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Determining Urban Freight Terminal Location Using the Gravity Location Model and Analytical Hierarchy Process

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ABSTRACT

Urban freight activity in Singkawang City has increased alongside its role as a regional trade and transit hub in West Kalimantan. However, the absence of a dedicated freight terminal requires heavy freight vehicles to conduct parking and loading and unloading activities on public roads, reducing effective road capacity and disrupting urban logistics. This study determines an optimal freight terminal location by sequentially integrating the Gravity Location Model (GLM) and Analytical Hierarchy Process (AHP) within the STEEP framework. GLM was applied to three freight-distribution scenarios involving 19 major freight-generating firms to identify spatially efficient candidates. AHP then evaluated three GLM-derived locations and one alternative designated in the Regional Spatial Plan (RTRW), based on assessments by five multi-institutional experts. GLM identified Sijangkung, Sanggau Kulor, and Pasiran, whereas AHP selected Sedau as the preferred location with a priority weight of 0.456, followed by Sanggau Kulor (0.233), Pasiran (0.168), and Sijangkung (0.143). Political criteria received the highest weight (30.7%), followed by Economic (24.6%) and Technical (23.1%). A preliminary 30,000 m² terminal plan allocates 11,351.20 m² to facilities, 6,810.72 m² to circulation, and 11,838.08 m² to green space and future expansion.

Keywords: Analytical Hierarchy Process; Gravity Location Model; Urban Freight Terminal

ABSTRAK

Aktivitas angkutan barang di Kota Singkawang meningkat seiring dengan perannya sebagai simpul perdagangan dan transit regional di Kalimantan Barat. Namun, belum tersedianya terminal khusus angkutan barang menyebabkan kendaraan berat melakukan parkir dan bongkar muat di ruang jalan, sehingga mengurangi kapasitas efektif jalan dan mengganggu aktivitas logistik perkotaan. Penelitian ini menentukan lokasi optimal terminal angkutan barang melalui integrasi sekuensial Gravity Location Model (GLM) dan Analytical Hierarchy Process (AHP) dalam kerangka STEEP. GLM diterapkan pada tiga skenario distribusi barang yang melibatkan 19 perusahaan pembangkit angkutan barang untuk mengidentifikasi kandidat lokasi yang efisien secara spasial. Selanjutnya, AHP mengevaluasi tiga kandidat hasil GLM dan satu alternatif dalam Rencana Tata Ruang Wilayah berdasarkan penilaian lima pakar lintas instansi. GLM mengidentifikasi Sijangkung, Sanggau Kulor, dan Pasiran, sedangkan AHP menetapkan Sedau sebagai lokasi prioritas dengan bobot 0,456, diikuti Sanggau Kulor (0,233), Pasiran (0,168), dan Sijangkung (0,143). Kriteria Politik memperoleh bobot tertinggi (30,7%), diikuti Ekonomi (24,6%) dan Teknis (23,1%). Rencana awal terminal seluas 30.000 m² mengalokasikan 11.351,20 m² untuk fasilitas, 6.810,72 m² untuk sirkulasi, dan 11.838,08 m² untuk ruang hijau dan pengembangan.

Kata Kunci: *Analytical Hierarchy Process*; *Gravity Location Model*; Terminal Angkutan Barang Perkotaan

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INTRODUCTION

Rapid urbanization and the intensification of regional trade have increased the complexity of freight movement in developing urban areas. As urban agglomerations expand, demand for timely, reliable, and cost-effective goods distribution also increases, making urban freight transport an important component of economic competitiveness and urban functionality (Arvis et al., 2023; Holguín-Veras et al., 2020).

At the national level, the World Bank's 2023 Logistics Performance Index (LPI) ranked Indonesia 61st among 139 countries, with an overall score of 3.0. Logistics infrastructure and logistics competence both received scores of 2.9, indicating areas in which further improvement is needed to strengthen national supply-chain performance (Arvis et al., 2023). These challenges may be particularly important in secondary cities and regional economic nodes, where increasing freight volumes are not always accompanied by adequate logistics infrastructure. Under such conditions, urban freight activities can contribute to traffic congestion, noise, greenhouse gas emissions, pavement deterioration associated with over-dimension and overloading (ODOL) vehicles, and competition for limited road and curbside space (Alho et al., 2018; Dalla Chiara & Cheah, 2017).

