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WEIGHTING TRANSIT-ORIENTED DEVELOPMENT INDICATORS FOR REGIONAL RAILWAY STATIONS IN THAILAND USING THE SPHERICAL FUZZY ANALYTIC HIERARCHY PROCESS

Summary. This research develops an integrated assessment framework for evaluating Transit-Oriented Development (TOD) potential around regional railway stations in Thailand using the Spherical Fuzzy Analytic Hierarchy Process (SFAHP). An extensive literature review was conducted to identify and analyze seven main factors and 24 sub-indicators from previous TOD studies across different railway station types. Expert evaluations were systematically incorporated to determine the relative importance of these factors within Thailand's specific context. The results indicate that density (20.1%) and diversity (18.1%) are the most critical factors, followed by transit (15.1%), design (14.7%), destination

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accessibility (11.7%), economic development (10.8%), and distance to transit (9.5%). Among the sub-indicators, land use diversity, population density, and level of mixed land use emerged as the most influential elements. The SFAHP methodology effectively addressed the uncertainty and complexity in expert judgments, resulting in a more robust evaluation system than traditional methods. This assessment framework offers a valuable tool for policymakers, urban planners, and developers to prioritize investment and development efforts in Thailand's expanding regional rail network. The findings provide significant implications for integrating transportation and land use planning to achieve sustainable urban development in Thailand's regional context, ultimately supporting the country's national strategic goals for infrastructure development.

Keywords: transit-oriented development, regional railway stations, spherical fuzzy AHP, sustainable suburban development, TOD indicators

1. INTRODUCTION

Transit-oriented development (TOD) is a globally recognized urban planning approach aimed at creating sustainable communities centered around public transportation hubs. This concept emphasizes the development of mixed-use, high-density, and pedestrian-friendly environments within walking distance of transit stations [1]. In Thailand, the application of TOD principles to regional rail networks has gained significant importance as the country continues to expand its railway infrastructure under the 20-Year National Strategy (2018-2037) and Thailand's Transport Infrastructure Development Strategy, which seeks to position rail as Thailand's primary transportation network [2].

Thailand's regional rail system examined in this research consists of four main corridors spanning approximately 2,680 kilometers with 92 stations. The Northern Line connects Bangkok to Chiang Mai Station through key economic centers such as Lopburi, Nakhon Sawan, and Phitsanulok. The Northeastern Line extends from Bangkok to Nong Khai, while the Eastern Line links Bangkok to Aranyaprathet, facilitating cross-border movement with Cambodia. The Southern Line runs from Bangkok to Hat Yai Junction, serving as a vital connection for goods transport and tourism between the central and southern regions [3].

Despite the growing interest in implementing TOD around regional railway stations in Thailand, there are considerable challenges in assessing the development potential of these areas. Notably, existing TOD indicator frameworks were developed primarily for urban environments in more developed economies. They may not adequately reflect the unique socioeconomic, physical, and cultural characteristics of Thailand's regional contexts. Additionally, conventional assessment approaches often lack systematic methodologies for weighting indicators according to their relative importance in the Thai setting, potentially resulting in evaluations that fail to capture the true development potential of these areas [4].

This research addresses these limitations by developing an integrated framework for evaluating Transit-Oriented Development (TOD) potential around regional railway stations in Thailand, utilizing the Spherical Fuzzy Analytic Hierarchy Process (SFAHP). This methodology offers distinct advantages over traditional approaches through its ability to incorporate uncertainty and complex expert judgments via three-dimensional membership functions [5]. The SFAHP enables the systematic determination of the relative importance weights for both of main factors and sub-criteria while accounting for the inherent complexity and variability in expert assessments when evaluating TOD indicators specific to Thailand's context [6].

The anticipated outcomes of this research have significant implications for urban and transportation planning in Thailand. By establishing a tailored set of weighted indicators that reflect Thailand's specific development needs and regional characteristics, this work will provide planners, policymakers, and developers with a more accurate tool for evaluating TOD potential around regional railway stations. Furthermore, by ranking station areas according to their development potential, this research will inform strategic investment decisions and guide the implementation of TOD initiatives based on each area's unique attributes and readiness. These contributions will ultimately support the sustainable development of regional centers throughout Thailand, improving the quality of life for residents in alignment with the country's broader national development objectives.

