Effect of Urban Metabolism on Energy Consumption in Mobility System

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A R T I C L E I N F O

Article history:
Received: 1 March 2021
Revised: 27 July 2021
Accepted: 14 October 2021

Keywords:
Energy Efficient
Factor Analysis
Future Mobility
Mobility Systems
Urban Metabolism

A B S T R A C T

The recent trend of urban developments has shown in the wrong direction due to the continued impacts of urban problematics. It is obviously seen from the impacts of growing urban population coupled with global climate change which require both the provision of basic resources and resilience against environmental threats. Together with the rapid rate of urbanization, one of the main pieces of evidence of urban metabolism is energy consumption. From the comparison of urban areas expansion and the amount of energy consumption per person from 1950 to 2050 by World Bank (2020), it was found that the increasing in the expansion rate of urban areas is more than 8 times. It demonstrated that the size of urban areas has a significant effect on people's energy utilization. This study analyzes the importance of mobility plan among those working in transport planning and development concerning future urban mobility energy-efficient systems. This study makes practical used factor analysis with a principal component method to define and recommend effective travel patterns by figuring out the traffic demand management in terms of efficient mobility systems in policy planning in Bangkok and its vicinities.

1. INTRODUCTION

Urban metabolism is fundamental for developing countries in sustainable communities and cities through advancement of digital technology [1], [2]. The urban metabolism is defined as "the total technical and socio-economic-environment processes in cities, resulting in growth, energy production-consumption, and waste elimination." which require an understanding of a multitude of the flows in urban process and operation [3]. In other words, it is a process that reflects the urban system through the utilization of the natural resources of the city and conducts its activities in such areas. It also creates a mechanism to control the level of air quality, wastes, wastewater or pollution from the energy metabolism of urban systems in an appropriate approach while minimizing negative impacts [4]. However, with the constantly changing urban dynamics and urban development, therefore, need to be driven from many sectors includes policies to set the urban strategies for city development towards a balance of living and utilization of resources, environment and energy. Hence, it is a difficulty among various urban contexts that need to be planned and managed [5], [6], [7].

Currently, it is found that the urban area occupies only 5 percent of the total world area. It is noticeable that urban people utilize energy in transportation more than 70 percent as main sources of causing urban metabolic activities which represents more than 50 percent of the world's population [8], [9]. Also, comparing the expansion of urban areas and the amount of energy consumption per person during 1950 to 2050 demonstrated the trend of energy consumption is going to increase with the expansion of urban areas [10]. It reflected that the size of urban areas has a significant effect on people's energy use.

The primary urban metabolism assessment is crucial for understanding urban contexts and identifying what further knowledge is needed, especially mobility systems, in terms of greenhouse emissions. The notable is the addition of mobility energy management systems, which management strategies must be allocated for more sustainability in different contextualized level. This study focuses on analyzing the importance of mobility plan among those professionals who are working in transport planning and development in the point of view of developing energy-efficient systems for appropriate future urban mobility. Accordingly, urban and transportation planning must be reconsidered due to technology disruption and urgently require for improving energy efficiency in transportation planning systems [11] – [13]. It is necessary to pay attention in enhancing energy conservation while changing travel behavior of people [14]. As well as the pattern of the city has also affected longer distance travel from residential area to other nodes of activities. Allocation of poor public

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transport would inevitably worsen the energy consumption in transportation sector [15]. Within the planning limitations of mobility patterns both in spatial planning and policy planning, the Bangkok and vicinities context has not been studied before [16].

2. LITERATURE REVIEW

2.1. Transport's contribution to emissions

When considering global energy-related CO2 emissions, the transport sector accounts for about 23 percent. Furthermore, its share of global energy is rapidly increasing more than other sectors [17]. Between 1971 and 2006, the trend of energy use in the transport sector are doubled [18] (Fig.1). Therefore, efficient and sustainable urban planning in transportation systems is a significant factor in reducing carbon emissions and mitigating climate change problems and various impacts at present. The problem of traffic jams has produced direct affecting the release of carbon dioxide. It also indirectly leads to low productivity while reducing accessibility of urban activities [19]. In addition to human energy activities in the transport sector, the trend of change also depends on human travel patterns of mode choices. By travelling among diverse zones of the city's activities, it has resulted in carbon dioxide emissions, especially travelling by private cars, which is also influenced by each component of urban transportation system (infrastructures and vehicle dimensions) [20].

