CO_2 MITIGATION SCENARIOS IN CHINA'S INTER-CITY FREIGHT TRANSPORT

by Ji HAN**, Yoshitsugu HAYASHI***

1. Introduction

Transportation plays a vital role in nations' economy and is also a leading sector in energy consumption and associated CO_2 emissions. As one of the most rapidly growing countries and the second largest CO_2 emitter in the world, China is experiencing a rapid increase in economy and motorized mobility. The transport related energy consumption and CO_2 emissions are ready to soar further and predicted to exceed the level of USA[1]. Thus, to direct the development of transport sector in a sustainable way has become an issue of prime importance for both researchers and policy makers.

A number of studies have been conducted on the issue of GHG emissions and policies concerning transport sector. WCTRS and ITPS[2] analyzed the current situations of urban transport and the environment, and summarized the related strategies and policies for improving the local and global environment. Tsamboulas *et al.*[3] assessed the potential of a specific policy measure to produce a modal shift in favor of intermodal transport on European scale. Mao[4] established a model framework for evaluating the sustainability of transport policy. Wang *et al.*[5] employed a bottom up approach to estimate different CO_2 emissions inventories for different development strategies in China's road transport. These studies provide useful tools and insights for understanding useful policy options and the associate dynamics of CO_2 emissions in transport sector. However, most of them rely more on qualitative analysis, while those systematic and quantitative evaluations of the exact impact of transport policy, and the potential extent that transport could achieve in CO_2 mitigation are seldom found.

2. Methodology and data

System Dynamics (SD) model is emerging as a powerful tool for policy makers to predict complex system changes and future scenarios as a dynamic process. A variety of studies have applied this approach related to environment.[6)-7)] In this study, a SD approach is applied to assess the CO_2 emissions form inter-city freight transport in China. Fig 1 shows the structure. The base year of projection is taken as 2000, and 2020 is set as target year. A number of factors affecting the modal share such as freight volume, network length, fuel price and fuel intensity are considered. Two policies namely, extension of traffic network and imposition of fuel tax are assessed. An adjustment parameter is adopted to ensure the summation of projected modal shares is 100%. Fuel consumption is converted to gasoline due to the data limitation in fuel price. Double-framed symbols denote arrays of four modal freight transport system (railway, highway, waterway and airway).

Historical data from 1978 to 2000 has been mainly complied from the China Statistical Yearbook (1996-2005), Yearbook of China Transportation & Communication (1986-2005), Price Yearbook of China (1997-2005), China's Energy Yearbook (2005) and published papers, etc.

Table 1 shows the characteristics of four transport modes in some selected years. In general, inter-city freight transport in China relies heavily on water, rail and road whereas the share of air has remained negligible in its comparison. The modal share growth rates have varied, with road transport and air services growing at a much faster rate than waterways'.

To assess the role of possible determinants of modal share, a linear model is used;

$$\mathrm{MS}_{i,t} = C_i + a_{1,i}\mathrm{FV}_{i,t} + a_{2,\mathrm{i}}\mathrm{NET}_{i,t} + a_{3,\mathrm{i}}\mathrm{FC}_{i,t} + a_{4,i}T \tag{1}$$

* Keywords: CO_2 mitigation, policy assessment, system dynamics, China

** Dr. Eng., Graduate School of Environmental Studies, Nagoya University,
(Furo-cho, Chikusa-ku, Nagoya, Japan, TEL052-789-2773, FAX 052-789-1454)
*** Member of JSCE, Dr. Eng., Graduate School of Environmental Studies, Nagoya University,
(Furo-cho, Chikusa-ku, Nagoya, Japan, TEL052-789-2772, FAX 052-789-1454)

