The Association of Transportation and Land Use Planning towards Sustainable Urban Energy Planning

バンコクのような大都市では急速な拡大により都市機能が悪化している。土地利用と新しい交通インフラの統合で都市の活性化を目指す。

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Abstract Recently, global warming has affected paradigm design and restoration of the city with urban infrastructure and energy planning and development. It has received attention from government agencies and related organizations to search for methods of problem solving to sustain the situation of climate change effect, especially in metropolises like Bangkok. Due to complicated structure of land use and overpopulation, Bangkok has inefficient infrastructure and development has focused on expanding road infrastructure to cover the transportation demands. This phenomenon inevitably affects the lifestyle of people in the city, thus this study presents as a potential solution an integrated approach to sustaining urban land use and transportation planning in order to reinvigorate the city through the promotion of integrated land use within the district. The analysis shows that the composition of urban form impacts choices of Bangkok residents which has resulted in residential allocation in the suburban areas and longer commutes. Finally, the increase in energy consumption in the transportation sector will remain unless there is an alternative urban planning with renewable energy sources or vehicle technology choices to replace the outdated version.

Keywords Transportation planning; Land-use planning; Sustainable development; Energy planning

1. Introduction

Rapid urbanization has had both negative and positive impacts on urban residents, especially in uncontrolled urban expansion coupled with inefficient transportation. The negative impact of automobiles on the physical environment and quality of life have become concerns due to the current trend of the global environmental problem of climate change. Not only has pollution from vehicle congestion had a significant impact on urban population, the overconsumption of fuel and energy-consuming automobiles for daily commuters in Bangkok has become a problem for experts and concern authorities of energy planning. Hyper-urbanization has occurred when there is a migration of the population and relocation in urban areas. These changes also influence urban density, which is increasing in growth rate in several dimensions (Litman, 2010). Especially, when consideration is given to developing countries, the rapid growth of urban areas involves the use of private automobiles, energy consumption and deterioration of the urban environment. In Thailand, as a rapidly developing country, the transportation sector comprised of motor vehicles plays a significant

role crucial to the economy and urban development. Especially, the growth of the city with the scattering of density and settlement in peripheral zones influences long-distance travel patterns which require more energy consumption (Newman & Kenworthy, 1989). When considering the urban development pattern of the central city of Thailand, Bangkok represented its highest development area during the period from the 1980s to the 2000s as demonstrated in Fig. 1.

It is obvious that Bangkok has become greatly dispersed with the heavy migration, particularly the settlement outside of the urban core, also known as greater Bangkok. This growth of the urban area beyond the boundary of its surrounding has renamed the original Bangkok Metropolitan area to Bangkok Metropolitan Region (BMR) which includes 5 adjacent provinces: Nonthaburi, Samut Prakan, Pathumthani, Samut Sakhon and Nakhon Pathom. With the position of urban core, the present of institutions, employment areas and several activity centers located in this area induced high intensification in these areas with a mix of land uses, including public, commercial, employment and housing activities. However, this intensity demonstrates different degrees of mix in different degree of development in the peripheral or suburban areas.

The wide range of intensity has direct relationship with the density of population and migration which can be noticeably seen in Table 1. The variety rate of population together with the density represent a good indicator to characterize the level of attractiveness for human settlement which would be reflected in the number of households and the immigration and migration numbers. In order to understand this linkage, a basic understanding of transportation infrastructure along with the modal usage is required to encompass the commuting pattern and life style of people in this region. Furthermore, suburbanization allowing the city to spread would also increase the necessity of owning an automobile (Newman, Kenworthy & Vintila, 1995). Based on the World Bank Report (2007), in 2003, Bangkok's in-use national motor vehicle fleet was about 2.9 million. This accounted for about 22% of the nation's registered motor vehicles including 57% of the private car fleet, 12% of national motorcycles and 42% of the combined truck and bus registrations. The majority of commuters were relying on private vehicle rather than transit usage. Considering the transition of urbanization while the congestion spreads outward geographically, BMA, which is the main organization to manage land use and infrastructure development in Bangkok and its vicinities, launched the first transit line. MRT line was completed in 1999 and operated as the Bangkok Transit System (BTS) or