2. LITERATURE REVIEW

2.1. Literature Review of TOD Factors and Indicators

The literature review reveals comprehensive insights into Transit-Oriented Development (TOD) factors and indicators from previous research, as shown in Table 1, which presents seven main factors: Density (D1), Diversity (D2), Design (D3), Distance to transit (D4), Destination accessibility (D5), Transit (TS), and Economic development (EC), categorized by railway station types including central, regional main, sub-regional, and other related stations. Table 2 provides further details on the 24 sub-indicators under these main factors that researchers have employed to evaluate TOD potential across different types of railway stations, illustrating which indicators have been prioritized in various studies and contexts. Table 3 provides in-depth information on the definitions and measurement methods of these sub-indicators from previous research, which is invaluable for developing an appropriate assessment framework for Thailand's context. This includes measures such as population density, land use diversity, quality of street and pedestrian design, as well as economic indicators and transit connectivity. This systematic categorization demonstrates the evolution of TOD assessment approaches and provides a solid foundation for selecting and adapting indicators that are most relevant to regional railway stations in Thailand.

Tab. 1

Study of Main TOD Factors from Previous Research Categorized by Railway Station Types

No.	Main factors	Central railway station				Regional Main railway station				Sub-Regional railway station		Other related	
		[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]
D1	Density	●	●	●	●	●	●	●	●	●	●	●	●
D2	Diversity	●	●	●	●	●		●	●	●	●	●	●
D3	Design	●	●	●	●	●	●	●	●			●	●
D4	Distance to transit	●		●		●					●		●
D5	Destination accessibility	●		●	●	●		●					●
TS	Transit	●		●		●		●		●	●		
EC	Economic development	●		●		●	●			●	●		

Tab. 2

Study of TOD Sub-Indicators Categorized by Railway Station Types

No.	Sub-factors (Indicators)	Regional Main railway station				Sub-Regional railway station		Other related	
		[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]
D11	Population density	●	●	●	●	●	●	●	●
D12	Commercial density	●	●			●	●		
D13	Employment/Job density		●	●		●	●	●	●
D14	Business density	●			●				●
D21	Land use diversity	●	●	●	●				●
D22	Mixed land use	●				●	●		●
D23	Level of mixed land use					●	●		
D31	Intersection density		●		●			●	●
D32	Walkable/Cyclable infrastructure		●		●			●	●
D33	Street network characteristics			●				●	
D34	Station design elements			●				●	
D41	Accessibility to station					●	●		
D42	Walking Distance to transit facilities			●					●
D43	Distance to bus stops			●					●
D51	Access to job opportunities	●							●
D52	Access to services and amenities							●	●
D53	Connectivity to destinations				●				●
TS1	Passenger volume			●		●	●		
TS2	Safety and amenities					●	●		
TS3	Intermodal connectivity					●	●		●
TS4	Parking facilities					●	●		●
EC1	Business measures	●				●	●		
EC2	Employment measures		●			●	●		

Tab. 3

Study of Measurement Methods and Definitions of TOD Sub-Indicators

No.	Sub-factors (Indicators)	Definition	Measurement
D11	Population density	Population density per square kilometer	[11]: Higher residential and commercial densities are required for more efficient public transport. [13]: Population per square kilometer (Person/km^2). [15]: Population/sq km. [16]: Minimum 1500 persons/km^2/Local Authority.
D12	Commercial density	Commercial activity density per square kilometer	[11]: Higher commercial densities support more efficient public transport. [15]: Commercial activity/sq km. [16]: Minimum 20% from TOD zone.

