Kasetsart Journal of Social Sciences 46 (2025) 460204

Kasetsart Journal of Social Sciences

journal homepage: http://kjss.kasetsart.org

Assessing TOD indicators for urban quality design guidelines through the analytic hierarchy process: A case study of Chiang Mai's light rail transit project

Sirakorn Tanburana*, Umpiga Shummadtayar

Faculty of Architecture, Chiang Mai University, Chiang Mai 50200, Thailand

Article Info

Article history:
Received 7 April 2023
Revised 29 May 2024
Accepted 11 June 2024
Available online 27 June 2025

Keywords:
analytic hierarchy process,
Chiang Mai,
LRT,
transit-oriented development,
urban quality approach

Abstract

The 12th National Economic and Social Development Plan (2017–2021) of Thailand is based on Sustainable Development principles. As such, Chiang Mai Mass Transit Project has been established in the form of a Light Rail Transit (LRT), which is using the Transit-Oriented Development (TOD) concept in study and planning processes to achieve the goal of being sustainable development. This study uses the Analytic Hierarchy Process (AHP) to determine the importance of Transit-Oriented Development (TOD) indicators in Chiang Mai, Thailand, based on their alignment with three aspects of sustainable development: social and cultural, physical and environmental, and economic. Results revealed the adjusted indicator weightages indicate that social and cultural aspects have the highest weight (0.4561), followed by physical and environmental aspects (0.3465), and economic aspects (0.1974). The study proposed a TOD design guideline for areas around LRT stations in Chiang Mai, using Chang Puak station as an example of an "Urban Center" TOD typology, which prioritizes urban quality by considering factors such as land use, accessibility, and public spaces. The findings of this study offered valuable insights for TOD development in Chiang Mai and contributed to a better understanding of the significance of TOD indicators in a city context.

Introduction

Rapid urbanization in Chiang Mai has led to issues of urban sprawl and traffic congestion. In an effort to address these problems, the government has tasked the Office of Transport and Traffic Policy and Planning (OTP) with conducting a study and creating a master plan for the 'Chiang Mai LRT Project', a network of various modes of public transportation that includes light rail transit (LRT) as the primary system.

* Corresponding author.
E-mail address: sirakorn.foon@gmail.com (Tanburana, S.).

https://doi.org/10.34044/j.kjss.2025.46.2.04
2452–3151/© 2025 Kasetsart University.

The adoption of Transit-Oriented Development (TOD) in the development of the Chiang Mai LRT project, is similar to the application of TOD in many cities around the world, such as Addis Ababa (Teklemariam & Shen, 2020), Beijing (Lyu et al., 2016), Brisbane (Kamruzzaman et al., 2014), Denver (Ratner & Goetz, 2013), and New York City (Liu et al., 2020). Each city has its own focus and main development goals, depending on the context of local activities and geography (Lyu et al., 2016). Chiang Mai LRT project's TOD aims to address transportation and environmental issues, while supporting the city's economic development. TOD focuses on mixed land use, high density, and promotion of public transportation in proximity to residential, commercial, office, and other land uses. It also aims to create a pedestrian and bicycle-friendly environment around the LRT station in Chiang Mai. To determine suitable TOD indicators for the context of Chiang Mai, it is necessary to study them according to global and national trends. These trends aim to promote sustained growth. Additionally, Chiang Mai TOD indicators should align with the principles of sustainable development to ensure long-term growth and sustainability.

This study aims to analyze and determine the importance of Transit-Oriented Development (TOD) indicators for the Chiang Mai Light Rail Transit (LRT) project using the Analytic Hierarchy Process (AHP). The focus is on assessing the weight of TOD indicators that align with three aspects of sustainable development: social and cultural, physical and environmental, and economic. By analyzing these indicators, the study seeks to propose TOD design guidelines that enhance urban quality around the LRT stations, with a particular focus on the Chang Puak station as a case study. Though there are many previous studies about TOD indicators in the context of cities around the world, including regional TOD typology frameworks such as the Allegheny County strategy (Center for Transit-Oriented Development [CTOD], 2013), this research proposes TOD indicators for Chiang Mai using AHP, providing detailed insights into experts' perceptions of each sustainable aspect and indicator. The main research question guiding this study is: How can the importance of TOD indicators be determined and applied to enhance urban quality around the Chiang Mai Light Rail Transit (LRT) stations using the Analytic Hierarchy Process (AHP) method?

Literature Review

In order to understand the indicators of Transit-oriented Development (TOD) that align with sustainable development in Chiang Mai, Thailand, this study will adopt several key concepts to establish the research framework.

Sustainable development is a concept that seeks to balance economic, social, and environmental considerations in order to meet current needs without compromising the ability of future generations to meet their own needs (United Nations, 2015). It is a holistic approach that considers the long-term consequences of actions, policies, and development on the planet and its inhabitants, with a particular focus on cities and urban areas. In the urban context, sustainable development recognizes the interconnectedness of these three aspects and aims to achieve a balance among them to create healthy and thriving cities for all.

