GIS-based Land Suitability Analysis to Support Transit-Oriented Development (TOD) Master Plan: A Case Study of the Campus Station of Thammasat University and Its Surrounding Communities

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Abstract

This article presents a study of land suitability analysis and Transit-Oriented Development (TOD) of a campus station of Thammasat University (Rangsit Campus). The Geographic Information Systems (GIS) and multi-criteria evaluation were used to identify the most suitable areas, in which its geospatial databases were derived from various organizations of Thailand. Eventually, the collective data was analyzed by map overlay analysis technique in an ArcView Model Builder program. In addition, integrating spatial analysis technique with the Spatial Multi-Criteria Decision Making Analysis (SMCDA) as applied to establish criteria weights and ranking them in order to analyze impacts on the transit-oriented communities and to supporting urban designer and planners with some practical approaches in decision making while planning. These analysis techniques are effective and prevalently used in various fields of studies such as geography, environmental science, landscape architecture and urban planning. Subsequently, the gathering analyzed data was applied for design guidelines of Transit-Oriented Development (TOD) Master Plan of Thammasat University and its surrounding communities. The study purposed various land uses such as commercial areas, real estate development, and necessary facilities.

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Keywords: Geographic Information Systems (GIS), Spatial Multi-Criteria Decision Making Analysis (SMCDA), Transit-Oriented Development (TOD), Campus Station

1. Background

Decision making is a thought-provoking issue in complex urban planning problems, and it contains many variables and alternatives inherently. Multi Criteria Decision Making (MCDM) is a common method to solve the problems involving many uncertainties, and it is employed here for answering the Transit-Oriented Development or TOD issue. In urban planning, a TOD is a type of urban development that maximizes the amount of residential, business and leisure space within walking distance of public transport (Iamtrakul & Ruangratanaamporn, 2016, pp. 13-26). Therefore, the evaluation of MCDM methods compares different spatial elements according to their characteristic properties in order to select the best localization alternative (such as distance to community areas, distance to employment area, topography, etc.).

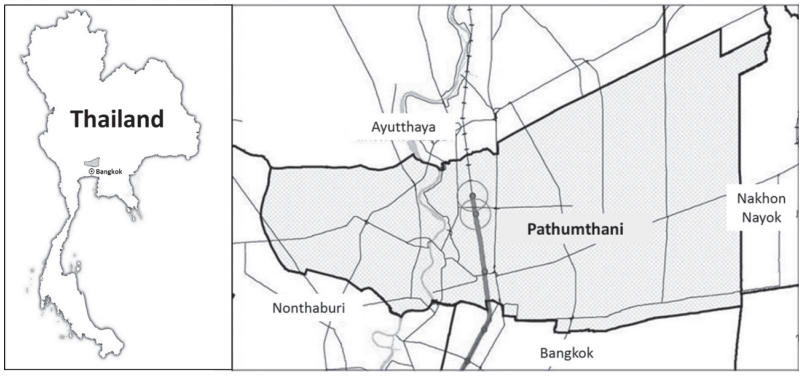
The MCDM method in this research were processed with Geographical Information Systems (GIS). The use of GIS allows the organization, storage, manipulation, analysis and modeling of large amounts of data from the real world that are linked to a spatial reference shaped grid. GIS facilitates the incorporation of social, cultural, economic and environmental criteria that leads to a more effective decision making. Furthermore, when GIS is joined to MCDM methods, it provides a good tool for selecting the optimum site for urban transportation planning. On the basis of these conditions, the MCDM methods provide a range of techniques and procedures for structuring the advantages, disadvantages and risks associated with the decision making problem, evaluating the alternatives under specific considerations (Malczewski, 1999).

This study is a part of the research project, "A Study of Connectivity between the Sub-Urban Railway Stations and Surrounding Communities around Thammasat University (TU)" which the Office of Transportation and Traffic Policy and Planning (OTP), Ministry of Transport had hired the Faculty of Architecture and Urban Planning, Thammasat University. This research aimed to analyze the most feasible location for planning TOD based on GIS-MCDM also called the Spatial Multi-Criteria Decision Making Analysis (SMCDA). The study of land suitability analysis to support TOD was completed by the use of the GIS application, which was firstly developed in the 1960s. The re-arrangement of land suitability was based on various related factors as consideration's criteria such as urban population's settlement, natural environment, natural hazards, land uses, infrastructure. The study also applied the SMCDA based on the project's specialists in four areas including land-use and planning; transportation; environmental impact assessment; and urban designer. The master plan of the Thammasat University campus station and its surrounding communities was subsequently developed.

