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EVALUATION OF POLICIES TO REDUCE TRANSPORTATION POLLUTION USING SYSTEM DYNAMICS

Pollution caused by road transportation is the major factor affecting human health and adversely affecting the global warming. In the study, a system dynamics model has been applied to forecast vehicle emissions from road transport to evaluate policies in the transportation management. The proposed model was applied to evaluate and compare three transportation policy scenarios including road expansion, public transit incentive and enforcement of quality norms for vehicles. The pollution emission data is taken in Chennai, Tamil Nadu. The pollution in the study area will increase substantially if no management plans are implemented. The impact of population increase on transportation pollution has also been considered. It was found that among the proposed policies, implementation of the transit incentive policy to adopt public transports and the implementation of Bharat Stage IV norms for vehicles proved to be efficient in reducing the transport pollution to a great extent.

1. INTRODUCTION

The forecasting of vehicle emission and industrial pollutant emission is complicated in nature because the characteristics of transportation are related to many attributes and change over time. Therefore, the objective of this study is to forecast the pollutant emission represented in terms of g/km unit, measured at a particular point of time in a day, from the road transportation system. In addition, this study also evaluates the proposed policy scenarios that can minimize the pollutant emission. Various policy scenarios in transportation management are compared for transportation planning. To study air pollution related problems, considerable efforts have been taken around the world [1, 2]. According to Tao Huai et al. [3], vehicular emission is the major contributor of air pollution mainly in the cities. As highlighted by Strum [4] and Faiz and

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Sturm [5] one of the major environmental problem is urban air pollution and road traffic. Traffic exhaust emission is one of the most important air pollution sources in urban areas [6]. According to Fenger [7], air pollutant concentrations are dominated by the exhaust emissions of carbon monoxide, oxides of nitrogen and suspended particles from the usage of vehicles in mega cities. The contribution of transport sector as 72% while understanding the problem of vehicular pollution vis-a-vis ambient air quality of a highly traffic affected megacity, Delhi was estimated [8]. The discharge of motor vehicular carbon monoxide in Lahore is due to mass transit system which is because of frequent stoppages, entering and exit in flow of traffic [9, 10].

A number of policies have been activated in India in order to control the level of air pollutants such as particulate matter, oxides of sulfur and oxides of nitrogen [11]. The study described by Vrat et al. [12] was the first to propose the use of system dynamics for policy modeling to reduce global warming and greenhouse effect. Their rudimentary model has also suggested that if the usage of public transport is increased by 70% of total transport, then the reduction of 34% in carbon dioxide emission is possible. To curtail the emission levels in Delhi's urban transport system, a system dynamics model was used [13]. Transport emission is related to the type of fuel, vehicle travel and engine technology [14]. The impact of several policy options to reduce fuel consumptions was evaluated by a system dynamics model developed [15] for Delhi's urban transport system. System dynamics has been used to forecast the energy consumption and pollutant emission from the road transportation to evaluate the policies in transportation management [16].

Global warming has emerged as the dominant environmental problem of our time [17]. The next fifty years will be a period of growing accumulation of greenhouse gases (GHG) in the atmosphere and in rising temperatures. It could also be a period in which all the nations of the world adopt more stringent policies to control the emissions of carbon dioxide (CO_2) and other GHG. If emissions are cut sufficiently, it is possible to stabilize GHG within the first half of this century. The risks of global warming could be reduced but not eliminated.

On-road transportation (ORT) and power generation (PG) sectors are major contributors to CO_2 emissions and a host of short-lived radioactive air pollutants [18]. Effective mitigation of global climatic change necessitates action in these sectors for which technology change options exist or is being developed [10].

The scope of the work involved:

1. Taking into account the population growth and vehicular growth and predicting the pollution loads for a selected region in the city of Chennai (India) for the year 2024.

2. Evaluating different control options and identifying the most sensitive option which would give a drastic reduction in the concentration levels of emission applied to a particular area of study.

3. Facilitating the government to formulate a policy to allow feasible growth without compromising on air quality.

2. REASONS OF TRANSPORTATION POLLUTION

2.1. AREA OF THE STUDY

The primary emission inventory has been carried out at four selected locations in Chennai, each of 2 km×2 km (4 km^2) area during January–December 2011 (Table 1). This data was collected from Tamil Nadu Pollution Control Board, Guindy, Chennai. It is found that Thiyagaraya Nagar (T. Nagar) has produced the maximum pollution in terms of hydrocarbons (HC) and nitrogen oxides (NO_x) produced in the air. Hence, the study of emissions due to transportation and its impact on transportation pollution was evaluated in T. Nagar area in Chennai, Tamil Nadu state as shown in Fig. 1. This area mainly consists of commercial centers, major roads and residential complexes.

