GIS-MCDM TECHNIQUE IN DETERMINING TYPOLOGY OF TRANSIT-ORIENTED DEVELOPMENT (TOD)

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KEY WORDS: Land-use, Transit-Oriented Development (TOD), Geographic Information Systems (GIS), Multi-Criteria Decision Making (MCDM).

ABSTRACT: This article presents a study of land-use analysis in determining transit-oriented development (TOD) typology planning by using Geographic Information Systems (GIS) on multi-criteria decision making (MCDM) in Shah Alam, Malaysia. The analysis of research was conducted through land-use evaluation criteria that have been selected, which are coverage area, land availability, gentrification potential, density and diversity. The collective data was analyzed by using the Analytic Hierarchy Process (AHP) technique in QGIS application with further integrate it into the matrix comparison technique. The multi-criteria decision making (MCDM) was applied to establish criteria weights and ranked them in order to analyze the suitable typology of the transit-oriented development (TOD) stations. The finding shows that stations in Shah Alam are only involved in three TOD typologies which are 'second-highest TOD intensity', 'third-highest TOD intensity' and 'specialized TOD'. Finally, this study will contribute to sustainable transportation development in the future.

1. INTRODUCTION

The concept of Transit-oriented development (TOD) has become popular in the United States, the most car-dependent country in the world since 1990s (Cervero, 2013). Malaysia was also no exception to seize the opportunity to introduce TOD, which was proven successful in other countries. TOD is often seen as a remedy to the car-dependent community. It is because, by attracting a mix of residences, commerce, works, and public activities within walking distance from the railway station, this approach can attract people to use transit and thus can reduce traffic congestion, enhance air quality and contribute to climate stability. According to Cervero (2006), planning of land use for stations should be integrated as early as possible. In such a rational manner, transport and land use are connected (Waddell, 2011). One aspect will influence the other. Land use also affects travel behaviors (Sarkar and Mallikarjuna, 2013), while Ratner and Goetz (2013) claim that TOD also affects land use and urban structure.

In addition, TOD typology was established to distinguish the characteristics of the different TOD network nodes (Huang et al., 2018). Based on the typology established, the effects of complementarity between TOD nodes were analyzed to understand how their effects contribute to the TOD network on a large scale (Huang et al, 2018). According to Kamruzzaman et al. (2014), the benefit of establishing the TOD typology as efficient for urban planning and design processes and operations since a similar range of approaches can be integrated within the same TOD typology nodes and also the recognition of general development potential. Besides, GIS and MCDM have been widely used in the last two decades to address site selection problems. When GIS was joined to MCDM methods, it provides a useful tool for selecting the ideal location for urban transport planning. Based on these conditions, the MCDM methods offer various techniques

and procedures for formulating the advantages, disadvantages and risks associated with the issue of decision-making, assessing the alternatives under specific requirements (Malczewski, 1999).

Therefore, this study aims to identify the typology of TOD based on five land-use dimension analysis using MCDM technique at the selected transit stations in Shah Alam, Malaysia. The existing land use around the transit stations is essential to be studied in order to determine its potential and also can be synchronized with its typology.

2. THEORETICAL ON TOD AND MCDM

One of the most popular definitions of TOD comes from Peter Calthorpe, 1993. He defined TOD as a land-use approach that focuses on improving accessibility by encouraging the creation of compact, high density and mixed uses within walking distance of the transit station. A typical TOD neighborhood has a walking distance of 2000 feet which is equivalent to 10 minutes walk. More specifics were added to the definition such as the design, configuration and mix of uses, emphasize a pedestrian-oriented environment and strengthen the use of public transport. Since the early development of TOD, the terminology of TOD typologies has been applied. Calthorpe (1993) made a distinction between TOD housing and work-generating. These normative typologies are applied by Dittmar and Potich (2004) with a delineation between cities and suburbs. The main benefit of providing TOD typology is that it can reduce complexity in the management and planning of this development and enable the good action plan in identified areas by considering the advantages and disadvantages (Zemp et al., 2011). The technology used in transit is an important aspect that distinguishes a type of TOD.

