a ratio of roughly four to one. Even within a single day the Tuesday flow rose by 80.1 per cent in the space of one hour, from 920.9 pcu/hour between 15.00 and 16.00 to 1,657.2 pcu/hour between 16.00 and 17.00. Second, motorcycles dominate the stream at 84.3 to 87.0 per cent, yet it is the presence of heavy trucks in the afternoon that determines the safety problem, because the disparity in size and speed is so large.

Given this pattern, the peak hour was fixed under two conditions simultaneously, as set out in Table 2. The representative peak hour describes the typical daily condition, while the absolute peak hour serves as a worst-case loading test.

Table 2. Peak Hours Determined from Survey Data

Period	Day / date	Flow (pcu/h)	Remark	Status
07.00–08.00	Monday, 1 June 2026	1,200.5	Morning peak	Representative
12.00–13.00	Monday, 1 June 2026	1,224.8	Midday peak	Representative
16.00–17.00	Tuesday, 2 June 2026	1,657.2	Highest volume	Absolute peak

Source: analysis of survey data, 2026

The AADT of 19,388 vehicles per day has a direct bearing on the roundabout type that should have been adopted. It already exceeds the upper service limit of a simple roundabout, which reaches only 15,000 vehicles per day, so the minimum suitable type is a single-lane roundabout serving up to 20,000 vehicles per day and requiring a diameter of 27 to 55 metres. In other words, even before any dimensional check is made, the gap between the 5-metre proposal and the actual requirement widens rather than narrows.

3.2 Results of the Geometric Standard Conformity Test

A comparison of every dimensional parameter of the plan against the regulatory minima is presented in Table 3.

Table 3. Planned 5-Metre Roundabout Dimensions Compared with Regulatory Minima

Parameter	Planned 5 m roundabout	Regulatory minimum	Assessment
Central island diameter	5.00 m	20–27 m	Not conforming
Minimum circulating radius	2.50 m	≥ 10 m	Not conforming
Weaving section width	± 5 m (ROW-limited)	9 m	Not conforming
Weaving section length	± 4–8 m	21 m	Not conforming
Entry design speed	< 10 km/h	25–30 km/h	Not conforming
Weaving capability for heavy vehicles (L > 12 m)	Not possible	Mandatory	Not conforming
Summary	**6 of 6 parameters not satisfied**		**Not feasible**

Source: analysis against Circular Letter No. 14/SE/Db/2024 and Regulation PM 96/2015, 2026

All six parameters fall below the minimum values. The finding should nevertheless be read in proportion. The non-conformity is not merely a design error; it follows from a spatial limitation that is real on the ground. With a right-of-way of about 15 metres bounded by market and office buildings, a central island of 20 to 27 metres simply cannot be accommodated without large-scale land acquisition. What the test reveals, then, is more fundamental than the failure of one particular design. So long as the width of the road corridor remains unchanged, no compliant variant of a roundabout can be placed at this location; the difficulty lies in the mismatch between the form of treatment and the capacity of the space, not in the size of the island alone.

Among the six parameters, the decisive failure is the inability to accommodate the weaving manoeuvre of heavy vehicles. With a central island of 5 metres the effective circulating radius available is only about 2.5 metres, whereas a semi-trailer longer than 12 metres requires at least 12 to 15 metres to complete its turn. The shortfall is far too great to be offset by any traffic management measure. The consequence on site can be predicted with confidence: trucks will cut across the central island, so the roundabout loses its function as a weaving control device and becomes, in effect, an uncontrolled crossroads. Such a condition carries greater risk than an ordinary unsignalized intersection, because other drivers have already adapted to the circulating discipline implied by the physical form, a discipline that never actually applies.

3.3 Performance of the Existing Roundabout (Scenario A)

Before the results are presented, one methodological decision needs explaining, since it frequently prompts questions. The performance computed in this scenario is that of the existing roundabout, not of the planned 5-metre roundabout. The reason is technical and unavoidable: every input variable of the 5-metre design — entry width, weaving width, weaving length, and the Ww/Lw ratio — lies outside the data range on which the PKJI 2023 weaving capacity equation was calibrated, as set out in Section 2.5. Forcing the equation onto a 5-metre geometry would yield figures that look convincing but have no empirical basis. That a design cannot be modelled at all within a standard capacity equation is itself a finding, not a shortcoming of the analysis.