Within urban supply chains, freight vehicles require appropriate space for temporary stopping, loading and unloading, cargo consolidation, vehicle weighing, and driver rest. Where dedicated off-street freight facilities are insufficient or unavailable, some of these activities may occur within the public road right-of-way (*Ruang Manfaat Jalan*, RUMAJA), which reduces effective roadway capacity and creating conflicts with other road users. Holguín-Veras et al. (2020) emphasize that infrastructure provision and the management of loading and parking areas are important components of urban freight policy, while Pinto et al. (2019) and Mor et al. (2020) demonstrate the importance of the spatial location and capacity of loading and unloading facilities for urban network performance.

From a broader logistics-system perspective, the absence of an urban freight terminal may also limit opportunities for organized transshipment between long-haul freight vehicles and smaller urban delivery vehicles (Oliveira et al., 2020; Wygonik & Goodchild, 2018). Introducing an intermediate freight terminal can generate additional handling and transfer costs; however, an appropriately located facility may also support cargo consolidation, improve vehicle utilization, reduce the need for heavy intercity vehicles to enter congested urban areas, and facilitate the coordination of freight movements with

urban delivery requirements (Anderluh et al., 2020; Kumar & Anbanandam, 2020). The net benefit of such a facility therefore depends not only on its existence but also on its location, accessibility, operational characteristics, and compatibility with the surrounding transport and land-use systems.

These issues are particularly relevant to Singkawang City, an important regional trade and transit node in West Kalimantan Province, Indonesia. Regional Regulation No. 1 of 2022 concerning the Singkawang Regional Spatial Plan (*Rencana Tata Ruang Wilayah*, RTRW) for 2022–2042 provides the spatial-planning framework for the city's development. Singkawang occupies a strategic position along the northwestern coast of Borneo, connecting Pontianak and the Kijing Port area in Mempawah Regency to the south, the Aruk Cross-Border Post (*Pos Lintas Batas Negara*, PLBN) near the Malaysian border in Sambas Regency to the north, and production areas in Bengkayang Regency to the east (BPS, 2025).

In addition to the national road network, Singkawang's transport system includes Kuala Singkawang Port, planned port development in Sedau, and Singkawang Airport in Pangmilang. The airport began operations in 2024 and includes a runway that has been extended to 2,000 m and a 312 m² cargo terminal. These transport facilities indicate the growing importance of Singkawang within regional passenger and freight movements. Recent economic growth further reinforces this role. Singkawang's Gross Regional Domestic Product (GRDP) reportedly grew by 5.39% in 2025, while transportation and warehousing recorded one of the city's higher sectoral growth rates (BPS, 2025).

Despite its strategic position within the West Kalimantan logistics network, Singkawang currently lacks a dedicated urban freight terminal. Municipal vehicle-inspection records indicate that 2,871 freight vehicles were registered for periodic roadworthiness inspection in 2024, with 13,761 inspections recorded between 2020 and 2024. Cordon traffic counts further recorded approximately 3,214 freight-vehicle movements per day entering and leaving the city.

Under the existing distribution pattern described in this study, heavy trucks and *tronton* vehicles carrying approximately 8–24 tons transport intercity commodities from Pontianak, Kijing Port, Sambas, and Bengkayang directly into the urban road network. In the absence of a dedicated off-street facility for cargo transfer and consolidation, these vehicles may continue into urban distribution areas rather than transferring loads to medium single-axle trucks carrying approximately 3.5–8 tons or light pick-up vehicles carrying up to 3.5 tons.

Field observations along 11 major urban road corridors—Jalan Raya Sedau, Jalan GM. Situt, Jalan Sejahtera, Jalan Alianyang, Jalan Ahmad Yani, Jalan Budi Utomo, Jalan Setia Budi, Jalan Niaga, Jalan Pajintan, Jalan Singkawang–Bengkayang, and Jalan Stasiun—identified on-street freight parking and loading–unloading activities. Of the observed freight stops, 68% were associated with cargo handling, comprising 54% unloading and 14% loading activities. Other recorded purposes included driver rest (18%), queueing (9%), and cargo inspection (5%). The study further estimates that these activities reduced effective road capacity by approximately 11%–54% across the affected road segments and were associated with increased volume-to-capacity (V/C) ratios.