Transit-Oriented Development (TOD) is an urban design and planning concept that involves the creation of mixed-use neighborhoods centered around a transit stop and core commercial area. These neighborhoods blend residential, commercial, office, open space, and public spaces within a convenient walking distance, offering residents and employees in the neighborhood options to travel by transit, bike, foot, or car (Bertolini, 1999; Calthorpe Associates, 1990; Center for Transit-Oriented Development [CTOD], 2011). To be classified as a TOD, the site must be within an average of 400 meters walking distance from a transit stop. TOD design, layout, and use mix prioritize the pedestrian experience and promote the use of public transportation (Ratner & Goetz, 2013).

The Chiang Mai LRT project is a public transportation system intended to improve mobility and reduce congestion in the city. The LRT project is currently in the planning and development stages and is expected to include a network of 3 light rail lines that will connect various parts of the city. The Mass Rapid Transit Authority of Thailand (MRTA) will begin construction on the first red line, with a route that starts at the Nakornping Hospital station and ends at the Mae Hia Intersection station, with 14 stations in between, for a total distance of 16 kilometers. From the master plan study conducted by The Office of Transport and Traffic Policy and Planning (OTP), it was found that there are 9 areas designated as TOD development areas, namely: government complex station, Chang Puak station, Nimman station, Tha Phae station, Chiang Mai airport station, Chiang Mai railway station, Arcade bus terminal station, Ruam Chok station and Sribuangen station.

TOD indicators are measures or metrics used to assess the performance and effectiveness of TOD projects. They are typically used to evaluate the degree to which a TOD project is achieving its intended goals and objectives,

such as promoting sustainable development, increasing the use of public transportation, or reducing traffic congestion (Singh et al., 2014). TOD indicators can be used to assess a wide range of factors, including land use patterns, transportation modes and connectivity, environmental impacts, economic benefits, and social and community outcomes (Chorus & Bertolini, 2011; Huang et al., 2018; Ivan et al., 2012; Li et al., 2019; Monajem & Nosratian, 2015; Shastry, 2010; Su et al., 2021; Taki & Maatouk, 2018; Teklemariam & Shen, 2020; Vale, 2015; Zemp et al., 2011). The results of a prior study by researchers show that there were 15 TOD indicators used to measure the development of TOD in Chiang Mai, divided into three groups of sustainability aspects, including Social and cultural aspect: This refers to the consideration of the characteristics of land use, the type of activities that occur within the area, and the historical importance of the district. It includes indicators such as residential building density (S1), non-residential building density (S2), number of public facilities (S3), number of historical buildings (S4) and land use mixedness (S5). Physical and environmental aspect: This refers to the physical readiness of the area to support TOD, which focuses on the integration of public transportation with walking and cycling. It includes indicators such as public transportation performance (P1), number of building blocks (P2), intersection density (P3), car parking capacity (P4), pedestrian and cycling networks/ walkability (P5) and open space, void, and green area (P6). Economic aspect is those that consider the feasibility of economic development and opportunities for trade and investment within the area. It includes indicators such as average household income (E1), number of land plots (E2), average land price (E3) and the ratio of privately owned land (E4).

The Analytic Hierarchy Process (AHP) is a decision-making method that helps individuals or groups to prioritize complex issues and make informed decisions by breaking down a decision problem into smaller, more manageable parts or criteria and evaluating and comparing them based on their relative importance (Saaty, 1990). It uses a hierarchical structure and pairwise comparisons to determine the relative importance of each criterion and to weigh the options or alternatives being considered.

Therefore, Analytic Hierarchy Process (AHP), a decision-making method that helps individuals or groups to prioritize complex issues and make informed decisions, has been widely used in a variety of fields to support decision-making processes that involve multiple criteria and conflicting objectives. It is a flexible and adaptable method that has been applied to a wide range of decision problems and contexts, including strategic planning, resource allocation, project management, and policy analysis. AHP has been recognized as a powerful and effective decision-making tool, and it has been the subject of numerous research studies and applications. The model works through the processes of breaking down a decision problem into smaller, more manageable parts or criteria and evaluating and comparing them based on their relative importance. It uses a hierarchical structure and pairwise comparisons to determine the relative importance of each criterion and to weigh the options or alternatives being considered.

Methodology

This research employs both a quantitative and qualitative approach to study the Chiang Mai TOD indicators. The weight of each indicator was determined using the Analytic Hierarchy Process (AHP) method. The results of the AHP were combined with TOD area survey data from a previous study to analyze the TOD typology of nine pilot TOD areas of the Chiang Mai LRT project. Descriptive analysis was performed to provide a proposal for the TOD design guideline.

This research is based on the feasibility and conceptual design stages of LRT station development, as the project is currently in its studying and planning phase.

Participants

The expert assessment using the AHP method was conducted through a survey on TOD indicators in relation to sustainable development principles, which included three aspects: social, environmental, and economic, in the context of the Chiang Mai Light Rail Transit (LRT) project. Similarly, the experts were divided into three groups: (1) urban design and planning experts and Chiang Mai social development experts, who come from different career backgrounds including academia, civil society, and local government; (2) urban physical experts and rail transport experts, who come from both academia and local government; and (3) economic development experts, who come from academia and civil society. There are 7 experts in each group, totaling 21 experts, combining both local and visitor perceptions of their suitable indicators for Chiang Mai TOD.

