A Multi-criteria Evaluation and Geographic Information System-based Study: Measuring the Transit-oriented Development Suitability Index of the Proposed Metro Rail Transit 4 Stations in Taytay, Rizal

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Abstract: The complex urbanization in Metro Manila, characterized by ineffective implementation of decades-old master plans for addressing the rapid, unplanned growth in the city, compromises the urban development extending in Greater Manila Region with worsening traffic congestion due to spatial separation between residential areas and urban activities. This highlights the need for extensive integration of urban planning and transportation development—through transit-oriented development (TOD)—especially in new townships planned with railways. This study evaluated TOD suitability within 800-meter catchment areas in the selected MRT-4 stations: Tikling Junction, Manila East Road, and Taytay, using a TOD index based on 11 indicators from the 6Ds framework covering social, economic, travel behavior, and built environment aspects. The results obtained using multi-criteria evaluation (MCE) process and QGIS software showed Taytay station obtaining the highest TOD suitability index, while Tikling Junction and Manila East Road stations obtained the moderate and the lowest TOD suitability index, respectively.

Keywords: Urbanization, Transit-oriented Development, TOD Index, Multi-criteria Evaluation, QGIS

1. INTRODUCTION

1.1 Background and Its Context

Throughout the years, modernizing plans in the Philippine transportation system have been neglected, and if not, were inadequately implemented without addressing the roots of the current problems and issues being faced by the country's urban and transportation system. While Metro Manila has an undeniable substantial growth and development through urbanization for decades, the unplanned state of the region in facing rapid growth has struggled to address the challenges such as overpopulation, traffic congestion, environment deterioration, and unsustainable characteristics of the city. According to Japan International Cooperation Agency (1999), the complexity of urban development growth in the metropolitan areas is characterized by a cycle of pattern—urban densification, followed by commercialization, and the resulting influx of residents to the outer urban areas that causes spatial separation and traffic congestion due to increased number of trips and travel distances. The same report from JICA (1999) also highlighted that despite having several master plans that account for the urban transportation integration studies of Metro Manila, the ineffective or non-implementation of these plans prompted the residential movement to the outer cities as the National Capital Region (NCR) is already intensified with urban activities that it can no longer accommodate the growing demands. Hence, urbanization extends to the Greater Manila Region (GMR), including Bulacan, Cavite, Laguna, and Rizal, in an uncontrolled manner. However, these outer urban areas that experience urban sprawl have inadequate infrastructures and establishments that support the public interest, and the local government units (LGUs) are not fully prepared with the demands that this may bring.

Currently, JICA reassures its commitment to the expansion of its railway infrastructures as it also emphasizes the potential of transit-oriented development (TOD) in the Philippines. This necessitates the integration and harmonization of urban planning and transport development which forms the fundamental concept of transit-oriented development – a concept that aims to form a community that is compact, mixed use, pedestrian friendly, and bicycle-friendly, with concentration of jobs, housing, and other services that are closely integrated around a mass transit (JICA, 2022). According to the Institute for Transportation and Development Policy (n.d.), TOD is a universal planning tool to plan and shape the community to be more oriented towards the use of public transport, and has a standard framework constituted by 8 principles: 1) walk, 2) cycle, 3) connect, 4) mix, 5) densify, 6) shift, 7) compact, and 8) transit. Good practices and effects of TOD has been successfully demonstrated in the transit systems of Japan (JICA, 2015), where access improvement and integrated development along the railway corridor have greatly benefited the people in having vibrant and livable cities. And with the Philippine government's commitment to establish its 30-year railway masterplan for the Greater Manila Region, TOD is envisioned to be integrated along with the railway network to further boost not only the country's economic growth, but most especially to improve the quality of life of the Filipino commuters.

1.2 Statement of the Problem

Taytay holds great potential for urban development especially with the MRT-4 station endpoint in its town proper. With the three stations located at the municipality, the rail line connectivity of Rizal province to Manila is expected to bring intense urbanization and commercialization in the municipality. However, having a planned transit system but with underdeveloped connectivity and unplanned land use integration, Taytay, along with other areas placed in such a situation, are at risk of having the same outcomes of urban challenges in Metro Manila if not planned, or if plans were failed to be implemented before uncontrolled, rapid growth of urbanization occurs. This realm of urban and transport difficulties calls for an extensive integration of urban planning and transport development. Recognizing the potential of the proposed MRT-4 to integrate land use and railway development through TOD, the researchers were led to conduct a TOD suitability study in selected MRT-4 stations in Taytay, Rizal. As the roadmap study structure and suggests creating new townships outside Metro Manila to build a polycentric spatial structure, and following the notion that redeveloping the highly dense metropolitan area imposes difficulties in construction and policy implementation, then it could be a great move to start with the surrounding cities and municipalities, like Taytay, and gradually disperse the people living in NCR. As the MRT-4 is yet to be constructed and start operations in the late 2020s, the researchers also aim to fill the gap in existing studies where most often, underdeveloped and future transit-served areas are overlooked in TOD studies, especially in the Philippine setting.

1.3 Objective of the Study

The main objective of this study is to develop and assess the TOD suitability index of the proposed MRT-4 stations in Taytay, Rizal based on its current conditions, and in view of the social, economic, built environment, and travel behavior aspects. The findings of the study will then provide recommendations and areas of improvements to further increase the TOD levels of the stations, that would later contribute to a TOD planning and conceptualization system to guide the decision makers in both public and private sectors, and in local and national level.

2. LITERATURE REVIEW

To further support the implementation of TOD in the Philippine setting and in the selected study area, Singh (2015) emphasized the importance of maximizing TOD planning beyond existing transit-served areas to include potential TOD locations with transit-like characteristics. The JICA road map report in 2019 also suggested creating new townships outside Metro Manila to ease population overcrowding and reshape the metropolitan landscape. Abe (2022) discussed the stepwise approach of TOD with railway development during a forum at Ateneo de Manila University. All these supports conducting a TOD study alongside future railway development, like MRT-4, rather than just focusing solely on existing lines located in Metropolitan Manila. Furthermore, it is also supported by the World Bank (2018) as it advocates a bottom-to-top approach to widen the TOD scale, making it feasible to start with smaller station area-based TODs before expanding to larger city or regional scales. Conducting a TOD study for a future transit line such as the MRT-4 in Taytay can be more cost-effective and allow seamless integration of the project's planning, design, and construction. Hence, Taytay was chosen as the study area with its TOD scale as a station area and its urban development context, justifying its selection over other MRT-4 station locations. Moreover, it is important to note that this study does not account for how long the benefits and success of TOD will take into effect as this study was conducted in an approach that TOD will be implemented along railway development.

In identifying the TOD aspects, criteria, and indicators, several studies account for the use of 5Ds of built environment of Ewing and Cervero (2010), namely density, diversity, design, distance to transit, and destination accessibility, which was later expanded into 7Ds, with demand management and demography as additional criteria (De Gruyter *et al.*, 2020). However, this study only employed the 6Ds, adding demand management to the widely used 5Ds to represent travel behavior in terms of transit utilization, such as in the study of Ogra and Ndebele (2014). Additionally, social perception was incorporated to gauge people's attitudes towards TOD and public transportation in the study area. The indicators assessed were then selected from the framework used by Singh (2015) who studied TOD at regional scale, Lukman (2014) who refined the indicators used by Singh and formed his own based on the relevance and comprehensive principles, and Transit Cooperative Research Program (TCRP) Report 95 (2007) which presented the 15 success measures of TOD from the national survey that was conducted with 30 professionals from Transportation Research Board (TRB).