Determining a suitable location for an urban freight terminal is a complex planning problem because spatial and transportation efficiency must be considered alongside multidimensional site feasibility. Previous studies often addressed these dimensions using different analytical approaches. Quantitative spatial methods such as the Gravity Location Model (GLM) provide a mathematical mechanism for identifying a center-of-gravity location based on weighted freight origins, destinations, transportation distances, and distribution costs (Susanto, 2022; Yamashita et al., 2000; Zhafarina et al., 2021). However, a mathematically efficient coordinate generated in continuous space may not correspond to a feasible development site because of road-access conditions, land availability and acquisition costs, environmental constraints, social considerations, or incompatibility with statutory land-use plans (Putri, 2018; Soimun et al., 2024).

Conversely, Multi-Criteria Decision-Making (MCDM) approaches, particularly the Analytical Hierarchy Process (AHP), allow planners to structure complex trade-offs and synthesize expert judgments across multiple quantitative and qualitative criteria (Anderluh et al., 2020; Leal, 2020). Such evaluation can incorporate Social, Technical, Economic, Environmental, and Political (STEEP) dimensions relevant to infrastructure-location decisions (Choudhary & Shankar, 2012; Kumar & Anbanandam, 2020). However, using MCDM without an initial quantitative assessment of freight-distribution patterns may favor a site that performs well institutionally or environmentally but imposes relatively high transport distances or operating costs.

To bridge this methodological gap, this study develops a sequential two-stage location-selection framework integrating GLM and AHP-STEEP to determine the optimal freight terminal location in Singkawang City. The analysis is extended to establish preliminary terminal facility-area requirements and layout design. In the first stage, GLM is applied across three major freight-distribution scenarios involving 19 freight-generating companies to generate spatially efficient candidate locations. In the second stage, these GLM-derived candidates are evaluated alongside Sedau, a policy-designated alternative stipulated in the Singkawang RTRW, using AHP structured around five STEEP criteria and 18 subcriteria and supported by multi-scenario sensitivity testing.

Accordingly, this study has three primary objectives: (1) to evaluate existing urban freight challenges and identify spatially efficient candidate locations in Singkawang City using GLM; (2) to prioritize candidate locations by integrating GLM-derived alternatives and the spatial-planning alternative through AHP-STEEP; and (3) to formulate the analytical land-area and facility allocations required for a sustainable and implementable urban freight terminal.

THEORETICAL FRAMEWORK

Urban Freight Terminals and City Logistics Systems

A freight terminal is a strategic node within a logistics network designed to facilitate cargo loading and unloading, intramodal and intermodal transshipment, freight consolidation and deconsolidation, temporary storage, warehousing, and freight-vehicle parking and maintenance (Kumar & Anbanandam, 2020; Widodo et al., 2021). Under Indonesian transportation regulations, especially Government Regulation (*Peraturan Pemerintah*) No. 79 of 2013 on Road Traffic and Transportation Networks and Minister of Transportation Regulation (*Peraturan*

Menteri Perhubungan) No. 102 of 2018 on Freight Terminal Operations, a public freight terminal must be integrated with designated freight corridors, located on an arterial or collector road meeting at least Class IIIA structural standards, and equipped with mandatory main and supporting facilities.

The required main facilities include arrival and departure lanes, heavy-vehicle parking areas, loading and unloading docks, warehousing, consolidation and packaging areas, static weighbridges, and administrative offices. Supporting facilities include driver rest areas, repair workshops, clinics, worship facilities, security posts, and green open space.

Within the broader structure of city logistics, an urban freight terminal functions as a gateway connecting regional intercity supply chains with urban last-mile distribution networks (Oliveira et al., 2020; Wygonik & Goodchild, 2018). Wygonik and Goodchild (2018) demonstrated that urban spatial structure and the proximity of logistics facilities to commercial service areas significantly influence vehicle kilometers traveled (VKT) and transport-related emissions. In cities without peripheral consolidation facilities, long-haul heavy trucks may enter high-density commercial areas directly and occupy public road space during freight handling, potentially contributing to traffic bottlenecks (Alho et al., 2018; Dalla Chiara & Cheah, 2017).

