Sustainable Energy Development in Urban Transportation System under TOD Pattern: a Case Study in China

Min He*, Mingwei He, Zhanqiong He, Zidong Zhang

Abstract— *Energy sustainable development faces tremendous challenge today. Transportation is one of the major sources of energy demand and its consumption of energy is rising continually around the world. How to build a sustainable energy development transportation system is an important research topic for transportation engineers, planners and policy makers. The paper pays attention to energy consumption under TOD (Transit-Oriented Development) strategy and gives a case study in china. Energy consumption and energy-related emission under TOD and AOD (Auto-Oriented Development) pattern are computed based on the transportation planning data of Dongguan, China. As a result, TOD is more efficient and environment friendly than AOD, the former pattern is a good choice for sustainable energy development in urban transportation system.*

Keywords— **Energy consumption, Sustainable development, TOD.**

1. INTRODUCTION

In 1987, a report entitled *our common future*□which was published by the World Commission on Environment and Development (WCED) □put forward the sustainable development strategy. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1]. However, energy sustainable development faces tremendous challenge today. Energy supply security is a big concern to major industrialized countries like U.S.A., Europe and Japan, they depend increasingly on several unstable supplying regions with uncertain reservation of gas and oil, China follows soon.

With the rapid economic development, energy consumption in China goes up greatly. China has become the second largest energy consumer in the world after U.S.A. According to the data from National Bureau of Statistics of China [2], China's total primary energy consumption reached 2.22 billion tons of standard coal in 2005. From 1990 to 2004 china's oil consumption has kept a consistent upward trend, with an annual increase of 9.2%, far higher than that of other resource consumption during the same period (3.9%). By 2003, China, with its total oil consumption of 240 million tons, overtook Japan and became the second largest oil consumer in the world. According to the predictions by the National Development and Reform Commission (NDRC) of China [3], oil import will reach 150□220 million tons by 2020, and 50% of China's oil demand will rely on import. The growing oil import will influence the economic development of China.

Transportation is one of the major sources of energy demand and its consumption of energy is rising continually around the world. International Energy Agency (IEA) projects that over the next 20 years energy demand growth in transport will be greater than that in other end-use sectors. Transport's share of total energy usage will increase from 28% in 1997 to 31% in 2020[4]. Despite efforts to use alternative fuels, oil will continue to dominate this sector. In America, oil accounts for 97 % of the transportation sector's energy [5]. Transport will account for more than half of the world's oil demand in 2020[4]. In china, the share of energy consumption of transport sector has experienced a continuous increase, and has gradually become the dominant part. From the report of the IEA, 50% of crude oil consumption has been consumed by road transport in China. In 2003, road transport consumed 38.114 million tons of gasoline and 17.096 million tons of diesels, accounting for 87.9% of the national gasoline and 22.1% of the national diesel production respectively [3]. Due to the fossil fuel such as oil dominate this sector, the massive gas emission of transport such as CO_2 and NOx is harmful to environment. In China, 60% of air pollution comes from the emission of mobilized vehicles in many urban areas. Transportation becomes the biggest pollutant source for urban environment [6].

Energy consumption and the energy-related emission in transportation sector are closely related with the mode of urban transportation system. Over the past two decades, China has experienced an unprecedented rate of urbanization and motorization. Urban population now accounts for 41.8% of the total Chinese population, and it will reach 57% in 2020. At present, 10% of the world's population lives in China cities, and the

*Min He (corresponding author) is Prof. Dr., Faculty of Transportation Engineering, Bailong Campus, Kunming University of Science and Technology, Kunming, P.R.China; P.O. 650224; E-mail: kmhemin@gmail.com

Mingwei He is Graduate Student, Faculty of Transportation Engineering, Bailong Campus, Kunming University of Science and Technology, Kunming, P.R.China; P.O. 650224; E-mail: hmwei01@yahoo.com.cn

Zhanqiong He is Lecturer, Faculty of Management and Economics, Kunming University of Science and Technology, 121 Street, Kunming, P.R.China; P.O. 650093; E-mail: hezhanqiong@yahoo.com.cn.

Zidong Zhang is Transportation Engineer, Transport Institute of China Academy of Urban Planning and Design

proportion will rise to 15% by 2020[7]. The urbanization in china brings great mobility demand and huge energy consumption. How to build a sustainable development urban transportation system to improve energy efficiency and reduce energy-related pollution is an important research subject for transportation engineers, planners and policy makers.

