Evaluating Policies for CO₂ Mitigation in India’s Passenger Transport

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Transport plays a vital role in every nation’s economy. It is also one of the leading sectors in energy consumption and associated CO₂ emissions. This study adopts a system dynamics approach and examines the effectiveness of policies in mitigating CO₂ emissions from all four modes of passenger transport (i.e., railway, highway, waterway and civil aviation) in India. Results indicate that future passenger mobility in India is expected to increase at a annual rate of 7% amounting to six trillion passenger-km in 2020. Passenger transport offers great potential for emissions reduction. In 2020, without any specific policies stressing mitigation, the reduction of CO₂ emissions ranges from 5% to 12% with policy controls. CO₂ mitigation can be best achieved by accelerating the development of the railway network, together with slowing down the extension of the highway network and imposing fuel taxes.

Keywords: CO₂ mitigation, policy assessment, passenger transport, India

1. INTRODUCTION

Transport plays an important role in the overall development of a nation’s socio-economy, and an efficient transport system is a prerequisite for sustained growth. However, it is also a leading sector for energy consumption together with associated greenhouse gas (GHG) emissions, and it is one of the most difficult sources to control.

As one of the most rapidly growing countries and the fifth largest CO₂ emitter in the world (IEA, 2007), India is experiencing rapid growth in economy and motorized mobility. Transport-related energy consumption and pollution problems are poised to soar further. India boasts one of the world’s largest transport networks of railway, highway, waterway and aviation, serving a land of 3.3 million km² and a population of over one billion.
The transport sector in India is a major consumer of the total national energy and constituted 6.5% of the overall CO₂ emissions in 1994, according to India’s Initial National Communication to the United Nations Framework Convention on Climate Change (Ministry of Environment and Forests, 2004). Sustainable development in the transport sector has been an issue of prime importance for both researchers and policy makers all over the world.

A number of studies have been conducted on the issue of GHG emissions and policies concerning India’s transport sector. Sharma et al. (2006) assessed the current situation and projected trends of GHG emission in India by comparing the trends with some selected countries. Singh (2006) projected the level of traffic mobility, energy demand and the consequent CO₂ emissions from land-based passenger mobility in India. Singh et al. (2008) elaborated on the trends of energy consumption and consequent emissions of GHGs from the highway transport sector in India. A limited number of studies focus on the issue of policy assessment in the transport sector in India. Ruijven et al. (2008) explored the potential of the use of hydrogen in the transport sector in India and Western Europe. Pailuly and Parikh (1993) explored the feasibility of replacing diesel and fuel oil with natural gas in the transport sector. These studies provide useful tools and insights for understanding policy options and the associated dynamics of CO₂ emissions in India’s transport sector. However, most of them focus on energy consumption and CO₂ emissions issues in one or two transport modes separately rather than analyzing the passenger transport system aggregately. Moreover, when evaluating the transport policies, previous studies rely more on theoretical abstraction and qualitative analysis, whereas systematic and quantitative evaluation of the policy implication and the potential of CO₂ mitigation are seldom found.

In order to fill the literature gap and improve the shortcomings of previous studies, this paper develops a system dynamics model to quantitatively assess transport policies and the potential for CO₂ reduction in India’s entire passenger transport sector at an aggregate level. The two main policies considered in this study are variation in the network extension rate for different modes and implementation of fuel taxes. All four types of transport modes (i.e., railway, highway, waterway and civil aviation) in India have been considered.

2. PASSENGER TRANSPORT IN INDIA

For policy assessment and future scenario evaluation, historical data pertaining to the four modes have been collected from various sources. Time series data from 1980 to 2000 have been complied mainly from the TERI Energy data Directory and Yearbook (TATA Energy Research Institute, 2007), Statistical Abstracts by Central Statistical Organization (Central Statistical Organization, 2004), reports of the planning commission and various published papers and through the internet.

Table 1 shows the characteristics of the four types of transport mode in select years. As a whole, passenger mobility in India relies heavily on rail and highway whereas the share of water and air has remained negligible in comparison. The transport system handled a total of 1.55 trillion passenger-km (pkm) in 2000 with the total transport mobility growing at around 10% per annum from 1980 to 2000. The share of railway in passenger mobility has declined from 28% in 1990 to 26% in 2000, whereas the share of highway transport has increased from 70% in 1990 to 72% in 2000.
From 2001 to 2007, the growth of railway passenger mobility registered an average growth rate of 7%. In the eleventh five-year plan (2007-2012), the passenger mobility is expected to grow at a rate of 5% per annum. As for network length enhancement, the plan allocates a total investment of 334 billion rupees to achieve 942.2 km of railway length. The estimated passenger number for 2012 is 8.4 billion.
2.2 Highway

In the past, highways in India have contributed to over 70% of the total passenger mobility across the country. And in the eleventh five-year plan, an investment of up to 18 trillion rupees is planned under the National Highway Development Program.

