Use of System Dynamics Forecasting Model in Transportation System to Reduce Vehicular Emissions-A Mathematical Approach

Sandeep Singh¹, Bishnu Kant Shukla²* and Pushpendra Kumar Sharma³

¹ Department of Civil Engineering, National Institute of Technology, Tiruchirappalli, India
²*,³ School of Civil Engineering, Lovely Professional University, Phagwara, India

E-mail of corresponding author : bishnukantshukla@gmail.com

Abstract. In recent years, the surface water quality has been observed deteriorating due to industrial activities and pollution in the Punjab state. Evaluation of surface water quality is an important issue to assure from its safe and stable use. However, describing quality conditions is generally difficult considering spatial variability of pollutants and a wide range of indicators like biological, physical and chemical substances which can be measured. This paper includes the study of surface water quality parameters in the northern Punjab region. Samples from different sources across northern Punjab were analysed for pH, TDS, TSS, turbidity, DO, chloride content, iron content and hardness of surface water. The pH, TDS, TSS, turbidity, DO, chloride content, iron content and hardness were found in the range of 6.7-8.7, 1358.00-1430.60 mg/l, 135.10-141.21 mg/l, 0.001-0.62 NTU, 0.96-7.80 mg/l, 0.80-15.56 mg/l, 0.01-0.02 mg/l and 1.2-13.9 mg/l respectively. The obtained results were compared with the acceptance limits as given by Indian standard code IS: 10500-2012. The high values of water quality parameters obtained as a result of this study indicates the level of pollution of the different sources of surface water of northern Punjab. At the end the obtained results were critically examined and suggestions were made for better management of surface water resources.

An efficient transportation system is vital to economic development and a sustainable environment in a country. India's road transportation contributes to approximately 5.4% of the GDP carrying 65% of freight traffic and 85% of passenger traffic. India's fuel imports are growing at an average of 18% annually for which India spends 3.5% of GDP, thereby posing a major threat to the economy of the country in the future. Also, the use of such a high quantity of fuel causes vehicular pollution, which is responsible for fuel emission in urban areas. This study concentrates on carrying out an interdisciplinary work involving the sectors of transportation, energy, and environment considering the parameters like vehicle model split, fuel consumption and vehicular emissions. This is done by building, System Dynamics (SD) forecasting simulation models using STELLA software to mathematically forecast these parameters in the upcoming years until 2030. Hence, a scenario of augmenting the growth rate of public transportation and simultaneously restricting the growth rate of personalised transportation showed a substantial decrease in fuel consumption and fuel emissions, which eventually resulted in a reduction of fuel cost as well as an increase in the GDP in the transportation system for Chennai city.

Keywords : Transportation System, System Dynamics (SD), Model Split, Gross Domestic Product (GDP), Vehicular Emission

1. Introduction
Before a few decades, the concept of sustainable development was not remarkably known across the globe; the sustainable development was primarily an issue concerned with the developed nations. Thereafter, due to the adverse effects of climate change all around the world, sustainable development
became a buzz word. That is when all the nations understood the importance of sustainable development and decided to change the environmental policies. So an integrated and multidisciplinary approach to tackle this issue become the need of the hour. Hence policies were framed based on these grounds, but not with adequate interdisciplinary research. Therefore, it become very much important to understand the influence of one sector over the other. The critical relationship between transportation, energy, economy and environment comes into the picture as one takes into account the exact importance of transportation for economic growth in which the energy sector and environmental sector are also involved. The energy sector and environmental sector play a vital role in performing the balance between the transportation sector and the economic sector. Hence it could be said that the transportation sector is driven by the energy sector, whereas the economic sector is driven by the transportation sector. So it can be concluded that the transportation sector and economic sector are like the balancing wheels of each other for driving the energy sector and environmental sector of any country. Any imbalance in these sectors of transportation and the economy could cause an unforeseen effect on the energy and environmental sector. This may result in significant losses to the country in the form of intangible monetary values. Fluctuations in the oil prices overnight have never gone without surprising the Indian people who majorly depended on personalized transport. So keeping these things in mind the policies are to be framed which are accountable and assists in maintaining a balance amongst these four sectors. Hence collective effort and unified policy measures are the essential requirements to face these challenges and minimize these losses in order to achieve efficiency in the usage of sustainable transportation systems.