No.	Sub-factors (Indicators)	Definition	Measurement
D13	Employment/ Job density	Job density per square kilometer	[12]: Employment density as a key factor for Transit-Oriented Development (TOD). [15]: Jobs total/sq km. [16]: Minimum 20% from TOD zone.
D14	Business density	Number of business establishments per unit area	[11]: The higher number of business establishments represents a higher level of economic development and, hence, higher TOD levels. [14]: Concentration of businesses in TOD area.
D21	Land use diversity	Diversity of land uses measured using indexes like Shannon-Wiener	[11]: Higher diversity of land use reduces vehicular trips and enhances the liveliness and safety of a place where people socialize. [13]: Measured using Shannon-Wiener Index.
D22	Mixed land use	Degree of mixed land uses with respect to residential use	[11]: Higher mixedness of land uses (w.r.t residential land use) encourages a higher degree of walking and cycling for non-work trips. [15]: Measured using dissimilarity index, activity center mixture, and commercial intensities. [16]: A minimum of 100% of the TOD zone can be developed.
D23	Level of mixed land use	Percentage of mixed land use in TOD area	[15]: Mixed land use of housing and others. [16]: A minimum of 50% of the TOD area is mixed land use.
D31	Intersection density	Number of road intersections per unit area	[12]: Density of road intersections. [14]: Number of intersections per unit area.
D32	Walkable/ Cyclable infrastructure	Length of infrastructure suitable for walking and cycling	[12]: Total length of road fit for walking and cycling. [14]: Length of bicycle and pedestrian networks.
D33	Street network characteristics	Road length, block face length, sidewalks, lights, etc.	[13]: Road length per catchment (km). [17]: Block face length, proportion of blocks with sidewalks, planting strips, overhead lights, flat terrain (< 5% slope), quadrilateral shape.
D34	Station design elements	Features like number of exits, lighting, accessibility	[13]: Number of exits per railway station. [17]: Distance between overhead lights (feet).
D41	Accessibility to station	Spatial readiness and population with access to transit node	[15]: Spatial readiness and total population that can afford the transit node. [16]: Minimum Distance is 400/800 m from station.
D42	Walking Distance to transit facilities	Distance to transit facilities based on walkable principles	[13]: Based on general TOD principles regarding walkable Distance to transit facilities.

No.	Sub-factors (Indicators)	Definition	Measurement
D43	Distance to bus stops	Proximity and number of bus stops per catchment area	[13]: Bus stops per unit catchment area.
D51	Access to job opportunities	Access to jobs within walkable distance of transit node	[11]: Access to job opportunities within a walkable Distance of a transit node. [17]: Accessibility index to all jobs (via auto).
D52	Access to services and amenities	Access to retail, services, recreation within walkable distance	[17]: Access to sales and services jobs (via walk), per developed acre rates of retail stores, activity centers, parks, and recreational sites.
D53	Connectivity to destinations	Connectivity between transit node and key destinations	[14]: Connectivity between transit node and key destinations in the area.
TS1	Passenger volume	Passenger capacity during peak and non-peak hours	[15]: Total passenger/transport capacity during peak hour and outside peak hour. [16]: 300 passengers (2 trips) during peak hours; 100 persons (1 trip) during non-peak hours. [13]: Average daily commuters per station (Person).
TS2	Safety and amenities	Safety features and passenger amenities at stations	[15]: Waiting and vehicle safety; station amenities (shelter, seating, shops, lighting); information panels; accessibility features. [16]: Security (CCTV, guards); facilities (seating, toilets, cafeteria, ventilation); information displays (boards, LED signs, directions).
TS3	Intermodal connectivity	Connection between routes and transport modes	[15]: Connection between routes and modes of connectivity. [16]: Minimum one mode of public transportation connected with the station; minimum one route connected to the station.
TS4	Parking facilities	Ratio of users to parking spaces, bicycle parking, etc.	[15]: User and space ratio. [16]: Existing parking for cars, bicycles, and specific groups (such as disabled persons).
EC1	Business measures	Number of businesses and level of economic development	[11]: The number of business establishments represents a higher level of economic development. [15]: Total business/sq km. [16]: Minimum 20% from Local Authority jurisdiction.
EC2	Employment measures	Tax earnings, investment, employment levels	[12]: Tax earnings of municipalities. [15]: Total investment. [16]: Minimum RM 100 million/year (Majlis Perbandaran); Minimum RM 50 million/year (Majlis Daerah); Minimum 30% of land use are industry and commercial.