Moreover, transportation and land-use integration are amongst the most promising ways to reverse the trend of car-reliant sprawl and to place cities in developing countries in a sustainable way (Suzuki et al., 2013). For instance, all worldwide of transit and land-use integration had a clear picture of land use that shaped investments in regional transit more than vice versa. It is important to plan transit and land-use integration visions, but adequate resources are needed for successful implementation. Transportation and mix land use can help to mobilize the people. The integration of transport and land-use planning needs to be enhanced in developing cities before it is too late (Cervero, 2013). Land use perspectives in transit station areas are described by a wide range of different aspects, including area, type, density, urban design, the presence of public facilities, etc. All these elements commonly were classified into the five "Ds": density, diversity, design, destination accessibility and distance to transit (Cervero et al., 2009). Even though other Ds have been introduced over the period to discover additional TOD parameters, density, diversity and design remain the key elements of TOD (Singh et al. 2014). Furthermore, Translink (2012) and Ogra & Ndbele (2014) added more Ds to the assessment and planning of TOD, consists of density, diversity, distance to transit, design, destination and demand management. These variables are considered essential in achieving TOD goals.

Furthermore, GIS and technical decision support are a good combination of perfectly complementary methods (Sanchez-Lozano, et al., 2013). GIS offers the possibility of analyzing, managing, storing and visualizing all geospatial information to decision-makers. Based on these functions, the MCDM offers a range of techniques and procedures that allow decision problems to be organized and alternatives to be evaluated (Malczewski J., 1999). Since they were released, the GIS–MCDM has been used in numerous studies of territorial planning such as urban planning and urban infrastructure (Sanchez-Lozano, et al., 2013). It is past efforts to combine the capabilities of GIS and MCDM to provide decision support in choosing alternatives for transport (Malczewski, 1999). GIS-MCDM was not a new approach in urban planning especially in the transportation sector. GIS and MCDM can assist policymakers and planning authorities in getting a better overview of the tools they had to bring forward with less harm to the environment.

3. STUDY AREA

The study area is located in Shah Alam City Council. Shah Alam is the state capital of Selangor. It is situated within the Petaling District and a small portion of the neighboring Klang district. At the moment, the transit transport is one of the modes that is beginning to gain popularity in Shah Alam. The rail transit service in Shah Alam was initially just a commuter service involving the station and now, the LRT and MRT services are rapidly expanding in the Shah Alam area. Three modes of 17 stations in Shah Alam City Council consist of Keretapi Tanah Melayu (KTM) that served line from Port Klang to Tanjung Malim. Light Rapid Transit (LRT) Gombak – Petaling Jaya; LRT3 Bandar Utama – Klang and Mass Rapid Transit (MRT) from Sungai Buloh – Kajang have been selected; four stations function as a hub which integrates two types of rail service and also as interchange or connecting stations. The area of analysis will be in a 400-meter radius from the stations as shown in Figure 1.