Conversely, locating a freight terminal at a strategic gateway can support a two-tier urban distribution system in which intercity shipments arriving from seaports, airports, cross-border corridors, and industrial areas are consolidated or broken down at the terminal through cross-docking and subsequently distributed to urban markets using smaller, higher-frequency delivery vehicles (Anderluh et al., 2020; Oliveira et al., 2020).

From a supply-chain economics perspective, terminal planning must balance consolidation benefits against potential double-handling costs. If a terminal is poorly connected to primary freight corridors or requires substantial route detours, additional handling time and transfer costs may outweigh operational savings and discourage freight operators from using the facility (Holguín-Veras et al., 2020; Nong, 2022). Terminal-location analysis therefore needs to consider regional corridor connectivity, intermodal links to ports and airports, and proximity to warehousing clusters.

Spatial Screening via the Gravity Location Model (GLM)

The Gravity Location Model (GLM), also referred to as the center-of-gravity or Weber location model, is a continuous-space mathematical optimization technique used to identify a geographical coordinate ($X*$,$Y*$) that minimizes the total weighted transportation cost between a proposed facility and a set of spatially distributed supply origins and demand destinations (Susanto, 2022; Zhafarina et al., 2021). Unlike discrete network location models (such as *p-median* or *set-covering* models) that restrict selection to predefined nodes, GLM evaluates continuous spatial coordinates weighted by physical freight flows. The model postulates that the gravitational attraction of each freight activity point i is directly proportional to its freight shipment volume (Vi) and unit transportation cost rate (Ci), and inversely related to the spatial distance (di) between the facility and point i (Yamashita et al., 2000; Zhafarina et al., 2021).

Through an iterative numerical procedure, the model updates the candidate coordinates ($X*$,$Y*$) and recalculates inter-point distances until the aggregate transportation cost

(TC=Σ$CiVidi$) converges to a stable minimum (Susanto, 2022; Zhafarina et al., 2021). In logistics facility planning, GLM offers a rigorous, data-driven mechanism for narrowing a broad urban study area into specific zones that maximize distribution efficiency and reduce vehicle operating costs (*Biaya Operasional Kendaraan* or BOK).

Nevertheless, pure gravity models operate under the simplifying assumption of an isotropic, homogeneous plane. They do not intrinsically capture localized physical constraints, road network capacity (V/C ratio), land parcel availability, land market prices, environmental hazards, or statutory land-use zoning (Putri, 2018; Soimun et al., 2024). Therefore, within a public infrastructure planning framework, GLM is most effectively deployed as a first-stage spatial screening tool whose mathematical outputs are subsequently subjected to multi-criteria feasibility evaluation.

Multi-Criteria Evaluation: AHP and the STEEP Sustainability Framework

To incorporate non-spatial, institutional, and sustainability considerations into location selection, Multi-Criteria Decision-Making (MCDM) methods provide a structured analytical complement to spatial optimization (Anderluh et al., 2020; Nong, 2022). The Analytical Hierarchy Process (AHP), developed by Saaty, decomposes a complex decision problem into a multilevel hierarchy that consists of an overarching goal, evaluation criteria, subcriteria, and opposing alternatives (Saaty, 1977; Leal, 2020).

Through pairwise comparisons conducted by domain experts using Saaty's fundamental 1–9 scale, AHP derives normalized priority weights via eigenvector computation while rigorously verifying logical coherence through the Consistency Ratio (CR≤0.10) (Leal, 2020; Saaty, 1977).

To ensure that freight-terminal evaluation extends beyond narrow cost-efficiency metrics, Choudhary and Shankar (2012) and Kumar and Anbanandam (2020) proposed the STEEP (Social, Technical, Economic, Environmental, and Political) sustainability framework for infrastructure and multimodal freight-terminal location selection. Based on the Mutually Exclusive and Collectively Exhaustive (MECE) principle, the five STEEP dimensions and 18 operational subcriteria adopted in this study are structured as follows:

1. **Social Criterion (SC):** This criterion assesses the socio-demographic and community impacts of terminal development (Kumar & Anbanandam, 2020). It comprises three subcriteria: (a) job creation (SC1), reflecting direct and indirect employment opportunities for residents; (b) improvement of local living standards (SC2), including potential benefits generated through surrounding microeconomic activities; and (c) socio-cultural and local-wisdom compatibility (SC3), to ensure that terminal siting and heavy-truck routing take into account heritage sites, religious facilities, and cultural corridors within Singkawang's multi-ethnic Tidayu community, comprising Chinese, Dayak, and Malay populations.