2.2. Methodology of Sphere-Based Fuzzy Multi-Criteria Decision Analysis

Spherical fuzzy sets (SFS) provide a valuable framework for addressing uncertainty and complexity in expert judgments for multi-criteria decision analysis. This methodology was applied to assess the Transit-Oriented Development (TOD) potential around regional railway stations in Thailand. Table 4 in the research presents the linguistic scale for pairwise comparisons in the Spherical Fuzzy Analytic Hierarchy Process, defining membership (μ), non-membership (v), and hesitancy (π) degrees for each importance level, along with corresponding Score Indices (SI) for converting linguistic judgments into numerical values for computation [6]. The scale ranges from "Absolutely Higher Importance" (AHI) with values (0.90, 0.10, 0.00) and a score of 9, to "Absolutely Lower Importance" (ALI) with values (0.10, 0.90, 0.00) and a score of 0.11.

Tab. 4

Spherical fuzzy linguistic scale for criteria pairwise comparisons

Linguistic Term	(μ, v, π)	Score Index (SI)
Higher Importance (AHI)	0.90, 0.10, 0.00	9
Very High Importance (VHI)	0.85, 0.15, 0.04	8
	0.80, 0.20, 0.10	7
	0.75, 0.25, 0.14	6
High Importance (HI)	0.70, 0.30, 0.20	5
	0.65, 0.35, 0.23	4
Slightly Higher Importance (SHI)	0.60, 0.40, 0.30	3
	0.55, 0.45, 0.30	2
Equally Important (EI)	0.50, 0.40, 0.40	1
	0.45, 0.55, 0.30	0.5
Slightly Lower Importance (SLI)	0.40, 0.60, 0.30	0.33
	0.35, 0.65, 0.23	0.25
Lower Importance (LI)	0.30, 0.70, 0.20	0.20
	0.25, 0.75, 0.14	0.17
Very Low Importance (VLI)	0.20, 0.80, 0.10	0.14
	0.15, 0.85, 0.04	0.13
Lower Importance (ALI)	0.10, 0.90, 0.00	0.11

For converting linguistic judgments to numerical values in pairwise comparisons, the research used the following formulas:

$$SI = \sqrt{\left|100 * \left[\left(\mu_{\tilde{A}_s} - \pi_{\tilde{A}_s}\right)^2 - \left(v_{\tilde{A}_s} - \pi_{\tilde{A}_s}\right)^2\right]\right|} \quad (1)$$

for AMI; VHI; HI; SMI; and EI

$$\frac{1}{SI} = \frac{1}{\sqrt{\left|100 * \left[\left(\mu_{\tilde{A}_s} - \pi_{\tilde{A}_s}\right)^2 - \left(v_{\tilde{A}_s} - \pi_{\tilde{A}_s}\right)^2\right]\right|}} \quad (2)$$

for EI; SLI; LI; VLI; and ALI.

The research followed a systematic approach to determine the relative importance of criteria and sub-criteria through the following steps:

1. Expert evaluations were collected using the linguistic terms presented in Table 4.
2. Pairwise comparison matrices were constructed for main factors (Table 5) and sub-indicators (Table 6-12).
3. For each comparison, the membership (μ), non-membership (v), and hesitancy (π) values were recorded.
4. The score ($S_{\tilde{w}^s_j}$) was calculated for each factor or sub-factor.
5. Finally, normalized weights ($\bar{w}^s$) were determined.

This SFAHP methodology effectively addressed the uncertainty and complexity in expert judgments, resulting in a more robust evaluation system than traditional methods for evaluating TOD potential around regional railway stations in Thailand.

3. ANALYSIS RESULTS

Tables 5 through 12 present the results of pairwise comparisons of various factors for evaluating TOD potential around regional railway stations using the Spherical Fuzzy Analytic Hierarchy Process (SFAHP). As shown in Table 5, the comparison of seven main factors reveals that Density (D1) has the highest importance weight (0.201), followed by Diversity (D2) at 0.181 and Transit (TS) at 0.151. Tables 6-12 display the pairwise comparisons of sub-indicators under each main factor: Table 6 shows comparisons of density sub-indicators (D11-D14) with population density (D11) having the highest weight (0.318); Table 7 presents diversity sub-indicators (D21-D23) with land use diversity (D21) receiving the highest weight (0.356); and Tables 8-12 show similar results for the sub-indicators of design, Distance to transit, destination accessibility, transit, and economic development factors, respectively. Each table provides the membership (μ), non-membership (v), and hesitancy (π) values of the spherical fuzzy sets, along with the score ($S_{\tilde{w}^s_j}$) and normalized weights ($\bar{w}^s$) resulting from the aggregation of three experts' opinions. This comprehensive analysis yields reliable importance weights that systematically reflect the complexity of decision-making in TOD assessment, accounting for uncertainty and expert judgment in a structured mathematical framework.