In this paper, a model is formulated to analyze energy use and emissions in meeting the travel requirements of the residents of Dongguan city, China. Most variables of the model such as travel demand, modal split, vehicle ownership and vehicle miles traveled are obtained from an interactive planning of Light Rail Transit (LRT) system and land use. The model illustrates the effect of two strategies, namely TOD and AOD, on energy use and emissions. Under the TOD strategy, if both the LRT projects and corresponded land use plan can be implemented, 51.93% of energy, that is about 0.18 million tons of oil equivalent, could be saved in 2020. Compared with AOD, this strategy could also reduce the emissions of CO_2, NOx by 51.90% and 53.05% respectively.

In section 2, the paper discusses the reduction of energy consumption under TOD pattern by improving urban transport structure and land use pattern. A case study in Dongguan, china, is presented in section3. The last part provides some conclusions.

2. TOD PATTERN AND ENERGY

Put forward by American architect and planner Peter Calthorpe in 1980s, Transit-oriented development (TOD) is moderate to higher-density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use [8]. In recent years, many researches and case studies have discussed TOD strategy extensively. Some cities which carried out TOD such as Hongkong, Tokyo, and Curitiba, have achieved great success. Analysis of the reduction of energy consumption under TOD pattern mainly includes two dimensions, namely urban transport structure and land use.

2.1 Optimization of Urban Transport Structure under TOD Pattern

TOD pattern can optimize urban transport structure based on the travel mode change of people. TOD pattern gives preference to pedestrian and bicyclists, increase the use of mass-transit, reduce people's dependence on the automobile. Mixed land use and higher densities under TOD pattern mean that many destinations can be reached by transit, walking or by bicycle, thereby enable these methods to become more viable travel options. A study points out that, travel by automobile decease 20%-25% in the district based on TOD pattern, compared with that of conventional development pattern [9].

Compared with bus, rail transit can provide higher quality of service with comfort and less delay. So, it is a good choice in TOD design. Rail transit tends to leverage additional automobile travel reductions by providing a catalyst for more accessible land use patterns and reduced per capita vehicle ownership [10]. It reduces automobile travel both directly and indirectly. The former happens when a rail passenger-mile substitutes an automobile vehicle-mile, and the latter happens when it creates more accessible land use and reduces automobile ownership in that area. Although indirect effects are difficult to measure, some studies suggest that they are often larger than direct effects. Research indicates that each rail transit passenger-mile represents a reduction of 3 to 6 automobile vehicle-miles [11].

According to a report in 1999 by the Energy Foundation on energy consumption and energy-related emission of different travel modes (shown in table 1), transit modes, especially BRT (Bus Rapid Transit), Rail transit, is the most energy efficient and environmental friendly transportation mode.

It is very clear that TOD pattern can greatly reduce the energy consumption in urban transportation system. This energy savings is achieved not only by shifting riders to more energy efficient transportation modes, but also by reducing vehicle miles traveled (VMT).

Table 1. Emission and Energy Consumption of Different Modes (per million per kilometer)

Mode / Indexes	Private Car	Taxi	Conventional Bus	BRT	Rail Transit	Motorcycle
CO_2 (ton)	140.2	116.9	19.8	4.7	7.5	62.0
NO_x (kg)	746.0	662.0	168.4	42.0	17.5	90.0
Oil consumption (ton)	49.2	41.0	6.9	1.6	2.6	21.8

Source: the Energy Foundation (1999).

2.2 Land Use under TOD Pattern

Energy consumption in urban transportation system is strongly related to land use. O. Mindali et al (2004) set up a conceptual model of a set of factors influencing urban transportation energy consumption from the viewpoint of land use policy [12].

Conventional wisdom asserts a strong correlation between urban density and transportation energy consumption, which suggests that higher density generates lower VMT and therefore, exhibits lower energy consumption[13-14]. Planning for high density aims at reducing trip length and total mobility needs by concentrating residential, employment and services within a compact area[15]. Many studies also suggest that mixed land-use is likely to reduce trip length, and divert trips from the private car to public transportation and walking. As a result, the reduction in the energy consumption of the transportation system is one of the main advantages of mixed land-use planning policy.

Urban spatial structure can be defined as a combination of land use formation, its densities and the spatial design of infrastructure such as transportation and communication [16]. Through study in representative cities in America and Australia, Roy (1992) found energy consumption in urban transportation also has some relationship with subcenters of city. While subcenters increase from 6 to 12, the transportation condition improves evidently, moreover, average energy consumption per person decreases 14.1% and 16.4% respectively [17]. Atsushi Akisawa (1998) investigated an optimal land use in urban areas from the viewpoint of reducing energy consumption for transportation and analyzed the urban structure of minimal transportation energy consumption [18].