2. Literature survey

The literature of various research works carried out in different countries in the same field of System Dynamics (SD) modelling involving transportation, energy, economy and environment sector have been collected and studied [1-10]. Study conducted on strategic modelling of transportation, economy, and energy scenarios resulted in evaluation of two different strategic SD models, namely the ASTRA model (SD model focused on describing the linkages between transportation, economy, and environment) and the MARS model [7]. Both models make use of certain modules to determine travel behaviour by running their sub-models iteratively for 25 years. The salient features of both the above models were incorporated and the final model to depict the future energy supply was developed.

Several authors worked on feasibilities of energy options for India for an interdependent world [7, 11-14]. They analysed the implications of the available domestic energy potential for the energy supply and demand situation in the transportation sector. A quantitative model had been built taking into account the possible forms of energy consumption for the purpose of transportation of the people and freight. Simulation was carried out from the base year 2000 up to the year 2050. Demand projections were made based on key factors like economic growth and demographics and their corresponding dynamics. Method was evolved to quantify the energy consumed by the transport sector, which is necessary to develop travel demand models that can predict the travel needs of the population by mode, time of day, duration and location [3]. Such travel demand models must consider the travel needs not only of individuals but also of businesses and other organizations. The author concluded that in understanding energy consumption vis-à-vis transport, it is important to take into account not only the short-term decisions such as destination and mode choice but also the medium to long-term decisions made by individuals and firms with respect to residential and workplace location, auto-ownership, and labour force participation.

Forecasting model was built for the future number of different types of vehicles and their energy consumption using a System Dynamics approach as a result of study on the transportation and energy sector [10]. Three scenarios were analysed to predict the future demand in transportation and energy sector estimation by considering vehicle ownership, growth in income level and CO₂ emissions rate per annum. These three scenarios were studied by changing their growth rates [15-18]. Finally, the best scenario has been suggested for policy implementation. Research was conducted on the effect of transport emissions on economic development [13]. This basically deals with the pattern of the spatial
development of the transportation sector and its effect on the environment in India. The author made use of a general equilibrium framework for estimating the contributions of transportation emissions to the spatial development of a particular region.

As evident from the aforementioned literature review, several studies [7, 11-12, 14-21] have been done in the past by researchers, but still, an interrelationship based study is not critically analysed in the sectors involving transportation, energy, and environment. Therefore, this instigates the need for this research work. Hence the primary objective of this research work is firstly, to study the energy and emission factors that influence the road transportation sector. Secondly, to build various alternative scenarios based on System Dynamics (SD) simulation models for forecasting future demands involving the sectors of transportation, energy and environment, thirdly to critically investigate and analyze the SD models which would potentially address and reduce the losses in transportation, energy and environmental sectors and finally, to recommend appropriate transport policies that ensure prosperity in building up a sustainable transportation system.

3. Study framework

After various literature reviews, a study framework is designed in the form of a flow chart to investigate and analyze the research work to be carried out which is shown in figure 1.

![Figure 1. Study framework](image)

Nevertheless, one of the valuable tools available to deal with the multifarious complex and dynamic problems is the SD simulation approach for forecasting the interrelated variables for different scenarios. The SD operates on the basis of feedback information, it is used as a methodology to simulate the future demand in the four sectors and their impact on the various policy options. So the data collection is the initial stage for the study after which the SD model conceptualization has been carried out in establishing the relationship between the variables of transport, energy and environment sector. This followed by building up and analysis of SD models for different scenarios (Do minimum, Partial and Desirable Scenario). The model calibration and model evaluation has been carried out by
adjusting and fine-tuning the variables under consideration to reflect the real system. The comparison of results under the different scenarios has been carried out to determine the advantages of the policy measures adopted. Further, based on the obtained results critical and appropriate recommendations for adopting the policy have been given.