Data Collection

The data collection for this study was performed using a questionnaire as the research instrument. The questionnaire was designed to assess the relative importance of TOD indicators by soliciting expert opinions through the use of the Analytic Hierarchy Process (AHP) for pairwise comparisons. The experts were asked to compare the indicators by providing their responses to the four parts of the AHP questionnaire, which included: (1) the three sustainability aspects pairwise comparison, (2) the social and cultural indicators pairwise comparison, (3) the physical and environmental indicators pairwise comparison, and (4) the economic indicators pairwise comparison. The expert responses were then collected and used in the AHP to calculate the weight of each indicator, providing crucial insights into the relative importance of the different TOD indicators.

Data Analysis

The data collected were analyzed using Analytic Hierarchy Process (AHP) method to determine the relative importance of the 15 TOD indicators for sustainable development. The indicators were divided into three main groups: social and cultural aspect, physical and environmental aspect, and economic aspect, as shown in Table 1. The AHP analysis used pairwise comparisons to evaluate the relative importance of the indicators and their impact on sustainable development.

Table 1 The aspects and indicators used in the analysis of Chiang Mai TOD indicators

Sustainable Development Aspects	Chiang Mai TOD Indicators
(S) Social & Cultural Reflects the social dynamics, cultural heritage, and overall quality of life within a community.	(S1) Residential Building Density The number of residential buildings per unit area. This indicator measures the density of housing units. (S2) Non-residential Building Density The number of non-residential buildings per unit area, including commercial, office, and institutional buildings. (S3) Number of Public Facilities The count of public amenities such as schools, hospitals, parks, and community centers. (S4) Number of Historical Building The total number of buildings with historical or cultural significance. (S5) Land Use Mixedness The degree of land use diversity within a specified area, calculated based on the mix of residential, commercial, and other land uses.
(P) Physical & Environmental Assesses the physical infrastructure and environmental quality of an area.	(P1) Public transportation performance The efficiency and coverage of public transportation services, including frequency, reliability, and accessibility. (P2) Number of Building Blocks The total count of distinct building blocks within a specified area. (P3) Number of Intersection Density The number of intersections per unit area. High intersection density indicates a well-connected street network (P4) Car Parking Capacity The total number of car parking spaces available. (P5) Pedestrian Networks / Walkability The extent and quality of pedestrian pathways, including sidewalks, crosswalks, and pedestrian-only zones. (P6) Open Space, Void & Green Area The amount of open, undeveloped space and green areas such as parks and gardens.
(E) Economic Reflects the economic vitality and development potential of an area.	(E1) Average Household Income The average income of households in the area. This indicator provides insights into the economic status of residents. (E2) Number of Land Plots The total number of individual land parcels within the area. (E3) Average Land Price The average price of land per unit area. This indicator assesses the economic value and investment potential of the land. (E4) Private owned Land ratio The proportion of land that is privately owned compared to publicly owned land. This indicator measures the extent of private investment.

Analytic Hierarchy Process (AHP) has been widely used in a variety of fields to support decision-making processes that involve multiple criteria and conflicting objectives. It is a flexible and adaptable method that has been applied to a wide range of decision problems and contexts, including strategic planning, resource allocation, project management, and policy analysis. AHP has been recognized as a powerful and effective decision-making tool, and it has been the subject of numerous research studies and applications.

There are 6 steps of AHP including (1) Defining the decision problem: Clearly define the problem or decision that needs to be made. Identify the objectives and constraints of the decision and define the scope and boundaries of the analysis; (2) Constructing the hierarchy Structure: Arrange the criteria in a hierarchy, with the overall decision problem at the top, and the various criteria and options arranged in a hierarchy beneath it; (3) Determining the relative importance of the criteria: Use pairwise comparisons to determine the relative importance of each criterion in the hierarchy. Compare each criterion to every other criterion in the hierarchy and assign a weight or priority to each criterion based on its relative importance as shown in Table 2; (4) Calculating the importance values of the criteria or aspects; (5) Calculating the importance values of the alternatives or indicators and evaluate them considering their relative importance or weights. And lastly; (6) Calculating the Consistency Ratio (CR): if CR < 0.1, the result is consistent, otherwise the result of comparison is not consistent.

The results provided valuable insight into the strengths and weaknesses of each indicator and their relative importance in promoting sustainable development. By determining the weights of the indicators, the AHP results will aid in the development of the Chiang Mai TOD design guideline, which is aimed at promoting sustainable development in the city. The findings will inform decision-making and help prioritize initiatives that support sustainable development in TOD areas.

Results

This study has provided a comprehensive understanding of the relative importance of TOD indicators as assessed by experts through the use of the Analytic Hierarchy Process (AHP) questionnaire. The questionnaire, consisting of four parts of pairwise comparisons, was administered to the experts in relation to the Chiang Mai Light Rail Transit (LRT) project, and their responses were analyzed to determine the weight of all 15 Transit Oriented Development (TOD) indicators. The study began by comparing the level of importance of key values that aligned with the concept of sustainable development in three aspects: social and cultural, physical and environmental, and economic. The results of the assessment on the relative importance, as shown in Table 3 and Table 4, indicated that experts considered social and cultural aspects to be the most important. This was interpreted to mean that when planning the development of the area surrounding the Chiang Mai LRT Station, serving as both an economic center and a city with cultural and historical significance, it was crucial to take into account the impact on the residents and activities within the TOD development district. This included the physical and environmental potential of the city, as well as accessibility to the area, pedestrian and cyclist convenience within the neighborhood, and the economic aspect, which, although it might not have appeared as significant, played a crucial role in driving the area's growth and attracting people and investments. Through this approach, the district and the area around the LRT station were developed sustainably.