2.3 Waterways

India has about 14500 km of navigable waterway. The concept of waterway was introduced in 1982 to boost the inland water transport in the country. At present, there are three waterways that have been declared. These are Haldia to Allahbad (1620 km), the Brahmaputra from Dhubri to Dadiya (891 km) and the West coast canal from Kotapuram to Kolam (205 km). However, the passenger transport in this sector has been neglected. The eleventh five-year plan emphasizes promoting passenger transport on inland waterways by making appropriate policy intervention.

2.4 Civil Aviation

Civil aviation is growing at a rapid pace and is playing an increasingly important role in providing connectivity for passengers. Air travel in India is currently 0.1 trips per person per year, a fraction of the global average of 2.0 (Connell and Williams, 2006). A total of 14 domestic flight services operate in India. The India aviation industry has witnessed a traffic boom in the last two to three years. During the eleventh five-year plan period, the number of domestic passengers is expected to increase at a rate of 19.9% per annum. The aircraft fleet is proposed to be 347 in 2012 from the existing 202 in 2006.

3. METHODOLOGY

As an important tool supporting policy experiments, system dynamics (SD) methodology not only arranges and describes the complicated connections among each element at different levels, but also deals with dynamic process with feedback in social systems. Moreover, it can predict complex system changes under different “what-if” scenarios, which is useful in examining and recommending policy decisions (Mohapatra et al., 1994). A number of studies have applied this approach related to environment, such as analysis of GHGs and global warming (Vrat et al., 1993; Kunsch and Springael, 2008), environmental sustainability (Saysel et al. 2002) and CO₂ emissions from cement industry (Anand et al. 2006).

Figure 1 shows the relationships among the goals, policies and resulting effects in a system dynamics model. Each arrow indicates the influence of one element on the other. Symbols in a rectangle, diamond and circle denote level, constant and auxiliary respectively. Doubly-framed symbols represent arrays of each transport mode. The base year of projection is taken as 2000, and 2020 is set as the target year. Through the implementation of some specific policies, the inter-modal transport system is expected to generate some environmental effects, which can meet planning goals such as energy saving, mitigation of CO₂ emissions, and reduction of local environmental pollution. A number of factors affect the CO₂ emissions from the transport systems. These are total number of passengers, network length, fuel price and fuel consumption per transport unit. Each of these variables influences the modal shares and consequently the CO₂ emissions. The ultimate aim of the government is to adopt policies for effective CO₂ abatement. In this model, the effect of two policies, namely, extension of network length and imposition of fuel tax, is assessed quantitatively to study their effectiveness in reducing CO₂ emissions from the passenger transport sector in India. An adjustment parameter is adopted to ensure the annual summation of all projected modal shares is...
100%. As a disincentive to use private motorized modes, India’s government also proposes the implementation of fuel taxes and annual highway tax based on carbon emissions (Livemint, 2007). The future growth rate of passenger mobility is set as 7% per annum through 2020 according to the India Vision 2020 report (Government of India, 2002). This study utilizes Powersim as a visual modeling software program for the analysis.

\[ MS_{i,t} = C_i + a_1 \cdot CAP_{i,t} + a_2 \cdot NET_{i,t} + a_3 \cdot FC_{i,t} + a_4 \cdot T \]  

(1)

where, subscripts \( i \) and \( t \) denote transport mode and year; MS is modal share in percentage; CAP is cumulated passenger capacity, which is assumed to have a positive effect on modal share, (that is, the more passengers carried, the larger the modal share will be); and NET is traffic network length. Extension of the network length is one of the most important factors that encourage the use of motorized vehicles. FC is fuel cost per transport unit, calculated by multiplying fuel price with fuel consumption per transport unit. The fiscal policy measure of imposing a fuel tax can be evaluated using this parameter. The higher the fuel cost per transport unit is, the less attractive the mode will be; \( T \) is time trend variable, which ranges from 1 through 21
from 1980 to 2000. It is introduced to reflect an upward or downward trend in the modal share change that cannot be explained by the explanatory variables; C is a constant. Stepwise estimation is adopted to eliminate the correlations among the independent variables although it is recognized that this has very serious technical pitfalls but is easier to interpret than, say, factor analysis. Table 2 shows the results. The adjusted \( R^2 \) in each case is close to 1.0, which indicates the linear combination of explanatory variables is sufficient and reliable for modal share estimation.