Tab. 5

Aggregated pairwise comparisons of main factors

	D1	D2	D3	D4	D5	TS	EC	$\tilde{w}^s$	$S_{\tilde{w}^s_j}$	$\bar{w}^s$
D1	(0.50, 0.40, 0.40)	(0.62, 0.39, 0.23)	(0.68, 0.32, 0.18)	(0.77, 0.24, 0.12)	(0.66, 0.35, 0.20)	(0.58, 0.42, 0.27)	(0.71, 0.31, 0.15)	(0.65, 0.35, 0.22)	17.43	0.201
D2	(0.43, 0.57, 0.25)	(0.50, 0.40, 0.40)	(0.63, 0.37, 0.22)	(0.74, 0.27, 0.14)	(0.69, 0.33, 0.15)	(0.54, 0.46, 0.30)	(0.64, 0.37, 0.19)	(0.60, 0.40, 0.24)	15.72	0.181
D3	(0.32, 0.68, 0.19)	(0.37, 0.63, 0.23)	(0.50, 0.40, 0.40)	(0.70, 0.31, 0.18)	(0.62, 0.39, 0.20)	(0.57, 0.44, 0.25)	(0.61, 0.42, 0.22)	(0.53, 0.46, 0.24)	12.68	0.147

	D1	D2	D3	D4	D5	TS	EC	$\tilde{w}^s$	$S_{\tilde{w}^s j}$	$\bar{w}^s$
D4	(0.24, 0.76, 0.12)	(0.29, 0.72, 0.16)	(0.33, 0.69, 0.21)	(0.50, 0.40, 0.40)	(0.46, 0.55, 0.28)	(0.40, 0.61, 0.24)	(0.47, 0.58, 0.27)	(0.38, 0.63, 0.25)	8.25	0.095
D5	(0.38, 0.63, 0.20)	(0.32, 0.69, 0.18)	(0.41, 0.60, 0.22)	(0.56, 0.45, 0.29)	(0.50, 0.40, 0.40)	(0.45, 0.58, 0.26)	(0.54, 0.49, 0.23)	(0.45, 0.55, 0.26)	10.12	0.117
TS	(0.44, 0.58, 0.29)	(0.49, 0.53, 0.32)	(0.43, 0.58, 0.27)	(0.61, 0.40, 0.24)	(0.58, 0.44, 0.26)	(0.50, 0.40, 0.40)	(0.59, 0.42, 0.20)	(0.52, 0.49, 0.28)	13.05	0.151
EC	(0.31, 0.71, 0.16)	(0.38, 0.64, 0.20)	(0.41, 0.62, 0.24)	(0.53, 0.49, 0.28)	(0.48, 0.52, 0.25)	(0.43, 0.60, 0.21)	(0.50, 0.40, 0.40)	(0.43, 0.59, 0.25)	9.36	0.108

Tab. 6

Aggregated pairwise comparisons of density sub-factors

	D11			D12			D13			D14			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
D11	0.50	0.40	0.40	0.64	0.36	0.22	0.71	0.29	0.16	0.68	0.32	0.18	0.63	0.35	0.24	16.92	0.318
D12	0.38	0.63	0.24	0.50	0.40	0.40	0.58	0.42	0.26	0.61	0.39	0.20	0.52	0.46	0.28	13.47	0.253
D13	0.30	0.71	0.17	0.44	0.57	0.28	0.50	0.40	0.40	0.57	0.44	0.27	0.45	0.53	0.27	11.21	0.210
D14	0.35	0.66	0.19	0.42	0.60	0.22	0.45	0.56	0.29	0.50	0.40	0.40	0.43	0.55	0.28	11.68	0.219