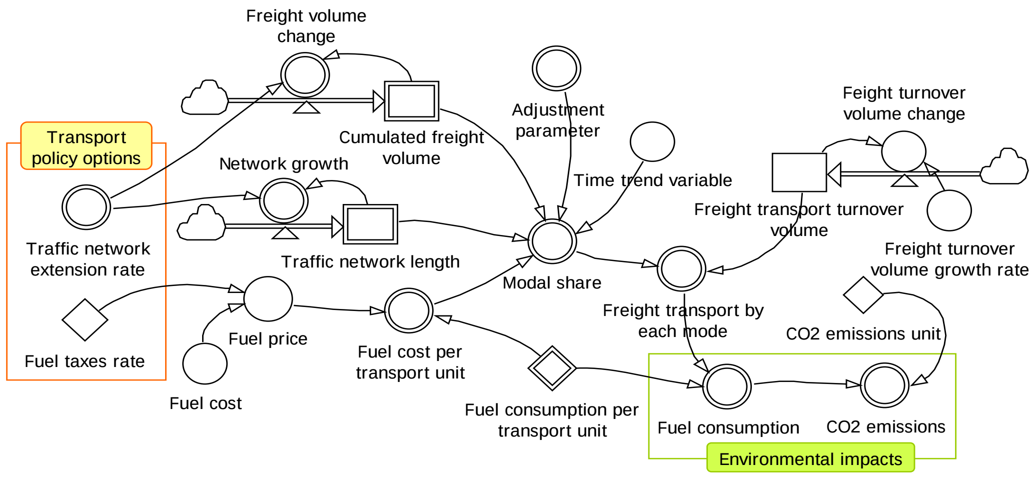

Figure 1: Flow diagram of the system dynamics model

Table 1: Mode characteristics of China's freight transport

Mode	1980	2000
Railway		
Freight turnover volume (trillion ton-km)	0.6	1.4
Freight volume (million tons)	1112.8	1780.2
Network length ('000 km)	53.3	68.7
Fuel intensity ($l/10^4$ ton-km)	66.1	35.1
Highway		
Freight turnover volume (trillion ton-km)	0.076	0.61
Freight volume (million tons)	3820.5	10388.1
Network length ('000 km)	883.3	1402.7
Fuel intensity ($l/10^2$ton-km)	12.8	11.0
Waterway		
Freight turnover volume (trillion ton-km)	0.5	2.4
Freight volume (million tons)	426.8	1223.9
Network length ('000 km)	108.5	119.3
Fuel intensity ($l/10^3$ton-km)	10.9	8.4
Airway		
Freight turnover volume (trillion ton-km)	0.0001	0.005
Freight volume (million tons)	0.1	1.9
Network length ('000 km)	114.1	994.5
Fuel intensity (l/ton-km)	0.6	0.5

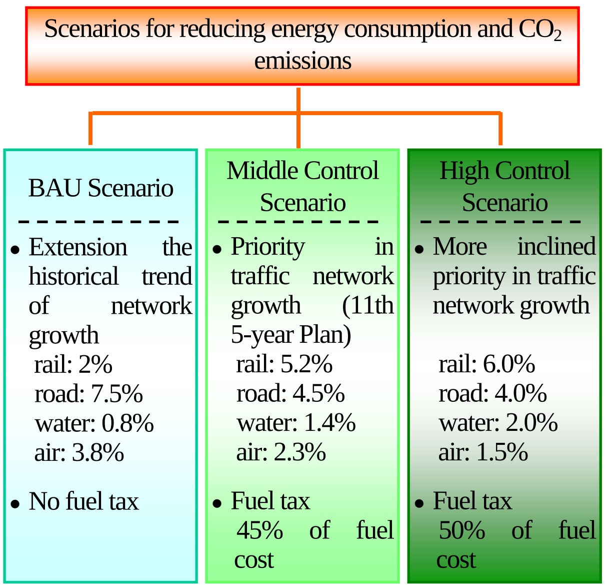

Figure 2: Mitigation scenarios for inter-city freight transport

where, subscript i and t denotes transport mode and year; MS is modal share in percentage; FV is freight volume; NET is traffic network length, which is regarded as one of the most important factors encouraging the modal development. FC is fuel cost per transport unit. Through which, policy measures by imposing taxes can be evaluated; T is time trend variable. Results show the adjusted R^2 in each case is close to 1.0 indicating the linear model is sufficient and reliable (Table 2).

Table 2: Determinants of modal share in inter-city passenger transport 1978-2000

	Railway		Highway		Waterway		Airway	
	coefficient	*t* value	coefficient	*t* value	coefficient	*t* value	coefficient	*t* value
Freight volume (FV)	0.0035	1.93*	0.0001	1.76*	0.006	2.27**	0.005	4.90***
Network length (NET)	0.30	2.60**	0.002	2.07*	0.20	3.11***	0.00002	2.25**
Fuel cost per unit (FC)	-0.13	-3.33***	-0.07	-1.87*	-0.11	-3.66***	-0.009	-1.78*
Time trend variable (T)	-0.76	-4.71***	0.1	4.58***	0.29	2.05*	0.0004	1.79*
Constant (C)	45.04	10.98***	9.8	5.13***	17.26	2.58**	0.06	9.76***
Adjusted R^2	0.98		0.97		0.97		0.99	
F value	420.41***		180.81***		247.96***		523.90***	

*significance:10% **significance:5% ***significance:1%. Stepwise is adopted to eliminate the multicollinearity.