2.2. Energy efficiency policies in the transportation sector

With the energy consumption problem mainly from transportation, it is essential to create efficient energy use to foster a synergistic integration among the three key concepts (Fig.2) [20]. Policymakers can apply the Avoid-Shift-Improve (A-S-I) framework in developing cities which consists of: (1) Avoiding or reducing energy consumption (Avoid), (2) Shift of energy consumption method (Shift) and (3) Improvement of energy consumption patterns (Improve). By following these three principles for managing the use of personal vehicles and the travel pattern that depends on the characteristics of each person, it can help energy use in the transport sector more efficient [21]. Transforming cities and urban infrastructures through experts' opinion would help for conceptualize the creation of efficient demand of transport energy which comprises of three essential elements of management in the transportation sector:

1. Avoiding activities caused increasing energy use and reducing demand for energy in the transport sector;
2. Shift energy needs by promoting more usage of public transport;
3. Improve vehicle usage and fuel consumption.

2.3. System management efficiency (system efficiency strategy)

In the city system, natural resources and energy flow in commuting pattern is well connected with the management of transportation needs. However, the form of travel is different which is necessary to plan and design space and urban structures to consistent the needs of various city systems and users (e.g., local residents, commuters, visitors). Since energy consumption per capita has increased in proportion [21], [22]. Traffic reduction is a critical problem of energy efficiency. Land-use planning should be placed in appropriate settlement arrangements to reduce travel distances or avoid traffic congestion in relevant to the context of balancing urban metabolism.

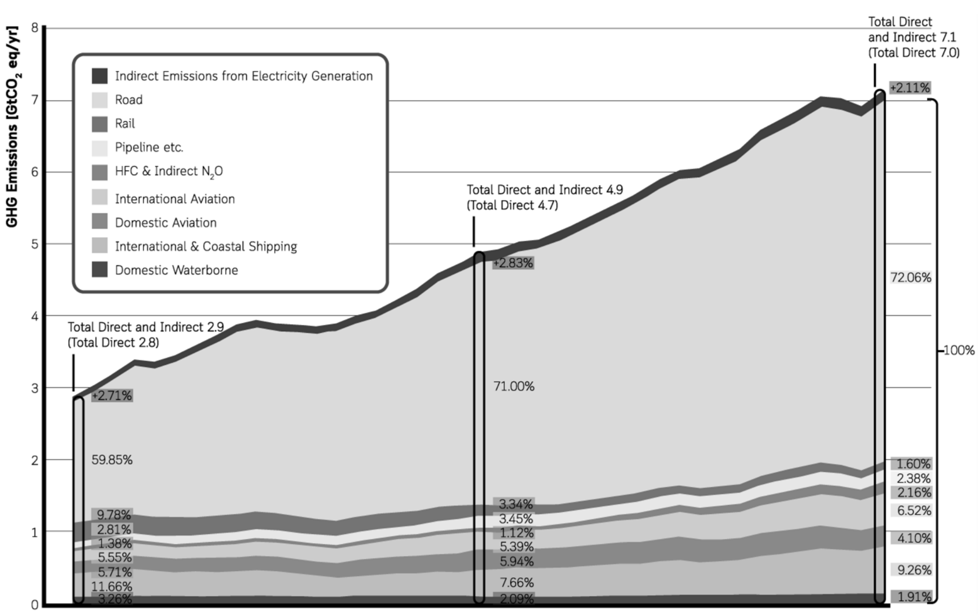

Fig. 1. Global energy use by transport mode.
Source: EIA, International Energy Outlook, 2016