In all, TOD pattern make urban land use more efficient. It requires the mixed land use and higher densities around transit station, and facilitates subcenters of city. Therefore, TOD can improve energy efficiency and save energy.

3. A CASE STUDY IN DONGGUAN, CHINA

3.1 Background of Dongguan

Dongguan city is located in south China, near Hong Kong. It is a rapidly growing industrial city. The population of the city reached 6.49 million in 2004 and would keep growing from 2004 to 2020 according to the plan of the city. Population of the city will reach 8 million in 2010 and near 10 million in 2020.The population structure of Dongguan is remarkably different from that of other cities: migrant worker population is far larger than permanent registered resident population. In 2004, the population of migrant worker reached 4.87 million, accounting for 77.5% of the total. The particular population structure of Dongguan results in a remarkably different travel characteristic.

From 1994 to 2004, the GDP growth of Dongguan has kept a high speed with average rate up to 20%, and reached 11.55 billion RMB (1.43 billion USD) in 2004. Similarly, the number of vehicles in Dongguan has been increasing rapidly in recent years (shown in figure1). By 2004, the total number of all kinds of vehicles has reached 1.01million, among which, automobile account for 32%, motorcycle account for 69%. According to the travel survey in 2005, the proportion of motorization journey accounted for 59% in Dongguan. As the uppermost travel mode, motorcycle accounted for 44.6% of the total trips of the city, private car accounted for only 7.5%, but kept increasing rapidly. The yearly growth rate of private cars reached as high as 40%. However, the transit system was not well developed and transit ridership was very low, accounting only 2.1 % of the total trips of the city.

In China, Pearl River Delta region has been the most prominent urban sprawl region during the past two decades. In 1990, Dongguan was dominated by cultivated land, orchard, and forested land, shown in figure 2. This indicated that Dongguan was still an agricultural dominated area at that time. From 1990 to 2002, urban sprawl maintained a rapid speed and most available land has become urban built-up area. And further, the trend of urban sprawl continues today. However, urbanization of Donguan is low density, unordered and low quality. Under this pattern, people travel mainly by auto or motorcycle. Presently, motorcycle is the main travel tool. With the development of economic, auto will substitute motorcycle soon. Without control, Dongguan will become Auto-oriented development (AOD) at last.

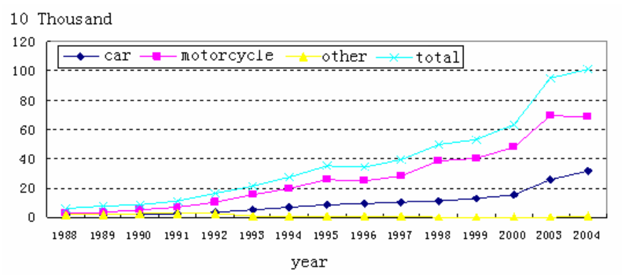

Fig.1. Development of Vehicles in Dongguan in Recent Years

From the viewpoint of Sustainable energy development, main disadvantages of transportation system of Dongguan can be concluded as following:

Firstly, rapid increase of population and vehicles will exert pressure on the limited resource and road capacity. The corresponding aftermaths such as oversized land recourse, energy shortage, traffic congestion will become serious gradually. Especially, serious traffic congestions are now common in Donguan’s major traffic corridors, such as the state highway 107 and Guanchang Road. During peak hours, the average speed of motor vehicles on these roads is only 15 km/h. The impact of congestion on energy consumption and emission is obvious.