3. METHODOLOGY

3.1. Research Locale

The study was conducted in the direct impact areas (DIAs) of Taytay where MRT-4 line is planned to operate, with a total land area of 38.8 square kilometers and a population density of 8,200 per square kilometer. Barangay Dolores, San Juan, and San Isidro are the identified DIAs that cover the MRT-4 right-of-way as well as the proposed depot site (IDOM, 2022). There are four TOD scales presented in the study of Ollivier *et al.* (2021) which are identified as 1) city-region, 2) corridor, 3) station area, and 4) site level, and the authors conducted the study in a station area TOD scale whereas the catchment areas are concentrated. To visualize, Figure 1 shows the designation of the station, station hub, catchment area and area of influence within the TOD areas of Taytay, which will be the terms used throughout this study. The catchment area is identified as the buffer area generated in the map using the basis of 800 meters, as illustrated in Figure 2, while the area that extends beyond it is the area of influence. The researchers selected 800 meters, that is estimated as 10-minute pedestrian walking distance, which is also used by Jamaleddin *et al.* (2022) as basis for the radius of area of assessment from the station. This will be called the catchment area throughout the study.

On the grounds for selecting this area for study, Taytay being categorized along the first-class municipalities in the country, it is seen to pose strong capability for further development especially in the aspect of integrating urban and transportation development. As this study takes into account the TOD study conducted by JICA (2015) for the North South Commuter Railway line, where it states that a practical approach to TOD planning is acquiring sufficient land, with existing land uses and open spaces/lots, to ensure enough space is available for integrated development where new townships and transport facilities can be established to which is also reflective of Calthorpe (1993)'s aim for TOD, that is to have a mix of residential, retail, office, open space, and public land uses to create a walkable environment for people. Hence, the conduct of TOD study to the Municipality of Taytay also reflects prospects to restructuring land uses.

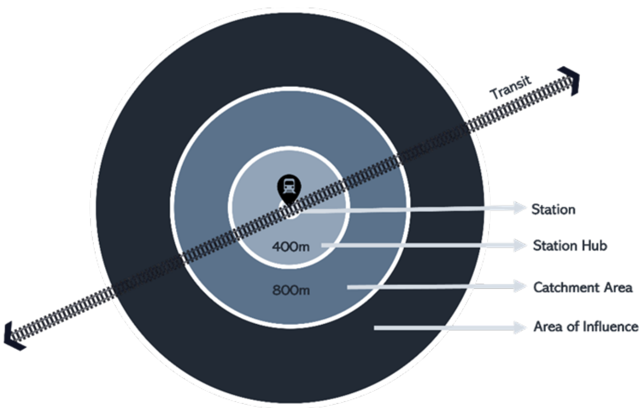

Figure 1. TOD area concept

Figure 2. Catchment areas of the three MRT-4 stations in Taytay

3.2 Research Instrument

The involvement of stakeholders has been a common practice in planning. As generally acknowledged, stakeholders are individuals or key actors who vest interest or hold a stake in the decision-making and impact of an activity. Similarly, in the prospect of TOD planning, as stated by Singh (2013), it is imperative to include TOD practitioners who have active, direct and influential role in TOD planning, development, and implementation. As there are no standard criteria found in literature review in the selection of stakeholders, the research adviser of the authors suggested to invite transport professionals which are already considered as TOD practitioners, in both local and foreign projects, which knowledge of TOD is not just limited to the theoretical approach.

Stakeholders' involvement is crucial at the stage of assigning weights to each TOD criterion and indicator which are integral input in the calculation of TOD index. The data for these weights were collected through a ranking survey distributed to those with technical stake in TOD planning such as academic researchers, transport and urban planners, LGUs, and other concerned agencies. Such ranking survey significantly depended upon the stakeholders' workshop of Singh (2015) that was further used by Lukman (2014) in his TOD study.

Meanwhile, as the community (who live and operate within the study area) also holds a share in the influence and impact of TOD, the general public is a crucial stakeholder as well. Since this group is not a practitioner of TOD, indicating that their participation is not in the technical domain, their involvement was rather represented in another area of this study which is the conduct of public perception survey. The set of questions employed was based on the study of Chen *et al.* (2021) who utilized public perception in assessing the usefulness of TOD.

3.3 Data Gathering

The data gathering proceeded with obtaining primary and secondary data by requesting access from Taytay Local Government Unit (LGU) and conducting on-site field visits and surveys. Multiple requests were sent to various municipal hall departments to have access to data such as Comprehensive Land Use Plan (CLUP) and others. A request for the forecasted train ridership of MRT-4 was also made through electronic Freedom of Information (eFOI). Field visits are conducted to gather primary data in identifying the occurrences of feeders and verifying the routes served by public modes of transportation. Also, the researchers utilized both online platform and actual field survey to administer the public perception survey material.

3.4 Calculation of TOD Indicators

Considering the different methods and TOD concepts examined in the literature review, the researchers identified the set of indicators used in constructing the TOD suitability index of the study. This follows the aspects of 1) social, 2) economic, 3) built environment and 4) travel behavior, which encompass the seven criteria to be used, namely: 1) density, 2) diverse, 3) design, 4) destination, 5) distance to transit, 6) demand management, or the 6Ds of built environment (Ogra and Ndebele, 2014), and 7) social perception. Eleven indicators were finalized, as shown in Table 1, which follow the principle of each criterion and aspect, and their respective unit values. As the indicators need to be quantified, different methods were employed to calculate the spatial and non-spatial indicators. It is important to note that there are no thresholds for these indicators with corresponding sufficient conditions. The methodology employed in the study follows the study of Singh (2015) and Lukman (2014) which were also conducted on a condition that there are no baseline (threshold) values to be followed yet, and the indicators will be compared to each other instead.

Table 1. Set of TOD indicators used in the study

	Indicators	Criteria	Aspects	Method of Quantifying Indicator Value	Unit Value
1	Population Density	Density	Built Environment	QGIS	population/km²
2	Commercial Density		Economic	QGIS	number of commercial buildings/km²
3	Land Use Diversity	Diversity	Built Environment	entropy formula, QGIS	diversity index
4	Connection	Design	Travel Behavior	counting	number of routes
5	Feeders		Travel Behavior	counting	number of feeders
6	Intersection Density		Built Environment	QGIS	number of intersections/km²
7	Mixedness of Land Use	Destination Accessibility	Built Environment	formula, QGIS	mixedness index
8	Foot/Cycle Path Length	Distance to Transit	Built Environment	QGIS	kilometers
9	Ridership	Demand Management	Travel Behavior	counting	number of boarding passengers
10	Cyclists		Travel Behavior	counting	number of cyclists
11	Public Perception	Social Perception	Social	Likert scale	Likert score

3.4.1 Population density

Population density, measured within 800 meters of a station, is crucial for Transit-Oriented Development (TOD) planning as it represents the residents in the TOD area (Cervero *et al.*, 1997). To determine this density, the QGIS software and the 2020 population census by the Philippine Statistics Authority (PSA) were used. The QGIS software calculates the catchment population by comparing the 800-meter radius area to the total barangay population density.

$$Population\ Density = \frac{No. of\ Population}{Catchment\ Area} \tag{1}$$

3.4.2 Commercial density

Commercial density is as important as population density in TOD planning; both represent the people residing within the TOD area. It was calculated using the Quick Open Street Map (QuickOSM) plugin in QGIS by reclassifying building data to identify commercial buildings within an 800-meter radius. Due to outdated data, additional building keys were added to the QuickOSM plugin after reclassification. Counted commercial buildings were divided into each station's catchment area.