2. **Technical Criterion (TC):** This criterion evaluates engineering suitability, traffic operations, and multimodal connectivity (Kumar & Anbanandam, 2020; Putri, 2018; Soimun et al., 2024). It comprises four subcriteria: (a) transportation-network accessibility (TC1), reflecting connectivity to primary arterial roads, regional freight corridors, seaports, and

airports; (b) roadway traffic performance (TC2), considering sufficient residual road capacity ((V/C < 0.75)) and Class IIIA pavement standards; (c) land availability and topography (TC3), considering the availability of sufficiently level land of at least 3 hectares to accommodate heavy-vehicle maneuvering requirements; and (d) terminal expansion potential (TC4), reflecting the capacity to accommodate long-term freight growth.

3. **Economic Criterion (EC):** This criterion captures financial feasibility, capital expenditure, and logistics-cost efficiency (Nong, 2022; Zhafarina et al., 2021). It comprises five subcriteria: (a) land acquisition cost (EC1), based on prevailing market or tax-assessed land values (NJOP); (b) transportation-cost efficiency and regional tax incentives (EC2), reflecting proximity to warehousing and market nodes as well as fiscal support; (c) infrastructure-construction cost (EC3), including costs associated with geotechnical conditions and rigid-pavement requirements; (d) contribution to regional economic growth (EC4), including potential multiplier effects on local GRDP and municipal revenue (PAD); and (e) investment payback period or Return on Investment (EC5).

4. **Environmental Criterion (EnC):** This criterion addresses ecological externalities associated with freight-terminal operations (Alho et al., 2018; Wygonik & Goodchild, 2018). It comprises three subcriteria: (a) environmental regulatory compliance (EnC1), including Environmental Impact Assessment (AMDAL), air-emission control, and wastewater-treatment (IPAL) feasibility; (b) noise and vibration impacts on adjacent residential areas (EnC2); and (c) vulnerability to natural and hydrometeorological hazards (EnC3).

5. **Political, Regulatory, and Institutional Criterion (PC):** Within the infrastructure policy literature (Choudhary & Shankar, 2012; Kumar & Anbanandam, 2020), the "Political" dimension refers to public-policy alignment, statutory spatial-planning conformity, institutional commitment, and regulatory certainty rather than partisan politics. It comprises three subcriteria: (a) conformity with the Regional Spatial Plan (RTRW) and designated development zones (PC1), which affects legal land-use permitting (*Izin Pemanfaatan Ruang*); (b) government commitment and institutional support (PC2), reflecting cross-agency commitment to long-term capital budgeting and post-construction enforcement against illegal on-street parking within RUMAJA; and (c) terminal and corridor security (PC3), addressing the protection of cargo and drivers from theft, extortion, or illegal levies (*pungli*) through coordinated institutional law enforcement.

METHODOLOGY

Research Design and Sequential GLM-AHP Framework

This study employs a quantitative descriptive approach structured through a two-stage sequential analytical framework. In the first stage, the Gravity Location Model (GLM) is used as a spatial screening instrument to identify candidate coordinates based on transportation-cost and travel-distance efficiency involving 19 major freight-generating companies and consumer hubs. In the second stage, the Analytical Hierarchy Process (AHP) is applied to prioritize the GLM-derived candidates together with a pre-designated spatial-planning location stipulated in the Singkawang Regional Spatial Plan (RTRW), using the STEEP (Social, Technical, Economic, Environmental, and Political) sustainability criteria.

Data Sources and AHP Expert Profiles

Primary data were collected through traffic-count surveys, observations of on-street parking and loading–unloading activities along 11 major arterial road segments, and operational interviews with truck drivers and freight-expedition firms. For AHP evaluation, pairwise-comparison questionnaires based on Saaty's fundamental 1–9 scale were distributed independently to five key experts representing strategic institutional stakeholders in Singkawang City. The expert profiles and their relevance to the STEEP evaluation are presented in Table 1.