Table 3 The pairwise comparison matrix of sustainable development aspects

	Sustainable development aspects		
Aspects	Social	Physical	Economic
Social	1.00	1.47	2.08
Physical	0.68	1.00	1.96
Economic	0.48	0.51	1.00

Table 2 Scale of analytic hierarchy process for pairwise comparisons

Degree of Preference	Definition	Explanation
1	Equally important	Both indicators are equally important
3	Moderately important	One indicator is more effective than the other
5	Highly Important	One indicator is highly more effective than the other
7	Very Highly Important	One indicator is highly dominated over the other
9	Extremely Important	One indicator is extremely dominant over the other
2, 4, 6, 8	Intermediate Values	If a compromise between two indicators is required, intermediate values can be used

Table 4 The normalized matrix & weights of sustainable development aspects

Sustainable Development Aspects				
Aspects	Social	Physical	Economic	Weights
Social	0.46	0.49	0.41	0.4561
Physical	0.32	0.34	0.39	0.3465
Economic	0.22	0.17	0.20	0.1974
Total	1.00	1.00	1.00	1.00
Consistency Ratio (CR) = 0.0105				

Weighting of Social and Cultural Indicators

Regarding the relative importance assessment of social and cultural aspect, as shown in Table 5, which had a total of five TOD indicators, the result showed that experts ranked the 5 sub-indicators of social and cultural aspect, (S1) Residential Building Density, (S5) Land-Use Mixedness, (S2) Non-residential Building Density, (S3) Number of Public Facilities, and (S4) Number of Historical Buildings with a total weight of 0.2373, 0.2345, 0.1916, 0.1701, and 0.1565 respectively, using the same process as finding the weights of the importance of the three aspects. The average Consistency Ratio was 0.0022, which was acceptable.

Table 5 The pairwise comparison matrix of social and cultural indicators

Social and cultural indicators					
Indicators	S1	S2	S3	S4	S5
S1	1.00	1.28	1.48	1.39	0.95
S2	0.78	1.00	1.17	1.15	0.82
S3	0.68	0.86	1.00	1.19	0.68
S4	0.72	0.87	0.84	1.00	0.80
S5	1.05	1.22	1.47	1.25	1.00

Based on the results of weighting the importance of main aspects as determined by experts, it was interpreted that as shown in Table 6, in terms of social and cultural indicators, experts ranked high population density and the intensity of the diversity of activities taking place within the area as the first and second most important. From this perspective, it was concluded that to achieve high efficiency in TOD development, it was necessary to build in a development area with a sufficient number of people, both living and using the area, where the area, shops, and various activities could grow according to the economic mechanism. At the same time, in terms of the number of buildings with historical significance, despite having the smallest weight among the TOD indicators, it was considered an indispensable and important part. This was due to the economic growth from tourism in the historical sites of Chiang Mai, which directly affected the development of the area surrounding the station, including population, employment, and the promotion of the improvement of the landscape of various districts in the city.

Weighting of Physical and Environmental Indicators

Regarding the relative importance assessment of physical and environmental indicators, as shown in Table 7, a total of six TOD indicators, (P3) Number of intersection density and separation in the area around the public transportation station, (P1) Public transportation performance, type and number of roads serving the public transportation system, (P4) Car parking capacity in the area around the public transportation station, (P5) Pedestrian networks/walkability of the transportation system, (P2) Number of building blocks in the area around the public transportation station, and (P6) The green space around the public transportation station, were found to have a weight of 0.1853, 0.1775, 0.1734, 0.1684, 0.1669, and 0.1284, respectively, by using the same process as was used for finding the weights of the importance of the main aspects. The average Consistency Ratio was found to be 0.0062, which was acceptable.

Table 6 The normalized matrix & weights of social and cultural indicators

Social and cultural indicators						
Indicators	S1	S2	S3	S4	S5	Weights
S1	0.24	0.24	0.25	0.23	0.22	0.2373
S2	0.19	0.19	0.20	0.19	0.19	0.1916
S3	0.16	0.16	0.17	0.20	0.16	0.1701
S4	0.17	0.17	0.14	0.17	0.19	0.1665
S5	0.25	0.23	0.25	0.21	0.24	0.2345
Total	1.00	1.00	1.00	1.00	1.00	1.00
Consistency Ratio (CR) = 0.0022						

Table 7 The pairwise comparison matrix of physical and environmental indicators

Physical and environmental indicators						
Indicators	P1	P2	P3	P4	P5	P6
P1	1.00	0.94	1.15	0.92	1.05	1.46
P2	1.07	1.00	0.94	0.73	1.01	1.40
P3	0.87	1.07	1.00	1.19	1.23	1.45
P4	1.09	1.37	0.84	1.00	0.85	1.20
P5	0.96	0.99	0.81	1.17	1.00	1.25
P6	0.68	0.71	0.69	0.83	0.80	1.00