$$Commercial\ Density = \frac{No. of\ Commercial\ Buildings}{Catchment\ Area} \tag{2}$$

3.4.3 Land use diversity

Land use diversity, the sole representation of diversity criteria in this study, refers to the diverse types of multiple destinations generating multiple activities within walking distance from the station. As cited by Lukman (2014), numerous TOD experts considered this as one of the most important TOD indicators as it highly encourages a more walkable environment providing people several choices of destinations and making the space more vibrant and livable without having to travel further. The entropy formula shown was used in getting the diversity index. The classification of the existing land use types enabled the researchers to calculate the shared area per land use and finally get the diversity index, where having an index of 0 indicates no diversity and 1 with maximum diversity a station can have.

$$Entropy = \frac{-\sum_i Q_{lu_i} \times ln\ (Q_{lu_i})}{ln\ (n)} \tag{3}$$

where,

lu_i : land use class within the analysis area i

Q_{lu_i} : share of specific land use within the analysis area i

n : number of land uses

The Equation (3) was based on the same entropy formula adapted by Lukman (2014) and Singh (2015) and originated from Ritsema van Eck and Koomen (2008) to measure land use diversity.

3.4.4 Feeders

With the existence of other transportation modes near the station, the passengers will have better access to various destinations not reached by trains. The vehicles considered in the route inventory for this indicator were only public transportation excluding tricycles considering the limited capacity and the travel distance. Under the accessibility criterion, the feeders' data were gathered from the online applications called Sakay.ph and Moovit.com, and through site survey to observe other existing feeders not listed in the applications.

3.4.5 Connection

The connect principle of TOD refers to the well-connected networks of paths and streets that result in short, varied, and direct connections that promote access to goods and services and other mass transport. Similar to the fourth indicator, the route inventory is its main data source as it is used to distinguish the number of routes that the identified feeders pass by. The connection is identified based on the route of each feeder with a unit value of total number of routes.

3.4.6 Intersection density

Intersection density, used by Lukman and Singh (2015) as an indicator for walkability and cycling in TOD measurement, refers to the count of road intersections within a specific catchment area. A higher number of intersections indicates better walkability and cyclability, providing pedestrians and cyclists with shorter paths and better connectivity. Researchers calculated intersection density using the Line Intersections tool in QGIS, generating a map of intersecting points within the catchment area of three stations, then dividing it by the total catchment area.

$$Intersection\ Density = \frac{No.of\ Intersection\ Points}{Catchment\ Area} \tag{4}$$

3.4.7 Mixedness of land use

Mixedness of land use, a sole indicator under the destination (accessibility) criterion, pertains to how the residential land use within the area under investigation is sufficiently mixed with other land use types. The mixedness index can be quantitatively calculated through QGIS using the same data used in land use diversity, incorporated with the formula derived from the study of Zhang and Guindon (2006). The mixedness index formula is as follows:

$$MI\ (i) = \frac{\sum_{\cap i} S_c}{\sum_{\cap i}(S_c + S_r)} \tag{5}$$

where,

MI : Mixedness Index for area of analysis i

S_c : land area under non-residential land uses within the TOD area

S_r : land area under residential land use within the TOD area

The value of the Mixedness Index could range from 0 to 1. Meanwhile, a value of 0.5, balanced land use mix, implies an equal share of residential land use to other land uses. This was also adapted from the works of Singh (2015) which used the formula from Zhang and Guindon (2006).

3.4.8 Foot/Cycle path length

The foot/cycle path length indicator represents the distance to transit, measuring road accessibility for pedestrians and cyclists. Lukman and Singh (2015) used this indicator to assess walkability and cyclability in their TOD studies. QGIS measured the length of foot/cycle paths using the Service Area (from layer) tool in the Network Analysis section of the Processing Toolbox.

3.4.9 Ridership

To encourage people to use public transit, it is important to ensure that the passenger load capacity of the transit is at optimum level which refers to the use of transit while utilizing its capacity to accommodate passengers. Less number or ridership would indicate less people using public transit and therefore result in waste of train resources, while high ridership would result in optimum level use of trains as its capacity is being maximized. This follows the principle of TOD in which having an efficient transit will provide access to people and connect them with lots of resources and opportunities. To supplement the data needed for this indicator, the estimated ridership in each station of the MRT-4 was used, and the total number of boarding per day in each station was utilized in an assumption that the proposed 5-car train of MRT-4 can carry 1,000 passengers based on the MRT-4 project briefer.

3.4.10 Cyclists

The researchers counted the number of cyclists that traveled over the selected station areas via CCTV footage provided by the municipal officials. It was recorded during the peak hour, both in the morning (6:00 AM to 7:00 AM) and afternoon (5:00 PM to 6:00 PM), on a Wednesday that is assured to be under normal conditions to avoid the irregularity of traffic due to the surge of commuters to and from provinces. The cyclists traversing each road in the area were counted with a unit value of direct total number of cyclists observed in the given time.

Given that this study explored the implications of foot/cycle path network to the level of transit-orientation in the station areas, the cyclists were counted to assess the current demand for cycling facilities that will further give implications to the cycling intiatives and connectivity within the station areas. On the other hand, it must be taken note that as the study considers other relevant TOD indicators, pedestrian count is indirectly measured via ridership, population density, and public perception. Moreover, the foot/cycle path length data is being used as a general complementary data for cyclists or pedestrians as the quality of the infrastructure is not assessed.

3.4.11 Public perception

Public perception survey, only indicator under the social perception criterion, refers to the collective views of people about TOD that helps support local policy makers in tailing and optimizing the implementation of a TOD project based on public needs and priorities (Papagiannakis and Yiannakou, 2022). A five-point scale public perception survey was then employed within each of the studied catchment area, while the total number of respondents (n) was obtained through the Cochran's formula:

$$n = \frac{Z^2(p * q)}{E^2} \tag{6}$$

where,

n	: sample size
Z	: Z-score
p	: probability of success in population
q	: probability of failure expressed as 1- p
E	: margin of error

The Z-score used was based on the 90% confidence level, the estimate of variance relied on the p of 0.5, and the margin error used was 5%. With this, a total of 272 sample size was calculated where 100, 73, and 99 of this is the number of respondents for Taytay, Manila East Road, and Tikling Junction stations, respectively. The perceptions gathered were quantified by obtaining the general average of the responses which is the traditional calculation of Likert scores. This study adopted the verbal interpretation used in the study conducted by Bringula *et al.* (2012) for the calculated Likert scores which is presented in Table 2.

Table 2. The 5-point scale, its mean range, and verbal interpretation

Weight/Scale	Mean Range	Verbal Interpretation
5	4.51 - 5.00	Strongly Agree
4	3.51 - 4.50	Agree
3	2.51 - 3.50	Moderately Agree
2	1.51 - 2.50	Slightly Agree
1	1.00 - 1.50	Disagree

3.5 Weighting Indicators

The weights were quantified through a stakeholders' ranking survey where each criterion and its indicator/s were ranked according to their importance from the stakeholders' view. Using the Borda Count Method, points are assigned to each item in order of preference, with 1 being the point for the last choice, 2 for the second-to-the-last choice, and so on. Upon tally, the ranking results were then converted to weights using Rank Sum Method. The formula is as follows:

$$W_k = \frac{n+1-k}{\sum_i^n (n+1-i)} \quad (7)$$

where W_k is the normalized weight for the criterion with a rank k, n is the total number of criteria or indicators in the set, and i is the index of summation that ranges from the value of 1 to n.