The computation uses a city-size adjustment factor FUK = 0.82, corresponding to the population of Balangan Regency of fewer than 0.1 million, and an environmental adjustment factor for a commercial setting with high side friction. By way of a worked example, weaving section BC yields a capacity of 4,193 pcu/hour against a weaving flow of 2,977 pcu/hour, so DS = 2,977/4,193 = 0.71. Results for all weaving sections are summarised in Table 4.

Table 4. Performance of the Existing Roundabout at the Representative Peak Hour (Monday, 07.00–08.00)

Weaving section	Ww (m)	C (pcu/h)	q (pcu/h)	DS	Delay (sec/pcu)
AB	18.21	11,367	2,027	0.65	0.252
BC	18.19	5,371	2,977	0.71	0.651
CD	21.87	13,866	2,062	0.68	0.233
DA	22.22	5,100	3,625	0.71	0.654
Roundabout	–	–	–	**0.71 (max)**	**6.25 (mean)**

Source: analysis following PKJI 2023, 2026

The highest degree of saturation, 0.71, occurs on weaving sections BC and DA. The value remains below the 0.85 threshold, but the reserve capacity left is under 20 per cent — a thin margin for a national-road node whose traffic will continue to grow.

3.4 Performance of the Signalized Alternative (Scenario B)

The configuration analysed is four phases with one phase per approach. Such an arrangement renders every approach fully protected, so no movement crosses another at the same instant. The intergreen interval is set at 5 seconds per phase, giving a total lost time of 20 seconds per cycle.

a. Worked example: the Tanjung approach at the absolute peak hour

Flows are converted using the PKJI 2023 equivalence factors for protected approaches, namely 1.0 for light vehicles, 1.3 for heavy vehicles, and 0.15 for motorcycles. With a composition of 197 light vehicles, 39 heavy vehicles, and 856 motorcycles per hour:

$$q = 197 + (39 \times 1.3) + (856 \times 0.15) = 376.1 \text{ pcu/hour}$$

With an effective approach width We = 7.75 m and a combined adjustment factor F = FUK × FHS = 0.82 × 0.93 = 0.763, the saturation flow becomes:

$$S_o = 600 \times 7.75 = 4{,}650 \text{ pcu/hour of green} \; ; \; S = 4{,}650 \times 0.763 = 3{,}546 \text{ pcu/hour of green}$$

$$RQ/S = 376.1 / 3{,}546 = 0.106$$

Applying the same procedure gives flow ratios of 0.073 for Halong, 0.217 for Barabai, and 0.043 for Amuntai, so that the intersection flow ratio IFR = 0.439. The Webster optimum cycle time is therefore c = (1.5 × 20 + 5)/(1 − 0.439) = 62.3 seconds. A similar value, 51.7 seconds at an IFR of 0.324, is obtained for the Monday morning peak. Because both figures fall below the lower bound of the cycle-time range recommended by PKJI 2023 for four-phase operation (80 to 130 seconds), a practical cycle time of 80 seconds is adopted, the shortest permitted so that delay is kept to a minimum. The total green time of 60 seconds is distributed in proportion to the flow ratios, subject to a minimum of 10 seconds per phase.

$$C = 3{,}546 \times 13/80 = 576 \text{ pcu/hour} \; ; \; DS = 376.1 / 576 = 0.65 \; ; \; D = 34.1 + 4 = 38.1 \text{ sec/pcu}$$

How to read this: *the fact that the computed cycle time falls short of the recommended range carries important information. It indicates that the core problem at Paringin is not a shortage of capacity but the absence of any mechanism to govern conflicting movements. Precisely because the loading is not yet heavy, the shortest permitted cycle suffices, so the delay penalty introduced by signalisation can be held to its lowest level.*

b. Summary of performance across all approaches

Complete results for both peak-hour conditions are presented in Table 5.