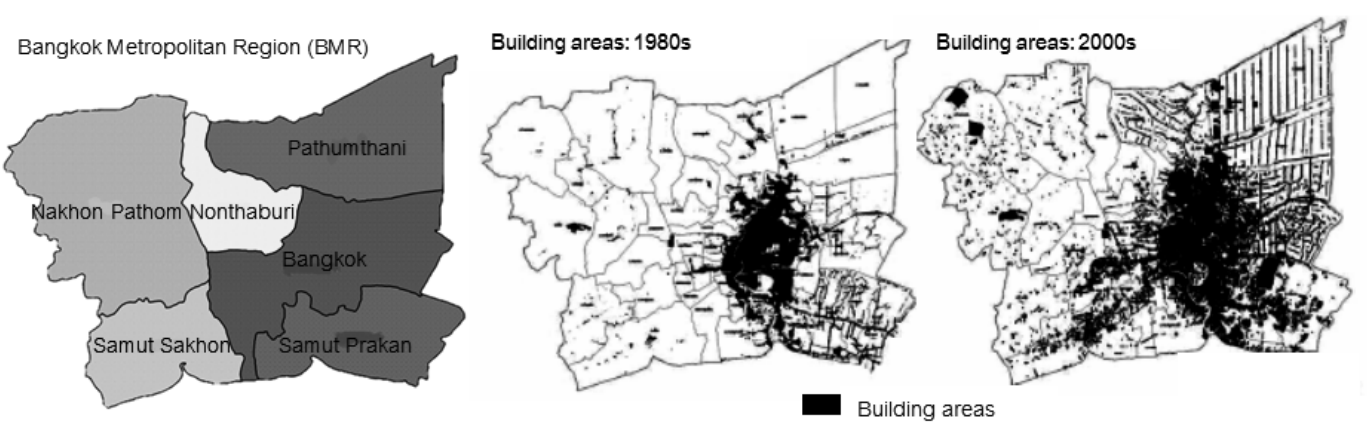

Fig. 1 The growth of built-up areas in Bangkok Metropolitan Region (BMR) Source: Department of City Planning, Bangkok Metropolitan Administration, 2005

Sky Train (Green Line) with a total length of 22.9 km. (IMAC, 2005). However, given the limited service of transit line compared with the road and expressway development, Bangkok and its vicinities have continued to be dominated by roads-oriented development with the unsolved traffic congestion crisis (Rujopaharn, 2003).

However, the other driving force of this pattern may be influenced by not only the transportation infrastructure development but also policy-making for the development plan in this area (Iamtrakul and Hokao, 2011). With the consideration of the development plans at national, regional, sub-regional, provincial and municipality level, Pathumthani was positioned as the prevalent satellite town of educational institutions and industrial area. To accommodate the huge attraction of urbanization in this area including population and commercial development among others, it has been recognized that one of the most effective ways to facilitate urban restructuring is to move towards a polycentric system from the current mono-centric system in Bangkok. Furthermore, this approach can be successfully planned to deliberately utilize the urban rail transit systems. Additionally, to reduce the demands on automobile while most people are now highly dependent on car travel is presented as a new challenge to the planners, the operators, the public, and other stakeholders (Beirão and Cabral, 2007). However, as previously mentioned, the limited mass transit service provided only in the urban core could not accommodate the demand for providing maximum access and connectivity between the central core area and the surrounding areas. It is crystal clear that urban sprawl has become the main influence on settlement along the network expansion. The greater use of private cars raises challenges to sustainable development.

2. Methodology

To investigate urban land development patterns in the study area, the travel behavior approach plays an important role as powerful tool for reflecting the interaction between land use and mobility patterns. This approach has been widely used by several researchers through quantitative and qualitative interviews (Dieleman et al., 2002; Krizek, 2003; Næss, 2006). This study aims to explore the particular dimensions of the built environment in terms of land use and transportation linkage which aim to enhance the attractiveness and accessibility of suburbanized area. The attractiveness could be assessed based on the land-use analysis since most of the development plan induced the new development type to form the new activity center, especially in the outlying area. The form of activity centers should be reviewed from both secondary data and primary analysis of its spatial distribution. The physical characteristics could be geographically analyzed by using the geographic information system (GIS). It was employed to graphically demonstrate the detail of spatial site distinctiveness and allow for more understandable manner about the compatibility of existing land use and living environment.