2. The study's objectives

1. To analyze all factors, which have impacts on the development of surrounding area of the Thammasat University campus station and its surrounding communities. In this study, the analysis process also cover the surrounding area of the Chiang Rak station, as it is closely connected with the Thammasat University campus station[1].
2. To propose a master plan for Thammasat University campus station and its surrounding communities.

Figure 1. The study area (marked in two circles). (Source: Author)



3. The study areas and boundaries

The study covers areas with 2-kilometer diameter of the Thammasat University campus station, Chiang Rak station and its surrounding communities. Figure 1 illustrates the study area. Boundaries of the study are in the following:

1. To analyze physical potentials of the target area by using the ArcView Model Builder technique along with the SMCDA, which result in the factors' scores.

2. Summarize of the land suitability analysis of the Thammasat University campus station and its surrounding communities was subsequently developed.

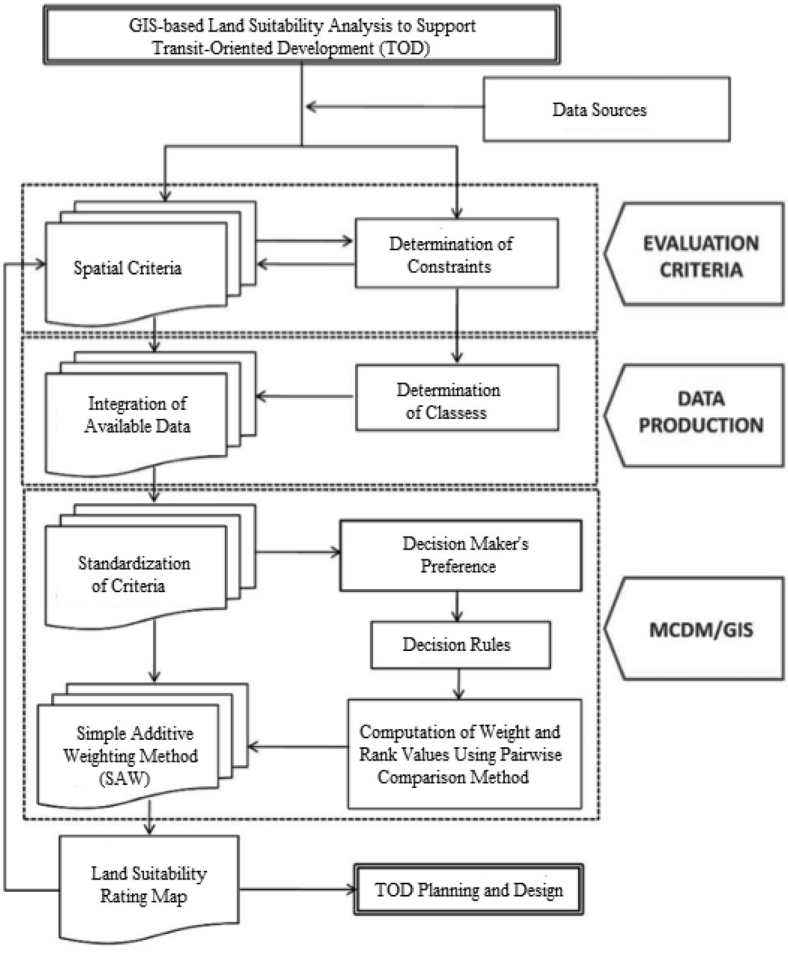


Figure 2. The study's framework and processes. (Source: Author)

Subsequently, the paper demonstrates a proposal for the Master Plan of the Thammasat University campus station and its surrounding communities. Framework and process of the study are as shown in Figure 2.

4. Literature review on the Multi Criteria Decision Making (MCDM)

The International Society on the MCDM (2017) defines the MCDM as "the study of methods and procedures by which multiple and conflicting criteria can be incorporated into the decision process." The MCDM provide decision-makers with an advance tool in solving a multi-criteria decision problem, where several conflicting criteria are taken into account (Zardari, Ahmed, Shirazi & Yusop, 2015). The MCDM has been an active area of research since the 1970s. For over 40 years, the MCDM has been considered one of the most suitable methods for land suitability analysis process. Yang et al. (2008) remarks that the method focuses mainly on the identification of the evaluation criteria and on the determination of the preference structure such as weights, ranking, etc.

In the MCDM process, each criterion is assigned a weight, which indicates its values and its importance to evaluation of criteria and other criterion under consideration (Zardari, Ahmed, Shirazi & Yusop, 2015). A criterion weight can be assigned either large or small attributions. The more weights and the higher numbers, the more significant of the criterion. Therefore, the assigning weight is a vital step in eliciting the decision maker's preference. According to Malczewski (1999), there are four methods for assessing criterion weights comprising of ranking, rating, pairwise comparison, and trade-off analysis. Table 1 summarizes the important features of the criterion weights methods.