(Table 2) Determinants of Modal Share in Passenger Transport 1980-2000

<table>
<thead>
<tr>
<th></th>
<th>Railway</th>
<th>Highway</th>
<th>Waterway</th>
<th>Civil Aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>coefficient</td>
<td>t value</td>
<td>coefficient</td>
<td>t value</td>
</tr>
<tr>
<td>Transport capacity (CAP)</td>
<td>0.006</td>
<td>4.36***</td>
<td>0.003</td>
<td>5.64***</td>
</tr>
<tr>
<td>Network length (NET)</td>
<td>4.702</td>
<td>2.03*</td>
<td>0.011</td>
<td>2.03*</td>
</tr>
<tr>
<td>Fuel cost per unit (FC)</td>
<td>-22934.3</td>
<td>-3.86***</td>
<td>-4219.9</td>
<td>-5.71***</td>
</tr>
<tr>
<td>Time trend variable (T)</td>
<td>-0.627</td>
<td>-2.97***</td>
<td>0.641</td>
<td>2.03*</td>
</tr>
<tr>
<td>Constant (C)</td>
<td>-254.344</td>
<td>-1.78*</td>
<td>50.107</td>
<td>6.58***</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.93</td>
<td>0.98</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>( F ) value</td>
<td>84.65***</td>
<td>263.41***</td>
<td>272.44***</td>
<td>484.80***</td>
</tr>
</tbody>
</table>

*significance: 10% **significance: 5% ***significance: 1%

4. TRANSPORT POLICIES AND SCENARIO DESIGN

(Table 3) Transport Policies Related to Energy Conservation and GHG Mitigation

<table>
<thead>
<tr>
<th>Year</th>
<th>Policy (Issuer)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>National Highway Development Project (National Highway Authority of India)</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Auto Fuel Policy (Government of India)</td>
<td>Set standards for efficient vehicles, cleaner fuels</td>
</tr>
<tr>
<td>2006</td>
<td>Energy Policy (Planning Commission)</td>
<td>Addresses the energy security issue; Policy seeks to improve energy efficiency by reducing energy intensity across many sectors including transport</td>
</tr>
<tr>
<td>2006</td>
<td>National Hydrogen Energy Highway Map (Government of India)</td>
<td>Green Initiative for Future Transport (GIFT); aims at develop H(_2) powered fuel cell based vehicles</td>
</tr>
</tbody>
</table>
Various ministries and agencies are involved in decision making related to transport in India. These include, ministry of surface transport, civil aviation, shipping, railway, urban development, petroleum and environment and forests. In addition, the Planning Commission has been entrusted with formulating integrated transport policies for the country as a whole. Table 3 lists the major polices and actions from the 1980s to the present.

Scenario designs are eminent constructs to analyze alternate futures and are, therefore, useful for policy makers to provide projections of the same. Although they are not predictive, they provide an insight into the future based on the interaction of the key driving factors. In the present study, we construct three scenarios to assess the impact of policy measures on CO$_2$ emissions. The first is the “Business as usual” (BAU) scenario, which assumes average growth in the network length of transport systems and no fuel tax. The second construct is the “middle control” scenario, which assumes growth in traffic network with priority to railways and waterways as compared to highway and airways. In addition, it also introduces the fuel tax as one of the fiscal instruments to mitigate CO$_2$ emissions. A more stringent scenario, “high control” scenario is tested where greater emphasis is given on rail and water network investments and the fuel tax is increased to 50% of fuel cost.

(Figure 2) Mitigation Scenarios for Passenger Transport 2000-2020
5. RESULTS

5.1 Future Passenger Mobility and Modal Share

Figure 3 presents the future trends of passenger mobility and modal share up to 2020. It shows the total volume will properly touch the mark of six trillion pkm at the end of 2020, with an annual average growth rate around 7%.

For modal share, in the BAU scenario, each mode extends the historical trend. Highways contribute the most to total mobility growth, and its share is assumed to keep increasing from 72% in 2000 to 75% in 2020. Market share of civil aviation also grows from 0.75% in 2000 to 0.79% in 2020. On the other hand, the share of railway and waterway will decrease to about 26% and 0.25%, respectively, in 2020. In those control scenarios, with the introduction of specific policies aimed at CO₂ mitigation, environmentally-friendly modes such as railway and waterway are encouraged to expand their shares, while the highway and aviation modes are discouraged due to the relatively high energy consumption and CO₂ emissions. In the high control scenario, the share of railway increases from 26% in 2000 to 38% in 2020. Highway and aviation decreases to 61% and 0.65%, respectively, in 2020. Although waterway only shares 0.35% of the total mobility in 2020, it is enhanced compared to those in the BAU and middle control scenarios.