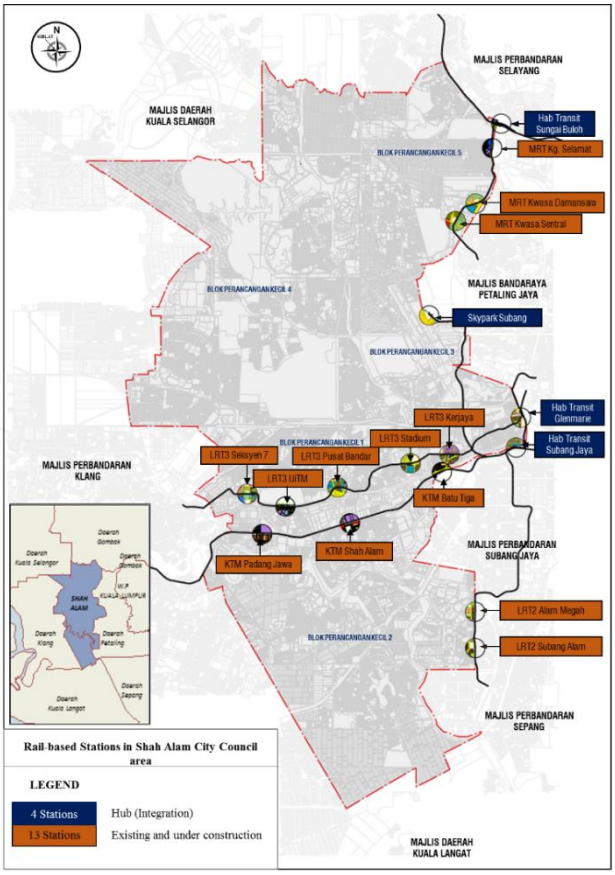

Figure 1: The study area of Rail-based Stations in Shah Alam City Council area

4. METHODOLOGY

This study requires both primary and secondary data. The primary data are derived from site survey and fieldwork which involved observation, counting method and site inventory. The data collected will be analysed and become an evaluation criterion for TOD potential analysis. While, the secondary data involved are GIS databases obtained from the Shah Alam City Council department. Before continuing with the MCDM on TOD evaluation, the data need to update and key-in into the GIS database. All the information about the stations was profiled and tabulated into database accordingly. Some of the attributes were calculated using GIS features and tools.

The potential of the stations will be analysed based on its existing land-use within a 400-meter radius from the stations. The process for TOD potential evaluation analysis comprises of five-step (Figure 2). The first step is involved in the land-use dimension criteria setting. The criteria will be determined through an extensive review of TOD literature. For this study, there will be five criteria involve in analysing TOD potential which are area coverage, land availability, gentrification potential, density and diversity.

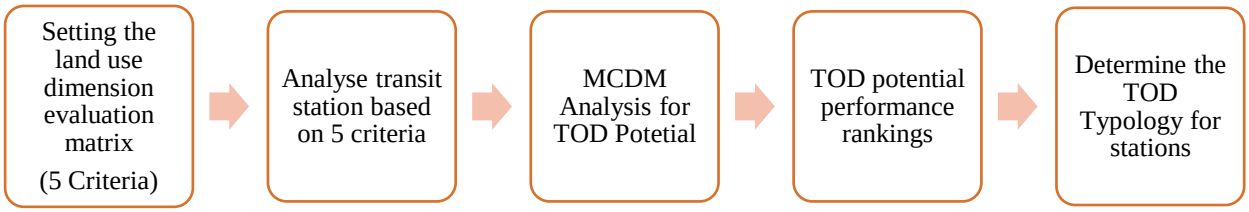

Figure 2: TOD Potential Evaluation Process

In the next step, the stations will be analyzed based on the criteria respectively. All 17 stations will be deeply evaluated to attain the existing situation of the stations' area. Furthermore, the most crucial step is the MCDM analysis. The analysis has been conducted in order to rank the potential of rail-based stations as TOD through the MCDM technique in GIS. The weightage for each criterion has been determined through extensive review on previous studies towards the importance of each criteria. Based on that weightage, the analysis was further evaluated using Analytic Hierarchy Process (AHP) technique in QGIS application by using formula as follow:

$$A = \begin{bmatrix} a^{11}a^{12} & \dots & a^{1n} \\ a^{21}a^{22} & \dots & a^{2n} \\ \dots & \dots & \dots \\ \dots & \dots & \dots \\ a^{n1}a^{n2} & \dots & a^{nn} \end{bmatrix} \quad \begin{aligned} &[Aij], \text{where}, i, j = 1, 2, \dots., n, \\ &Aij = 1 \text{ for } i = j, \\ &Aij = \frac{1}{Aji} \text{ for } i \neq j \end{aligned}$$

The above formula deals with the matrix of dimension (n x n), where n = comparison number of factors. The elements value that are related to the diagonal of the matrix is equal to 1 such as Aij = 1. There are five criteria and 17 alternatives for this study. The MCDM analysis of this study has been translated using 'vectorMCDA' tools in order to achieve TOD potential performance ranking. All 17 stations will be rank from high potential of TOD to least potential. The last stage for this study is determining the TOD typology for each station. Based on the ranking result of the TOD potential analysis, the stations will be specified its typology referred to *Garis Panduan Pelaksanaan Transit-Oriented Development* prepared by PLAN Malaysia. The technique used in this stage is by matrix comparison between the station findings with the element of TOD typology description prepared by PLAN Malaysia.