Table 5. Performance of the Four-Phase Signalized Intersection at a Cycle Time of 80 Seconds

Approach	g (s)	S (pcu/h green)	C (pcu/h)	q (pcu/h)	DS	Delay (sec/pcu)
Representative peak hour — Monday, 07.00–08.00 (total q = 1,014.2 pcu/hour)						
Tanjung (A)	15	3,546	665	291.0	0.44	32.8
Halong (B)	16	2,059	412	174.4	0.42	32.0
Barabai (C)	16	3,468	694	303.9	0.44	32.1
Amuntai (D)	13	3,546	576	244.9	0.42	34.1
Intersection average	–	–	–	1,014.2	**0.44**	**32.7 (LOS D)**
Absolute peak hour — Tuesday, 16.00–17.00 (total q = 1,430.3 pcu/hour)						
Tanjung (A)	13	3,546	576	376.1	0.65	38.1
Halong (B)	10	2,059	257	149.8	0.58	39.8
Barabai (C)	27	3,468	1,171	751.7	0.64	27.6
Amuntai (D)	10	3,546	443	152.7	0.34	36.0

Approach	g (s)	S (pcu/h green)	C (pcu/h)	q (pcu/h)	DS	Delay (sec/pcu)
Intersection average	–	–	–	1,430.3	**0.65**	**32.6 (LOS D)**

Source: analysis following PKJI 2023, 2026

How to read this: *the totals in this table (1,014.2 and 1,430.3 pcu/hour) appear smaller than those in Table 1 (1,200.5 and 1,657.2 pcu/hour) even though both derive from the same count. The difference is not an error but a consequence of the motorcycle equivalence factor: 0.2 for unsignalized intersections and 0.15 for protected approaches at signalized intersections. Because motorcycles dominate the stream at this site, that difference has a marked effect on the total.*

At the representative peak hour the degree of saturation ranges only from 0.42 to 0.44 across the approaches, with an average delay of 32.7 sec/pcu. When loading peaks on Tuesday afternoon, the highest value reaches 0.65 on the Tanjung approach and the intersection average delay becomes 32.6 sec/pcu. Both conditions fall within level of service D, while every degree-of-saturation value stops well short of the 0.85 threshold, leaving between 35 and 58 per cent of capacity in reserve. It should also be noted that the projection is conservative, having been prepared on the assumption of fixed-time operation; with actuated control, off-peak delay could be reduced considerably further.

3.5 Reading the Comparison Between the Two Scenarios Correctly

At first glance the comparison appears paradoxical. The existing roundabout returns an average delay of only 6.25 sec/pcu, whereas the signalized intersection returns 32.6 sec/pcu, more than five times as much. Read side by side without regard to what underlies them, the two figures invite precisely the wrong conclusion.

The difference arises from the control mechanism, not from capacity. At a roundabout, delay occurs by chance: a vehicle slows or stops only if another vehicle happens to be crossing its path at that moment. The mean is low, but the delay experienced by any individual vehicle varies widely and cannot be anticipated — and it is that variability which generates safety risk, particularly for semi-trailers requiring far greater stopping distance and manoeuvring space. At a signalized intersection, delay is determined in advance because the length of the red phase is fixed through signal timing design. The mean is larger, but its magnitude is known, can be accounted for beforehand, and can be improved by adjusting the cycle. The 32.6 sec/pcu is therefore not evidence of degraded performance but the price paid for eliminating all thirty-two primary conflict points.

The methodologically appropriate indicator for comparing capacity adequacy is the degree of saturation, and on that indicator the signalized intersection is in fact superior, 0.65 against 0.71, with reserve capacity of roughly 35 per cent against 29 per cent. The advantage is the more meaningful for having been obtained under the heaviest loading observed across the weekly cycle. A comparable pattern was reported by Derry (2025): where flow loading is not yet critical, signalisation remains justified if the primary objective is to reduce crash risk, provided the cycle time is tuned as efficiently as possible. The pattern is consistent with international evidence. The crash-reduction benefit commonly attributed to roundabouts (Elvik, 2017; Gross et al., 2013) is conditional on a geometry that physically enforces deflection and provides room for the design vehicle to circulate; where that geometry cannot be provided, the safety argument shifts to signal control, which removes conflicts by separating movements in time rather than in space.