5.2 Future Energy Requirements and CO₂ Emissions
In the analysis, since all the fuels consumed by each transport mode are all converted to diesel according to their equivalent heat volume, Eq. (2) is used to estimate CO$_2$ emissions from passenger transport based on IPCC methodology (IPCC, 1997).

\[
EM_t = \sum_i (PKM_i \cdot MS_{i,t} \cdot FU_{i,t}) \cdot \alpha \cdot \beta \cdot \gamma \cdot \frac{44}{12} \quad (2)
\]

where, subscripts $i$ and $t$ denote transport mode and year; $EM$ is CO$_2$ emissions from passenger transport; $PKM$ is total passenger mobility; $MS$ is modal share; $FU$ is fuel consumption per transport unit, which is assumed to remain the same in 2000; $\alpha$ is heat conversion factor for diesel, which is $3.6 \times 10^7$ J/L; $\beta$ is carbon emission factor per unit heat generation which is 20.2 kg-carbon/billion-J; $r$ is the proportion of carbon oxidized, which is estimated as 99%.

Figure. 4 demonstrates the results. In the BAU scenario, historical patterns are assumed to continue in the future, and no specific policies stress CO$_2$ mitigation. Energy consumption in 2020 is projected to reach 3763 Peta Joules, which is more than four times the amount in 2000. CO$_2$ emissions also record the same sharp increase and amount to 276 million tons in 2020. In the middle and high control scenarios, the transport structure is adjusted and a fuel tax is introduced. With more and more inclined priorities for the development of railway and waterway and a higher fuel tax, in 2020, energy demand under the middle and high control scenarios is projected to be 3564 and 3296 Peta Joules, respectively. Similarly, the corresponding CO$_2$ emissions are also expected to be reduced by 5% and 12% of that in the BAU scenario.

5.3 Sensitivity Analysis

In this study, policy parameters include varying network growth rate for different modes and levying of fuel tax. However, some parameters may have a greater effect on CO$_2$ mitigation, while others may be less effective. Thus, we conduct sensitivity analysis of each policy parameter.

\[
S = \frac{\Delta EM_t}{EM_t} \cdot \frac{\Delta X_t}{X_t} \quad (3)
\]

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; $\Delta EM$ and $\Delta X$ are the increments or decrements of CO$_2$ emissions (EM) and parameter (X), respectively.

In the calculations, we assume each parameter will increase by 10% every five years from 2001 to 2020. Eq. (3) will produce four sensitivity values for each parameter. Then, we use their average value to
represent the general sensitivity of the parameter to CO₂ emissions. Results are shown in Figure 5, where the highway and airway networks’ growth rates are sensitive to the increase of CO₂ emissions, and the other three parameters are sensitive to the reduction of CO₂ emissions. Moreover, when considering the absolute value of sensitivity, growth rate of railway network, growth rate of highway network and fuel tax rate are the three most sensitive parameters. Their values are 4.8%, 2.1% and 1.1%, respectively. The growth rate of waterway and airway network is the least sensitive to CO₂ emissions in the system dynamics model, with their sensitivity only valued at 0.4% and 0.2%, respectively.

6. CONCLUSION AND DISCUSSION

Firstly, the total passenger mobility in India is expected to increase at a rate around 7% per annum, from 1.55 trillion pkm in 2000 to six trillion pkm at the end of 2020.

Secondly, with the high demand for mobility in the near future, the associated energy consumption and CO₂ emissions will keep increasing no matter what kind of policies are implemented. However, a huge reduction potential exists in the current passenger transport. In 2020, compared to the case without any specific policies stressing mitigation, the reduction of CO₂ emissions ranges from 5% to 12% under those scenarios with policy controls.

Thirdly, among all the policy options examined in this paper, sensitivity analysis suggests that acceleration of the railway network, slowing down of the highway network extension and implementation of fuel taxes will be effective policy options to mitigate CO₂ emissions from passenger transport in India.

Although this paper proposes a system dynamics model for evaluating the influences of policies on India’s passenger transport, the method can also be applied to urban transport if the data are available. In addition, many potential uses and further studies can be derived. For example, by adding assumptions to the model, emissions of some local air pollutants such as CO, SOx and NOx can also be evaluated.

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