To assess the spatial configuration of the study area and the employment distribution influence the mobility pattern of the residents in the study area, several studies pointed out that the impact of urban structure may change commuters' choices (Ewing and Cervero, 2001; Meyer and Miller, 2001). The opportunities offer flexibility for certain activities such as shopping, banking and other services and affect destination choices. To graphically differentiate the activities in different sub-centers, this study employed the GIS tool to analyze the site characteristics and to ensure the structures of the site which will be placed in a manner to induce major trips to their locations. To provide a more objective way and to exhibit more about mobility patterns, a questionnaire survey was then conducted to categorize the behavior of people regarding private automobile and public transportation usage. However, integrated analysis of both approaches (physical analysis and behavior analysis) provides interesting results regarding the occurrences of mobility limitations for some parts of the study area.

The sampling method was followed Taro Yamane's population sampling table with ±7% error in order to cover the area sampling. The samples of respondents from this sampling method were a total of 200. Face-to-face interviews were carried out in the survey as well as self-answering by each respondent. Based on this data collection, descriptive statistical analysis and linear discriminant analysis (LDA) was adopted as the methodology to differentiate the travel behavior response to different sub-centers. The findings of this study would be beneficial in terms of incorporating a number of factors other than the land-use environment that can also encompass a profound impact on commuting behavior. Finding the correct combination of land use and non-land use initiatives for achieving various mobility and environmental objectives remains a significant public policy challenge. Moreover, an implication of this study could help as a guideline for an integrating of land use and transportation system development. In particular, it would not only help for promoting ridership of public transport systems in terms of an enhancement of its urban environment while reducing the need for and use of private vehicles, but it would also drive policies for sustainable urban development.

3. Study area: Pathumthani Province

Pathumthani is located in the central region, at approximately 14° North latitude and 100° East longitude approximately 2.30 meters above sea level. The area covers 1,520.856 square kilometers or 950,535 rai, and is situated at the north of Bangkok along the highway No. 1 (Phahon Yothin Road) with a distance of approximately 27.8 kilometers. It has been developed from canal side areas, particularly in Sam Khok District, lateral canal in Klong Luang and Lam Lukka District. It includes a dense residential area along Phaholyothin Road, which is a mixed-use area of residential and commercial buildings. These areas are covered by a dense mix of residential units that are mainly comprised of large commercial buildings and condominium. In addition, the areas also consist of high-density housing in the Navanakorn Industrial Zone where the housing project is certificated by the National Housing Authority to provide for Navanakorn workers for leasing and hire purchase. The project comprises several housing types such as single-detached houses and townhouses. The growth trends are expected in the areas along Chiang Rak–Klong Luang, Phahonyothin–Lumlukka and the lateral canal areas close to other transportation projects. Commercial land is always located along roadsides, particular in easy access areas, turning point areas or dense community such as Rangsit Market Area, Si Mum Muang Market Area and Bangkhan Market Area. Most of such areas were established in the Pahonyothin Road Corridor and were used for commercial purposes including retail stores, sale offices, shopping malls, markets and entertainment areas. Furthermore, due to the increasing price of land, the expansion of industrial sectors is only possible for industrial estate. For warehouses, it also is expected to show growth up because of truck terminal providing in the north of pit stop and transshipment into Bangkok that the growth of warehouse is expected in the areas near Klong Luang Road. In the part, agriculture land plays a key role in this area. But now, agriculture land has decreased because of urban development. Such land is also expected to continually decrease in the future due to the increase of land values. So, land owners will turn to other opportunities that make a higher yield such as selling land to investors for launching land business. Currently, agriculture land remains in some areas including Sam Kok, Klong Luang and Lumlukka District.