Based on the results of the weighting of the importance of TOD indicators by experts, as shown in Table 8, it can be concluded that in terms of the physical and environmental aspect, the experts ranked the number of intersections and separations in the area around the public transportation station as the most important. This reflects the significance of the area surrounding the station as a physical connection that facilitates people movement and results in a hub for various activities. The public transportation performance, type, and number of roads serving the public transportation system were ranked as the second most important. Despite the provision of a comprehensive public transportation system being crucial in promoting the area surrounding the station as a hub for a variety of activities, having enough car parking capacity was also considered important for those who prefer to travel by personal vehicles. Provisions for pedestrian walkways and bike lanes were deemed equally important in promoting TOD. The number of building blocks within the area was also deemed important in terms of promoting accessibility and diversity of activities. Lastly, the provision of open and green spaces within the area was seen as a crucial factor in maintaining a balance in the area's development and preventing overcrowding, while also providing spaces for relaxation and activities for the people.

Table 8 The normalized matrix & weights of physical and environmental indicators

Physical and environmental indicators							
Indicators	P1	P2	P3	P4	P5	P6	Weights
P1	0.18	0.15	0.21	0.16	0.18	0.19	0.1775
P2	0.19	0.16	0.17	0.12	0.17	0.18	0.1669
P3	0.15	0.18	0.18	0.20	0.21	0.19	0.1853
P4	0.19	0.23	0.15	0.17	0.14	0.15	0.1734
P5	0.17	0.16	0.15	0.20	0.17	0.16	0.1684
P6	0.12	0.12	0.13	0.14	0.13	0.13	0.1284
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Consistency Ratio (CR) = 0.0062							

Weighting of Economic Indicators

Regarding the relative importance assessment of economic indicators, a total of four TOD indicators as shown in Table 9, found that, of the four indicators, (E1) Average household income, (E2) Number of land plots in the area around the public transportation station, (E4) Private owned land ratio, and (E3) Average land price, had weights of 0.3059, 0.2447, 0.2356, and 0.2138, respectively. The same process that was used to determine the weights of the TOD indicators was employed. The resulting average Consistency Ratio was 0.0147, which was deemed acceptable.

Based on the results of the assessment of the weighting of the indicators by experts, as shown in Table 10, it can be inferred that in terms of the economic aspect, the experts prioritized the average household income. This highlights the importance of the living standards and purchasing power of individuals in the area, which determined the nature of economic development. The next indicator that the experts focused on was the number of land plots in the area around the public transportation station. The number of land plots indicated the type of land ownership, whether it was controlled by the government, a large capital group, or small private sector. This information was crucial in the planning process for land use development and corresponded to the next indicator, the ratio of private-owned land.

Table 9 The pairwise comparison matrix of economic indicators

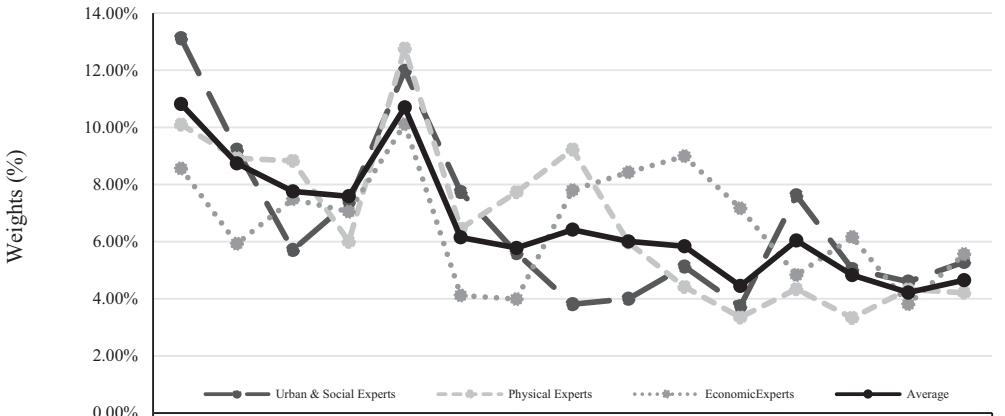
Economic indicators				
Indicators	E1	E2	E3	E4
E1	1.00	1.65	1.18	1.18
E2	0.61	1.00	1.36	1.13
E3	0.85	0.73	1.00	0.89
E4	0.84	0.89	1.12	1.00

Table 10 The normalized matrix & weights of economic indicators

Economic indicators					
Indicators	E1	E2	E3	E4	Weights
E1	0.30	0.39	0.25	0.28	0.3059
E2	0.18	0.23	0.29	0.27	0.2447
E3	0.26	0.17	0.21	0.21	0.2138
E4	0.26	0.21	0.24	0.24	0.2356
Total	1.00	1.00	1.00	1.00	1.00
Consistency Ratio (CR) = 0.0147					

Comparing the Weight of 15 TOD Indicators according to 3 Groups of Experts Assessment

Regarding the results of the analysis of the weighting of the importance of TOD development factors among the 15 indicators by experts in three fields, urban design and planning, Chiang Mai social development, urban physical and rail transport, and economic development showed that the results of the assessment by each expert group were generally similar. However, there are differing opinions on some indicators as shown in Figure 1.