Methods				
Feature	**Ranking**	**Rating**	**Pairwise Comparison**	**Trade-off Analysis**
Number of Judgement	*n*	*n*	*n (n-1) / 2*	*< n*
Response Style	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes
Underlying Theory	None	None	None	None
Ease of Use	Very Easy	Very Easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximations	Not Precise	Quite Precise	Quite Precise
Software Availability	Spreadsheets	Spreadsheets	Expert Choice	Logical Decision
Use in a GIS environment	Weights can be imported from a spreadsheet	Weights can be imported from a spreadsheet	Component of IDRISI	Weights can be imported from LD

Table 1. Methods for assessing criterion weights. (Source: Malczewski, 1999)

As presented in the Table 1, these four methods of assessing criterion weights differ in various ways. Determination of the method selection depends on various factors such as ease of use, accuracy, the degree of understanding on the part of decision maker, and the theoretical foundation underlying a given method. Ranking is a method, which arranges weight in order to be a preference for the decison's maker (Zardari, Ahmed, Shirazi & Yusop, 2015). Rank reciprocal is a type of the ranking method, which its weights are derived from the normalized reciprocals of a criterion's rank. This rank reciprocal method is appropriate for experiential multi-disciplinary experts in TOD's land suitability analysis, which share the same goal. As a result, the method is applied in this research. The MCDM method is sometimes criticized especially in terms of omitting some relevant criteria; therefore, the final outcome is not straightforward. In this research, the accounted criteria are in as many areas as possible to avoid the MCDM's inaccuracy.

5. The land suitability's analysis processes

5.1 Determining factors of the land suitability's analysis

For this project, the first process is to determine a set of criteria in selection of factors that have impacts on the land suitability's analysis. The consideration of criteria and the selection of the factors, which are based on literature review and team consultation, are categorized in four groups as follows;

1) Geographical factors

The geographical factor covered a range of consideration regarding of geographical attributions of the study area, which could be potential and constraints for the development. The geographical factors include hydrology, topography, and other geographical characters in macro and micro scales. Most geographical data of the study derives from the Shuttle Radar Topography Mission (SRTM) satellite[2].

2) Plant preservation factors

Due to existing conditions of the study area, which is suitable for agricultural uses, the factor regarding plant preservation was essential in the land suitability's analysis. The study obtained the plant preservation information from the Normalized Difference Vegetation Index[3] (NDVI), which derived from the LANDSAT-7[4] with the ETM+ system[5]. Good soil and water resource are essential factor for growth of plants; therefore, the study is also concerned with quality of soil and availability of the water resources.

3) Accessibility factors

The accessibility factor comprises of three main categories including 1) accessibility to the main avenue; 2) accessibility to the secondary road; and 3) accessibility to the campus stations. Areas adjacent to the main transport routes would have more accessibility to the city's infrastructure than other areas. Buffer distances of each transport route vary following regulations provided by the Department of Public Works and Town and Country Planning.

4) Center of activity factors

The center of activity is crucial as it provides various types of services to the study area. In the center of activity context, there are two main concerns comprising of residential density and sources of employment. The study applied the Kernel Function[6] for estimation of the density following with use of the point pattern analysis method to investigate distribution of activity point.

The following Table 2 provides layout of feature or index, criteria and maps, which were used for the measurement of each determining factor of the land suitability's analysis. Cartographic information and identification of factors and restrictions are as presented in Figure 3.

5.2 Ranking the factors

After determining factors of the land suitability's analysis, the next process is to transfer the measurement indexes. Due to differences of unit and range of scores in measurement indexes, criterion weighting or so-called method of normalization factors are necessary. In this study, range of score is between 0 and 1. The Chapin Kaiser formula (1975) can be applied as follows. After calculating, we can transfer the figured numbers on the grid system of analysis map (see Eq.1).

$$P_{ij}^{*} = \frac{P_{ij}}{P_i^{max}} * K \qquad \text{(Eq.1)}$$

Where: P_{ij}^{*} = Adjustment score in the K base

P_{ij} = Raw score in the factor j

P_i^{max} = The highest raw score of the factor i

K = Base score (in this case is 1)

Table 2. The determining factors of the land suitability's analysis, indexes, criteria and maps for measurement.