3.6 Data Analysis

In order to arrive at the final TOD index, the following procedure elaborated the methods used and how the results were interpreted with respect to the concepts of TOD and its implications to the study area.

3.6.1 Standardization of values

Given the spatial and non-spatial indicators calculated on the previous procedures, the outputs generated from these indicators carried different units. In order to facilitate significant comparisons between indicators, the values underwent the standardization process to have comparable units. Moreover, methods such as Maximum Method were used to transform the calculated indicator values into a standardized value range between 0 and 1, where 1 is the maximum value. From this, all the indicator values were calculated to be less than 1.

3.6.2 Constructing TOD suitability index

The values obtained from the weight calculation and standardization process were used to construct the TOD indices. This produced an individual index for each TOD criterion that identified which parts of the study need development and prioritization. Furthermore, such individual index produced one single TOD suitability index for each station area. These TOD suitability indices were ranked from highest (3) to lowest (1). High-ranking station/s indicated high transit-orientation, implying the area's potential for TOD planning. Meanwhile, low-ranking station/s indicated low transit-orientation, which means the prevailing TOD features within the area need improvement and development. Additionally, radar charts were used to present each TOD suitability index and its components.

3.6.3 Sensitivity analysis

In the TOD studies conducted by Fard (2013), Lukman (2014), Singh (2015), and Ibrahim *et al.,* (2023), The resulting TOD index were greatly dependent on the assigned indicator weights, considering that such weights obtained from stakeholders' ranking were subjective and are quite likely to change overtime especially when the given criteria and indicators are to be viewed by the stakeholders in different time and setting. To fill in the subjectivity and to further assess the robustness of the calculated TOD suitability index, sensitivity analysis was performed. Sensitivity analysis was performed on the criteria level to prevent complications through numerous combinations. As the criteria weights can be changed within a range (Malczewski, 2006), each criterion in the study will be changed by ± 10%, one at a time, while others were equally increased or decreased based on that 10%. If the changes are not sufficient to significantly affect the ranking of the original TOD suitability index, then it indicates that the constructed TOD suitability index before sensitivity analysis is indeed robust.

3.7 Operational Plan

Figure 3 shows the operational plan of this study. The right side of the figure presents the order of the main process involved in the construction of the final TOD suitability index which started from identifying the TOD aspects, criteria, and indicators suitable for the TOD study in the Taytay up to the process of interpreting the resulting TOD index to which will be further used for the implications of TOD for TOD planning and conceptualization. It could be taken note from Singh (2013) that the constructed TOD index can be used beyond the multi-criteria assessments, creating a venue for the general stakeholders to provide technical intervention towards TOD planning and conceptualization that can further be utilized for TOD-related policies and studies. Furthermore, it also presents the subprocesses (middle) involved for each of the main processes. Lastly, the figure also shows what particular means can these subprocesses be done.

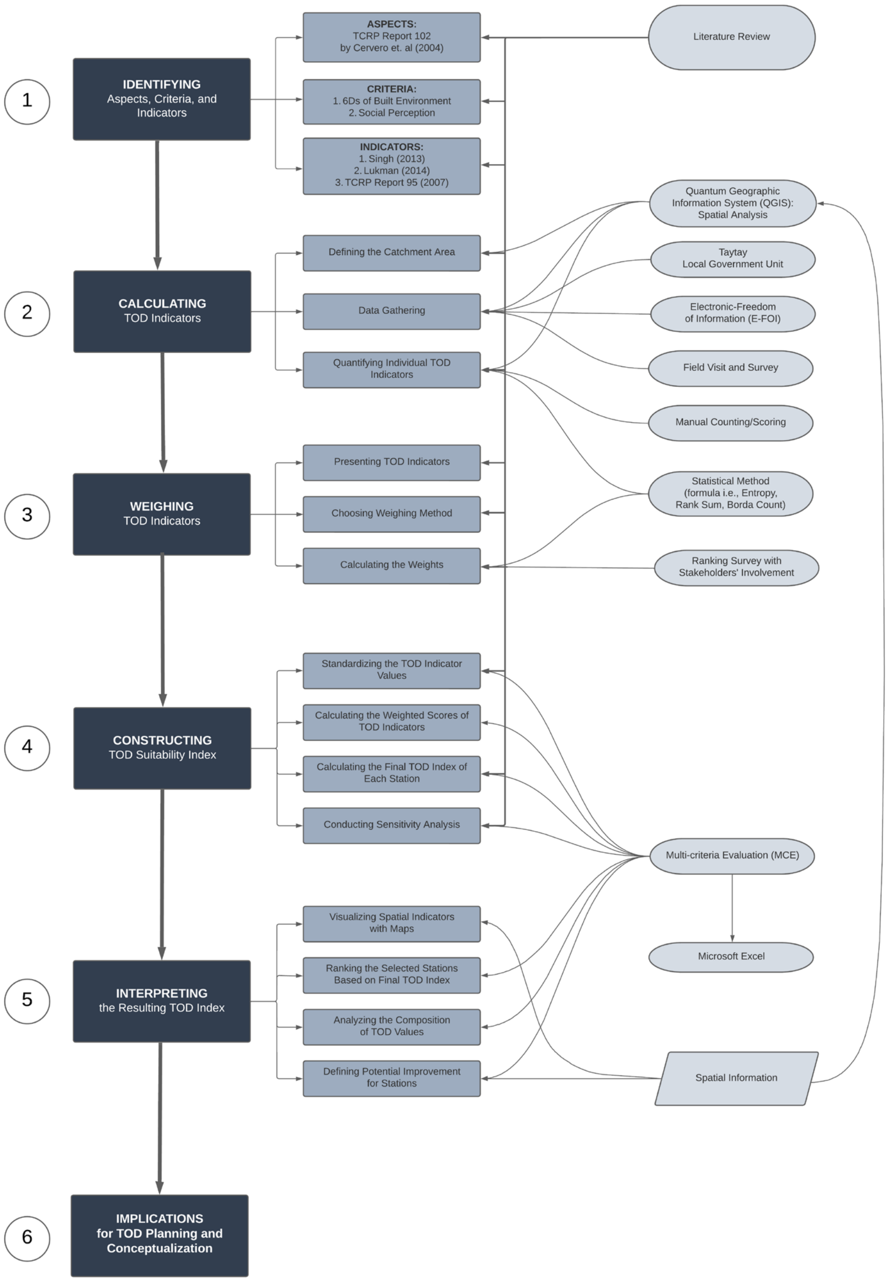

Figure 3. Operational plan of the methodology

4. RESULTS AND DISCUSSION

4.1 Calculated TOD Indicators

Utilizing the previously discussed methods Table 3 summarizes the quantified 11 indicators in different unit values. These values need to be standardized and assessed using criteria and weights from stakeholder input, which may affect the initial TOD indicator results and their corresponding criterion's total scores. The following sections discuss the individual indicator results categorized by criteria.