4. Land Use Pattern of Pathumthani

4.1 Transition of Land Use

When considering the settlement of housing and transformation of land use in the study area, it was found that there is major change along the highway (Phaholyothin Highway). This is due to the variety of infrastructure services provided to support job

and housing development outside CBD under the geographic constraints of the area. Moreover, due to the expanding population of suburban communities according to the polycentric plan, it is required that the government in the surrounding area of Bangkok use the scarce land resources effectively in support of the economic development and housing of the increasing population. Thus, it was found that the employment areas in term of institutions and industrial sectors are growth increasingly in this area. Furthermore, when considering the commercial center, it becomes more concentrated in this zone as well. Thus, the land-use planning also needs to be effectively linked with the transportation plan which could sustain high population density over the years. However, it was found that most of the settlements occur along the highway in the form of ribbon development, which represent the unique mobility pattern of the study area .

4.2 Land Use Distribution

The continuous expansion of cities and the emergence of new concentration nodes at the urban periphery of Bangkok to Pathumthani province is obvious. Due to the rapid rate of the urbanization of Bangkok, the suburban area of its vicinities, especially Pathumthani province, has naturally become the sub-center. This formulation has also been driven by the regional and sub-regional policy to support the land extensive demand with the lower price of housing and other opportunities for business. It can be seen that the reduction in the agriculture land from 1990–2008 (15.18%) was replaced by the building for several purposes to accommodate the growth of the city. The major transition is in commercial (2.4 times), industrial (1.4 times) and residential areas (12%), respectively.

4.3 Urbanization of Bangkok and its Vicinities

When considering the spatial pattern in the study area, urban structure formulation comes into question. This is due to the fact that the population and employment areas settle away from the sub-center which serves as a node of concentration. The scattering of housing, commercial and residential locations form along the road alignment to facilitate accessibility. This is consistent with the detonation of urban sprawl by Ewing (1997). The phenomenon of sprawl was demonstrated to be scattered development as a strip development along the road network. As previously mentioned about the majority building use, the presence of vast residential land use of 50.8% in the study area is followed by industrial (31.5%) and academic institutions (6.3%). Among the abundant proportion of residential use, most of the housing type in the study area is single housing that is about 96.9%.

4.4 Urban Form and Transportation Network

According to the polycentric plan of the study area, the pattern of several centers could be sorted into three sub-categories (economic, industrial and community centers) . Although, its spatial structure could be seen in multiple urban centers with the high level of economic interaction, there is nothing clear about the linkage among these suburban centers. This is due to the definition of Parr (2004) concerning polycentric urban regions should consist of multiple urban centers separated from each other by tracts of open land, in which the maximum travel time between urban centers is one hour. The mobility pattern of people in this study area plays a key role in confirming the interaction of people to the different attractions of the centers. Different urban centers have their own spatial specialization to shape level of mobility of people which will be useful information to confirm the characteristics of study areas of polycentric urban structure. Furthermore, the finding will be utilized for future plan of transit development in the study area which would diminish the current problem while provide an effective link with existing service of transportation and land utilization promotion.

5. Exploring Land Use and Transportation Interaction of Study Area

A total of 200 effective questionnaires on the basis of face-to-face interviews were applied to investigate the interaction of land use and transport in the study area. This relationship could be determined by assessing the travel behavior of people to reflect their mobility pattern. The major destinations of working areas were selected to include into the interview process that are around residential areas, employment area (commercial and industrial zones) and other zones as depicted in Fig. 2. When considering the physical structure of the study area among these three sub-centers, it can be seen that the development of employment centers are situated along the major highway network (Paholyothin No.1). One is the shopping center which is represented as the regional commercial center in this area.

The other employment center is the industrial park which induces massive public investment for low-income housing to create job-housing balance which also helps to promote the new residential construction and massive high-density apartments of this employment area. To obtain the mobility data, the other zones have to be included as the last group for analysis. Accordingly, the actual mobility of citizens could be explored among all means of transportation system available in the network. This travel behavior data will be used to identify the relationship between land use and the transportation system due to the fact that the destinations of trips represent their attraction to accomplish individual trip purpose and travel from housing location (Van Wee, 2002).