Factors	Feature/Index	Criteria in Measurement	Maps Used for the Measurement
1) Geographical Factor	Altitude elevation of the area, which is suitable for development. Typically, the information's in Digital Elevation Data (DEM) format (usually range from 0 to over 3.5 metres above mean sea level (MAMSL)	Good measurement score from the elevation information proposed by the suitability ratings will be divided into permanently unsuitable (0 MAMSL) to highly suitable (over 3.5 MAMSL)	Maps from the SRTM satellite. Latitude's position is p129r050. Spatial resolution is 90 meter.
2) Plant Preservation Factor	Plant index in the Normalized Difference Vegetation Index (NDVI) format that ranges from minus one (-1) to plus one (+1). A zero means no vegetation and close to +1 indicates the highest possible density of green leaves	Protecting area with abundant natural plants to provide food sources for natural wildlife and preserve ecosystem	The LANSAT-7 with ETM+ system Path 129/Row050 (2009-11-02)
3) Accessibility Factor	Distances from the accessibilities	Close proximity (indicating very high opportunity) and remote from the accessibilities (very low opportunity)	Transportation map Scale 1: 4000 by the Department of Public Works and Town and Country Planning
4) Center of Activity Factor			
4.1) Density of Residential area	Estimation of density by Kernel Function method	Search Radius or Band Width for 500 meters (indicating high-density residential areas seeks to maximize access to mass transit)	Residential Area Map in 1:4000 scale by the Department of Public Works and Town and Country Planning (2005)
4.2) Density of Employment's Sources such as education and commercial, etc.	Estimation of density by Kernel Function method	Search Radius or Band Width for 500 meters (indicating high-density employment areas seeks to maximize access to mass transit)	Map located employment source (i.e. industry, education, government, and commercial) in 1:4000 scale by the Department of Public Works and Town and Country Planning (2005)

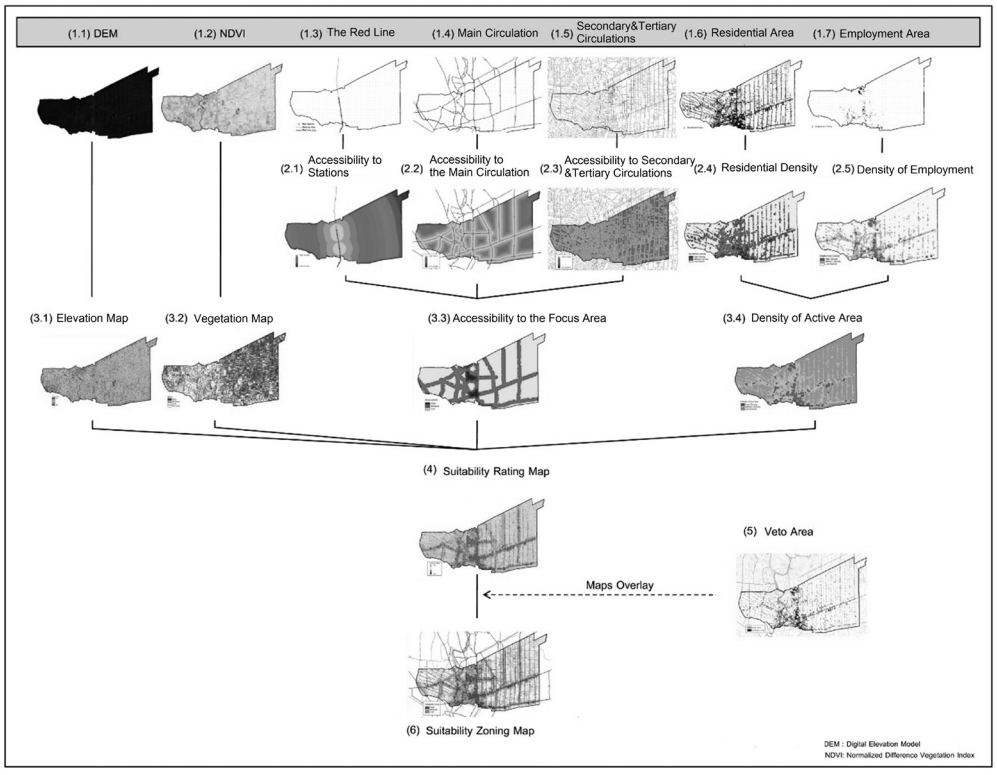


Figure 3. Cartographic information and identification of factors and restrictions. (Source: Author).

5.3 Criterion weighting

After ranking the factors, the next step is to decide which criteria should be considered and weighted in the land suitability's analysis process. This weighting of factors represents relationship between the study's objectives and decision alternatives. Factors, which are more value to the land suitability and the study's objectives, have more weights and are ranked in high numbers. On the other hand, factors with less important to the land suitability and the study's objectives, have less weights and are rated in low numbers. Ranking method could also be helpful in estimation of weighting factors. Subsequently, the assessment of the weighting factors is operated by using of the SMCDA, which is based on specialists from 4 different areas comprising of 1) land use and planning specialists; 2) transportation specialists; 3) environmental specialists; and 4) urban designers. Examples of weighting land suitability's factors are as shown in Table 3.