	S1	S2	S3	S4	S5	P1	P2	P3	P4	P5	P6	E1	E2	E3	E4
Urban & Social Experts	13.12%	9.22%	5.71%	7.39%	11.98%	7.74%	5.60%	3.81%	4.00%	5.13%	3.74%	7.62%	5.04%	4.60%	5.29%
Physical Experts	10.10%	8.92%	8.83%	6.00%	12.76%	6.46%	7.73%	9.23%	5.97%	4.42%	3.35%	4.34%	3.33%	4.33%	4.21%
EconomicExperts	8.56%	5.93%	7.49%	7.05%	10.11%	4.12%	3.99%	7.80%	8.43%	8.99%	7.17%	4.83%	6.16%	3.81%	5.56%
Average	10.82%	8.74%	7.76%	7.59%	10.70%	6.15%	5.78%	6.42%	6.01%	5.84%	4.45%	6.04%	4.83%	4.22%	4.65%

TOD Indicators

Figure 1 Comparing the weights of TOD indicators assessing by 3 groups of experts

For the TOD indicators in the social and cultural aspect, all three groups of experts agree that it is the most important aspect for developing TOD in Chiang Mai. The urban design and planning experts gave the highest importance weight to residential land use (S1). On the other hand, the other two groups of experts believe that the indicator Land Use Mixedness (S5) had the highest weight.

For the TOD indicators in the physical and environmental aspect, there are clear differences in opinions about the weight of the indicators among the experts in all three fields. Economic experts see the indicator (P2) as having the lowest importance, while the other two groups give the indicator (P6) the lowest weight. Urban planning experts gave the highest importance to (P1), as this indicator signifies the opportunities and effectiveness of bringing people into the area and generating activities around the LRT station. Experts in physical and transportation systems give the highest weight to (P3), and economic experts give the highest weight to (P5).

For the TOD indicators in the economic aspect, the experts in urban design and planning and the experts in urban physical fields have a similar opinion that (E1) has the highest weight. However, opinions on the other three indicators in this aspect vary. Overall, the weight of the economic aspect shows that the experts view this aspect as something to be considered after the other two aspects.

15 TOD Indicators of Chiang Mai

To summarize, the weightages for all 15 TOD indicators of Chiang Mai were proportionately distributed based on the overall percentage of the three main aspects. The results of adjusting the indicator weights indicated that the group of social and cultural indicators had a weight of 0.4561, the group of physical and environmental indicators had a weight of 0.3465, and the group of economic indicators had a weight of 0.1974. Detailed information and distribution of the weights of the indicators was provided in table 11.

According to the AHP analysis, the group of social and cultural indicators (S) was determined to have the highest weight of 0.4561 based on the individual indicators within the group. After being proportionally adjusted to the main aspect value, the following weights were assigned to each indicator: (S1) Residential Building Density received a weight of 0.1082, (S2) Non-residential Building Density received a weight of 0.0874, (S3) Number of Public Facilities received a weight of 0.0776, (S4) Number of Historical Buildings received a weight of 0.0759, and (S5) Land Use Mixedness received a weight of 0.1070.

The analysis showed that the physical and environmental indicators (P) had a weight of 0.3465, which was determined by the indicators within the group. After adjusting the percentage value to the aspect, the weights of the sub-indicators were found to be as follows: (P1) Public transportation performance weighed 0.0615, (P2) the number of building blocks weighed 0.0578, (P3) the number of intersection density weighed 0.0642, (P4) car parking capacity weighed 0.0601, (P5) pedestrian networks/walkability weighed 0.0584, and (P6) open space, void, green area weighed 0.0445.

Table 11 Chiang Mai TOD indicators weights

Sustainable Development Aspects	Weights (a)	Chiang Mai TOD Indicators	Weights (a)	Global Weights (b)	Rank
(S) Social & Cultural	0.4561	(S1) Residential Building Density	0.2373	0.1082	1
		(S2) Non-residential Building Density	0.1916	0.0874	3
		(S3) Number of Public Facilities	0.1701	0.0776	4
		(S4) Number of Historical Building	0.1665	0.0759	5
		(S5) Land Use Mixedness	0.2345	0.1070	2
(P) Physical & Environmental	0.3465	(P1) Public transportation performance	0.1775	0.0615	7
		(P2) Number of Building Blocks	0.1669	0.0578	11
		(P3) Number of Intersection density	0.1853	0.0642	6
		(P4) Car Parking Capacity	0.1734	0.0601	9
		(P5) Pedestrian Networks / Walkability	0.1684	0.0584	10
		(P6) Open Space, Void & Green Area	0.1284	0.0445	14
(E) Economic	0.1974	(E1) Average Household Income	0.3059	0.0604	8
		(E2) Number of Land Plots	0.2447	0.0483	12
		(E3) Average Land Price	0.2138	0.0422	15
		(E4) Private owned Land Ratio	0.2356	0.0465	13

Note: a: Weights derived from a calculation of a single sustainable development aspects.
b: Global weights obtained by multiplying the weight of the TOD indicator by the weight of aspect.