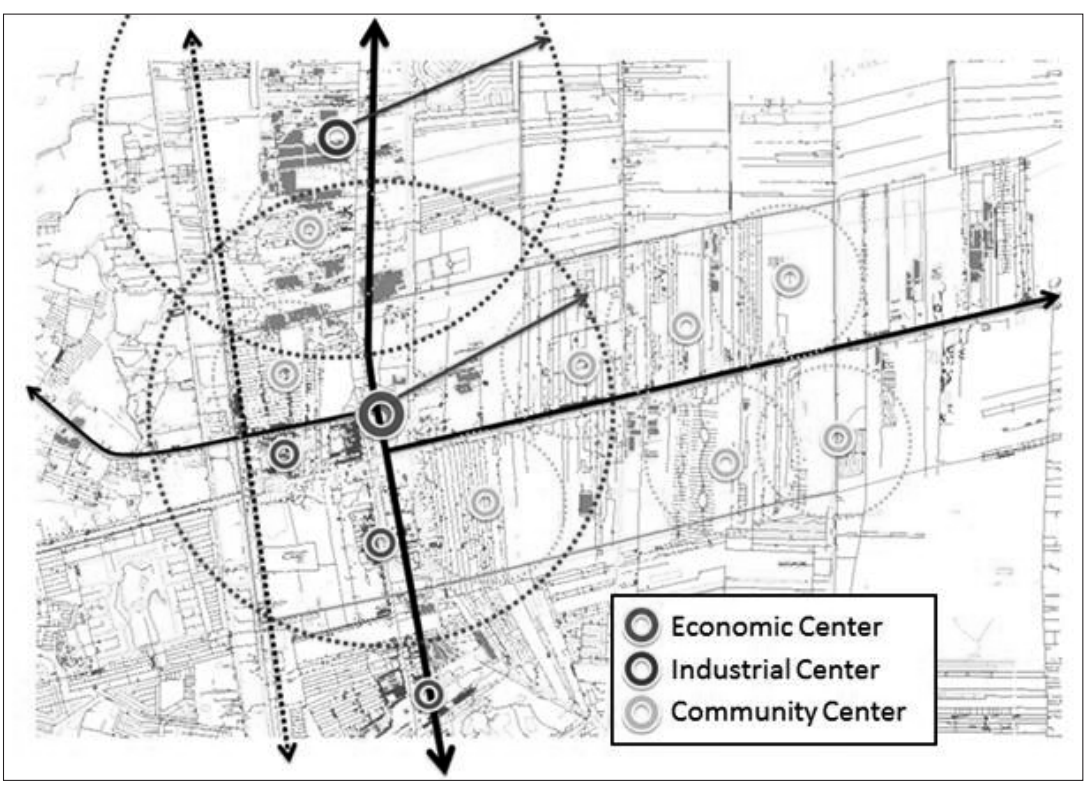

Fig. 2 Pattern of Sub-centers in the Study Area

Table 1 Summarization of Commuters' Mobility Characteristics

Variable		Destination			Total	Percentage	Asymp. Sig. (2 sided)/ Pearson Chi-square
		Residential Area	Employment Area	Outer area			
Mode of Transportation	Private	17	8	34	59	29.50	0.000
	Public	72	29	40	141	70.50	
No. of Connections	0	17	9	34	60	30.00	0.000
	1	10	0	1	11	5.50	
	2	48	21	16	85	42.50	
	3	14	7	23	44	22.00	
Weekday							
Frequency of Trip	1 Roundtrip	84	29	62	175	87.50	0.022
	More than 1	5	8	12	25	12.50	
Distance (kilometers)	6-10	13	1	0	14	7.00	0.000
	11-15	33	12	0	45	22.50	
	16-20	30	21	0	51	25.50	
	21-25	13	3	9	25	12.50	
	26-30	0	0	21	21	10.50	
	>30	0	0	44	44	22.00	
Time (minutes)	16-30	36	11	0	47	23.50	0.000
	31-45	46	23	3	72	36.00	
	45-60	7	3	27	37	18.50	
	>60	0	0	44	44	22.00	
Expenditure (Baht)	30-40	6	3	0	9	4.50	0.000
	40-50	40	18	0	58	29.00	
	50-100	43	16	49	108	54.00	
	100-200	0	0	25	25	12.50	
Weekend							
Activity on Weekend	Shopping	63	19	43	125	62.50	0.004
	Personal Business	6	1	13	20	10.00	
	Social Activity	20	17	16	53	26.50	
	Leisure/Recreation	0	0	2	2	1.00	
Frequency of Trip	1 Roundtrip	71	36	70	177	88.50	0.002
	More than 1	18	1	4	23	11.50	
Distance (kilometers)	6-10	18	5	1	24	12.00	0.000
	11-15	44	14	9	67	33.50	
	16-20	21	7	32	60	30.00	
	21-25	5	11	17	33	16.50	
	26-30	0	0	7	7	3.50	
	>30	1	0	8	9	4.50	
Time (minutes)	<15	6	5	1	12	6.00	0.005
	16-30	28	16	24	68	34.00	
	31-45	46	16	32	94	47.00	
	45-60	8	0	10	18	9.00	
	>60	1	0	7	8	4.00	
Expenditure (Baht)	<20	1	0	0	1	0.50	0.000
	20-30	1	0	0	1	0.50	
	30-40	11	6	0	17	8.50	
	40-50	35	7	26	68	34.00	
	50-100	40	24	32	96	48.00	
	100-200	1	0	14	15	7.50	
	>200	0	0	2	2	1.00	
Total		89	37	74	200	100.00	