4. Study area
The study area selected is Chennai city which is one among the four metropolitan areas in India with a population of around 90 million with an area of 174 km$^2$ and is governed by the Chennai Corporation. The Chennai city has a heterogeneous type of road traffic condition majorly occupied by personalized vehicles like Two Wheelers (TW) & Cars (CR) and public transportation system like Metropolitan Transport Corporation Buses (MTCB). Other types of vehicles like Auto-Rickshaws (AR), Taxies (TX), Private Buses (PB), Mini Buses (MB), Light Commercial Vehicles (LCV) and Heavy Commercial Vehicles (HCV) are also found to be plying on the city roads. Due to the increase in the growth rate of vehicular population, especially personalized vehicles in the Chennai city, there is a robust increase in fuel consumption and fuel emissions. This has resulted in increased fuel price due to fuel imports from other nations. Hence it is imperative to study this effect on the economic growth rate through a system dynamics approach aimed at analyzing the impact of the increase in the vehicular population on the energy usage in the transportation sector which in turn influences the environment of the city.

5. Data collection

5.1. Transportation Sector
Under the transportation sector, the data collected is the vehicle classification and its composition along with their respective growth rate values. These are used for the purpose of scenario analysis, such as the do-minimum scenario, partial scenario and desirable scenario. The system dynamic models are built using these data and the forecasting of the same values is done for the horizon year 2030. The different class of vehicles and their vehicle population for the Chennai city is considered for this study, which is shown in the below Table 1.

| Class of Vehicle | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  |
|------------------|-------|-------|-------|-------|-------|-------|
| MTCB             | 3421  | 3464  | 3527  | 3654  | 3798  | 4257  |
| AR               | 49062 | 63340 | 66674 | 68599 | 70933 | 73854 |
| TX               | 1259  | 1268  | 1354  | 1475  | 1517  | 1628  |
| LCV              | 11836 | 12736 | 19123 | 21469 | 33136 | 41248 |
| HCV              | 12846 | 17928 | 22165 | 33571 | 40833 | 49124 |
| MB               | 2095  | 2217  | 2355  | 2406  | 2491  | 2575  |
| TW               | 2201583 | 2581678 | 2891852 | 3053794 | 3279456 | 3509160 |
| CR               | 482970 | 581379 | 598762 | 615753 | 655356 | 687268 |
| Total            | 2767774 | 3266916 | 3608774 | 3803712 | 4090535 | 4372157 |

Source: Statistics of the transportation department, Chennai (www.tn.gov.in)

5.2. Energy Sector
Under the energy sector the average distance travelled by the various classes of vehicles in Km/day, efficiency of fuel in Km/litre and the consumption of fuel in litre/year for the different class of vehicle is taken into account and is used in the model building and simulation development process which is shown in Table 2.
Table 2. Fuel efficiency and fuel consumption of the different class vehicle

| Class of Vehicle | Average Distance Travelled (Km/day) | Fuel Efficiency (Km/litre) | Fuel Consumption (Litres/year) |
|------------------|------------------------------------|---------------------------|-------------------------------|
| MTCB             | 151                                | 4.1                       | 13415                         |
| AR               | 96                                 | 21                        | 1669                          |
| TX               | 21                                 | 13                        | 534                           |
| LCV              | 51                                 | 14                        | 1330                          |
| HCV              | 55                                 | 4.33                      | 4637                          |
| PB               | 111                                | 05                        | 11863                         |
| MB               | 22                                 | 8.7                       | 897                           |
| TW               | 18                                 | 53                        | 124                           |
| CR               | 24                                 | 12.9 (Petrol)             | 684                           |
|                 |                                    | 15.6 (Diesel)             | 652                           |

Source: Report of the Expert Group, Government of India Report.