Table 3. Examples of weight of land suitability's factors and normalization.

Criterion	Straight Rank	Weight	Normalized Weight
1. Geography	6	2	0.07
2. Vegetation	7	1	0.04
3. Accessibility to the main road	1	7	0.025
4. Accessibility to the secondary road	4	4	0.14
5. Accessibility to the stations	5	3	0.11
6. Density of residential areas	2	6	0.21
7. Density of employment areas	3	5	0.18
Total		**28**	**1.00**

5.4 Land suitability analysis

After finishing the weighting factors process, the land suitability analysis can be utilized. All weighting factors are applied using the following the land suitability analysis formula (see Eq.2);

$$S=W_1 X_1+W_2 X_2+W_3 X_3+...+W_n X_n \quad \text{(Eq.2)}$$

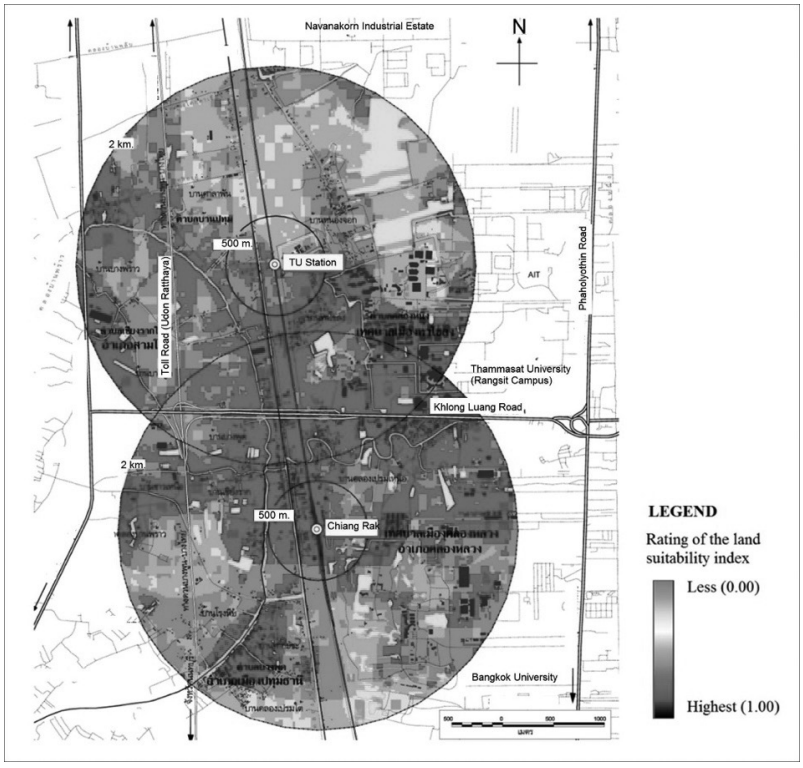


Figure 4. Rating of the land suitability index map in the study area. (Source: Author)

Figure 5. Zoning map demonstrating physical potential of the study area. (Source: Author)

Where:

S = Range of score, which demonstrate potential of the site

W_n = Total score, which present importance of the n Factor (Weight)

X_n = The appropriate score of the factor n (Criteria Score)

In order to analyze land suitability and potential of the site, the Grid-based Overlay Analysis is applied using adaptation of the ArcView Model Builder program, which is a high efficient and accurate program in overlaying data analysis. After applying the Grid-based Overlay Analysis, the areas with high potential and suitable for development according to the study's objectives are identified.

5.5 Output displays

The next phase is to display the outputs into the land suitability analysis map. Based on the outputs, the land suitability of the site can be categorized into three areas comprising of 1) Most Suitable; 2) Moderate Suitable; and 3) Least Suitable.

6. Land suitability's synthesis

According to the land suitability's analysis, high potential areas for the TOD of the campus station of Thammasat University and surrounding communities cover 7.33 percent of the study area or 100.78 square kilometers. These high potential areas are located on the both sides of the Phahonyothin road, which have high density of residential and commercial areas, high employment demands, and good public transportation. These high potential areas are such as surrounding areas of Rangsit municipality, Thammasat University Rangsit Campus, etc.

Meanwhile, 3.28 percent of the study area or 0.73 square kilometer (as illustrated in Figure 6) are low potential areas, which typically are located on the northern part of the Thammasat University station and southern portion of the Chiang Rak station.