3.6 Alternative Selection Using the Analytical Hierarchy Process

This section sets out the weighting process in full, from matrix construction through to final synthesis, so that readers can trace for themselves how the final figures were formed rather than simply accepting the outcome.

a. Pairwise comparison matrix of criteria

The judgements of the seven expert respondents were aggregated by geometric mean into a single 4×4 matrix, presented in Table 6. Each entry states how many times more important the criterion in the row is judged to be than the criterion in the column.

Table 6. Aggregated Pairwise Comparison Matrix of Criteria

Criterion	Safety & OHSE	Regulatory Compliance	Traffic Performance	Economic & Land
Safety and OHSE	1.000	1.500	3.500	2.250
Regulatory Compliance	0.667	1.000	2.500	1.750
Traffic Performance	0.286	0.400	1.000	1.750
Economic and Land	0.444	0.571	0.571	1.000
Column sum	**2.397**	**3.471**	**7.571**	**6.750**

Source: geometric-mean aggregation of questionnaires from seven expert respondents, 2026

Each entry is then divided by its column sum to give the normalised matrix, and the priority weight of each criterion is obtained as the average of its row. For the Safety criterion, for instance:

$$w(Safety) = (0.417 + 0.432 + 0.462 + 0.333) / 4 = 0.411$$

Table 7. Criteria Priority Weights and Consistency Test Results

No.	Criterion	Weight (w)	Percentage	Rank
1	Safety and OHSE	0.411	41.1%	1
2	Regulatory Compliance	0.289	28.9%	2
3	Traffic Performance	0.156	15.6%	3
4	Economic and Land Feasibility	0.143	14.3%	4
λmax = 4.120 ; CI = 0.040 ; CR = 0.045 < 0.10 (consistent). Verification in Expert Choice v.11 returns weights of 0.414, 0.291, 0.154, and 0.141 with an inconsistency of 0.04.				

Source: AHP analysis with verification in Expert Choice v.11, 2026

b. Consistency test

Consistency was tested by computing the vector A·w for each row. For the Safety row, $(A \cdot w)_1 = (1.000 \times 0.411) + (1.500 \times 0.289) + (3.500 \times 0.156) + (2.250 \times 0.143) = 1.712$, giving a ratio of 1.712/0.411 = 4.166. The same computation across the four rows yields 4.166, 4.163, 4.101, and 4.052, so $\lambda_{max} = 4.120$. With n = 4 and RI = 0.90:

$$CI = (4.120 - 4) / 3 = 0.040 ; \quad CR = 0.040 / 0.90 = 0.045 < 0.10$$

Since the consistency ratio lies well below the 0.10 threshold, the aggregated expert judgements are logically consistent and the resulting priority weights are valid for use.

c. Comparison of alternatives and synthesis of global weights

With only two alternatives, the comparison matrix under each criterion is 2×2 and its consistency ratio is therefore always zero. Local weights follow directly from the aggregated comparison value; under the Safety criterion, with an aggregated value of 5.0 to 1, w(signal) = 5.0/6.0 = 0.833 and w(roundabout) = 1/6.0 = 0.167. Full results and the synthesis of global weights are presented in Table 8.

Table 8. Local Weights of Alternatives by Criterion and Synthesis of Global Weights

Criterion	Criterion weight	Aggregated value (signal : roundabout)	5 m roundabout	Signalized intersection
Safety and OHSE	0.411	5.0 : 1	0.167	0.833
Regulatory Compliance	0.289	9.0 : 1	0.100	0.900
Traffic Performance	0.156	2.3 : 1	0.303	0.697
Economic and Land Feasibility	0.143	3.5 : 1	0.222	0.778
Total global weight	**1.000**	–	**0.178 (17.8%)**	**0.822 (82.2%)**

Source: AHP analysis with verification in Expert Choice v.11, 2026

Global weights are obtained by summing the products of criterion weights and the local weights of each alternative:

$$w(signal) = (0.411 \times 0.833) + (0.289 \times 0.900) + (0.156 \times 0.697) + (0.143 \times 0.778) = 0.822$$

Verification in Expert Choice v.11 returns 0.818 against 0.182 with an overall inconsistency of 0.04. The difference of 0.004 from the manual computation stems from the different eigenvector solution method and does not alter the conclusion.