5.3. Environmental Sector

The city of Chennai is ranked third among the Indian cities for Greenhouse Gas (GHG) emissions from the transport sector with 11.34% carbon dioxide equivalent (CO₂e) emissions. Chennai is the highest per capita emitter of GHG with 4.79 tonnes of CO₂e emissions per capita. Chennai also emits the highest carbon dioxide equivalent per GDP of 2.55 tonnes of carbon dioxide equivalent per lakh rupees. The data regarding the type of pollutants emitted from the class of each vehicle are given in Table 4.

Table 3. Pollutants emitted from different class of vehicles in grams/Km

| Pollutant type | MTCB | AR  | TX  | LCV | HCV | PB  | MB  | TW  | CR  |
|----------------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| CO₂            | 515.20| 60.30| 208.30| 423.84| 423.84| 515.20| 515.20| 26.60| 223.6 |
| CO             | 3.60  | 5.10 | 0.90 | 1.61 | 1.61 | 3.60 | 3.60 | 2.20 | 1.98  |
| NO₅            | 12.00 | 1.28 | 0.50 | 10.96| 10.96| 12.00| 12.00| 0.19 | 0.20  |
| CH₄            | 0.09  | 0.18 | 0.01 | 0.05 | 0.05 | 0.09 | 0.09 | 0.18 | 0.17  |
| SO₂            | 1.42  | 0.029| 10.3 | 1.39 | 1.39 | 1.42 | 1.42 | 0.01 | 0.05  |
| PM             | 0.56  | 0.20 | 0.07 | 0.33 | 0.33 | 0.56 | 0.56 | 0.05 | 0.03  |
| HC             | 0.87  | 0.14 | 0.13 | 0.50 | 0.50 | 0.87 | 0.87 | 1.42 | 0.25  |

Source: Ramachandra and Shwetmala (2009)

The above pollutants emitted from different class of vehicles are measured in terms of grams/Km, which are multiplied by the average distance travelled by the particular class of a vehicle and the total number of vehicles for that particular year to find the Fuel Emissions (FE) in Gigagrams/day (Gg/day). The FE values for the previous years are used for forecasting the fuel emissions for the horizon year 2030.

6. Scenario analysis and model results

Three different scenarios were developed to mathematically forecast the future demands with respect to the vehicle population, fuel consumption and fuel emissions. The developed SD simulation models for scenario I and scenario II & III are shown in figure 2 (a) and (b), respectively.
6.1. Scenario I-Do Minimum Scenario (When the existing trend is allowed to be continued)
In this scenario, the existing growth rates of the different class of vehicles like MTCB, AR, TX, PB, MB, LCV, HCV, TW and CR are considered to continue up to the horizon year 2030. Based on which the values of fuel consumption and fuel emissions by each class of vehicle have been simulated. The developed SD simulation model is shown in Figure 2 (a).

Table 4. Results from scenario I – Forecasted vehicle population

| Year | MTCB | AR   | TX   | LCV | HCV | PB   | MB  | TW   | CR   |
|------|------|------|------|-----|-----|------|-----|------|------|
| 2018 | 4257 | 73854| 1628 | 41248| 49124| 3043 | 2575| 35.09| 6.87 |
| 2019 | 4436 | 78211| 1939 | 49126| 50057| 3442 | 2858| 38.01| 7.52 |
| 2020 | 4622 | 82826| 2309 | 58510| 51008| 3892 | 3173| 41.18| 8.22 |
| 2021 | 4816 | 87713| 2750 | 69685| 51978| 4402 | 3522| 44.61| 9.00 |
| 2022 | 5019 | 92888| 3276 | 82995| 52965| 4979 | 3909| 48.32| 9.84 |
| 2023 | 5229 | 98368| 3901 | 98847| 53972| 5631 | 4339| 52.35| 10.77|
| 2024 | 5449 | 104172| 4646| 117726| 54997| 6369 | 4816| 56.71| 11.78|
| 2025 | 5678 | 110318| 5534| 140212| 56042| 7203 | 5346| 61.43| 12.89|
| 2026 | 5916 | 116827| 6591| 166993| 57107| 8147 | 5934| 66.55| 14.10|
| 2027 | 6165 | 123719| 7850| 198888| 58192| 9214 | 6587| 72.10| 15.43|
| 2028 | 6424 | 131019| 9349| 236876| 59297| 10421| 7312| 78.10| 16.88|
| 2029 | 6693 | 138749| 11135| 282119| 60424| 11787| 8116| 84.61| 18.47|
| 2030 | 7155 | 148632| 12257| 299484| 62074| 12756| 9446| 92.41| 19.89|