3. Transport policy and scenario design

Since the 1980s, the relevant government departments drafted and implemented policies such as Law on Fuel Saving Management in Transport Sector, Detailed Rules on the Implementation of Energy Conservation Law in Transportation Industries, Mid- and Long-term Specific Plan on Energy Conservation, etc. The general targets are to encourage the development of light vehicles and public transport, and to improve the fuel economy. Moreover, fuel tax legislation has already been enacted in 1999. The possible tax rate is supposed to range from 45% to 50%[8)].

Three scenarios are described in Fig.2. Generally, the growth rate of total freight turnover volume is set as 5.6% during 2006-2020 according to the Eleventh Five-Year Plan. BAU scenario extrapolates the historical trend and assumes the traffic network will increase at the rate during 2000-2005. Middle control scenario mainly bases on the Eleventh Five-Year Plan, and emphasizes on CO_2 mitigation by accelerating the railway and waterway construction and introducing fuel tax rate by 45%. High control scenario implements more intensive policies by giving more priority to railway and waterway while slowing down the pace of highway and airway network extension. Fuel tax rate will be increase to 50%.

4. Results

Fig. 3 presents the future freight transport demand and modal share up to 2020. It shows the turnover volume will properly touch the mark of 13.4 trillion ton-km in 2020. For modal share, waterway still plays a dominant role in freight transport under each scenario. In control scenarios, railway increases its share, whereas the proportions of highway and airway decrease.

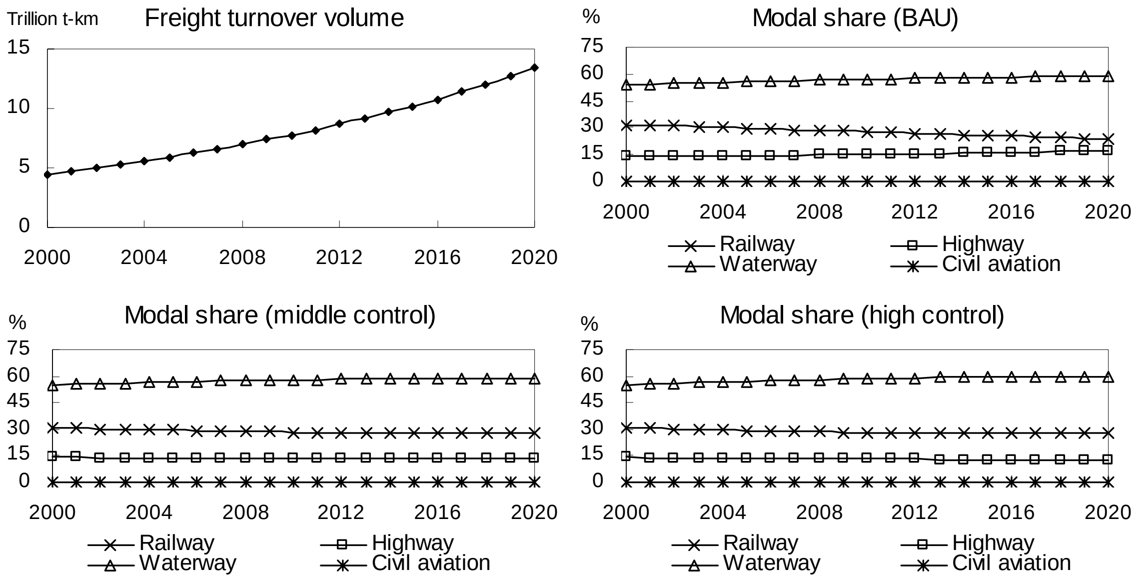

Figure 3: Inter-city freight turnover volume and modal share 2000-2020

Since the fuels consumed in transport are converted to gasoline according to their equivalent heat volume, Eq.(2) is used for estimating CO_2 emissions based on the methods provided by IPCC[9)]. Fig. 4 demonstrates future trends. In BAU scenario, energy consumption in 2020 is supposed to reach 10854 Peta Joules, which is more than 4 times the amount in 2000. CO_2 emissions also record the same sharp increase and amount to 745 million tons in 2020. However, great reduction potential exists in inter-city freight transport. Comparing to BAU, the reduction of CO_2 emissions ranges from 17% to 22% in 2020 under control scenarios.

In this study, policy parameters include traffic network extension and fuel tax rate. However, some parameters may have greater effect on CO_2 mitigation, while others may be less effective. Thus, a sensitivity analysis is conducted by Eq. (2).

$$S = \frac{\Delta \mathrm{EM}_t}{\mathrm{EM}_t} \bigg/ \frac{\Delta X_t}{X_t} \qquad (2)$$

where, S is the sensitivity of a specific parameter in year t; EM is CO_2 emissions; X is policy parameter influencing CO_2 emissions; ΔEM and ΔX are the increments or decrements of CO_2 emissions (EM) and parameter (X) respectively.