The size of the margin, however, is not what most deserves attention; what matters more is where it comes from. Around 70 per cent of the decision weight is concentrated in the top two criteria, and it is on those same two criteria that the signalized intersection attains its highest local weights, 0.833 on safety and 0.900 on regulatory conformity. The advantage is thus not a narrow win spread thinly across minor criteria but a decisive one on the criteria that matter most. An arrangement of this kind makes the outcome robust to changes in assumption: were the weights between criteria shifted within any reasonable band, the ranking of the two alternatives would remain unchanged.

The weighting pattern carries a message of its own. Traffic performance attracted only 15.6 per cent, far behind the leading pair. For the technical practitioners who manage national road corridors directly, smooth flow is evidently no longer regarded as the sole objective but as one among several considerations to be balanced against the protection of road users and legal certainty. The tendency accords with the principles of traffic administration laid down in Law No. 22 of 2009 and echoes what Yuliani (2020) reported.

3.7 Cross-Check Against Road User Preferences

To examine whether the expert assessment aligns with everyday user experience, the responses of the sixteen road users were compiled descriptively as shown in Table 9. These results were not weighted within the AHP and serve solely as a cross-check.

Table 9. Road User Preferences Between the Two Alternatives (n = 16)

Aspect assessed	Favour signalisation	Favour roundabout	Undecided / equal
Traffic safety	14 respondents (87.5%)	2 respondents (12.5%)	0
Traffic flow	12 respondents (75.0%)	3 respondents (18.8%)	1 respondent (6.3%)
Ease of land acquisition	11 respondents (68.8%)	5 respondents (31.3%)	0

Source: compilation of the road user questionnaire, 2026

Support for signalisation is in the majority and consistent across all three aspects, with the highest figure recorded on safety. Open-ended comments reinforce the pattern: most respondents considered signal installation sufficient and regarded a roundabout as something that would narrow the intersection still further, while those who still favoured a roundabout stipulated that it be rebuilt to the national standard diameter. The convergence of two viewpoints proceeding from different bases — technical knowledge on one side, daily experience of crossing the intersection on the other — lends further confidence that the resulting choice does not favour the perspective of either group alone.

3.8 Multi-Method Synthesis and Conceptual Design

Findings from the three analytical tracks are summarised in Table 10. The value of the summary lies in its convergence: three methods reasoning in entirely different ways arrive at the same conclusion.

Table 10. Synthesis of Findings from the Three Analytical Tracks

Analytical track	Principal finding	Decision implication
Geometric standard conformity	The 5 m roundabout satisfies none of the six minimum parameters; weaving by heavy vehicles is not physically possible	**The 5 m roundabout cannot be retained**
Performance analysis (PKJI 2023)	Maximum DS of 0.71 for the existing roundabout; 0.65 for the four-phase signal with 32.6 sec/pcu delay (LOS D)	**Signalisation matches on capacity with better safety**
Analytical Hierarchy Process	Global weight of 82.2% for signalisation against 17.8% for the roundabout at CR = 0.045; user preference aligns	**Signalisation is the preferred alternative**

Source: compilation of analysis results, 2026

The preferred alternative is then translated into a conceptual design. Every design element is derived from the analysis rather than adopted arbitrarily, as summarised in Table 11. Phase arrangement and the signal timing diagram are shown in Figure 5, while the placement of all elements within the existing right-of-way is shown in Figure 6.

Table 11. Conceptual Design Elements and Their Analytical Basis

Design element	Analytical basis	Criterion addressed
Four-phase configuration	Thirty-two conflict points at a four-arm intersection; significant right-turning flows on two approaches	Safety (0.411)
Cycle time of 80 seconds	Webster cycle of 51.7–62.3 s lies below the PKJI 2023 range for four-phase operation, so the lower bound of 80 s is adopted to minimise delay	Performance (0.156)
Vehicle detectors for actuated control	Flow fluctuation of 402.0–1,657.2 pcu/hour, a ratio of about four to one (Table 1)	Performance (0.156)
Right-turn lanes on the Tanjung and Barabai approaches	Approach widths are sufficient for lanes to be formed through pavement marking without land acquisition	Performance; Economic and Land
Supporting signs and a parking prohibition at least 25 m from the stop line	High side friction from on-street parking and street vendors depresses approach saturation flow	Regulatory Compliance (0.289)
Crosswalks on all arms and guard railing on the market side	High pedestrian generation on the Paringin Market side; signal phasing provides protected crossing gaps	Safety (0.411)
Heavy vehicle management	The design vehicle is a semi-trailer longer than 12 m, most concentrated during the afternoon period	Safety (0.411)