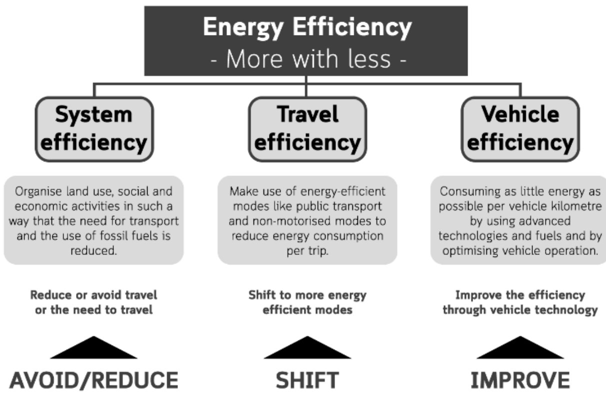

Fig. 2. Sustainable transport instruments and their impact on carbon emissions.

Source: Susanne Bohler-Baedeker, 2018

In addition, dense urban structures with mixed-use areas have great potential for transport energy because the travel pattern with less distance and ability in adjust the travel pattern (Mode Shift) [20]. From travelling by motorized to active mobility and public transport, it makes the friendly system with denser space usage, it also truly helps manage transportation demand and encourages people to use public transport consistently.

2.4. Travel efficiency-the shift strategy

Efficient travel is associated with the energy consumption of different travel patterns. The key indicators of effective travel are relevant to travel patterns and vehicle-related factors. It can be presented the energy consumption unit per person travelled in the index of the kilometre or per tonne-kilometre [20], [22]. The energy-efficient approach is to encourage travellers to use public transport and commute on foot and cycling. It helps lose less energy than public transport by considering the overall mode of transportation of commuters. The entire system should be designed for allow a suitable solution for social inclusiveness [22], [23]. However, energy consumption depends on the vehicle occupancy rate. Moreover, when all other factors are considered, it will depend on the economic development patterns. In addition, encouraging people to travel by cycling or on foot means avoiding consuming unnecessary energy. It should consider the provision of allocating public transport to become an option that can replace private car demand for long distance travelling. To help increase the utilization of buses and trains, it could contribute to more efficient use of energy [22].

2.5. Vehicle efficiency-the improve strategy

The use of energy-efficient vehicles is another way to improve energy efficiency. It can be applied to better technology and design adoption as shown by the following detail [20]:

1) Improvement of existing vehicles,
2) New fuel concepts,
3) Development of new vehicle concepts.

Therefore, improving the efficiency of vehicle use strategy can help reduce energy consumption and reduce air emissions towards environmental sustainability of urban public transportation systems.

3. RESEARCH METHODOLOGY AND RESULTS

This study was a pilot survey based on 52 data sets which were collected from transportation experts by focusing on the importance of mobility efficiency of those professional who are currently working in the areas of transportation planning and development. The questionnaire was divided into two parts: 1) General information and 2) Effective travel patterns data. The factors assessment was divided into six levels, ranging from 1-6 which presents rating score between the lowest to highest (1-6). The details of each part can be explained as follows:

Part 1: General information, it is comprising of institutional data, the role of operational, duration of work, the level of expertise in each area which consists of: 1) Transportation planning and policy, 2) Traffic management, 3) Transport infrastructure development, 4) Facilities and services to support transport development and 5) Other related transport agencies. The data were analyzed in a quantitative approach by statistical analysis. With different operational roles and expertise among all respondents, the details are shown in Table 1 and Table 2. From the analysis, the majority of the respondents were experts in transport infrastructure development, accounting for 32.70 percent, corresponding to their roles in operations, which is accounted for 32.70 percent as well, followed by the role of operations in transportation planning and policy (26.90 percent). However, other related transport agencies were accounted for 26.90 percent, which is an interesting point for further comparison among different role of respondents.