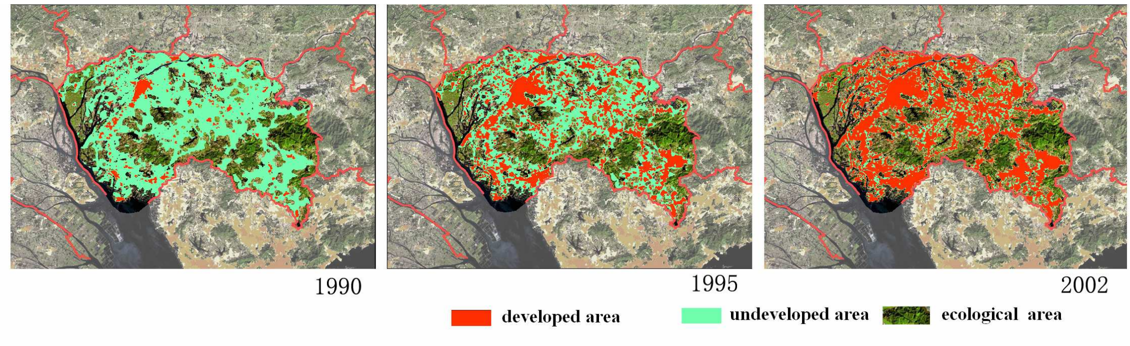

Fig. 2. The Urban Sprawl and Land Use Change of Dongguan

Source: CAUPD, The Report of LRT construction planning of Dongguan

The second, unordered and low density urban sprawl further engenders resource waste. It results in some problems such as more vehicles miles, longer trip length. It is also disadvantageous for mass-transit system development due to the low density land use. This pattern encourages the use of the private car and motorcycle, especially private car. As a result, it will increase energy consumption and decrease energy efficiency.

3.2 TOD Pattern in Dongguan

As a sustainable development strategy, TOD is adopted and carried out by Dongguan government. LRT as a mass transit system is applied in TOD design. To maximize the benefits and attract more people to use LRT as a travel mode, some effective measures are adopted in the rail transit planning projects of Dongguan, some examples are, interactive land use planning and LRT planning, carefully designed land use pattern near the LRT station, integrated LRT with bus system, financial support and so on.

The LRT network of Dongguan consists of four rail routes with the total length of 194.37 km and 49 stations. Before 2025, the whole network will be constructed. Rail transit lines are arranged alone passenger corridor in existence or potentially high density development areas which is planed to be strong development in the future. In order to improve the connection and convenience, LRT stations will integrate LRT, inter-city railway station, bus terminal as much as possible. The details can be found in the Report of Planning of Light Rail Transit by China Academy of Urban Planning and Design [19].

3.3 Evaluating the Energy Consumption Benefit of TOD in Dongguan

Two transportation scenarios for future Dongguan

Two scenarios of future Dongguan transportation system are designed to represent TOD and AOD strategies. Scenarios 1 is AOD pattern, which is the development without the LRT project, it is a do nothing scenario. Scenario 2 is TOD pattern, which is the development with the LRT project.

An improved “Four Steps” model was used in Dongguan LRT construction plan project. The detail plan of population and job opportunity within 500m from LRT station provides the model with ability to build some interactions between land use and transportation system. With the help of complicated, scientific transportation demand model, some necessary data for evaluating energy consumption are shown in table 2, table 3, and table 4.

Table2. Some General Statistics Indexes in Dongguan

Items / Years		2004	2020	2030
Population (million)	Permanent Resident	161.97	300	329
	Migrant Worker	486.95	700	871
GDP (Billion RMB)		11.55	44.2	52.6
Average Travel Frequencies	Permanent Resident	2.7	2.55	2.5
	Migrant Worker	1.0	1.5	1.6
Total Travel		924.3	2142	2353

As shown in table 3 and table 4, different development scenarios result in different traffic demand. Under AOD pattern, the proportion of car use will increase rapidly and become the uppermost traffic mode in 2020 and 2030. Accordingly, the proportion of transit use is lower than that under TOD pattern.

Under TOD pattern, more destinations can be reached by walking or by using a bicycle. Motorcycle and private car will keep a lower use proportion. Transit, including bus and LRT, will be encouraged and become the uppermost traffic mode gradually. The proportion of travel by transit will reach 22.5% in 2020, and 34.5% in 2030. At the same time, the total vehicle miles traveled reduce greatly. At the 2020 horizon, total vehicle miles traveled under scenario2 (90.97 million miles) is about 19.59 million miles lower than that under scenario1, and it makes a 17.7% decrease compared with scenario1.

Evaluation of energy consumption benefit

Through analog computation, simulation result of energy consumption and energy-related emission per year under different scenarios are shown in table 5 and figure 3.

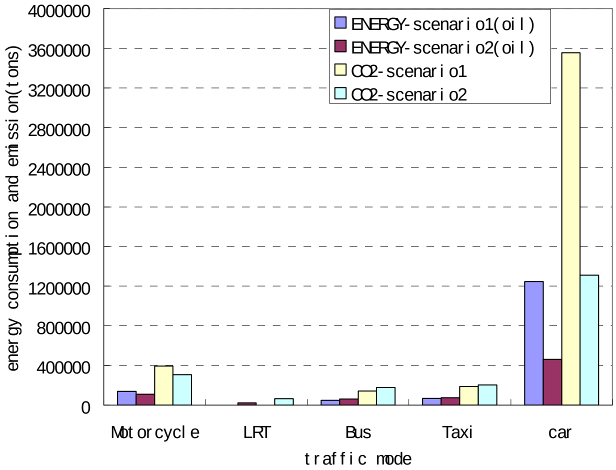

Fig. 3. Energy Consumption and CO_2 Emission of Different Transport Modes at the 2020 horizon