Source: analysis results, 2026

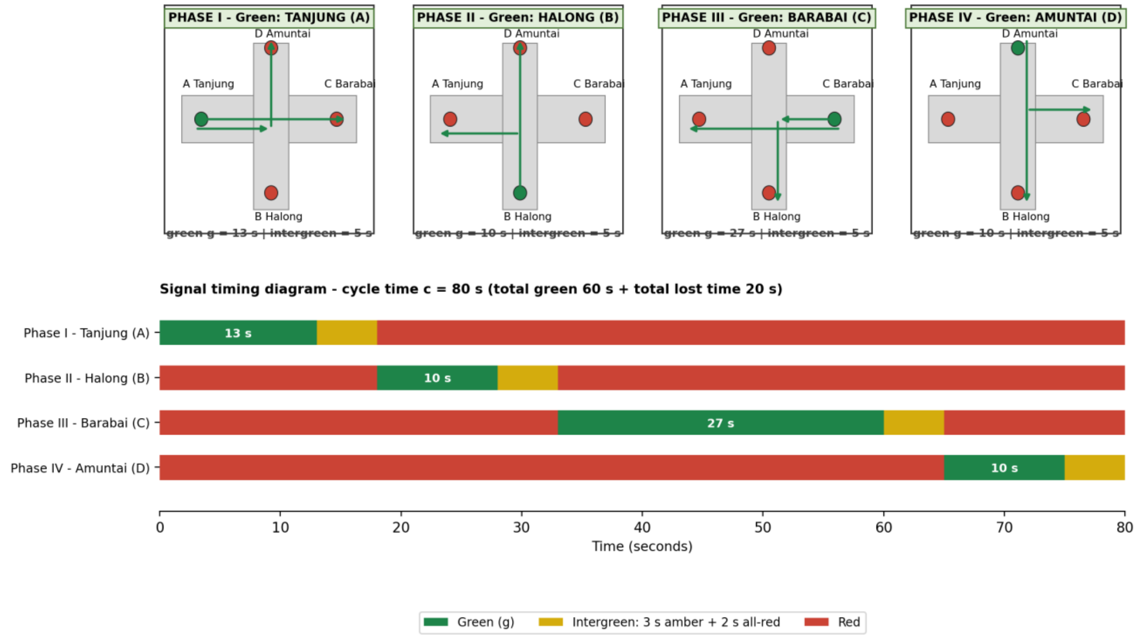

Figure 5. Four-Phase Signal Arrangement and Timing Diagram for an 80-Second Cycle
Source: analysis results, 2026