Table 1

HC + NO_x [μg/m^3] measured under
Chennai Air Quality Monitoring Programme in 2011

Month	Place			
	Annanagar	Adayar	Kilpauk	T. Nagar
January	188	92	249	267
February	275	80	236	264
March	345	76	245	249
April	289	82	242	247
May	289	117	250	293
June	296	85	213	302
July	277	90	227	257
August	270	96	230	290
September	280	87	229	308
October	244	113	198	355
November	189	111	135	328
December	222	146	236	353
Average	263.7	97.9	224.2	292.8

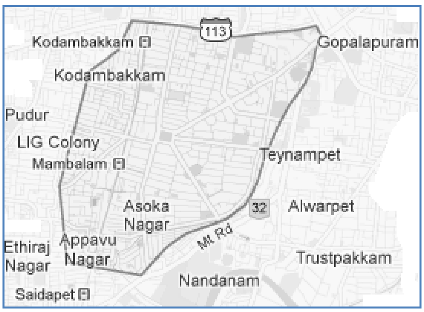

Fig. 1. T. Nagar, Chennai: the map of the area of the study

Figure 2 shows the details of the study area (4 km^2) and land use pattern at T. Nagar. Since it is a commercial with residential area, built up area is dominated in this grid (78%). The open space and roads spread about 8% in this area. Remaining 6% of the area is covered by greenery (4%) and water bodies (2%).

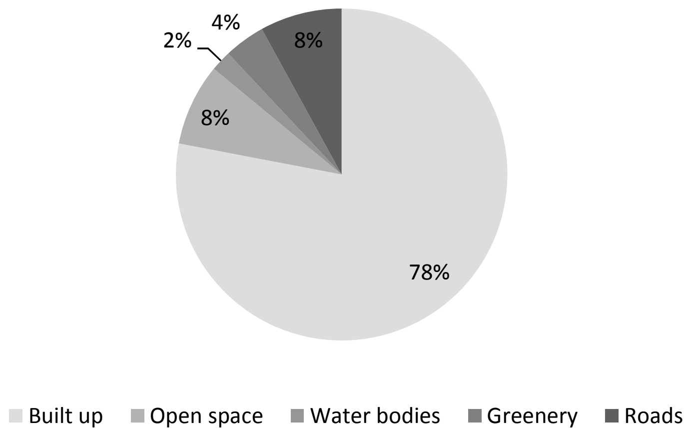

Fig. 2. Land use pattern of T. Nagar area

2.2. SIMULATION STUDY OF THE SYSTEM DYNAMICS

System dynamics model has been applied to forecast the pollutant emission from the road transportation and to evaluate the policies in transportation. The study of emissions due to transportation and its impact on transportation pollution was evaluated in the study area. The following hypothesis is tested using cause and effects simulation study assuming uniform distribution among passenger cars, heavy vehicles and 2/3 wheelers.

Positive feedback loops (R) in the system dynamics tend to increase or desrease without bound. It is called as reinforcement loop. Negative feedback loop (B) tend to adjust itself to some intended value. It is also called balancing loop [19].

- Total vehicles. The first hypothesis assumes that the increase in total vehicles will increase the transport pollution (R1).
- Vehicle density. The second hypothesis assumes that increase in vehicle density measured in terms of number of vehicles per coverage area (CA) increases the transport pollution (R2). Here, the CA of study is 4 km^2.
- Road width. The third hypothesis assumes that the increase in road width (with assumptions of constant vehicle density) will reduce the transport pollution (B1).

The Vensim PLE [20] software is used in this study for modeling and forecasting. The pollution is measured in terms of g/(km·h) in this study. But, in the simulation set up, it is labeled as the actual transport pollution multiplied by the factor of 8760

(24 h/day×365 days) which accounts to a pollution calculated in terms of g/year. But, to simplify the study, the constant factor (8760) is not shown in the results of the forecast study after 12 years of simulation, i.e. prediction for the year 2024.