Table 3. Result of calculated TOD indicators

Stations	**Population Density**	**Commercial Density**	**Land Use Diversity**	**Connection**	**Feeders**
	number of population/km²	*number of commercial/km²*	*index ratio*	*number of routes*	*number of feeders*
Tikling Junction	27,312	268	0.413	23	28
Manila East Road	24,190	121	0.472	13	13
Taytay	24,200	243	0.468	17	17

Stations	**Intersection**	**Mixed Land Use**	**Foot/Cycle Path Length**	**Ridership**	**Cyclists**	**Public Perception**
	number of intersection/ km²	*index ratio*	*km*	*total number of boarding per day*	*number of cyclists*	*Likert score*
Tikling Junction	299.946	0.428	34.781	1,381	386	4.151
Manila East Road	344.385	0.362	28.363	230	374	4.280
Taytay	366.649	0.561	32.643	2,403	955	4.361

4.1.1 Density

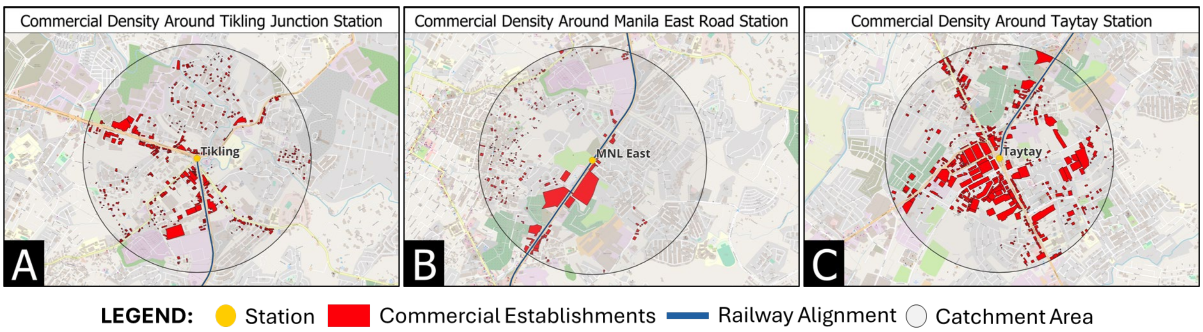

Figure 4. Commercial density maps around A) Tikling Junction Station, B) Manila East Road Station, and C) Taytay Station

Both Density criteria indicators show similar results, with differences in Population Density likely due to the characteristics of the catchment areas, as shown in Table 3. For instance, Taytay Station, despite being in the most populated barangay, has about one-third of its area unoccupied due to the presence of the main *tiangge* area. Similarly, Manila East Road Station includes unoccupied sections and other land uses, which impact its population density.

In terms of Commercial Density, Table 3 also shows that while Manila East Road has the lowest value, the assessment treated the mall as a single entity, as seen in Figure 4-B, potentially underestimating the area's actual economic activity. Taytay Station in Figure 4-C appears denser but has a lower commercial density due to calculations being based on the number of buildings, not their sizes, which gives Tikling Junction in Figure 4-A the highest density.

4.1.2 Diversity

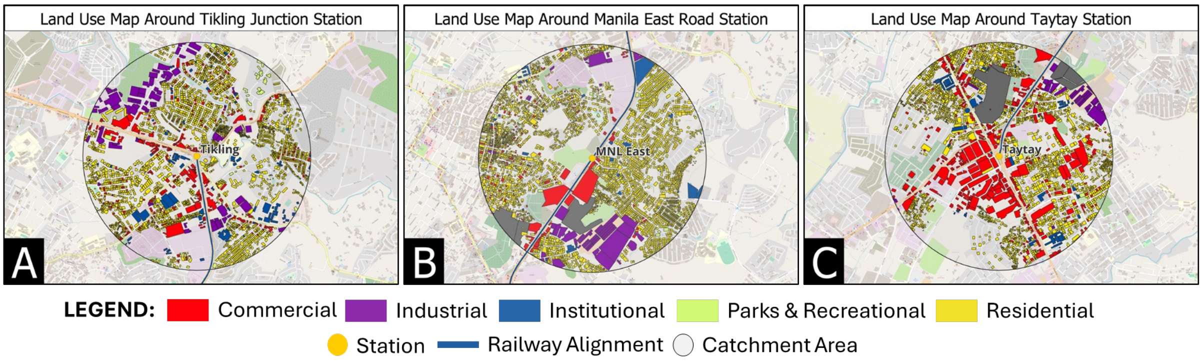

Figure 5. Existing land use maps around A) Tikling Junction station, B) Manila East Road station, and C) Taytay station

Using the six land use classification types adapted from the CLUP of Taytay, the land use diversity of the three stations were visualized with the maps in Figure *5* generated from QGIS. Table 3 shows that Manila East Road station has the most diverse use of its land with just a minimal gap from Taytay station. These indices ranging from 0.41 to 0.47 imply that the stations have not yet reached the maximum diversity that their lands can utilize. While there is high visibility of residential land use on the maps, it should be more evenly mixed with other land uses to generate more activities in the area and lessen the need to travel long distances to fulfill the basic daily needs.

4.1.3 Design

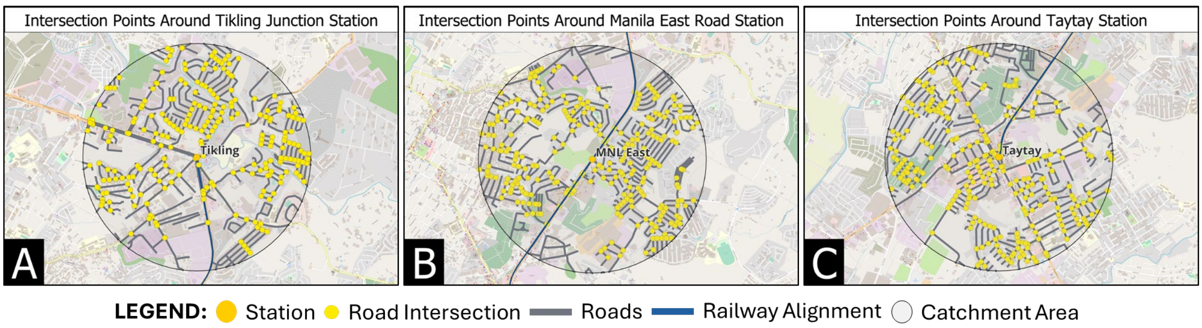

Figure 6. Intersection points map around A) Tikling Junction Station, B) Manila East Road Station, and C) Taytay Station

The Design criteria include the characteristics of a street network of the defined area. Under this criterion are Feeders, Connection, and Intersection Density indicators. Feeders and Connection indicators share the same rankings, with Tikling Junction Station being the highest, followed by Taytay Station, then Manila East Road, as shown in Table 3.

Meanwhile, Table 3 also shows that Taytay Station leads the ranking for the Intersection Density indicator, followed by Manila East Road, and then Tikling Junction. Figure 6-C highlights intersection points around Taytay Station, mainly in business and *tiangge* areas, enhancing accessibility and exposure for entrepreneurs and businesses. In contrast, Figure 6-B illustrates Manila East Road's intersections influenced by gated communities and residential areas. Tikling Junction, depicted in Figure 6-A, has the lowest intersection density, primarily due to the available spaces in the southern part of the station.