Table 1. Role of respondents

Role of an Operations	Frequency (Count)	Percent (%)
Transportation planning and policy	14	26.90
Traffic management	8	15.40
Transport infrastructure development	17	32.70
Facilities and services to support transport development	7	13.50
Other related transport agencies	6	11.50
Total	52	100.00

Table 2. Areas of expertise

Areas of Expertise	Frequency (Count)	Percent (%)
Transportation planning and policy	9	17.30
Traffic management	7	13.50
Transport infrastructure development	17	32.70
Facilities and services to support transport development	5	9.60
Other related transport agencies	14	26.90
Total	52	100.00

Part 2: This part is about the opinion on effective mobility patterns. The gathering data was divided into six levels which is ranged from 1-6 by presenting the lowest to highest (1-6) [24].

The factors are categorized and analyzed based on factor analysis. In this study, the categorizing of factor groups was perfrom by using the explanatory factor analysis method. It is a statistical technique by reducing the count of variables with similar statistical characteristics to the same group of factors that is used to reduce data to a smaller set of summary variables and to explore the underlying theoretical structure of the phenomena. In part 2, 17 factors were imported to reduce the redundancy of variables as shown the detail in Table 3. The descriptive statistical analysis of the main variables is shown in Table 4 and analyzed by using Principal Component Analysis; PCA. It was found that from 17 input factors, six groups of factors were extracted and the eigenvalue of each factor was determined.

Table 3. Input variables for analysis

Variables	X_n	Descriptions
Flexible working time	X_1	Creating flexible working time, such as working online channel or onsite 8 hours per day, will help reduce traffic congestion.
Promote to use public transit system and mass transit system	X_2	The institute provides reward points: lower ticket prices for personnel used to travel-related goods and services in the public and mass transit systems.
Promotes congestion pricing measure	X_3	Determining congestion fees only in urban areas, especially during the morning and evening crisis
Use clean energy vehicles	X_4	The government should set up policies to promote clean energy vehicles, e.g., electric vehicles (EV), charging stations, etc.
Parking fee ticket	X_5	Define Parking fee rate for people using private cars; the ticket service has various rates per day, week, or month.
Expansion of a BRT route	X_5	Expansion of a Bus Rapid Transit route with special traffic lanes and traffic crisis.
Promotes carpooling measure	X_7	The government should set up a policy to promote carpooling measures by specifying the same lanes as bus lanes.
Intelligent transportation system (ITS)	X_8	Intelligent transportation system (ITS) is developing technology and information to provide travelers with vital information when planning their trips.
Promotes to working online application system	X_9	People can work online in any location but must have daily work productivity according to each week's work plan.
Investment infrastructure development	X_{10}	The government and the private sector must be invested in infrastructure and other public transportation facilities.
Create automated ticketing service at the bus stop station area	X_{11}	The station area must have an automated ticketing service at the bus stop.
The bus stops station provides basic services	X_{12}	To provide basic services such as food and beverage, coffee shops automatic ATMs and vending machines, etc.
Determination design standard for public transit system	X_{13}	Promote to design standard for public transit system in Thailand context.

Web Application and mobile applications for public transit system information service	X_{14}	Developing web application and mobile applications for specific public transit system information service in metropolitan and vicinities areas and recommend appropriate route.
Extending public transit system routes	X_{15}	Extending public transport network connecting to suburban and metropolitan areas with feeder line.
Create smart cards to use public transit system in one card	X_{16}	The government promotes ensuring the seamless connectivity of the public transit system to reduce travel time.
Free ticket for vunerable people	X_{17}	The promotion must be promoted free ticket for vunerable people groups; the elderly, the disabled and children when travelling by public transit system