Table 1. AHP expert profiles and relevance to the STEEP evaluation

No.	Institutional Representation / Stakeholder	Academic Background & Professional Qualification	Relevance to STEEP Evaluation
1	Department of Transportation (DISHUB)	M.Sc. in Urban Planning; more than 10 years of experience in urban traffic engineering and management	Assesses Technical criteria, including road capacity, circulation, and accessibility
2	Regional Planning Agency (BAPPEDA)	B.Sc./M.Sc. in Urban Planning; strategic expertise in regional development planning	Assesses Political criteria related to spatial-planning conformity and Economic criteria at the regional level
3	Public Works and Spatial Planning Agency (PUPR)	B.Sc. in Architecture; M.Sc. in Urban Planning; more than 10 years of experience in building layout and infrastructure	Assesses Technical criteria related to land and infrastructure capacity and Environmental criteria
4	Industry, Trade, and SME Department	LL.B. in Law; more than 20 years of experience in bureaucracy, warehousing, and the investment climate	Assesses Economic criteria, including regional growth and multiplier effects
5	Road Transport Operators Association (ORGANDA)	Legal advocate and transport-association leader with practical knowledge of logistics operations	Assesses Social criteria and terminal-security aspects within the Political criterion

Establishment of the STEEP Hierarchy and Subcriteria

The AHP hierarchical structure was constructed based on the Mutually Exclusive and Collectively Exhaustive (MECE) principle and comprises five primary dimensions and 18 operational subcriteria. The "Political" criterion in this framework does not refer to partisan politics but reflects institutional governance, compliance with spatial-planning regulations, and government support for law enforcement. The detailed hierarchy is presented in Table 2.

Table 2. STEEP hierarchical structure and subcriteria

Primary Dimension	Operational Evaluation Subcriteria
Social (SC)	SC1: Local job creation; SC2: Improvement of local living standards; SC3: Conformity with socio-cultural heritage and local wisdom, including Tidayu multi-ethnic routes
Technical (TC)	TC1: Multimodal transport-network accessibility; TC2: Access-road performance ((V/C < 0.75); maximum axle-load requirement); TC3: Land availability for vehicle maneuvering; TC4: Future expansion capability
Economic (EC)	EC1: Land acquisition cost (market/tax-assessed value); EC2: Vehicle operating-cost efficiency (BOK); EC3: Infrastructure-construction cost; EC4: Regional economic multiplier effect; EC5: Return on Investment (ROI) period
Environmental (EnC)	EnC1: Environmental regulatory compliance (AMDAL/wastewater management); EnC2: Operational noise and vibration impacts; EnC3: Hydrometeorological and flood vulnerability
Political and Institutional (PC)	PC1: Conformity with Regional Spatial Plan (RTRW) zoning; PC2: Government institutional stability and law-enforcement support against illegal parking; PC3: Terminal operational security

Mathematical Formulation of GLM and AHP

In the GLM stage, the search for optimal coordinates $(X*,Y*)$ was conducted iteratively until the total transportation cost (TC) reached minimum convergence, using the following equations:

$$X^* = \frac{\sum_{i=1}^{n}(C_i \cdot V_i \cdot X_i)}{\sum_{i=1}^{n}(C_i \cdot V_i)} \quad ; \quad Y^* = \frac{\sum_{i=1}^{n}(C_i \cdot V_i \cdot Y_i)}{\sum_{i=1}^{n}(C_i \cdot V_i)} \quad TC^n = \sum(C_i \cdot V_i \cdot J_i)_{i=1}^{n}$$

where Xi and Yi represent the coordinates of the logistics activity nodes, Vi is the freight volume, Ci denotes the unit cost, and Ji is the travel distance.

In the AHP stage, the judgments of the five experts were aggregated into a single consensus matrix using the geometric mean:

$$GM = \sqrt[n]{x_1 \cdot x_2 \cdots x_n}$$

The validity of the judgments was evaluated using the Consistency Ratio (CR). The matrix is considered consistent if $CR \leq 0.10$, computed from the Consistency Index (CI) and Random Index (IR):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad ; \quad CR = \frac{CI}{IR}$$

RESULTS

Spatial Screening Using the Gravity Location Model (GLM)

Based on the origin–destination freight matrix and transportation-cost rates, GLM iterations were performed for three distribution clusters. For the Pasar Hongkong cluster, the iterations converged on Sijangkung Subdistrict; for the Pasar Beringin cluster, on Sanggau Kulor Subdistrict; and for the intercity cross-border cluster, on Pasiran Subdistrict. These locations represent the center-of-gravity

points associated with the lowest calculated transportation costs within their respective logistics clusters.