5.1 Travel Behavior

Travel behavior between three sub-centers plays an important role in identification of the level of coordination between land use and transport planning, since the location of sub-centers has a significant effect on daily mobility in terms of mode usage and number of connections. Among different modes, commuters travel to their destinations by two major methods, e.g. public transportation (n=141, 70.5%) and private transportation (n=59, 29.50%) as shown in Table 1. The majority of people travel by public transportation (n=141, 70.5%), which also includes paratransit service, e.g. sky train, subway, bus, van, two-row bus, motorcycle taxi. A variety of mode choices enable travelers to work in different areas. One interesting point is most of respondents who are working in the outer area (45.9%) travel without any connection. This means almost half of this group needs to drive to this destination (56.67%). Furthermore, this mode allows flexibility of both space and time to destination.

5.2 Weekday and Weekend Trip Comparison

A comparison of travel behavior of people during weekday and weekend reflects the level of accessibility to reach their destinations and their attractiveness. This consequently results in different expenditures of money and time to travel to their destinations. It is clearly seen that most of the people enjoy shopping trips (n=125, 62.5%) much more than other activities (personal business, social activity and leisure or recreation). Among several destinations of shopping trips, they choose to spend their weekend to travel nearby their residential areas.

Frequency of trip: When considering the frequency of trips on both weekday and weekend among all destinations, it can be seen that there is slightly more frequency of trip in the employment area (24.1% from n=29) and outer area (12.9% from n=62), respectively for 1 round-trip case. This might be due to the variety of shopping malls and other type of services available in the proximity of commercial and industrial area as well as more attractions of activity areas in the urban core of Bangkok.

- Travel Distance: For the distance of travel, most of the people travel in the moderate level of distance, which is about 16–20 kilometers (n=51, 25.5%), followed by 11–15 kilometer (n=45, 22.50), more than 30 kilometer (n=44, 22.0%), respectively. However, people who work nearby their residential area would not face with the problem of long-distance travel. On the opposing dimension, workers who work in the outer zones need to travel very long distances.
- Travel Time: The data on travel time distribution for different sub-centers represents almost the same trend with the travel distance. Most of the commuters travel a moderate duration of travel time, which is about 31-45 minutes (n=72, 36.0%). As expected, people who work in the outer zones need to travel more than 1 hour, which represents about 22.0%. This evidence revealed the urban sprawl situation which shows the excessive time for travel, especially for working trip. This might result in the lack of clear sub-centers with the inadequate or ineffective linkage of transportation network in the study area. Also, there is insufficient active development policy to control this urbanization condition and to concentrate job growth inside the limited number of peripheral centers under the mobility consideration. In the case of weekends, most people prefer moderate duration of travel time (31–45 minutes) to outer zones, especially for the group of people who work in the employment area (from 72, 30.6%).
- Travel Expenditure: As shown in Table 2, the most people spend money to travel for working and for weekend is about 50–100 baht, which could be estimated about 23.9% of their income (based on the previously mentioned average income). This expenditure increases for people who enjoy working and spending

weekends in outer zones. It is seen that of the 100% of the people who are workers in outer zones and approximately 94.1 for weekend trip spend the highest amount of money for their trip (>100 baht). If it is compared to their average income, it would be a major proportion of total spending for transportation cost (31.9%). It can be clearly seen that there is an urgent need to provide the solutions to cope with this inefficient distribution of location of the employment and service and efficient transport system.