The simulation result indicates that both energy consumption and emission decrease evidently under TOD pattern (scenario2), compared with AOD pattern (scenario1). At the 2020 horizon, energy consumption under scenario2 (721109 tons oil) is about 779038 tons lower than what under scenario1, that is a 51.93% decrease. CO_2 emission and NOx emission under scenario2 is 51.90% and 53.05% lower respectively than that under scenario1. At the 2030 horizon, the result indicates the same rule as in 2020.

As shown in figure 4, among different travel modes, car is the uppermost sources of energy consumption and emission, whose energy consumption almost accounts for 63% and CO_2 emission account for 83% of the system. So, controlling car use and seeking its substitute is very important for sustainable energy development in urban transportation system.

3.4 Some experiences from the case study in Dongguan

As the case study shows, TOD pattern can help to build a sustainable development urban transportation system. It provides a good transport service for the residents with high mobility and few VMT and related pollution. But it is not easy to achieve. From the case study, we get some experiences:

To begin with, planning and its administration are very important for the strategy. Land is valuable and rare in urban area; it's very hard to keep the space of transportation infrastructures unchanged by interest groups. So, a strong policy and implementation is needed.

To continue, cross boundary cooperation should be strengthened. TOD is a kid of coordination between land use and transportation, so a good arrangement of business, transportation and resident is needed. It also needs a good coordination between different sectors, such as bus, LRT, private car.

Thirdly, the balance between cost and income should be kept. Massive transit system is main means for TOD, but it is often costly, both in construction and operation. So, it is every important to find a sound financial support. For many undeveloped cities, it became a key constrain of TOD strategy application.

4. CONCLUSION

From the analysis above, it can be concluded that TOD strategy can improve energy efficiency, reduce energy-related emission. Beside Benefit of energy consumption, the main benefits of TOD also include: improving accessibility and mobility, higher density to preserve more land, providing needed development, and so on. From this dimension, TOD strategy is an attractive, effective and worthwhile strategy.

In the Greater Mekong Subregion, with the rapid economic development and urbanization in recent years, more and more people swarm into cities. Urban sprawl leads to not only more vehicle miles travels, more air pollution, inefficiencies in transportation, but also more energy consumption. Some cities in GMS, such as Kunming, Bangkok, have subjected to these similar problems of Dongguan. This research is expected to provide some experience to the transportation policy maker and planner.

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Table 3. The Data of Scenario1 (AOD)

Time (Year)	2001	2020			2030		
Traffic Mode\ Index	Proportion of Mode (%)	Average Distance Carried (km)	Proportion of Mode (%)	Total Travel Frequencies(million)	Average Distance Carried (km)	Proportion of Mode (%)	Total Travel Frequencies (million)
Motorcycle	25.2	6.3	12.9	2.76	6.1	11.5	2.71
LRT	---	----	---	---	----	---	---
Bus	5.3	8.2	11.0	2.36	8.1	12.7	2.99
Taxi	1.0	10.1	2.0	0.43	10	2.0	0.47
Car	9.8	11.8	27.5	5.89	12.6	30.4	7.15

Table 4. The Data of Scenario2 (TOD)

Time (Year)	2001	2020			2030		
Traffic Mode\Index	Proportion of Mode (%)	Average Distance Carried (km)	Proportion of Mode (%)	Total Travel Frequencies(million)	Average Distance Carried (km)	Proportion of Mode (%)	Total Travel Frequencies (million)
Motorcycle	25.2	6.3	10.0	2.14	6.1	8.5	2.00
LRT	---	16.37	6.5	1.39	15.46	10.8	2.54
Bus	5.3	7.1	16.0	3.43	7.1	23.7	5.58
Taxi	1.0	10.1	2.2	0.47	10	2.0	0.47
Car	9.8	11.6	10.3	2.21	12.3	11.4	2.68

Table 5. Simulation Results of Energy Consumption and Energy-related Emission

Years	2020			2030		
Scenario \ Index	Energy Consumption	CO_2 (ton)	NO_x (ton)	Energy Consumption	CO_2 (ton)	NO_x (ton)
Scenario1	1500146	4275125	21732	1881268	5361456	27707
Scenario2	721109	2056363	10202	897006	2558975	13206
Decrease (%)	51.93	51.90	53.05	52.32	52.27	52.34

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