4.1.4 Destination accessibility

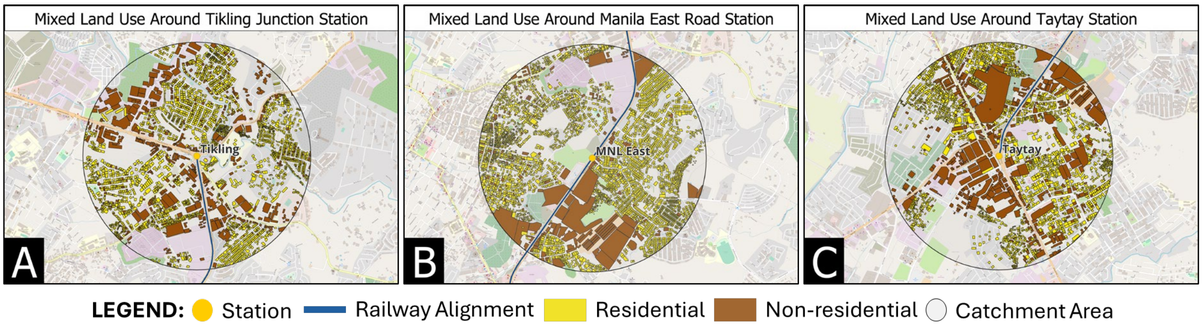

Figure 7. Mixedness of land use maps around A) Tikling Junction Station, B) Manila East Road Station, and C) Taytay Station

As presented in Table 3, Taytay Station obtained the highest mixedness index of 0.561, which is close to the 0.5 value of balanced land use mix. This is reflected in Figure 7-C where the residential land is seen to be sufficiently mixed with the non-residential land, further emphasizing land use integration that support shorter trips with increased accessibility to people. Results were followed by mixedness indices of 0.428 and 0.362 for Tikling Junction Station and Manila East Station, respectively. This means that there are limited non-residential opportunities within residential zones, thus implying longer trips and reduced accessibility to people around these stations.

4.1.5 Distance to transit

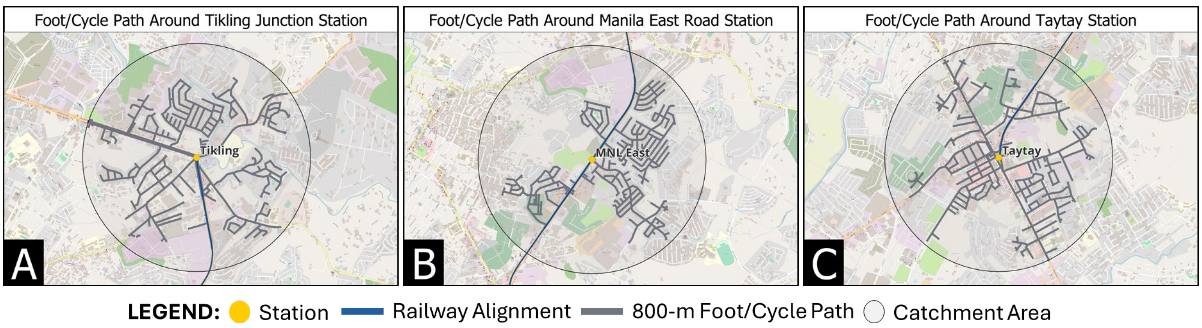

Figure 8. Foot/Cycle path maps around A) Tikling Junction Station, B) Manila East Road Station, and C) Taytay Station

The Foot/Cycle Path Length Indicator of the Distance to Transit criterion shows that Tikling Junction Station has the longest path length, followed by Taytay Station, and Manila East Road Station, as shown in Table 3. The length of these paths is influenced by smaller streets branching off major roads like Ortigas Avenue Extension and Rizal Avenue. Figure 8-B illustrates the lowest path length around Manila East Road Station due to multiple gated communities nearby. In contrast, Tikling Junction (Figure 8-A) and Taytay (Figure 8-C) show longer path lengths, reflecting their commercial landscapes and locations. These extensive road networks enhance access and connectivity, supporting efficient movement of goods, services, and customers, fostering vibrant commercial environments.

4.1.6 Demand management

Table 3 shows Taytay Station has the highest total number of boarding per day with 2,403 forecasted passengers being the first station to cater all the passengers from the southern part of Rizal, while Tikling Junction Station follows with a 1,381-ridership and the Manila East Road Station has the lowest ridership of 230. It can be deduced that the huge gap between the highest and lowest ridership among 3 stations is due to the short distance between Manila East Road and Taytay station. On the other hand, Taytay Station also has the greatest number of 955 cyclists recorded traveling during the peak hour in the morning and afternoon followed by Tikling Junction and Manila East Road Station.

4.1.7 Social perception

Survey responses were gathered via online and on-site surveys and were quantitively measured via Likert scores. Tikling Junction, Manila East Road, and Taytay Station obtained 4.152, 4.280, and 4.361 Likert scores, respectively. All of which indicate a discrete rating of "Agree". This means that most of the respondents from all three stations implied agreement towards the indicated usefulness of TOD and the indicated factors for positive utilization of mass transits. Both are with consideration of their respective station area's current conditions.

4.2 Constructing TOD Suitability Index

Table 4. Standardized TOD index

Stations	Population Density	Commercial Density	Land Use Diversity	Connection	Feeders
Tikling Junction	1	1	0	1	1
Manila East Road	0	0	1	0	0
Taytay	0.003	0.825	0.928	0.4	0.267

Stations	Intersection	Mixed Land Use	Foot/Cycle Path Length	Ridership	Cyclists	Public Perception
Tikling Junction	0	0.334	1	0.530	0.021	0
Manila East Road	0.666	0	0	0	0	0.618
Taytay	1	1	0.667	1	1	1

After the result of each indicator are obtained, it underwent standardization using the Maximum method. This method produced scores suitable for the calculation of weights needed in MCE in construction of the TOD Index. The result of each indicator has a score ranging from 0 to 1 using the maximum and minimum values for each indicator. In reference to Table 4, the station with the minimum value for each indicator got 0 as its standardized score, while the maximum values got 1.

Table 5. Calculated criteria and indicator weights

Criteria	Rank	Weight	Indicators	Rank	Weight
Distance to Transit	1	0.250	Foot/cycle path length	1	1
Demand Management	2	0.196	Ridership	1	0.67
			Cyclists	2	0.33
Density	2	0.196	Population density	1	0.67
			Commercial density	2	0.33
Destination	4	0.143	Mixed land use	1	1
Design	5	0.107	Connection	1	0.5
			Feeders	2	0.33
			Intersection	3	0.17
Diversity	6	0.071	Land use diversity	1	1
Social Perception	7	0.036	Public perception	1	1

As previously mentioned, the stakeholders' engagement was used to produce weighted criteria and indicators based on their significance to the TOD-ness of an area. The ranking of criteria and indicators was produced using the Borda Count Method. Subsequently, the weights in each ranking were calculated through Rank Sum Method. Table 5 shows the final weights multiplied to the standardized indicator values in Table 4 to produce weighted scores.

4.3 Final TOD Suitability Index

The level of transit-orientation of each station being studied is shown through the final TOD suitability index, which was further detailed in the Appendix. These values had undergone multi-criteria evaluation (MCE) process, and results revealed that Taytay station has the highest transit orientation with a Final TOD Suitability Index of 0.711. This means that Tikling Junction and Manila East Road station have a moderate and lowest transit-orientation with a Final TOD Suitability Index of 0.654 and 0.106, respectively.

Table 6. TOD index with stakeholders' engagement

	Final TOD Index			**Final TOD Index with Sensitivity Analysis**		
Stations	**Tikling Junction**	**Manila East Road**	**Taytay**	**Tikling Junction**	**Manila East Road**	**Taytay**
Distance to Transit	0.250	0	0.167	1	0	0.667
Demand Management	0.071	0	0.196	0.007	0.002	1
Density	0.196	0	0.054	1	0	0.275
Destination Accessibility	0.048	0	0.143	0.334	0	1
Design	0.089	0.012	0.049	0.83	0.113	0.458
Diversity	0	0.071	0.066	0	1	0.928
Social Perception	0	0.022	0.036	0	0.618	1
Final TOD Suitability Index	**0.654**	**0.106**	**0.711**	**0.654**	**0.104**	**0.709**
Rank	**2**	**3**	**1**	**2**	**3**	**1**

Table 6 presents both sets of TOD Suitability index calculated before and after the conduct of sensitivity analysis as the calculated values in the original final TOD index were still dependent on the weights derived from standardized values and stakeholders' rankings.