Table 4. The statistical analysis of the main variables

Variables	X_n	**Mean**	**Minimum**	**Maximum**	**Std. Deviation**	**N**	**Sig. (2-tailed)**
Flexible working time	X_1	3.42	2.00	6.00	0.977	52	.000
Promote to use public transit system and mass transit system	X_2	3.46	1.00	5.00	0.828	52	.000
Promotes congestion pricing measure	X_3	4.10	2.00	6.00	1.302	52	.000
Use clean energy vehicles	X_4	2.85	2.00	4.00	0.607	52	.000
Parking fee ticket	X_5	3.38	3.00	5.00	0.530	52	.000
Expansion of a BRT route	X_6	4.00	2.00	5.00	0.767	52	.000
Promotes carpooling measure	X_7	4.19	3.00	5.00	0.793	52	.000
Intelligent transportation system (ITS)	X_8	4.10	3.00	6.00	0.913	52	.000
Promotes to working online application system	X_9	3.96	3.00	5.00	0.394	52	.000
Investment infrastructure development	X_{10}	3.23	3.00	5.00	0.469	52	.000
Create automated ticketing service at the bus stop station area	X_{11}	3.67	2.00	5.00	0.964	52	.000
The bus stops station provides basic services	X_{12}	4.29	3.00	5.00	0.893	52	.000
Determination design standard for public transit system	X_{13}	4.29	2.00	6.00	0.915	52	.000
Web Application and mobile applications for public transit system information service	X_{14}	4.58	3.00	6.00	1.091	52	.000
Extending public transit system routes	X_{15}	4.37	3.00	6.00	1.085	52	.000
Create smart cards to use public transit system in one card	X_{16}	3.81	3.00	5.00	0.445	52	.000
Free ticket for vulnerable people	X_{17}	3.94	3.00	6.00	0.802	52	.000

Note: *Significance (p-value) < 0.05*

Table 5. The results of factor analysis

No.	**Variables**	**Factors**					
		Public Bus	**Facility Manage ment**	**Travel Reduction**	**Time Flexibility**	**Design Standard**	**Smart System**
X_{12}	The bus stops station provides basic services	0.878	0.056	0.097	0.036	0.144	-0.041
X_{15}	Extending public transit system routes	0.782	0.078	-0.314	0.313	0.198	-0.142
X_{11}	Create automated ticketing service at the bus stop station area	0.753	0	0.198	-0.091	0.504	0.082

X_4	Use clean energy vehicles	0.742	0.132	-0.237	0.379	0.049	-0.031
X_{16}	Create smart cards to use public transit system in one card	0.41	0.756	0	-0.198	0.057	-0.11
X_2	Promote to use public transit system and mass transit system	0.122	0.733	0.196	0.302	0.142	0.08
X_{10}	Investment infrastructure development	-0.462	0.681	-0.209	0.15	-0.001	-0.126
X_3	Promotes congestion pricing measure	-0.896	0.004	0.274	0.049	-0.031	0.048
X_5	Parking fee ticket	-0.275	-0.107	0.819	-0.183	0.016	-0.08
X_{14}	Web Application and mobile applications for public transit system information service	0.158	0.207	0.806	0.315	-0.097	0.047
X_9	Promotes to working online application system	0.052	-0.004	0.183	0.024	-0.879	-0.011
X_1	Flexible working time	-0.079	0.132	-0.028	0.792	0.023	0.185
X_6	Expansion of a BRT route	-0.833	-0.182	-0.194	0.123	0.288	0.092
X_{13}	Determination design standard for public transit system	0.302	0.378	0.171	0.126	0.649	0
X_8	Intelligent transportation system (ITS)	-0.547	-0.128	-0.19	-0.545	0.14	0.239
X_{17}	Free ticket for vulnerable people	-0.515	0.221	-0.246	-0.504	-0.29	0.266
X_7	Promotes carpooling measure	-0.109	-0.068	-0.016	0.088	0.021	0.946