2.3. EMISSION STANDARDS

Automobiles are major sources of air pollution in many Indian cities. For the estimation of their impact on the ambient air quality, one of the key data required is their emission rate per unit length of roadway q (g/(km·h)). It is calculated from the equation $q = E_f V_h$, where E_f is the pollutant emission factor (km/h) and V_h is the vehicle density (numbers/day).

Table 2

Emission per vehicle (HC + NO_x [g/km]) for various transportation norms

Vehicle exhaust norm	Passenger cars	Heavy vehicles (Diesel)	2/3 wheelers	Average emission per vehicle
India Stage 2000 norms	0.97	9.1	2	4.02
Bharat Stage II	0.50	8.1	1.5	3.36
Bharat Stage III	0.35	6.6	1.0	2.65
Bharat Stage IV	0.18	4.46	–	1.88

Table 3

Sensitivity analysis of various emission norms on the transport pollution [g/km]

Time (year)	India Stage 2000 norms	Bharat Stage II	Bharat Stage III	Bharat Stage IV
1	4	4	4	4
2	5.06	5.06	5.06	5.06
3	6.02	5.62	5.42	5.22
4	9.68	7.68	6.68	5.68
5	14.24	10.24	8.24	6.24
6	19.7	13.3	10.1	6.9
7	27.86	17.86	12.86	7.86
8	38.72	23.92	16.52	9.12
9	50.48	30.48	20.48	10.48
10	64.94	38.54	25.34	12.14
11	80.3	47.1	30.5	13.9
12	96.56	56.16	35.96	15.76

The following hypothesis was tested using simulation study, with the assumption of constant road width, road density and equal distribution of passenger cars, heavy vehicles and 2/3 wheelers. The average emission per vehicle [21] on road varies with the emission standards (Table 2) in force, which in turn leads to different levels of transport pollution. Bharat stage emission standards regulate the output of air pollutants from internal combustion engine equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board (CPCB) under the Ministry of Environment and Forests.

The effect of implementation of such emission norms (with initial value of 4 g/km) has been studied. The results are given in Table 3, assuming road width 25.90 m, number of vehicles – 1000, coverage area – 4 km^2.

2.4. TRAFFIC DENSITY

The traffic density (vehicle density) k is defined as the number of vehicles occupying one traffic lane of unit length of 1 km at any instant of time. It is measured as

$$k = \frac{q}{u}$$

where q is the volume of vehicles (1/h), u – mean speed (km/h).

The traffic density is estimated at Usman road, a major commercial road in T. Nagar under assumptions of homogenous traffic flow, where the speed variation among the vehicles is low and the substreams have constant spacing and constant speed. A two day study was undertaken to measure the average traffic volume (assuming average speed of vehicle as 30 km/h and the values measured during the forenoon (9 am–1 pm) and in the afternoon (2 pm–6 pm). Mean q values and associated k value is reported in Table 4. The mean traffic volume was calculated as 1323 vehicles/h and the average traffic density was 44 vehicles/km (with u = 30 km/h and 26 vehicles/km (with u = 50 km/h).

Table 4

Data collected for traffic volume in T. Nagar

Day	Time of the day	Average traffic volume q [vehicles/h]	Traffic density k [vehicles/km]
Day 1 (Wednesday)	forenoon (9 am–1 pm)	1004	33
	afternoon (2 pm–6 pm)	1239	41
Day 2 (Sunday)	forenoon	1463	49
	afternoon	1584	53

Figure 3 shows the impact of vehicle volume increase on the transport pollution, with sensitivity analysis done for 1000–2000 vehicles.

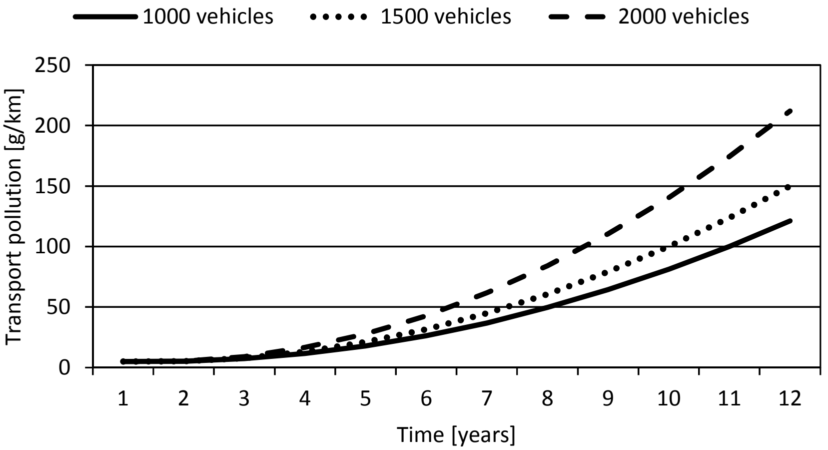

Fig. 3. Sensitivity analysis of varying vehicles volume in function of the transport pollution