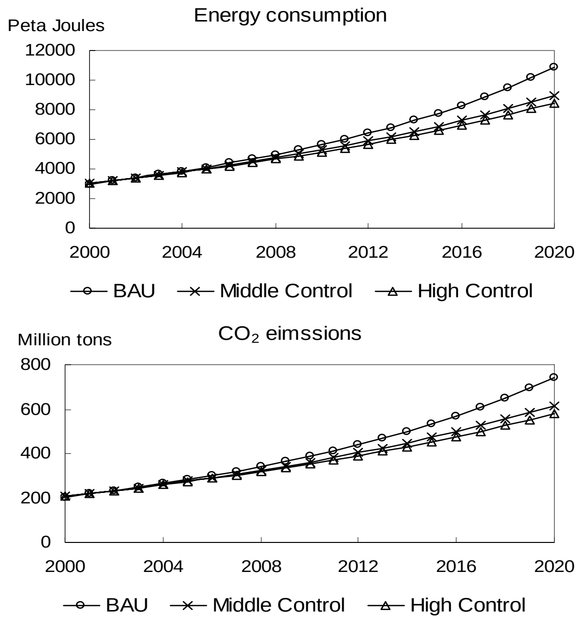

Figure 4: Projections of energy consumption and CO_2 emissions in 2000-2020

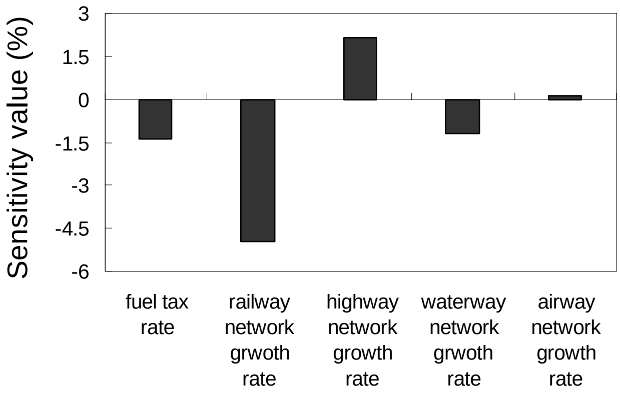

Figure 5: Sensitivity analysis of policy parameters

We assume each parameter will increase by 10% every five years during the period of 2001-2020. Results are shown in Fig. 5, where growth rates of railway, highway and waterway network together with fuel tax rate are the most sensitive three parameters in order. The growth rate of airway network is least sensitive with its sensitivity only valued by 0.1%.

5. Conclusion

Looking at inter-city freight transport in China, and using a system dynamics model for policy assessment and CO_2 mitigation scenario analysis, we find that accelerating the development of railway network is the most effective option. Slowing down highway network extension, improving waterway network and levying fuel taxes are also significant and useful policies for CO_2 mitigation.

References

1) IPCC: IPCC Fourth Assessment Report, Working Group III Report "Mitigation of Climate Change", 2007.
2) World Conference on Transport Research Society (WCTRS) and Institute for Transport Policy Studies (ITPS): Urban transport and the environment: an international perspective. Amsterdam, Elsevier, 2004.
3) Tsamboulas, D., *et al.*: Assessment of a transport policy potential for intermodal mode shift on a European scale. Transportation Research Part A, 41, 715-733, 2006.
4) Mao, B.H., Chen, H.B.: Sustainability analysis of Chinese transport policy. The International Journal of Sustainable Development and World Ecology, 8(4), 323-336, 2001.
5) Wang C., *et al.*: CO2 mitigation scenarios in China's road transport sector. Energy Conversion and Management, 48, 2110-2118, 2007.
6) Guneralp, B., Barlas, Y.: Dynamic modeling of a shallow fresh water lake for ecological and economic sustainability. Ecological Modeling, 167, 115-138, 2003.
7) Kunsch, P., Springael, P.: Simulation with system dynamics and fuzzy reasoning of a tax policy to reduce CO2 emissions in the residential sector. European Journal of Operational Research, 185, 1285-1299, 2008.
8) Zhang, T.J.: Research on quantitative analysis: change from fuel fare to fuel tax. Marketing Research, 12, 27-30, 2006.
9) IPCC: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Workbook. Vol. 2. IPCC, Organization for Economic Cooperation and development (OECD) and International Energy Agency (IEA), 1997.