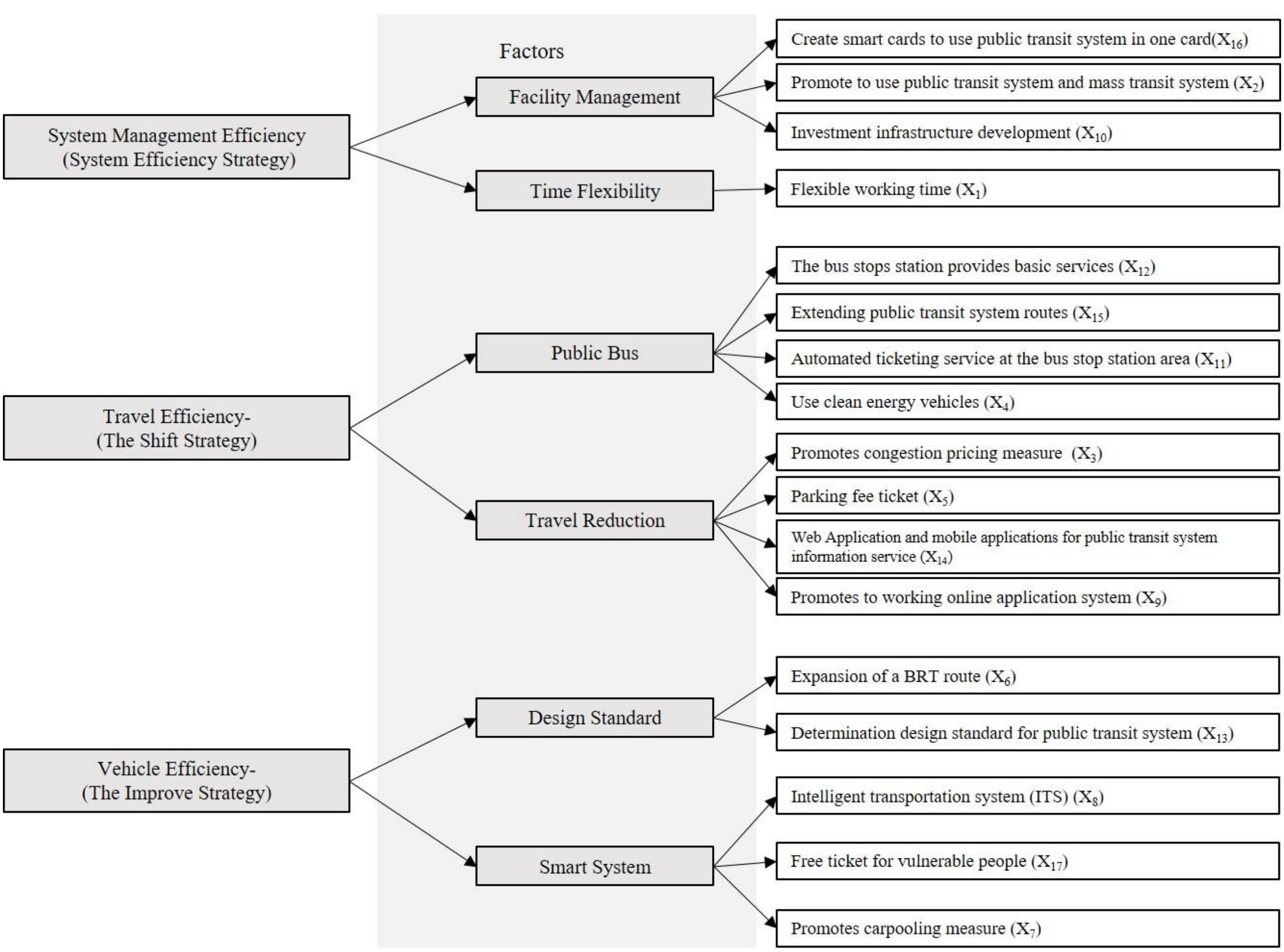

Fig. 3. System efficiency strategy results factors generated by factor analysis.

From the statistical analysis of the main variables, this study found the statistical test exceeded 1.0 with rotation sums of squared loadings which a factor solution is made more interpretable without altering the underlying mathematical structure. Considering the cumulative percentage (cumulative %), the factors obtained after the analysis among all 6 group factors can explain the total variability of the variables 79.98 percent. Table 4 shows that the most important factor was web application and mobile applications for public transit system information service (X_{14} = 4.58), followed by extending public transit system routes (X_{15} = 4.37), the bus stops station provides basic services (X_{12} = 4.29) and determination design standard for public transit system (X_{13} = 4.29). Furthermore, the result of expert opinions confirmed that people who work in transportation planning paid their attention on public transit system, especially public buses, which involves the mechanism of a advance system for public transit.