One way to reduce the vehicle density is to encourage more people to use public transport than private transport. Hence if the population is oriented towards the usage of public transports, then the transportation pollution will be reduced to a considerable level.

2.5. ROAD WIDTH

The average road width influences the transport pollution, under assumptions of constant vehicle density and it is also assumed that all the vehicles considered in the study area adhere to Bharat stage III emission norms with emission per vehicle of 2.65 g/km. Figure 4 shows the impact of road width for 9.14 m (low road width) and 24 m (high road width) on transport pollution.

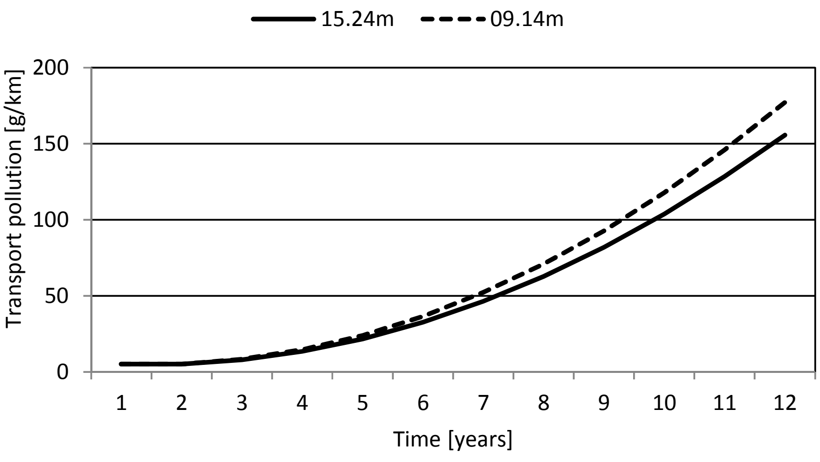

Fig. 4. Dependence of transport pollution on the road width

2.6. POPULATION GROWTH

It is hypothesized that the increase in population proportionally contributes to the increase in vehicles. Hence, the statistics relevant to Chennai population [22] were collected (Table 5) and the rate of increase of population was calculated and thus validated with the real time data. With the increase in population rate, it is found that vehicular density is proportionlly increased and thus leads to increase in pollution.

Table 5

Input data used for simulation (July 2011)

Data	Value
Birth rate	20.6 births/1000 population
Death rate	7.43 deaths/1000 population
Initial population	7.46 million
Population increase rate (PIR)	1.212%

The approximate rate of increase of population is 1.04 per year as per the simulation results. Hence the rate of increase of population is used to predict the corresponding population for the year 2024 and shown in Fig. 5

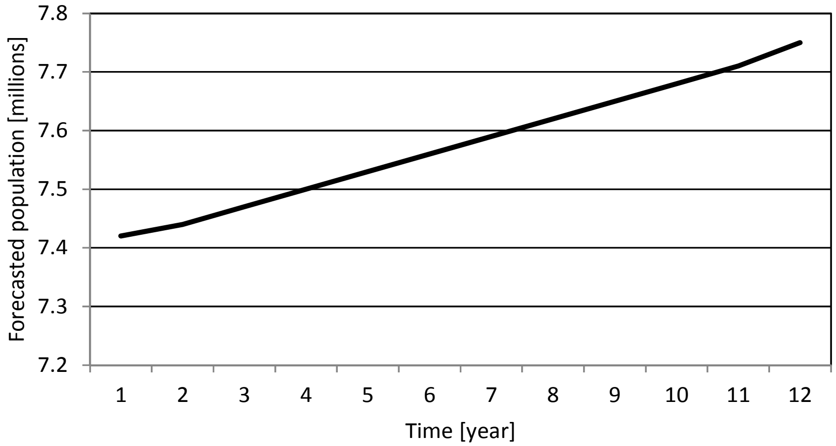

Fig. 5. Population forecast till 2024 for Chennai

When the population increases, there is a proportional increase in the number of vehicles, hence, the total transport pollution increases, assuming fixed coverage area of study. This hypothesis was tested with varying rates of population increase and the results of simulation are studied with the population increase rate (PIR) of 1.2% and 2.1% and the corresponding transport pollution is forecasted for 12 years (Table 6).