5. RESULTS AND DISCUSSION

5.1 Summary of Land use Dimension Findings for 17 Stations

From 17 stations that have been analysed, eight stations form 100% of 400-meter radius coverage which included all five under construction LRT3 stations while four stations covered 50% to 100%, and the remaining five stations covered below 50% of the area. For land availability, only three stations have more than 10 hectares of vacant land and agricultural land which are KTM Padang Jawa station, MRT Kwasa Sentral Station and MRT Kwasa Damansara with 14.65 ha, 32.87 ha, and 12.17 ha. respectively. For gentrification potential, eight stations have high potential to improve or redevelop to meet the TOD principles requirement. Whereas two stations which are Subang Jaya Integrated Station and LRT3 UITM Station have low a potential for gentrification. While, for density analysis, only three stations (KTM Shah Alam, MRT Kg. Selamat, and LRT2 Alam Megah) comprise population density in the range between 100 to 200 people per hectare. However, nine of the stations have a low population density. While for MRT Kwasa Sentral, MRT Kwasa Damansara, Skypark Link Subang Airport, LRT3 Kerjaya, and LRT3 Pusat Bandar Shah Alam currently there is no population. Lastly, for diversity, only KTM Shah Alam and LRT 3 UiTM have five types of land uses in their 400-meter radius area. While, Sg. Buloh Transit Hub, MRT Kg. Selamat and MRT Kwasa Damansara consist of two types of land uses. Table 1 shows the summary of land use dimension finding for 17 stations.

Table 1: Finding of five land-use dimension for 17 stations

	Sg. Buloh Transit Hub	Glenmarie Integrated Station	Subang Jaya	Skypark Link	KTM Batu Tiga	KTM Shah Alam	KTM Padang	MRT Kg Selamat	MRT Kwasa	MRT Kwasa	LRT 2 Subang	LRT 2 Alam Megah	LRT 3 Kerjaya	LRT 3 Stadium	LRT 3 Pusat	LRT 3 UITM	LRT 3 Seksyen 7
Area coverage	66 %	64 %	40 %	64 %	52 %	10 0%	10 0%	48 %	10 0%	86 %	48 %	48 %	10 0%	10 0%	10 0%	10 0%	10 0%
Land availability (hectare)	1.33	7.52	1.41	0	8.64	0.6	14.65	2.39	32.87	12.17	0.56	0	3.84	4.72	8.74	0	0.28
Gentrification potential	Moderate	Moderate	Low	High	High	High	High	High	High	High	Moderate	Moderate	Moderate	Moderate	High	Low	Moderate
Density (person/ hectare)	3.091	4.5	27.45	0	25.54	186.22	43.7	273.33	0	0	92.25	182.792	0	11.48	0	4.92	89.06
Diversity	2	3	3	0	4	5	3	2	0	2	3	4	4	3	3	5	4

5.2 Findings on MCDM Analysis

Based on the five evaluation criteria analysis, the findings have been used to evaluate TOD potential through the MCDM technique. The weightage for criteria has been determined as tabulated in Table 2.

Table 2: Weightage for MCDM analysis

	Area Coverage	Land Availability	Gentrification	Density	Diversity
Area Coverage	1	5	3	4	2
Land Availability	0.2	1	2	4	3
Gentrification	0.33	0.5	1	5	3
Density	0.25	0.25	0.2	1	0.5
Diversity	0.5	0.33	0.33	2	1

Based on the MCDM analysis, the ranking of the TOD potential of 17 stations has been created. Figure 3 shows the MCDM result and ranking of the stations. The stations have been grouped into three categories which are low, moderate and high potential as TOD. Overall, there are four stations that are marked as high potential as TOD. KTM Shah Alam marked at the top position. For second place, it is KTM Padang Jawa. Next, for third place, it was MRT Kwasa Sentral. While for fourth place, LRT3 Pusat Bandar. Eight stations were indicate as moderate potential as TOD. However, five stations have low potential to develop as TOD. Subang Jaya Integrated Station was the least potential to develop as TOD.