Municipality	Level of Potential					
	Low		Moderate		High	
	square km.	percentage	square km.	percentage	square km.	percentage
Klong Luang	222.61	34.26	114.07	18.3	4.13	4.09
Sam Khok	110.56	17.02	169.43	27.17	28.27	28.05
Lad Lum Kaew	41.4	6.37	65.4	10.49	12.25	12.15
Thanya Buri	107.34	16.52	78.06	12.52	4.38	4.35
Lum Looka	15.81	2.43	68.64	11.01	27.49	27.28
Pathumthani	152.02	23.4	127.91	20.51	24.26	24.07
Total	649.71	100	623.51	100	100.78	100

Table 4. Summarization of Physical Potentials for the TOD of the Thammasat University station and surrounding communities.

These low potential areas, which have limitations in terms of transportation and accessibility. They mostly are functioned as agricultural or waste land, which are generally located in low land and have deep of soil layers causing of low permeability, drainage problems and stability of building foundation. While, Figures 4 and Figures 5 demonstrate rating of the land suitability index map and zoning map illustrating physical potential of the study area, Figure 6 summarizes overall rating of the physical potentials for the TOD of Thammasat University station. Table 4 represents physical potentials for the TOD of Thammasat University station and surrounding areas.

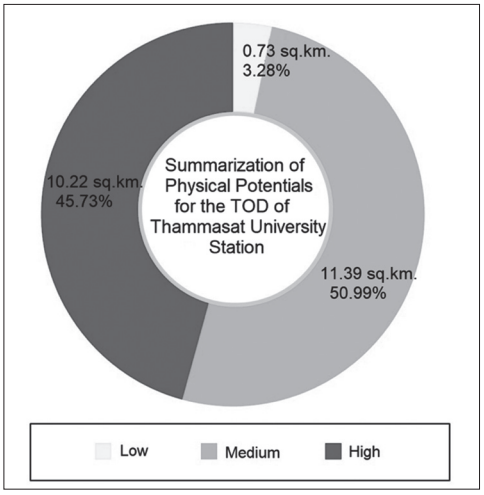


Figure 6. Summarization of physical potentials for the TOD of the Thammasat University station.

Besides the above physical analysis, "A Study of Connectivity between the Sub-Urban Railway Stations and Surrounding Communities around Thammasat University (TU)" also cover all other criteria in land suitability's analysis for the TOD including aesthetic and cultural aspects of the site, governmental policy, urban management, urban growth trends, and facility engineering system such as flooding drainage, water supply, etc.

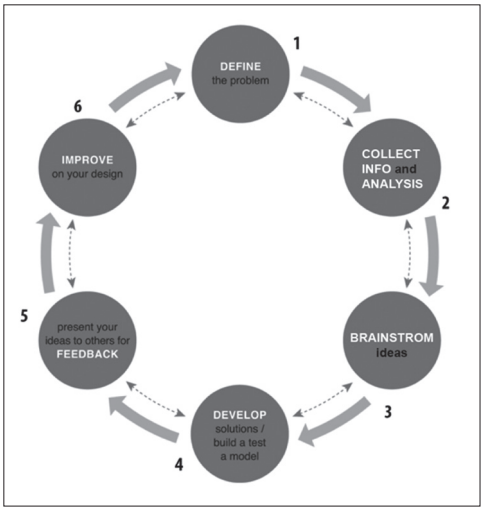


Figure 7. Process of making a master plan. (Source: Author)

7. Guidelines and a master plan for the Transit-Oriented Development (TOD) of the campus station of Thammasat University and its surrounding communities

To be able to draw guidelines for TOD of the Thammasat University station and make a master plan, there are several processes including brain storming ideas, developing solutions, etc. as shown in Figure 7. The results of the land suitability's analysis processes were demonstrated to all specialists of the project, "A Study of Connectivity between the Sub-Urban Railway Stations and Surrounding Communities around Thammasat University (TU)". The ideas for making guidelines and a master plan were gathered from many groups representing the diverse internal and external constituencies of the university and surrounding communities, who directly and indirectly affected by the TOD of the Thammasat University station such as Klong Luang Municipality, communities on the east and west sides of the station . The Campus Planning Committee of Case's Board of Trustees along with the project's specialists. Using the gathering ideas and guidelines, the alternations of master plan are developed, each of which are debated on its pros and cons by the Campus Planning Committee and the representing groups. Subsequently, the master plan for the TOD are finalized.

7.1 Overall concepts and guidelines

Overall concept of the development and the master plan for the TOD of the Thammasat University campus station and surrounding communities can be concluded in two aspects as follows.

1) The existing development needs efficiently supports so that the new development can make it full effect. Later on, the existing and new development should be balance to make the whole study area vibrant.

2) All developments of the study area should be centralized, in which its center is the Thammasat University campus stations. High development areas should be located on the center; whilst the low development should be placed at the further distance of the station. The center of the development should be linked to Bangkok CBD (Central Business District), other centers of Bangkok's sub-urbans, and other communities' centers.The linkage should be fast and convenient public transports but friendly energy uses to support all new developments.