Table 6

Sensitivity analysis of the impact
of PIR on transport pollution

Time (year)	Transport pollution	
	PIR = 2.1%	PIR = 1.2%
1	5	5
2	5.06	5.06
3	5.9156	5.732
4	9.158	8.24
5	13.196	11.36
6	18.0296	15.092
7	25.25	20.66
8	34.8572	28.064
9	45.26	36.08
10	58.0496	45.932
11	71.6348	56.396
12	86.0156	67.472

2.7. POLICY RECOMMENDATIONS

The summary of predictions for the year 2024 under various sensitivity analyses of policies are compared and shown in Table 7. Hence the strict enforcement of the following suggestions are recommended to the authorities.

- The Government can invest more to promote the state rapid transit/public transport.
- The use of tram can be revoked as from the past. Tram does not require separate space as railways. It can move with other vehicles on the road itself. Kolkata makes use of trams very effectively even today.
- Office/school/college commuters can make effective use of pooling system to avoid pollution.
- The use of e-bikes and electric cars can be promoted as they do not use petrol/diesel.
- The taxes on HDV (high definition vehicles) can be hiked and the revenue from them can be used to setup trams, emission control tests and researches on natural fuel. This will not affect the middle class or working class people. The hike will not make much of a different to the upper and higher income group.
- Research should be encouraged on biogas/gobargas as fuel for transportation. Short transport can make use of the above.
- Emission testing centers can be setup at the regional transport office (RTO) itself which will make the procedure easy for vehicle owners. Periodical checkup for emission testing should be enforced mandatory. This can be done in a separate wing at all RTO.

Hence, it is evident that enforcement of emission norms and promotion of the use of public transport are the best policies to reduce the transportation pollution compared to the other policies.

Table 7

Various policies to reduce transport pollution

<table>
<tr><td rowspan="2">Policy studied</td><td colspan="4">Transport pollution × 8760 [g/(km·year)]</td><td rowspan="3">Improvement [%]</td></tr>
<tr><td colspan="2">2012</td><td colspan="2">2024</td></tr>
<tr><td rowspan="2">Implementation of emission norms</td><td colspan="2">Bharat Stage III norms</td><td colspan="2">Bharat Stage IV norms</td></tr>
<tr><td>Initial = 4</td><td>Final = 35.96</td><td>Initial = 4</td><td>Final = 15.76</td><td>56</td></tr>
<tr><td rowspan="2">Promotion of public transport utility</td><td colspan="2">Traffic density = 50 vehicles/km</td><td colspan="2">Traffic density = 30 vehicles/km</td><td rowspan="2">51</td></tr>
<tr><td>Initial = 4</td><td>Final = 58</td><td>Initial = 4</td><td>Final = 28</td></tr>
<tr><td rowspan="2">Improvement of road width</td><td colspan="2">Road width = 9.14 m</td><td colspan="2">Road width = 15.24 m</td><td rowspan="2">13</td></tr>
<tr><td>Initial = 4</td><td>Final = 177</td><td>Initial = 4</td><td>Final = 155</td></tr>
<tr><td rowspan="2">Reduction of population</td><td colspan="2">PIR = 2.1%</td><td colspan="2">PIR=1.2%</td><td rowspan="2">21</td></tr>
<tr><td>Initial = 5</td><td>Final = 86.0156</td><td>Initial = 5</td><td>Final = 67.47</td></tr>
</table>

3. CONCLUSION

Transportation is one of the primary contributors to global warming. To effectively curve global warming, vehicular emissions should be drastically reduced. Hence, it is recommended that public mode of transport be encouraged and latest emission norms strictly adhered to reduce vehicular emissions. This could prevent emission of greenhouse gases and thus preventing global warming. Awareness programs, camps and also through visual communications, the dangers of global warming because of transport pollution can be reduced. Apart from all the above, to reduce vehicular emissions, a psychological and moral approach is also recommended.

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