Tab. 7

Aggregated pairwise comparisons of diversity sub-factors

	D21			D22			D23			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
D21	0.50	0.40	0.40	0.62	0.38	0.23	0.58	0.42	0.25	0.57	0.40	0.29	14.85	0.356
D22	0.40	0.61	0.25	0.50	0.40	0.40	0.54	0.46	0.29	0.48	0.49	0.31	12.35	0.296
D23	0.44	0.57	0.27	0.47	0.53	0.31	0.50	0.40	0.40	0.47	0.50	0.33	14.49	0.348

Tab. 8

Aggregated pairwise comparisons of design sub-factors

	D31			D32			D33			D34			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
D31	0.50	0.40	0.40	0.47	0.53	0.28	0.55	0.45	0.26	0.62	0.38	0.23	0.54	0.44	0.29	13.76	0.271
D32	0.54	0.46	0.29	0.50	0.40	0.40	0.59	0.41	0.24	0.67	0.33	0.19	0.58	0.40	0.28	15.32	0.302
D33	0.47	0.53	0.27	0.42	0.58	0.26	0.50	0.40	0.40	0.56	0.44	0.27	0.49	0.49	0.30	12.48	0.246
D34	0.39	0.62	0.24	0.35	0.66	0.22	0.45	0.55	0.28	0.50	0.40	0.40	0.42	0.56	0.29	9.21	0.181

Tab. 9

Aggregated pairwise comparisons of Distance to transit sub-factors

	D41			D42			D43			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
D41	0.50	0.40	0.40	0.59	0.41	0.24	0.63	0.37	0.22	0.57	0.39	0.29	15.32	0.372
D42	0.42	0.59	0.25	0.50	0.40	0.40	0.56	0.44	0.27	0.49	0.48	0.31	13.15	0.319
D43	0.38	0.63	0.23	0.45	0.55	0.29	0.50	0.40	0.40	0.44	0.53	0.31	12.74	0.309

Tab. 10

Aggregated pairwise comparisons of destination accessibility sub-factors

	D51			D52			D53			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
D51	0.50	0.40	0.40	0.48	0.52	0.29	0.54	0.46	0.27	0.51	0.46	0.32	13.28	0.333
D52	0.53	0.47	0.30	0.50	0.40	0.40	0.57	0.43	0.25	0.53	0.43	0.32	14.12	0.354
D53	0.47	0.53	0.28	0.44	0.56	0.26	0.50	0.40	0.40	0.47	0.50	0.33	12.52	0.313

Tab. 11

Aggregated pairwise comparisons of transit sub-factors

	TS1			TS2			TS3			TS4			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
TS1	0.50	0.40	0.40	0.57	0.43	0.25	0.61	0.39	0.23	0.66	0.34	0.19	0.59	0.39	0.27	15.53	0.294
TS2	0.44	0.56	0.26	0.50	0.40	0.40	0.55	0.45	0.27	0.59	0.41	0.24	0.52	0.46	0.29	13.25	0.251
TS3	0.40	0.60	0.24	0.46	0.54	0.28	0.50	0.40	0.40	0.54	0.46	0.29	0.48	0.50	0.30	12.11	0.229
TS4	0.35	0.65	0.21	0.42	0.58	0.25	0.47	0.53	0.30	0.50	0.40	0.40	0.44	0.54	0.29	11.95	0.226

Tab. 12

Aggregated pairwise comparisons of economic development sub-factors

	EC1			EC2			$\tilde{w}^s$			$S_{\tilde{w}^s j}$	$\bar{w}^s$
EC1	0.50	0.40	0.40	0.53	0.47	0.29	0.52	0.44	0.35	13.65	0.531
EC2	0.48	0.52	0.30	0.50	0.40	0.40	0.49	0.46	0.35	12.04	0.469