5.3 Exploring Land Use Transportation Interaction

5.3.1 Exploring Technique of Linear Discriminant Analysis (LDA)

Based on the descriptive statistics explained in the previous section, the basic figure of the spatial pattern influence on mobility pattern was explained. However, further exploration of the explanatory variables to discriminate the functional of different center is required to clarify the effectiveness of this spatial structure. This study employed the simple statistical technique of Linear Discriminant Analysis (LDA) to identify its deficiency in the relationship for further recommendations. LDA is a well-known statistical method to classify individuals or objects into mutually exclusive and exhaustive groups based on a set of independent variables (Iamtrakul et al., 2005). To confirm the usefulness of this techniques, there are a number of studies which have applied this method of analysis to land-use planning, especially in terms of spatial analysis of urban planning and development field (Mendes and Themido, 2004; Borzacchiello et al., 2010). Due to its excellent group classification performance, this study employed this technique to explain the travel behavior of respondents in working trips with their different mode choice selection. Based on this approach, the variables discriminated between three type of sub-centers could be found in the group of variables to discriminate among them. The independent variables (x), mentioned above, could be input into the analysis to explain the dissimilar sub-centers (S) of the study area. By using the data collection in Table 2, the functions to discriminate three sub-centers in each modal usage could be calibrated. This collected data on different users' socioeconomic and various daily mobility characteristics could then be used to determine which variables are best for classifying the interaction of different sub-centers' location and commuters' choice to travel to them.

Based on the LDA, various combinations of several variables were investigated to determine the most suitable classification model that allows the best discrimination among three sub-centers with a mixture of mode choice characteristics. Thus, this study divided the relationship between the sub-center location and travel behavior of people into two categories of mode selections: private and public transport. Based on the analysis of variance (ANOVA) results shown in Table 2, the F test revealed that all independent variables were important to the discriminant function and could be accepted for calibrating the model shown to be significant at confident level of 0.05. By using the SPSS statistic package, the Wilks' Lambda could be used to demonstrate the result of this analysis. The result of the test in Table 3 appears to be significant, which means that a linear combination of the selected variables can discriminate between the three groups of sub-centers. Furthermore, Box's M test revealed that all activity cases significantly met the assumption of homogeneity of covariance matrices due to the assumption and agreement under an obligation to utilize this statistically method.

This investigation was conducted through a combination of more than 20 variables, but only variables found to be the optimal combination of variables could be used to classify the travel behavior to different sub-center destinations. Table 3 provides information on each of the discriminate functions (equations) produced which also demonstrate that canonical correlation is the multiple correlations between the predictors and the discriminant func-

Table 2 Test of Equality of Group Means

Variables	Wilks' Lambda	F	df1	df2	Sig.
Age (year)	.704	11.758	2	56	.000
Income (baht/ month)	.716	11.103	2	56	.000
Travel time of Working Trip (minutes)	.252	83.247	2	56	.000
Age (year)	.850	12.155	2	138	.000
Income (baht/ month)	.928	5.346	2	138	.006
Travel distance of Working Trip (minutes)	.211	258.087	2	138	.000
No. of Connections	.878	9.591	2	138	.000

Table 3 Eigenvalues

Mode	Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
Private	1	3.522a	81.9	81.9	.883
	2	.778a	18.1	100.0	.662
Public	1	3.973a	95.3	95.3	.894
	2	.197a	4.7	100.0	.406

a. First 2 canonical discriminant functions were used in the analysis.

tions with an index of overall model fit. The result of a canonical correlation of private mode for function 1 and function 2 are 0.883 and 0.662, respectively; accordingly, the model explains 77.97% and 43.82% of the variation in the grouping variable. On the other hand, for the public transport, function 1 and function 2 are 0.894 and 0.406, respectively. This means the model can explain 79.92% and 16.48% of the variation in the grouping variable.