It can be seen from Table 4 that if the existing trend is allowed to continue, the number of TW and CR would reach 92.41 lakhs and 19.89 lakhs (personalized transportation), respectively in the horizon year 2030. The public transportation vehicles constituting the MTCB have increased to a fleet size of around 7155 in the horizon year 2030. The growth of vehicle population has an incidental increase in the respective level of fuel consumption and fuel emission for each class of vehicles. The
consumption of fuel for different vehicle class in litres per day and its respective fuel emissions is shown in Table 5 and 6 respectively.

Table 5. Results from scenario I – Forecasted fuel consumption by each class of vehicle

| Year | MTCB   | AR     | TX     | LCV | HCV | PB | MB | TW (lakhs) | CR (lakhs) |
|------|--------|--------|--------|-----|-----|----|----|------------|------------|
|      | (In lakh litres/day) |      |        |     |     |    |    |            |            |
| 2018 | 1.48   | 3.37   | 0.059  | 1.50| 6.23| 1.06| 0.065|8.65        |10.98       |
| 2019 | 1.54   | 3.57   | 0.070  | 1.78| 6.35| 1.20| 0.072|9.37        |12.01       |
| 2020 | 1.61   | 3.78   | 0.084  | 2.13| 6.47| 1.35| 0.080|10.15       |13.14       |
| 2021 | 1.67   | 4.00   | 0.010  | 2.53| 6.60| 1.53| 0.089|11.00       |14.38       |
| 2022 | 1.75   | 4.24   | 0.011  | 3.02| 6.72| 1.73| 0.09 |11.91       |15.73       |
| 2023 | 1.82   | 4.49   | 0.014  | 3.60| 6.85| 1.96| 0.10 |12.90       |17.21       |
| 2024 | 1.90   | 4.76   | 0.016  | 4.28| 6.98| 2.22| 0.12 |13.98       |18.83       |
| 2025 | 1.98   | 5.04   | 0.020  | 5.10| 7.11| 2.51| 0.13 |15.14       |20.60       |
| 2026 | 2.06   | 5.34   | 0.024  | 6.08| 7.25| 2.84| 0.15 |16.41       |22.53       |
| 2027 | 2.14   | 5.65   | 0.028  | 7.24| 7.39| 3.21| 0.16 |17.77       |24.65       |
| 2028 | 2.21   | 5.98   | 0.034  | 8.62| 7.53| 3.63| 0.18 |19.25       |26.97       |
| 2029 | 2.33   | 6.34   | 0.040  |10.27| 7.67| 4.11| 0.20 |20.86       |29.51       |
| 2030 | 2.49   | 6.98   | 0.046  |10.87| 7.95| 4.42| 0.21 |21.57       |30.32       |

In this scenario with the growth in the number of vehicles between the public and personalized transport, fuel consumption is also seen to increase. The forecasted fuel consumption by TW is 21.57 lakh litres per day, CR is 30.32 lakh litres per day and MTCB is just 2.49 lakh litres per day in 2030. Finally, the total fuel that would be consumed by all the vehicles in 2030 would be 309.72 crore litres per annum.