This shows that the sensitivity analysis conducted had only minimal influences in the original TOD suitability index where, despite having slight decreases in the indices, except the second station which retained its index, the three stations maintained their ranks, implying that the original results are robust.

4.4 Interpretation of TOD Suitability Index in Station Areas

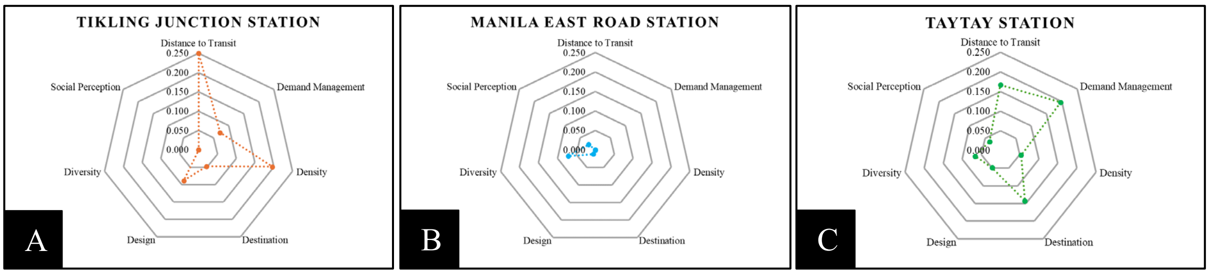

Figure 9. TOD suitability index around A) Tikling Junction Station, B) Manila East Road Station, and C) Taytay Station

Figure 9-A reflects the overall construction of the Tikling Junction Station's final TOD index where it could notably be seen that the Distance to Transit criterion attained the highest index among all the studied criteria due to the vast foot/cycle network present around the catchment area. It is followed by the Density and the Design criterion. The former is attributed to the high concentration of people and commercial establishments present within the vicinity and the latter is due to the large number of feeders traversing the Tikling Junction (considering that it links to Ortigas Ave. Ext., Manila East Rd., L. Wood Rd., and Cabrera Rd. which signified high connection as well). Meanwhile, Destination Accessibility, Demand Management, Diversity and Social Criterion obtained lower indices which imply that diverse land uses should be optimized to ensure that residential land use does not overpower other types and also to promote multifunctionality, thus enhancing interaction among people that would then cater to their diverse range of needs and preferences, therefore increasing the people's perceived usefulness of TOD.

Figure 9-B shows the score of Manila East Road with respect to the criteria given in the study. Among all the criteria, Density scored the highest as the area surrounding the station depicts a diverse land use. The scores the station got do not necessarily mean that the station is not suitable for TOD. The result is heavily influenced by the number of stations assessed and the weight of scores based on the ranking survey of the stakeholders, making Manila East Road the minimum basis of scores. Furthermore, this result suggests that there are areas to be improved in Manila East Road station compared to the two stations located in the study area.

Figure 9-C indicates that Taytay Station excels in Demand Management, Distance to Transit, and Destination Accessibility, all contributing to its high TOD index. As the starting point of the MRT-4 line connecting the southern part of Rizal to the metro, Taytay will serve many passengers, making it a promising area for TOD due to its diverse commuting population. Walkable and cyclable paths around the station also support its purpose as a main transit hub. Meanwhile, the balanced mix of residential and non-residential land uses promotes accessibility to various activities from homes.

Generally, the following areas of improvement are recommended to further enhance the TOD index of the three stations:

- Construct an intermodal station to increase the connectivity and presence of feeders around the station *(Design)*

- Conduct a comprehensive traffic management to install highly effective signals and avoid traffic jams in the intersections, especially in rotonda *(Design)*
- Restructure its land use and utilize the available areas into accessible public spaces and other non-commercial uses *(Diversity)*
- Designate bicycle lanes and walkways directly connected to the station *(Distance to transit)*
- Implement commercial policies in *tiangge* areas where spaces intended for pedestrian should not be obstructed *(Design)*
- Design a multi-level building facilities to cater the growing commercial (*tiangge)* stalls *(Design)*

Lastly, these improvements would positively impact social perception, encouraging more support for public and active transport, and further increase the station's TOD index.

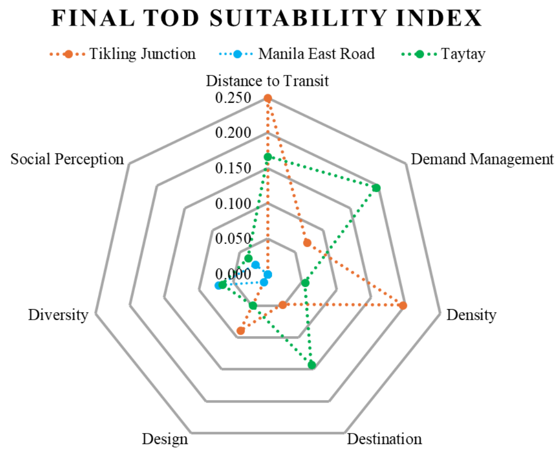

Figure 10. TOD suitability index around station catchment areas

Figure 10 illustrates the level of transit orientation of all the three stations whereas the larger the size of the resulting area, the higher the TOD suitability index. Taytay station stood apart from the other stations in terms of its transit orientation where not one criterion measured under this station attained a zero index, indicating that the station performed well across all the criteria assessed. Tikling Junction Station has a moderate level of transit orientation which can be further improved through areas needing development. Meanwhile, while Manila East Road Station performed poorly across all the criteria being assessed in the study, which indicates it having the lowest transit orientation among the three stations, this low TOD index does not imply that this station should be avoided or scrapped in the MRT-4 alignment. If the areas of improvement mentioned in the discussion above will be highly regarded by the decision makers, in both public and private sectors, the TOD levels will significantly increase making the stations more feasible and effective to be implemented with TOD.

5. CONCLUSIONS

Upon adopting the process of multi-criteria evaluation in standardizing the identified TOD indicators, it was found out that the foot/cycle path length, ridership and cyclists, and land use diversity were the indicators mostly present in Tikling Junction, Manila East Road, and Taytay Station, respectively. The criteria to which these indicators were under heavily contributed to the resulting final TOD suitability index. This set of indices was attested to remain robust following the exercise of sensitivity analysis, implying that the weights implicated through stakeholders' participation caused no significant changes. Taytay Station remained to have the highest transit orientation, thus presenting greater prospects for TOD planning and implementation alongside the construction of a mass transit system around this area. Conversely, the other two stations that obtained moderate to low transit orientation could prompt various developments aimed at enhancing the existing TOD features on their respective areas. Moreover, the following conclusions were drawn in alignment with the study's assumptions.