Lastly, the analysis showed that the sub-indicators within the group of economic indicators had a weight of 0.1974. After adjusting the percentage value to the TOD indicator value, the weight percentages of the following sub-indicators were established: (E1) The average household income was assigned a weight of 0.0604, (E2) the number of land plots was given a weight of 0.0483, (E3) the average land price was assigned a weight of 0.0422, and (E4) the private-owned land ratio received a weight of 0.0465.

Discussion

This study served as the foundation for the establishment of the Chiang Mai TOD Design Guideline, aimed at providing a design framework for areas surrounding LRT stations in the city. Puak LRT Station was selected as a case study after a thorough analysis of the area survey information, which revealed that the vicinity of the station had a high concentration of both residential and non-residential buildings, as well as public facilities. This diverse range of land uses, referred to as Land-Use Mixedness, made the area an ideal location for Transit-Oriented Development (TOD). However, the study also highlighted the current disregard for the historical significance of many of the buildings in the area. The station acted as a transportation hub in Chiang Mai, with abundant transportation links, but lacked pedestrian and bicycle connectivity, which remained a challenge. The mix of private and public land ownership in the area was favorable, with enough space for both residential and commercial development as the area was within a zone designated for commercial and residential use according to the Chiang Mai province city plan.

After a thorough analysis of the area survey information, the Chang Puak LRT station was identified as an ideal location for Transit-Oriented Development (TOD) due to its high density of residential buildings, mixed land use, and its role as a transportation hub. However, the study also highlighted the challenges of inadequate pedestrian and bicycle connectivity and preserving the historical significance of the area. Based on these findings, the Chang Puak LRT station area was categorized as an "Urban Center TOD typology" and the TOD design guideline was established to address these challenges and enhance the urban quality of the area. The TOD design guideline aimed to improve the area in three crucial areas: land utilization, accessibility and transportation, and public spaces and openness. The area's rich social and cultural indicators, such as population density and infrastructure, provided opportunities for enhancing connectivity through the creation of efficient walkways and bike lanes, which could make the transportation hub more attractive for commercial activities and investments.

The guideline emphasized the improvement of existing buildings and station facilities to enhance liveliness and functionality. Access and transportation were improved through the development of pedestrian, bicycle, and public transportation networks, traffic management, and connectivity, facilitating easy movement of people.

Public spaces were improved to meet standards, promote safety, and encourage green spaces in residential areas.

The TOD design guideline considered all 15 TOD indicators and 3 urban quality aspects, providing a comprehensive framework for the development of the Chang Puak LRT station area. It aimed to create a vibrant, accessible, and green neighborhood connected by both mass transit, pedestrian walkways, and bicycle networks. The guideline also ensured the preservation of the area's historical significance and improvement of the quality of life for residents and visitors.

This study contributes to the growing body of research on Transit-Oriented Development (TOD) by focusing on the unique context of Chiang Mai. Similar to the study by Teklemariam and Shen (2020) on Addis Ababa, which used a TOD index to identify potential transit nodes, our research also evaluates TOD indicators but through the Analytic Hierarchy Process (AHP). This method allows for a detailed assessment of expert perceptions across sustainable development aspects. Unlike the TOD typology developed for Beijing metro stations (Lyu et al., 2016), which categorizes stations based on existing conditions, our study specifically addresses the cultural and historical significance of Chiang Mai in TOD planning. By integrating local insights with established TOD principles, we provide tailored recommendations to enhance urban quality around the Chang Puak LRT station as shown in Figure 2.

Conclusion

The study and analysis of TOD Typology, combined with 15 TOD Indicators, required a ranking of the importance of the various indicators. To assess the importance of the indicators, the Analytic Hierarchy Process (AHP) was used, as each indicator holds different values. The AHP was conducted with the help of three expert groups, resulting in a ranking of the importance of each indicator. The study found growing interest among academics and government support for studying and developing cities within the framework of Transit-Oriented Development (TOD). This approach has been improved, advanced, and integrated with other urban development concepts globally, facilitated by advancements in technology and research equipment. Studies of TOD development emphasize collaboration, interdisciplinary studies, and a context-based approach.

Figure 2 TOD design guideline for Chang Puak LRT station

The TOD typology and indicators provide a framework for evaluating TOD potential, designing TOD projects, and prioritizing TOD development in cities, but their application must be adapted to the city's specific context. A holistic approach considering the city's context and lifestyle, and involving collaboration between urban designers, academics, government policymakers, and social organizations, is essential.

The findings of this study have significant policy implications for various stakeholder groups involved in the development and implementation of TOD in Chiang Mai, including the integration of TOD principles by local and regional governments to promote sustainable development, incorporating feedback from the community to help design spaces that are more livable and aligned with local cultural and historical contexts, and encouraging public-private partnerships to leverage private sector investment in TOD projects. This can help in financing the necessary infrastructure and amenities while promoting economic development around the LRT station. By addressing these policy implications, stakeholders can work together to create a more integrated, accessible, and sustainable urban environment in Chiang Mai. The successful implementation of TOD principles can lead to improved mobility, reduced congestion, and enhanced urban quality, benefiting both residents and the broader community.

Conflict of Interest

The authors declare that there is no conflict of interest.