5.3.2 Land Use Transportation Interaction Function

There were three classification functions of each subcenter to classify travel behavior by different mode of transport. By applying the methodology explained in the previous section, the generalized discriminant function in Eq. (1) could be used to obtain the most suitable case. The classification scores for each case of different groups can be computed by applying Eq. (1):

$$S_i = c_i + w_{i1}x_1 + w_{i2}x_2 + ...+ w_{im}x_m \quad (1)$$

In Eq. (1), the subscript i denotes the respective group; the subscripts 1, 2, ..., m denote the m variables; ci is a constant for the ith group; wij is the weight for the jth variable in the computation of the classification score for the ith group; xj is the observed value for the respective case for the jth variable; Si is the resultant classification score. Consequently, the successive functions could be determined as shown in Table 4.

These unstandardized coefficients are used to create the discriminant functions which contribute similar ways of regression function. Table 4 demonstrated that function 1 tends to separate group 1 (lowest value) and group 3 (highest value). Function 2 separates group 2 (lowest value) from groups 1 and 3 (highest value). The results reveal that func-

Table 4 Canonical Discriminant Function Coefficients

Mode of Transport	Variables	Function	
		1	2
Private	Age (year)	0.071	-0.155
	Income (baht/ month)	0.590	1.805
	Travel time of Working Trip (minutes)	2.220	0.449
	(Constant)	-11.375	1.097
Public	Age (year)	-0.029	0.127
	Income (baht/ month)	0.286	0.489
	Travel distance of Working Trip (minutes)	1.325	-0.217
	No. of Connections	0.069	0.684
	(Constant)	-5.496	-5.301

tion 1 is positively associated with all variables of age, income and travel time, whereas function 2 is negatively associated with the age variable. When considering the income variable, a more significant impact can be seen in income effect for travelers who choose private transport rather than public transport to all sub-centers, especially the outer sub-center. Furthermore, travel time will have more influence on this group, which might suggest they value the time spent in vehicles more than the group who take public transport.

For public transport mode, Function 1 is positively influenced by the variables of income, travel distance and number of connections; however, it is negatively influenced by the variable of age. Function 2 has opposite trend of function 1 since the travel distance has negative relationships among all positive relationship of other variables. This might represent the reverse relationship of inconvenient mode of travel of public transportation. However, there would be no problem with the more connections due to the positive sign of the coefficients in both functions. The graphically demonstration of the separation among three groups clearly provide the evidence to confirm the influence of outer zone among all sub-centers. This finding reveals the strong characteristics of the travel behavior to the sub-center of outer areas among both private and public transport clusters.

6. Concluding Remarks

The main challenge of rapid urbanization has been the negative effect of automobiles usage which recently has deteriorated the quality of the people's life. Especially, when it occurs in the area of enormous number of migration of the population distribution changes, this suburbanization induces the necessity of owning an automobile. Moreover, with the limited service of transit availability, the majority of commuters need to rely on their private vehicle with longer travel time and distance rather than transit usage. Due to the high growth rate of Bangkok Metropolitan Region (BMR), Pathumthani province was selected as a case study to confirm the evidence of sprawling effect though an exploration of the land use and transportation interaction. The results of analysis indicate the poor accessibility level and the connectivity of all selected sub-centers due to the high proportion of travel expenditure and some of them need to travel to outer areas not only on weekends but also in their daily work. Thus, the availability of destinations together with an interconnected street network makes sufficiency mode of transport either public transport or nonmotorization a more competitive and attractive mode of travel than other options. Accessibility should also be taken into consideration as the sub-centers are located far from trip generation point, the number of commuters would be expected to decline in accordance with the longer distance. Finally, the results of this study also demonstrate a number of factors other than land-use environment have a profound impact on commuting behavior. Thus, considering the enhancing of connecting sub-centers to the housing, commercial and employment area and infrastructure might be an initiative for achieving mobility policy challenges. Furthermore, a more compact and intermixed urban environment is preferable to shorten the distances between destinations. If the sub-centers or destinations for work and leisure trip are located far from the community, the numbers of person who ride both public transport modes will definitely shift to their private vehicles to avoid congestion of vehicles. Thus, the provision of sustainable development should be raised to encourage the suitable development of suburban plan.

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