5.3 Classification of TOD Typology

For the last stage of analysis, it is to determine the suitable typology for each of the stations in Shah Alam. Based on tpotential analysis above, the stations was specified its typology. From the rank analysis result, KTM Padang Jawa station was the highest potential to develop TOD as in top position. KTM Padang Jawa station has been used as benchmark for the highest typology for the highest typology Shah Alam City Council. The group of typology determined based on TOD

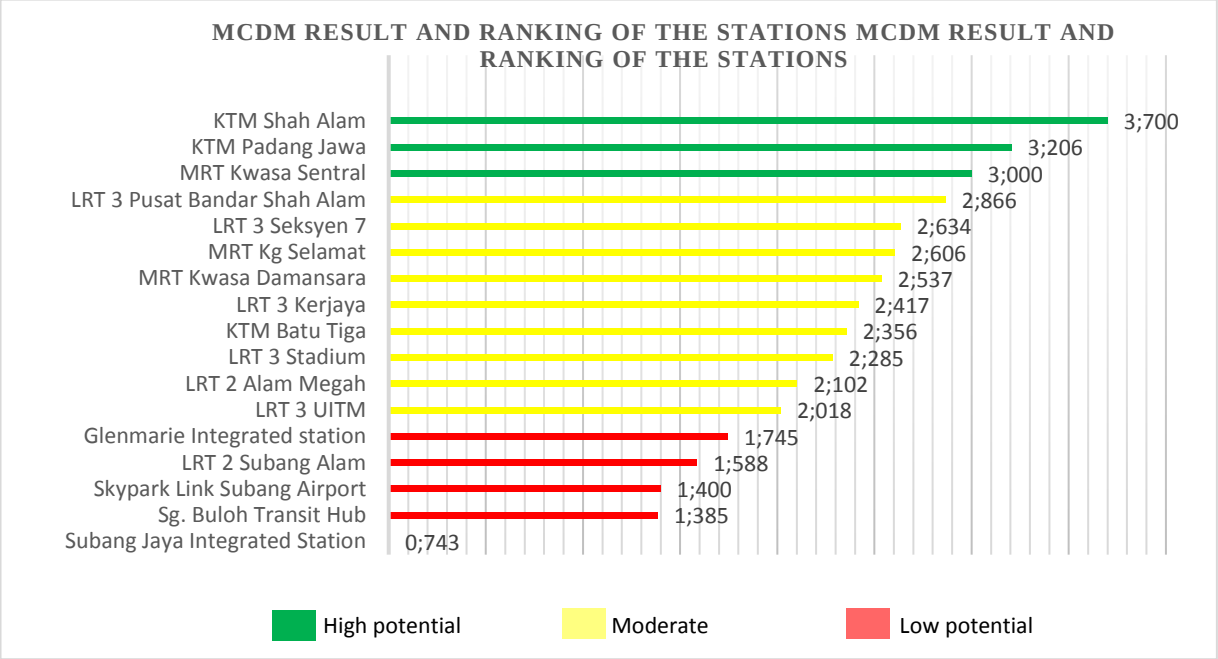

Figure 3: MCDM result and ranking of the stations

Guidelines from PLAN Malaysia. The guideline proposed four types of TOD that are compatible in Malaysia. KTM Padang Jawa station as the benchmark was classified under T2-TOD typology. Another three stations also were included in this T2-TOD as total of four stations. Moreover, only LRT 3 UITM Station was classified for T4-TOD which specialized TOD station as the station was purposely for the university population catchment. The remaining 13 stations were classified as T3-TOD. TOD stations in Shah Alam City Council area only involved three typologies which are 'second-highest TOD intensity', 'third-highest TOD intensity' and 'specialized TOD'. The result as shown in Figure 4.