Funding

This article is a part of A Study of TOD Typology and Urban Quality: Chiang Mai Light Rail Transit, which is funded by National Research Council of Thailand (NRCT) Granted number N41A640382.

References

Bertolini, L. (1999). Spatial development patterns and public transport: The application of an analytical model in the Netherlands. *Planning Practice and Research*, *14*(2), 199–210. https://doi.org/10.1080/02697459915724

Calthorpe Associates. (1990). *Transit-oriented development design guidelines*. Sacramento County Planning and Community Development Department.

Center for Transit-Oriented Development. (2011). *Transit-oriented development strategic plan for metro TOD program*. Center for Transit-Oriented Development. https://ctod.org/pdfs/2011PortlandTODweb.pdf

Center for Transit-Oriented Development. (2013). *Transit-oriented development typology strategy for Allegheny county*. Center for Transit-Oriented Development. https://ctod.org/pittsburgh/201302pittsburgh-tod-book-web.pdf

Chorus, P., & Bertolini, L. (2011). An application of the node place model to explore the spatial development dynamics of station areas in Tokyo. *The Journal of Transport and Land Use*, *4*(1), 45–58. https://doi.org/10.5198/jtlu.v4i1.145

Huang, R., Grigolon, A., Madureira, A. M., & Brussel, M. (2018). Measuring transit-oriented development (TOD) network complementarity based on TOD node typology. *Journal of Transport and Land Use*, *11*(1), 304–324. https://doi.org/10.5198/jtlu.2018.1110

Ivan, I., Boruta, T., & Horak, J. (2012). Evaluation of railway surrounding areas: The case of Ostrava city. *WIT Transactions on The Built Environment*, *128*, 141–152. https://doi.org/10.2495/UT120131

Kamruzzaman, M., Baker, D., Washington, S., & Turrell, G. (2014). Advance transit oriented development typology: Case study in Brisbane, Australia. *Journal of Transport Geography*, *34*, 54–70. https://doi.org/10.1016/j.jtrangeo.2013.11.002

Li, Z., Han, Z., Xin, J., Luo, X., Su, S., & Weng, M. (2019). Transit oriented development among metro station areas in Shanghai, China: Variations, typology, optimization and implications for land use planning. *Land Use Policy*, *82*, 269–282. https://doi.org/10.1016/j.landusepol.2018.12.003

Liu, Y., Singleton, A., & Arribas-Bel, D. (2020). Considering context and dynamics: A classification of transit-orientated development for New York City. *Journal of Transport Geography*, *85*(2), 102711. https://doi.org/10.1016/j.jtrangeo.2020.102711

Lyu, G., Bertolini, L., & Pfeffer, K. (2016). Developing a TOD typology for Beijing metro station areas. *The Journal of Transport Geography*, *55*, 40–50. https://www.worldtransitresearch.info/research/6108/

Monajem, S., & Nosratian, F. E. (2015). The evaluation of the spatial integration of station areas via the node place model; an application to subway station areas in Tehran. *Transportation Research Part D*, *40*, 14–27. https://doi.org/10.1016/j.trd.2015.07.009

Ratner, K. A., & Goetz, A. R. (2013). The reshaping of land use and urban form in Denver through transit-oriented development. *Cities*, *30*, 31–46. https://doi.org/10.1016/j.cities.2012.08.007

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Shastry, S. (2010, August). *Spatial assessment of transit oriented development in Ahmedabad, India* [Master's thesis, University of Twente]. https://essay.utwente.nl/59707/

Singh, Y. J., Fard, P., Zuidgeest, M., Brussel, M., & Maarseveen, M. V. (2014). Measuring transit oriented development: Aspatial multi criteria assessment approach for the city region Arnhem and Nijmegen. *Journal of Transport Geography*, *35*, 130–143. https://doi.org/10.1016/j.jtrangeo.2014.01.014

Su, S., Zhang, H., Wang, M., Weng, M., & Kang, M. (2021). Transit-oriented development (TOD) typologies around metro station areas in urban China: A comparative analysis of five typical megacities for planning implications. *Journal of Transport Geography*, *90*, 102939. https://doi.org/10.1016/j.jtrangeo.2020.102939

Taki, H. M., & Maatouk, M. M. (2018). Promoting transit oriented development typology in the transportation planning. *Communications in Science and Technology*, *3*(2), 64–70. https://doi.org/10.21924/cst.3.2.2018.103

Teklemariam, E. A., & Shen, Z. (2020). Determining transit nodes for potential transit-oriented development: Along the LRT corridor in Addis Ababa, Ethiopia. *Frontier of Architectural Research*, *9*(3), 606–622. https://doi.org/10.1016/j.foar.2020.03.005

United Nations. (2015). *The 17* goal*s*. https://sdgs.un.org/goals

Vale, D. S. (2015). Transit-oriented development, integration of land use and transport, and pedestrian accessibility: Combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *Journal of Transport Geography*, *45*, 70–80. https://doi.org/10.1016/j.jtrangeo.2015.04.009

Zemp, S., Stauffacher, M., Lang, D. J., & Scholz, R. W. (2011). Classifying railway stations for strategic transport and land use planning: Context matters! *Journal of Transport Geography*, *19*, 670–679. https://doi.org/10.1016/j.jtrangeo.2010.08.008