Table 13 presents the importance weights of primary factors and sub-indicators for evaluating the potential of Transit-Oriented Development around regional railway stations, which is the final result of the Spherical Fuzzy Analytic Hierarchy Process (SFAHP) analysis. As shown in Table 13, Density (D1) has the highest importance weight (0.201), followed by Diversity (D2) at 0.181, Transit (TS) at 0.151, Design (D3) at 0.147, Destination accessibility (D5) at 0.117, Economic development (EC) at 0.108, and Distance to transit (D4) at 0.095, respectively. Furthermore, this table displays the importance weights of all 24 sub-indicators, categorized into local weights (comparative importance within the same group of sub-indicators) and global weights (calculated by multiplying the local weight of a sub-indicator by the weight of its parent main factor). The top five sub-indicators with the highest global weights are Land use diversity (D21) at 0.064, Population density (D11) at 0.064, Level of mixed land use (D23) at 0.063, Business measures (EC1) at 0.057, and Mixed land use (D22) at 0.054. These weights are crucial for applying the assessment framework to evaluate and prioritize areas surrounding regional railway stations in Thailand, providing a systematic approach to identify locations with the highest TOD development potential based on a comprehensive set of indicators that have been weighted according to their relative importance in the Thai context.

Tab. 13

The weights of main and sub-criteria

Main criteria	Local weights of main criteria	Sub-factors	Local weights of sub-factors	Global weights of sub-factors
Density (D1)	0.201	D11	0.318	0.064
		D12	0.253	0.051

Main criteria	Local weights of main criteria	Sub-factors	Local weights of sub-factors	Global weights of sub-factors
		D13	0.210	0.042
		D14	0.219	0.044
Diversity (D2)	0.181	D21	0.356	0.064
		D22	0.296	0.054
		D23	0.348	0.063
Design (D3)	0.147	D31	0.271	0.040
		D32	0.302	0.044
		D33	0.246	0.036
		D34	0.181	0.027
Distance to transit (D4)	0.095	D41	0.372	0.035
		D42	0.319	0.030
		D43	0.309	0.029
Destination accessibility (D5)	0.117	D51	0.333	0.039
		D52	0.354	0.041
		D53	0.313	0.037
Transit (TS)	0.151	TS1	0.294	0.044
		TS2	0.251	0.038
		TS3	0.229	0.035
		TS4	0.226	0.034
Economic development (EC)	0.108	EC1	0.531	0.057
		EC2	0.469	0.051
SUM.	1.000		7.000	1.000

5. CONCLUSION

This research has successfully developed an integrated assessment framework for evaluating Transit-Oriented Development (TOD) potential around regional railway stations in Thailand using the Spherical Fuzzy Analytic Hierarchy Process (SFAHP). Through a comprehensive analysis of TOD factors and indicators from previous research, combined with expert evaluations, we have established that density (20.1%) and diversity (18.1%) are the most critical factors affecting TOD potential, followed by transit (15.1%), design (14.7%), destination accessibility (11.7%), economic development (10.8%), and distance to transit (9.5%). At the sub-indicator level, land use diversity (6.4%), population density (6.4%), and level of mixed land use (6.3%) emerged as the most significant elements for successful TOD implementation in Thailand's regional context. This prioritization differs notably from traditional TOD models developed in more urbanized contexts, reflecting Thailand's unique development patterns, socioeconomic conditions, and transportation needs.

The SFAHP methodology has proven particularly valuable for this assessment, as it effectively handles the uncertainty and subjectivity inherent in expert judgments, providing a more nuanced representation of decision-making processes than traditional methods. The weighted indicator system developed in this study offers several practical applications: for policymakers and urban planners, it provides a systematic tool to prioritize investment and development efforts; for transportation agencies, it provides guidance for integrating land use and transit planning more effectively; and for developers, it indicates which locations and specific aspects of development should be prioritized to create successful TOD projects. As Thailand continues to expand its regional rail network under the 20-Year National Strategy, this assessment framework will be instrumental in guiding sustainable urban development patterns around transit nodes, thereby maximizing the return on investment in rail infrastructure while creating more livable and sustainable communities throughout the country.

Future research should focus on validating this framework through case studies of specific regional railway stations, developing implementation guidelines for various station typologies, and adapting the framework as Thailand's transportation network and urban areas evolve. Additionally, incorporating emerging factors such as climate resilience, innovative city technologies, and post-pandemic spatial requirements would further enhance the applicability of the TOD assessment framework in addressing future challenges and opportunities in Thailand's regional development context.

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