Table 6. Results from scenario I – Forecasted fuel emission for each class of vehicles

| Year | MTCB | AR | TX | LCV | HCV | PB | MB | TW | CR |
|------|------|----|----|-----|-----|----|----|----|----|
|      | (In Gg/day) |    |    |     |     |    |    |    |    |
| 2018 | 0.343| 0.477|0.008| 0.923| 1.185| 0.180| 0.030|1.936| 3.732|
| 2019 | 0.360| 0.502|0.008| 0.956| 1.253| 0.188| 0.031|2.174| 4.147|
| 2020 | 0.378| 0.530|0.008| 0.990| 1.324| 0.196| 0.032|2.442| 4.607|
| 2021 | 0.397| 0.558|0.009| 1.026| 1.400| 0.205| 0.033|2.742| 5.118|
| 2022 | 0.417| 0.588|0.009| 1.063| 1.479| 0.214| 0.033|3.079| 5.686|
| 2023 | 0.438| 0.620|0.009| 1.101| 1.564| 0.224| 0.034|3.458| 6.318|
| 2024 | 0.460| 0.653|0.010| 1.141| 1.653| 0.233| 0.035|3.883| 7.019|
| 2025 | 0.483| 0.689|0.010| 1.182| 1.747| 0.244| 0.036|4.361| 7.798|
| 2026 | 0.507| 0.726|0.011| 1.225| 1.847| 0.254| 0.037|4.897| 8.664|
| 2027 | 0.532| 0.765|0.011| 1.269| 1.952| 0.266| 0.038|5.500| 9.625|
| 2028 | 0.559| 0.807|0.012| 1.314| 2.063| 0.277| 0.039|6.176|10.694|
| 2029 | 0.587| 0.850|0.012| 1.362| 2.181| 0.290| 0.040|6.936|11.881|
| 2030 | 0.616| 0.896|0.013| 1.411| 2.305| 0.302| 0.041|7.789|13.199|

It can be seen from Table 6 that if the existing trend is allowed to continue till the horizon year 2030, the fuel emission of TW, CR and MTCB would reach to 7.789 Gg/day, 13.199 Gg/day and
0.616 Gg/day, respectively. So the total annual fuel emission would be 9699 Gg/annum. These higher levels of fuel emissions are causing a major threat to the sustainable development of the city which needs to be reduced through appropriate policy regulations for which two major scenario-based models are developed and analysed in this research work.

6.2 Scenario II- Partial Efforts Scenario

In this scenario of partial efforts, the growth rate values of MTCB, TW and CR has been altered as per the Government policies which targets for a 50:50 modal split between public and personalized transport modes for the horizon year 2030. The forecasting process of the SD simulation built model is carried out for each class of vehicle on the basis of their incremental growth rate values which is shown in Figure 2 (b).

To achieve the target of 50:50 modal split between public and personalized transport modes, the growth rate of the former one has been increased to reach 11.10% and on the other hand, at the same time the growth rate of TW and CR is restrained to be 4.16% & 4.73% respectively which is nearly half of the already existing value of growth rate of TW and CR. Meanwhile, the growth rates of the other modes of transport like the AR, TX, LCV, HCV, PB and MB is assumed to be the same as that in the do-minimum scenario since the model split process is carried out between the public and personalized transport system. The simulated values of the forecasted vehicle population for each class of vehicle-based on the above-mentioned growth rates are shown in Table 7.