3) It is recommended that physical development such as residential and commercial areas should appear around the Thammasat University campus station. Building characters should reflect local distinctiveness in order to create unite image and sense of belonging, which should help prompting local people to enthusiast all participated community activities and keep the community sustain. In overall, the guidelines should eventually help increasing the red line performance system in three aspects as follows:

- reduce traffic congestion;
- increase passenger and profit; and
- increase land value and support investment around the station areas.

7.2 Guidelines for the master plan of the Thammasat University campus station

(a) The study area, which is within 500 meters from the Thammasat University campus station, is approximately 10-minute walkable distance.

(b) Potential areas around the Thammasat University campus station have distinctive characters as follows:

- The station is close proximity with two universities, which are 1) Thammasat University (Rangsit Campus), and 2) Asian Institute of Technology (AIT). The area is highly populated with a number of students, instructors, and staffs from the two universities. These populations tend to grow in the future.
- The station has adjacent area with the Thailand Science Park, which is the leading research institute of the country and tends to grow much more in the future.
- The station is also close to the Navanakorn Industrial Estate and the Thailand Science Park, which are identified by the Bangkok Principle City Plan as expanded future career supporting area.
- The station will perform as a support for the Northern Red Line system, which will happen in the future.

(c) Land Uses

- TOD boundary: Center of the TOD covers area within 250 meters from the station and east side of the avenue starting from the two universities and the Thailand Science Park. This area should be the most density and main distribution of the commercial and restaurant areas, which create travelers' activities the most. Ground level should be retails and services, whose façades should face the public pedestrian especially ones that along the station and main street. Many stories buildings, apartment, condominium, dormitory, and office building should be permitted in this area.
- Main Outer Areas: This area should have less or equal density with the TOD area. However, number

of ground level retails and service should be less. Most building should be one single use, which is resident, office, or accommodation. Retails should be located at the corner of the street only. This area should permit development of office building, hotel and residential area in form of apartment, town house, twin house, or single house.

- Areas Close Proximity of the TOD: This outer ring area of the station should be the least density and mix-used land areas. This area should mostly comprise of mix of residential types including various scale of single house, twin house, four-unit house, and town house. Due to development of the Thailand Science Park, it is possible that there should be investment in terms of small office building in the area. Regulations to build small office building and research-unit building in this area should be permitted.
- Areas adjacent to the railway: Half of the railroad right of way areas might be locations of retail service development, light production industry, product distribution, warehouse. Figures 8 and Figures 9 illustrate proposed master plan for the TOD around the campus station of Thammasat University and surrounding communities.

(d) Vision for the future TOD around the Campus Station of Thammasat University and its surrounding communities.

Overall vision of the TOD around the campus station of Thammasat University and its surrounding communities will include master plan and guidelines for future development such as land uses, principles of transit-oriented development, which reflect physical characters of the context, investment demand, and land ownership.

Both sides of the campus station are developed. Development on each side is centered around the campus station. The development on the side, in which the Thammasat University is located on, should

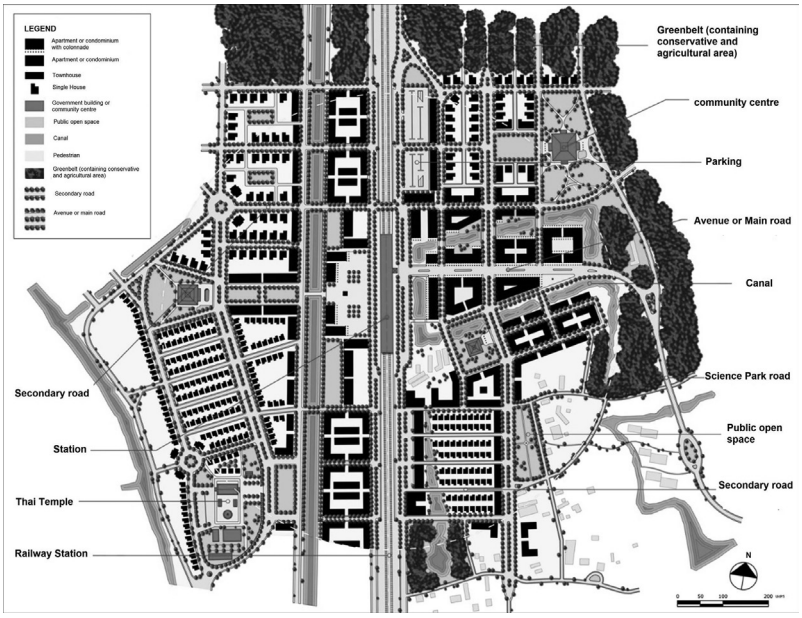


Figure 8. The TOD proposed master plan. (Source: Office of Transport and Traffic Policy Planning, 2009)