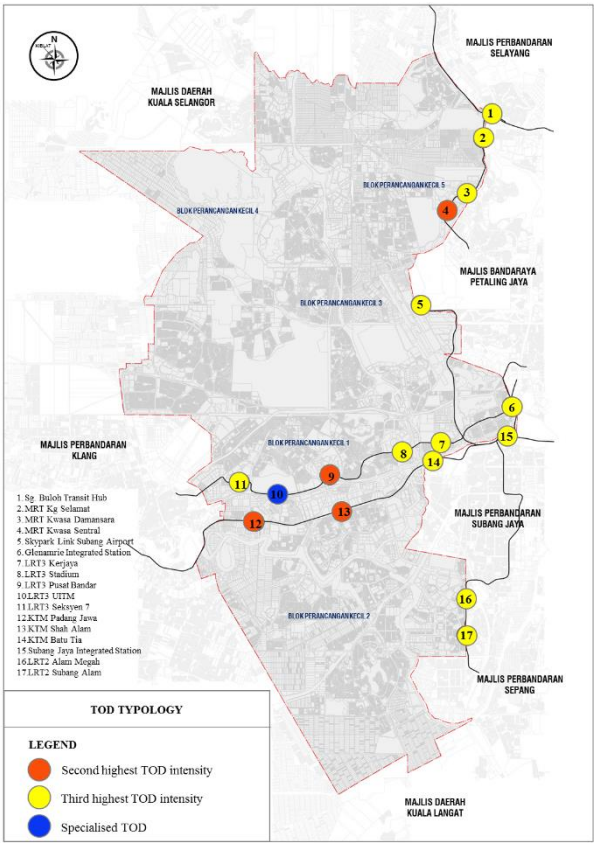

Figure 4: TOD Typology of the Stations

5.4 Discussion

Based on the analysis, the land-use dimension selected as the analysis criteria was very important. For area coverage, there will be conflict in terms of the TOD development plan for the stations that covered less than 50% in the Shah Alam City Council area. It needs collaboration between two local authorities that share the station's benefit in order to make TOD successful. For land availability, KTM Padang Jawa, MRT Kwasa Sentral and MRT Kwasa Damansara, have the highest opportunity to infill the respective development in order to achieve TOD principles within the station area. While, for gentrification potential had a look at the opportunities of the stations to impose redevelopment or improvement in the area. For eight

stations that have a high potential for gentrification to take place, it also will face the challenges of the land acquisition process that involves cooperation among the residences. Furthermore, for density, all stations need to increase the total population number. Shah Alam City Council needs to plan for the increasing population within the 400-meter radius of the station. For diversity, two stations are not diverse at all for an existing condition which is Skypark Link Subang Airport and MRT Kwasa Damansara station. Most of the stations comprise of three or two number of land-use types.

Next, the result of TOD potential evaluation analysis shows that KTM Padang Jawa station has high potential as TOD with the highest total score of 3.7. But this station needs to improve on increasing the population and also more diversify the land use type in order to achieve successful TOD. Five stations; Subang Jaya Integrated Station, Sg. Buloh Transit Hub, Skypark Link Subang Airport, LRT 2 Subang Alam and Glenmarie Integrated station has resulted as a low potential to implement TOD. These stations need a very comprehensive plan and strategies to develop as TOD. Furthermore, for typology, stations in Shah Alam City Council area only involved three TOD typology which are 'second-highest TOD intensity', 'third-highest TOD intensity' and 'specialised TOD'.

6. CONCLUSION

Upon completing of the study, it is discovered that there is still much room for improvement of TOD implementation in Shah Alam especially on integration with geospatial technology. The different potential levels of TOD in each station are based on the nature of the stations, areas, and challenges that need to be met in the implementation. Almost all stations are constructed on the existing built-up area. The rejuvenation and infill development will be occurred instead of a new development plan around the stations. Planners need to integrate the existing condition with new development in terms of its connectivity, diversity, density and all TOD principles. Furthermore, a low understanding of TOD among the community itself causes some problems. It will make the TOD concept not being delivered and applied successfully. The community also does not feel the benefit of TOD development. The prospects for TOD development in the Shah Alam area are broad but the authority itself needs to disseminate information about "What is TOD?" to the public in order to spread the benefit of TOD implementation to all layers of society. Furthermore, the compact development around the stations also will be one of the best ways to generate transit service. Dense and high-density development can help Shah Alam stay relevant in the future. The purpose of increasing the density is to provide transit opportunities for people as much as possible. In conclusion, the study for TOD potential by integrated with the GIS approach is significant to promote sustainable development and also leveraging the benefits of technology. Based on the findings, it can be concluded that the stations in Shah Alam have the potential to develop as TOD with particular initiatives and multiple efforts by the government authorities, especially in Klang Valley.

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