It can be observed from Table 7 that if minimal efforts are applied based on the government’s policy and by altering the growth rate of existing trend, the number of TW and CR would reach 46.06 lakh and 11.18 lakh respectively from 92.41 lakh and 19.89 lakh respectively (scenario I values) in 2030, whereas the public transportation vehicles constituting the MTCB have increased only to a fleet size of around 13217 from 7155 (scenario I value) in the horizon year 2030. This happens so because of the consideration of the hypothesis that 40 TW and 20 CR can be replaced by one single MTCB.

| Year | MTCB | AR | TX | LCV | HCV | PB | MB | TW (lakhs) | CR (lakhs) |
|------|------|----|----|-----|-----|----|----|-----------|-----------|
| 2018 | 4257 | 73854 | 1628 | 41248 | 49124 | 3043 | 2575 | 35.09 | 6.87 |
| 2019 | 4704 | 78211 | 1939 | 49126 | 50057 | 3442 | 2858 | 35.92 | 7.14 |
| 2020 | 5198 | 82826 | 2309 | 58510 | 51008 | 3892 | 3173 | 36.77 | 7.42 |
| 2021 | 5744 | 87713 | 2750 | 69685 | 51978 | 4402 | 3522 | 37.64 | 7.70 |
| 2022 | 6347 | 92888 | 3276 | 82995 | 52965 | 4979 | 3909 | 38.53 | 8.00 |
| 2023 | 7013 | 98368 | 3901 | 98847 | 53972 | 5631 | 4339 | 39.45 | 8.31 |
| 2024 | 7750 | 104172 | 4646 | 117726 | 54997 | 6369 | 4816 | 40.38 | 8.64 |
| 2025 | 8563 | 110318 | 5534 | 140212 | 56042 | 7203 | 5346 | 41.34 | 8.97 |
| 2026 | 9462 | 116827 | 6591 | 166993 | 57107 | 8147 | 5934 | 42.23 | 9.32 |
| 2027 | 10456 | 123719 | 7850 | 198888 | 58192 | 9214 | 6587 | 43.32 | 9.68 |
| 2028 | 11554 | 131019 | 9349 | 236876 | 59297 | 10421 | 7312 | 44.35 | 10.06 |
| 2029 | 12767 | 138749 | 11135 | 282119 | 60424 | 11787 | 8116 | 45.41 | 10.45 |
| 2030 | 13217 | 145731 | 12657 | 294184 | 61204 | 12149 | 9075 | 46.06 | 11.18 |

The decrease in the vehicle population with respect to the number of TW, CR and MTCB happens due to a modal split value of 50:50 among public and personalized transport modes in the transportation system. This has lead to a decrease in fuel consumption and fuel emission which is shown in Table 8 and 9 respectively.
Table 8. Results from scenario II – Forecasted fuel consumption by each class of vehicle

| Year | MTCB | AR  | TX  | LCV | HCV | PB  | MB  | TW (lakhs) | CR (lakhs) |
|------|------|-----|-----|-----|-----|-----|-----|------------|------------|
| 2018 | 1.48 | 3.37| 0.059| 1.50| 6.23| 1.06| 0.065| 8.65       | 10.98      |
| 2019 | 1.64 | 3.57| 0.070| 1.78| 6.35| 1.20| 0.072| 8.85       | 11.41      |
| 2020 | 1.81 | 3.78| 0.084| 2.13| 6.47| 1.35| 0.080| 9.06       | 11.85      |
| 2021 | 2.00 | 4.00| 0.010| 2.53| 6.60| 1.53| 0.089| 9.28       | 12.31      |
| 2022 | 2.21 | 4.24| 0.011| 3.02| 6.72| 1.73| 0.094| 9.50       | 12.79      |
| 2023 | 2.44 | 4.49| 0.014| 3.60| 6.85| 1.96| 0.106| 9.72       | 13.28      |
| 2024 | 2.70 | 4.76| 0.016| 4.28| 6.98| 2.22| 0.122| 9.95       | 13.80      |
| 2025 | 2.98 | 5.04| 0.020| 5.10| 7.11| 2.51| 0.139| 10.19      | 14.35      |
| 2026 | 3.39 | 5.34| 0.024| 6.08| 7.25| 2.84| 0.158| 10.43      | 14.89      |
| 2027 | 3.64 | 5.65| 0.028| 7.24| 7.39| 3.21| 0.167| 10.68      | 15.47      |
| 2028 | 4.02 | 5.98| 0.034| 8.62| 7.53| 3.63| 0.180| 10.93      | 16.07      |
| 2029 | 4.45 | 6.34| 0.040| 10.27|7.67| 4.11| 0.205| 11.19      | 16.70      |
| 2030 | 4.94 | 6.98| 0.046| 10.87|7.95| 4.42| 0.216| 12.46      | 17.85      |