Spatial-Planning Comparison and AHP-STEEP Evaluation

While the three GLM-derived candidates were identified based primarily on spatial and cost efficiency, public infrastructure location decisions also require conformity with statutory spatial-planning requirements. Sedau Subdistrict, which is designated in the Singkawang RTRW, was therefore included as a fourth alternative. The spatial, accessibility, and land-cost characteristics of the four alternatives prior to AHP synthesis are presented in Table 3.

Table 3. Spatial, accessibility, and land-cost comparison of candidate locations

Feasibility Parameter	Sedau (RTRW Alternative)	Sijangkung (GLM 1)	Sanggau Kulor (GLM 2)	Pasiran (GLM 3)
Main Access-Road Performance	Primary arterial (2/2 TT); V/C = 0.41	Secondary local road (2/2); V/C = 0.20	Local road (2/2); V/C = 0.18	Arterial/ collector road; V/C = 0.13
Distance to Warehousing Hubs	4.1 km	13.1 km	13.4 km	11.2 km
Distance to Regional Corridor	8.9 km	17.9 km	18.3 km	16.0 km
Land Acquisition Cost	Rp1,300,000/m²	Rp560,000/m²	Rp1,000,000/m²	Rp1,070,000/m²
Spatial-Zoning Conformity	Highly suitable (industrial)	Limited	Green/open land	Near settlements

The AHP results indicate that the aggregated judgments of the five experts achieved a Consistency Ratio (CR) of 0.010, or 1%, which is below the maximum threshold of 10%. The criteria weighting assigned the highest priority to the Political criterion (30.7%), followed by the Economic (24.6%) and Technical (23.1%) criteria. Within this decision structure, the relatively high Political weight reflects the importance assigned by the expert panel to spatial-zoning conformity, institutional support, and regulatory considerations.

Based on the global AHP synthesis, Sedau received the highest overall priority weight (0.456), followed by Sanggau Kulor (0.233), Pasiran (0.168), and Sijangkung (0.143). Sedau performed favorably across the Political, Technical, and Economic dimensions. In addition to its conformity with the RTRW, Sedau has the shortest reported distance to major warehousing hubs (4.1 km) and the shortest distance to the regional corridor (8.9 km), although its estimated land-acquisition cost is higher than that of the other alternatives.

Sensitivity Analysis

To validate the robustness of the decision, five sensitivity analysis simulations (Performance, Dynamic, Gradient, Head-to-Head, and 2D Sensitivity) were conducted

using the Expert Choice software. The testing proved that Sedau's top-ranking status remained entirely stable without experiencing any rank reversal, even when the weights of the Economic or Environmental criteria were drastically inflated or reduced. This stability confirms that the recommendation of Sedau does not rely on a single criterion but is supported by balanced performance across all STEEP dimensions.

Land-Area Requirements and Terminal Layout Design

The study adopts a total terminal site area of 30,000 m² (3 hectares). Based on calculations of average parking duration, heavy-vehicle Parking Space Units (SRP), and minimum service requirements, the site area is allocated as follows:

1. Main and supporting facilities (11,351.20 m²): This area accommodates loading docks, consolidation warehouses, parking bays for articulated trucks and pick-up vehicles, weighbridges, administrative offices, emergency repair facilities, driver rest areas, and worship facilities.

2. Internal vehicle circulation (6,810.72 m²): This area is allocated to internal circulation and vehicle maneuvering based on the design requirements of articulated trucks, including a 12 m turning radius, to reduce the potential for bottlenecks at arrival and departure points.

3. Reserve land and green open space (11,838.08 m²): Approximately 9,000 m², equivalent to 30% of the total site area, is allocated to green open space (RTH) as an ecological buffer, while the remaining area is reserved for future expansion to accommodate projected freight growth.

DISCUSSION

Integration of the Sedau Terminal within the Regional Logistics Network

The proposed Sedau Freight Terminal is intended not only as an off-street parking facility but also as a consolidation node within the broader West Kalimantan regional logistics network. From a supply-chain perspective, Sedau is located along the southern corridor of Singkawang City and is positioned in relation to freight flows from the Kijing Port area in Mempawah Regency and Pontianak.