1) Despite Taytay Station's overall high score, there are areas needing improvement where it scored lower on specific indicators. Detailed data interpretation for each station guided researchers in recommending targeted improvements to enhance each station's TOD characteristics.
2) Analyzing the study area through the lens of TOD at the station level within an urban development context suggests that starting with smaller station-based TODs and scaling up to city or regional levels is effective.
3) Limitations are found in a way that researchers relied on existing indicators observed within the catchment areas. Despite these constraints, it was concluded that this study can be conducted in areas with non-existing railway lines but possess TOD-like characteristics. This finding emphasizes the potential for simultaneous implementation of TOD alongside planning and construction phase.
4) The quantified data which created indices for each indicator were heavily influenced by weights derived from stakeholder preferences. Therefore, a station that carries low weights on criterion that weighs high in stakeholder rankings could have a low overall TOD index. This emphasizes the importance of conducting sensitivity analysis to properly account for the robustness of the stakeholders' intervention.
5) As the result shows the produced final TOD index comprised of 0.711, 0.654, and 0.106, a relevantly high interval from the highest and lowest index was observed. This is due to the limited number of three stations analyzed which gave a standardized score of just either 0, 1 or somewhere in between 0 and 1 for each station. Therefore, analyzing more than three stations in the study area will help produce a more concentrated TOD index with a narrow range of distribution.

6. RECOMMENDATIONS

The construction of MRT 4 enhances the local public transportation accommodating several commuters from Taytay, Rizal and its nearby cities and municipalities, and reduces the cost of driving and commute time. It allows the possibility of being a suitable area for TOD that would benefit the community, as this concept will develop a more accessible and mixed-use area that could reduce the dependency on private cars and encourage the use of mass transit and active transport systems, including walking and cycling. Aside from the transportation sector, this study could also be beneficial to businesses as TOD can strengthen local economies. According to the Center for Transit-Oriented Development, a small town with a good transit system may attract young, creative talent and create jobs. With Taytay being known as the Garments Capital of the Philippines, it has the potential to attract investments and grow its economy.

6.1 Recommended Actions of Key Stakeholders

Various studies have shown that transit-oriented development is an effective tool towards sustainable urban development that encompasses the transportation system, socio-economic and environmental aspects of a developing area. In light of this, the researchers recommend the key stakeholders identified below to act upon based on the results of this study.

1) Comprehensive land use study by local government units (LGUs)
   This study will be an instrument for the LGUs to identify the TOD features that need to be retained and improved and acquire the areas in the vicinity of the proposed stations that can be utilized into more suitable land use to increase the TOD level. The local traffic management and road infrastructure can be further improved in such a way that there will be designated walk and cycle paths around the station.
2) Creation of TOD policies and strategies by TOD practitioners
   The quantitative results provide a concrete foundation for TOD planning and contribute to the development of locally considered strategies and policies. Some examples of these policies include zoning regulations that leads to mixed-use developments and higher density around transit hubs, policies regarding prioritization of pedestrian and PWD-friendly facilities, and development of infrastructures that promotes active transport.
3) Major stakeholder meetings initiated by transportation agencies
   The results of this study can help transportation agencies in redesigning cities towards a less car-centric society. Mainly, the Department of Transportation can act as the leading agency to initiate opportunities and venues for stakeholders meeting as TOD aims to address various issues in terms of socio-economic and environmental aspects. Having stakeholders meeting could foster cooperation and supportive relationships to strategize how to get financial assistance and support from the private sector.
4) Public-Private Partnerships (PPP) Schemes
   Having comprehensive studies of TOD subject for implementation will attract private sectors to invest and share knowledge and resources to further strengthen the study turned into plans and grow investors for successful implementation. Through PPP schemes, both governments, in local and national level, and the private sector will join hands and further realize the benefits of TOD to both public and private interests.
5) Concept Plan of TOD for Station Areas
   Finally, overall major projects can be conceptualized and planned for both public and private sectors such as, but not limited to:
   - Public transport facilities and other public spaces under the viaduct
   - Activity centers and recreational facilities for public use
   - Access roads or walkways to the station within 200-400m from the station
   - Mixed use facilities within 800m from the station
   - Rehabilitation of creeks with pedestrian and bicycle lanes
   - Road widening to designate pedestrian and bicycle lanes within 200-400m from the station
   - Installation of traffic signals based on a traffic management study
   - Reservation of green areas (parks and plazas)

These projects are referenced from the Preparatory Survey on Promotion of TOD for Urban Railway in the Republic of the Philippines final report conducted by JICA (2015) with North-South Commuter Railway (NSCR) stations as their study area. Additional projects are suggested based on the applicable areas of improvements discussed in the results of this study.

6.2 Improvement Areas of the Study

To further improve the future direction of such studies, recommendations such as widening the scope of catchment area and including a wider range of established TOD aspects, criteria, and indicators used in the academe are highly encouraged. Future researchers should conduct more in-depth case studies of successful TOD projects in different contexts, be it in local or foreign, and utilize both quantitative and qualitative methods to identify the best practices and methods in conducting TOD suitability studies and further refine the TOD index. Furthermore, the involvement of key stakeholders, especially urban and transportation agencies, and the affected LGUs is important as engaging with these relevant and qualified experts and authorities can be beneficial for the researchers as it enhances the credibility and reliability of the study. TOD studies in potential areas for railway extension are also highly encouraged to be assessed to guide the decision makers in prospects of extending the railway alignment and effectively utilize the railway connectivity to the outer cities.

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APPENDIX

Calculation of TOD Index with Applied Weights

Criteria	Weights	Indicators	Weights	Standardized Score	Weighted Scores	TOD Index
Distance to Transit	0.250	Foot/cycle path length	1	1	1	0.25
Demand Management	0.196	Ridership	0.67	0.5297	0.36171483	0.0710511
		Cyclists	0.33	0.020654045		
Density	0.196	Population density	0.67	1	1	0.1964286

Criteria	Weights	Indicators	Weights	Standardized Score	Weighted Scores	TOD Index
		Commercial density	0.33	1		
Destination	0.143	Mixedness of land use	1	0.333840678	0.33384068	0.0476915
Design	0.107	Connection	0.5	1	0.83	0.0889286
		Feeders	0.33	1		
		Intersection	0.17	0		
Diversity	0.071	Land use diversity	1	0	0	0
Social Perception	0.036	Public perception	1	0	0	0
				Tikling Junction Station Final TOD Index		**0.6540998**

Criteria	Weights	Indicators	Weights	Standardized Score	Weighted Scores	TOD Index
Distance to Transit	0.250	Foot/cycle path length	1	0	0	0
Demand Management	0.196	Ridership	0.67	0	0	0
		Cyclists	0.33	0		
Density	0.196	Population density	0.67	0	0	0
		Commercial density	0.33	0		
Destination	0.143	Mixedness of land use	1	0	0	0
Design	0.107	Connection	0.5	0	0.11325772	0.0121348
		Feeders	0.33	0		
		Intersection	0.17	0.666221909		
Diversity	0.071	Land use diversity	1	1	1	0.0714286
Social Perception	0.036	Public perception	1	0.617612524	0.61761252	0.0220576
				Manila East Road Station Final TOD Index		**0.1056209**

Criteria	Weights	Indicators	Weights	Standardized Score	Weighted Scores	TOD Index
Distance to Transit	0.250	Foot/cycle path length	1	0.666941062	0.66694106	0.1667353
Demand Management	0.196	Ridership	0.67	1	1	0.1964286
		Cyclists	0.33	1		
Density	0.196	Population density	0.67	0.00322808	0.27455445	0.0539303
		Commercial density	0.33	0.825429206		
Destination	0.143	Mixedness of land use	1	1	1	0.142857
Design	0.107	Connection	0.5	0.4	0.458	0.049071
		Feeders	0.33	0.266666667		
		Intersection	0.17	1		
Diversity	0.071	Land use diversity	1	0.927766273	0.9277662	0.066269
Social Perception	0.036	Public perception	1	1	1	0.035714
				Taytay Station Final TOD Index		**0.711006**