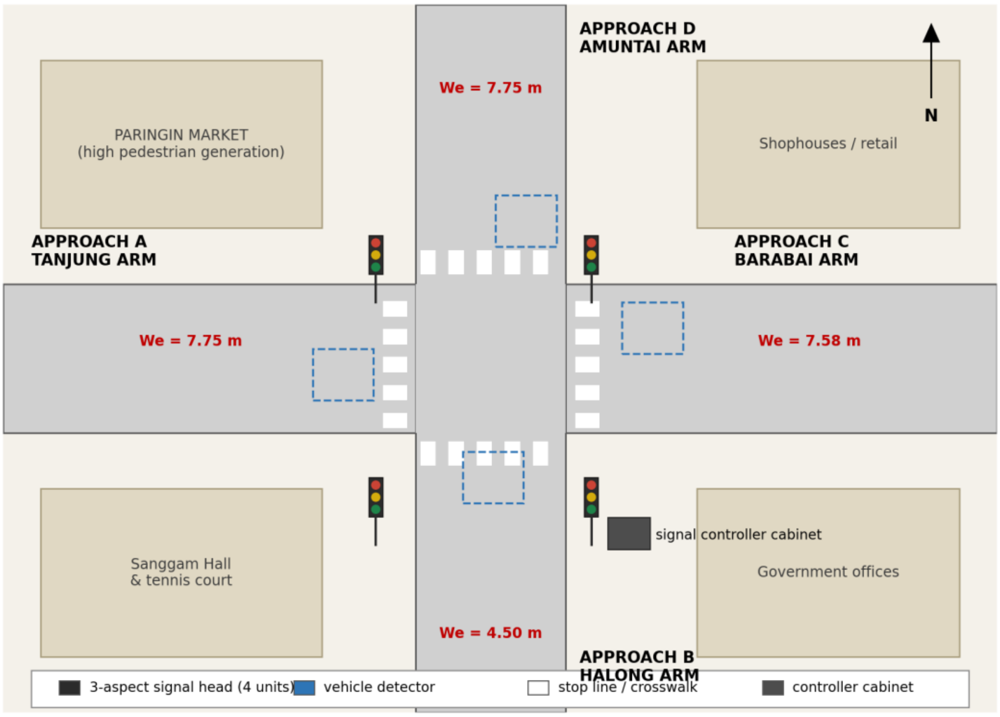

Figure 6. Conceptual Geometric Plan of the Paringin Intersection under Signal Control
Source: analysis results, 2026 (schematic, not to scale)

Every component shown in Figure 6 fits within the width of road currently available, roughly 15 metres, so implementation touches neither privately owned land nor the market buildings surrounding the site. It is this that makes the preferred alternative not merely superior on paper but also the easiest to deliver.

3.9 Implications and Limitations

In terms of application, the findings bear directly on the design decision process at the study location. Proceeding with the 5-metre roundabout carries a double risk — to the safety of heavy vehicles and in terms of non-conformity with the provisions in force — whereas the preferred alternative can be implemented entirely within the space available.

Methodologically, one lesson deserves emphasis. The fact that a design cannot be modelled within a standard capacity equation should in itself be enough to halt the design process at an early stage. Conformity testing against standards is therefore better placed as the first filter than as an appendix to the performance analysis. The three-track framework used here can be replicated at other national-road intersections of similar character.

Several limitations should be stated openly. Counting was conducted manually over seven days, so seasonal variation such as holiday periods or the harvest season was not captured. The signalized performance analysis rests on the assumption of fixed-time operation, so the improvement obtainable from actuated control has not been quantified. The number of expert respondents is limited by the number of technical officials available in the study area, although this has been offset through the consistency test and the cross-check against road user responses. Cost-benefit analysis and a full traffic impact assessment were also outside the scope. None of these limitations changes the direction of the conclusions, but each opens room for further research.

IV. CONCLUSION

The planned 5-metre roundabout at the Paringin Intersection cannot be retained. All six of its dimensional parameters fall below the minima prescribed by Circular Letter No. 14/SE/Db/2024 and Regulation PM 96/2015 and, most decisively, an effective circulating radius of 2.5 metres makes it impossible for a semi-trailer longer than 12 metres to complete its weaving manoeuvre. Its input variables lie outside the calibration range of the PKJI 2023 weaving capacity equation, so its performance as a functioning roundabout cannot be modelled at all.

A four-phase signal arrangement on an 80-second cycle, by contrast, satisfies every performance indicator required by PKJI 2023. Under the heaviest loading, capacity utilisation stops at 0.65 and average waiting time is 32.6 sec/pcu, equivalent to level of service D. Although the average delay exceeds that of the existing roundabout, it is structured and manageable, and it is obtained together with the elimination of every primary conflict point.

Multi-criteria weighting confirms the choice, with global weights of 82.2 per cent for signalisation against 17.8 per cent for the roundabout at a consistency ratio of 0.045. The advantage is robust because it is sharpest on the two most heavily weighted criteria, Safety and OHSE and Regulatory Compliance, and is corroborated by majority support among road users ranging from 68.8 to 87.5 per cent.

On this basis, the Directorate General of Highways is advised to treat these results as academic input to the design review before the detailed engineering document is finalised, while the Balangan Regency Government is advised to prepare a detailed design for a signalized intersection giving attention to adaptive phasing, heavy vehicle management, and pedestrian facilities. Further research may extend the framework through traffic impact assessment, cost-benefit analysis, and the use of drone and camera-based traffic counting to improve the accuracy of volume data.

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