Operationally, the proposed terminal is designed to support a two-tier distribution system. Although intermediate transshipment introduces additional handling activities and costs, the terminal could facilitate cargo consolidation and reduce the need for heavy intercity articulated trucks carrying approximately 8–24 tons to enter the Singkawang Central Business District (CBD). Cargo could instead be unloaded at Sedau and subsequently distributed to destinations such as Pasar Hongkong and Pasar Beringin using smaller pick-up vehicles or light trucks. The terminal is also positioned in relation to freight flows associated with the Aruk Cross-Border Post (PLBN) and the cargo facilities at Singkawang Airport in Pangmilang.

Rationale for Selecting Sedau: Trade-off between Spatial Efficiency and Spatial-Planning Conformity

A key finding of this study is the selection of Sedau, with a global priority weight of 0.456, over the three candidates generated by the Gravity Location Model (GLM): Sijangkung, Sanggau Kulor, and Pasiran. The GLM generated candidate locations based on travel-distance and vehicle-operating-cost considerations. However, the AHP-STEEP evaluation shows that spatial and cost

efficiency are not the only considerations relevant to public infrastructure location decisions.

The Political criterion received the highest weight in the expert evaluation (30.7%), reflecting the importance assigned to spatial-planning conformity, regulatory considerations, and institutional support. Although the GLM-derived candidates perform favorably in terms of selected spatial-efficiency indicators, Sedau has the advantage of conformity with the designated RTRW location. Sedau also has the shortest reported distance to major warehousing hubs (4.1 km) and the regional corridor (8.9 km), although its estimated land-acquisition cost of Rp1,300,000/m² is higher than that of the other alternatives.

Analytical Basis for Land Requirements and Facility Layout

The proposed 30,000 m² site is allocated among operational facilities, internal circulation, green open space, and future expansion. Of the total area, 11,351.20 m² is allocated to main and supporting facilities, including parking areas, warehousing, weighbridges, administrative facilities, and driver-support facilities. A further 6,810.72 m² is allocated to internal vehicle circulation and maneuvering, based on the operational requirements of articulated freight vehicles. The remaining 11,838.08 m² is allocated to green open space and reserve land for the future expansion.

Within this allocation, approximately 9,000 m², equivalent to 30% of the total site, is designated as green open space (RTH), while the remaining reserve area is intended to accommodate possible future expansion of terminal and warehousing functions.

Policy Implications and Implementation Roadmap

To advance the Sedau Terminal from conceptual planning toward implementation, several technical and institutional stages require further consideration. First, a comprehensive feasibility study and Detailed Engineering Design (DED) would be required to determine technical specifications, quantities, and construction costs. Second, the project would need to comply with applicable environmental and traffic-impact assessment requirements, including AMDAL and ANDALALIN where legally required.

Regarding financing, the municipal government could consider Public-Private Partnership (PPP/KPBU) arrangements with private logistics operators as one potential mechanism for supporting land acquisition and capital investment. Operational implementation would also require coordination among the Department of Transportation, BAPPEDA, relevant law-enforcement agencies, and other stakeholders, particularly in relation to freight-vehicle management and on-street parking within the public road right-of-way (RUMAJA).

CONCLUSION

This study examined urban freight-terminal location planning in Singkawang City by sequentially integrating the Gravity Location Model (GLM) and the Analytical Hierarchy Process (AHP). Field observations identified on-street freight parking and loading–unloading activities along major urban road corridors, with estimated reductions in effective road capacity ranging from 11% to 54% on affected segments.

Among the four alternatives evaluated, Sedau received the highest global AHP priority

weight (0.456), followed by Sanggau Kulor (0.233), Pasiran (0.168), and Sijangkung (0.143). The selection of Sedau reflects the combined influence of spatial-planning conformity, institutional considerations, technical characteristics, and economic factors within the adopted AHP-STEEP framework. The Political criterion received the highest weight (30.7%) in the expert evaluation.

The proposed terminal plan uses a 30,000 m² site allocated among main and supporting facilities, internal vehicle circulation, green open space, and reserve land for future development. Before implementation, the proposed location and layout require further feasibility, environmental, traffic-impact, engineering, and financial assessment. Thus, the study provides a preliminary analytical basis for future planning and evaluation of an urban freight terminal in Singkawang City.

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