Moreover, there were factors related to the travel support system, Intelligent transportation system (ITS) (X_8 = 4.19), promoting carpooling measure (X_7) and promoting congestion pricing measure (X_3), with an average value of 4.10. The score among these strategies present the high level of improtant score.

The factor analysis can be used for interpreting all factors into six main group factors according to the factor analysis method that can be considered the detail in Table 5. The six group factors were defined which were named as:

- *Factor 1: Public transport,*
- *Factor 2: Facility management,*
- *Factor 3: Travel reduction,*
- *Factor 4: Time flexibility,*
- *Factor 5: Design standard and*
- *Factor 6: Smart system.*

Based on the six factors categorizing, the strategic plan in mobility efficiency management can be suggested. The detail can be described as shown in Fig 3. The factors of facility management and time flexibility were related to managing mobility needs based on a variety of land use planning and public transit systems. The appropriate settlement can be suggested to reduce travel time and avoid traffic congestion, similar to the mobility system efficiency management [20], [21]. The factors of public transport and travel reduction were related to travel efficiency, the stimulating modal shift from urban transport mode. The most energy-consuming (e.g., private cars) towards low-carbon modes, particularly, the shift towards non-motorized transport public transit system must be recommended. In places where non-motorized transport and public transit system share is already high, the main objective is to maintain the modal share to consistent with the system management efficiency [21], [22].

The factors of design standard and smart system were related to vehicle efficiency. It seeks to improve the energy efficiency of transport modes and related vehicle innovation and technology. In addition, it is related to the potential of alternative energy use because innovation and technology can help in reducing the impact of greenhouse gas emissions from mobility through mechanism of improving vehicle efficiency and cleaner fuels toward mitigating the effect of urban metabolism on energy consumption in mobility systems [21], [22], [25], [26].

4. CONCLUSIONS AND DISCUSSION

Mobility system is part of urban planning, in other words, is the planning and design for urban infrastructure, especially traffic management. These are crucial components in mechanism perspectives for solving urban energy efficiency problems. It must be no longer overlooked to considers the complex issues with alternative solutions that arise among multi-dimensional urban problems. The integrated solution would provide better results in managing various environmental problems related to the processes of urban transportation metabolism. In particular, the understanding of urban transport system would allow for considering level of impacts for leading to an appropriate estimate of the results which potentially support the policymakers in the development of more appropriate strategy. This study recommends an approach of factor analysis to develop the set of policies which comprises of *system management efficiency, traffic efficiency, and vehicle efficiency*.

In addition to urban transportation planning, the linkages of community in urban areas and between cities space must also be consistent with an effective utilizing to its full potential. To add vitality and promote the daily traffic of the people as much as possible, it must consider creating a balance of node of activities, employment, and local resident locations. Improving public transport would create a modal shift which is well-designed to attract usability. Convenient access and travel time reliability from expanding the public transport network would be one way to improve the traffic management system. This consideration must be coupled with the promotion of an appropriate public transport system for different contextual areas. The system would differ depending on the cost, construction period of infrastructures, number of passengers, and the city structure, which must be connected both in the community area and to the regional level [23], [27].

Finally, there is a standard integration between public transport and commuting on foot and by cycling. This would enable more efficient travel by creating a suitable environment for commuters and commuting systems. The result based on the classification of a different set of policy variables based on factor analysis would be an alternative approach in transportation policy formulation in different readiness of the cities corresponding to the growing demand for local sustainability on the basis of urban metabolism concept [21] & [22].

ACKNOWLEDGEMENTS

This research was supported under Excellent Research Graduate Scholarship from collaboration Thammasat University and National Science and Technology Development Agency. It was also in part of "The tackling traffic management by focusing on travel behavior approach towards sustainable campus town development project" which was supported by Thammasat University Research Fund under the TU Research Scholar, Contract No. 6/2562. It is conducted under the Faculty of Architecture and Planning Research Fund, Thammasat University, contract no. TDS 10/2021, and partially supported by Center of Excellence in Urban Mobility Research and Innovation, Faculty of Architecture and Planning, Thammasat University, Pathum Thani, Thailand.

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