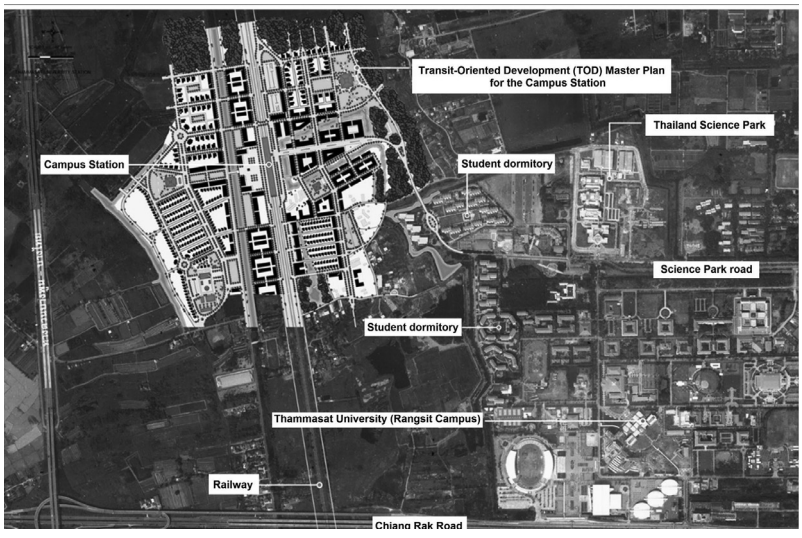


Figure 9. The proposed master plan with surrounding areas. (Source: Office of Transport and Traffic Policy Planning, 2009)

receive more focus and contains main commercial road. Main pedestrian close to the campus station should be covered with roof designed in Thai contemporary style to protect the station's users from the sun and rain. The center of the development on the Thammasat University side, which is close proximity to the canal, should contain functions such as public areas, apartment, office building, and townhouse. These functions should face the canal. The west side of the development should have public plaza, which is connected with an avenue surrounded with commercial areas.

Center areas on both sides are surrounded with four communities. The north east community is comprised of office building, research building, business area, all of which are located near the Thailand Science Park. There should be a meeting hall located at the center of the community dividing areas between the campus and new employment zone. The remaining three communities should mainly contain residential blocks. The centers of the communities should be green public spaces, which should be within 2-3 minutes walking distance. Center of the communities are linked to both sides of the station by avenues. Density and height of the buildings and mixed-use buildings can be increased when getting close to the campus station. On the contrary, when getting further from the campus station, the buildings' density and height and mixed-use buildings can be decreased. Green buffer areas should be located in the northern boundary zone to shield industrial zone from the north side. The new construction of the campus station creates a new form of service, facility and utility for the people around the new station area. Understanding of the new form of convenience should attract new investors, which should bring a new interesting form of development around the campus station.

8. Summary

This study developed and applied GIS with four MCDM methods to assess the suitability of TOD in the campus community of Thammasat University. The study contributes with new added credibility of the use of expert validation the existing literature about GIS-based land suitability analysis to support transit-oriented development studies. To conclude, this study demonstrates that the use of the SMCDA tools facilitate the selection of the most feasible location in the urban transportation planning. These techniques will help researchers in the future to find locations from an urban development perspective.

Acknowledgement

The study is a part of the research project, "A Study of Connectivity Between the Sub-Urban Railway Stations and Surrounding Communities around Thammasat University (TU)" which is funded by the Office of Transportation and Traffic Policy and Planning (OTP), Ministry of Transport. The project is directed by Associate Professor Dr. Pawinee Iamtrakul.

Notes

[1] In land suitability's analysis agenda, it is common that the analysis area is further beyond the designated area for master plan development.
[2] Shuttle Radar Topography Mission (SRTM) satellite is the digital topographic database that obtained digital elevation models (DEMs) on earth surface.
[3] Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator that can be used to analyze remote sensing measurements, and assess whether the target being observed contains live green vegetation or not.
[4] LANDSAT-7 is the seventh satellite of the Landsat program (Launched on April 15, 1999), carries the Enhanced Thematic Mapper Plus (ETM+) sensor.
[5] ETM+ System is the Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat-7 satellite.
[6] Kernel density is the geoprocessing tool that calculates the density of point features in a neighborhood around those point features.
[7] Latitude position is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles of earth.
[8] Spatial resolution is a measure of the accuracy or detail of a graphic display.
[9] The east side communities include Ban Sala Pan and Ban Pang Pood; whilst the west side communities cover Ta-Klong and Klong Ma Dun communities.

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