In accordance with the alteration of growth rate in the number of vehicles between the public and personalized transportation, the consumption of fuel by each class of vehicle in the transportation system gets varied correspondingly. The fuel consumed by TW decreases to 17.85 lakh litres per day from scenario I’s 21.57 lakh litres per day and the fuel consumed by CR decreases to 17.85 lakh litres per day from scenario I’s 30.32 lakh litres per day and the fuel consumed by MTCB increases to 4.94 lakh litres per day from scenario I’s 2.49 lakh litres per day in 2030. The total fuel consumption by personalized transportation is 30.31 lakh litres per day whereas that of public transportation has been just 4.94 lakh litres per day.

From the above results it can be said that the fuel consumption of MTCB has seen to increase, but when we take the values of fuel consumption per person travelling in MTCB into account with respect to that of persons using TW and CR combinedly, it can be said that the fuel consumption of the former mode of transport is seen to be much lesser than that from the latter one. When these resultant values are compared with the Scenario I results, it can be seen that the total fuel consumed by all the vehicles in scenario II decreases to 239.92 Crore litres per annum from scenario I’s 309.72 Crore litres per annum in 2030, which shows a reduction of 69.80 Crore litres per annum of fuel consumption by all the vehicles in the scenario II. Hence the annual saving in the fuel consumption results in 34.72%.

The variation of growth rate in the number of vehicles and the consumption of fuel by each class of vehicle between the public and personalized transportation in the transportation system has a direct impact on the fuel emissions correspondingly. This can be seen in Table 9.

Table 9. Results from scenario II – Forecasted fuel emission for each class of vehicles

| Year | MTCB | AR  | TX  | LCV | HCV | PB  | MB  | TW (in Gg/day) | CR |
|------|------|-----|-----|-----|-----|-----|-----|---------------|----|
| 2018 | 0.343| 0.477| 0.008| 0.923| 1.185| 0.180| 0.030| 1.936         | 3.732|
| 2019 | 0.381| 0.502| 0.008| 0.956| 1.253| 0.188| 0.031| 2.093         | 4.024|
| 2020 | 0.423| 0.530| 0.008| 0.990| 1.324| 0.196| 0.032| 2.263         | 4.338|
| 2021 | 0.470| 0.558| 0.009| 1.026| 1.400| 0.205| 0.033| 2.447         | 4.677|
| 2022 | 0.522| 0.588| 0.009| 1.063| 1.479| 0.214| 0.033| 2.646         | 5.042|
In this scenario, from Table 9 it can be seen that the fuel emissions by TW decreases to 4.92 Gg/day from scenario I’s 7.789 Gg/day and the fuel emissions by CR decreases to 9.203 Gg/day from scenario I’s 13.199 Gg/day while the fuel emissions by MTCB increases to 1.207 Gg/day from scenario I’s 0.616 Gg/day for the horizon year 2030. The total fuel emission incurred by personalized transportation is 14.145 Gg/day, whereas that of public transportation is just 1.207 Gg/day.

From the above results it is evident that though the fuel emissions for MTCB has seen an increase in it, yet when we take into account the fuel emissions per capita travelling in MTCB with respect to that of persons using TW and CR combinedly, it can be said that the fuel emissions of the former transportation mode is much lesser than that from the latter one. When these resultant values are compared with the Scenario I results, it is found that the total fuel emissions incurred by all the vehicles in scenario II decrease to 7417 Gg/annum from scenario I’s 9699 Gg/annum in the horizon year 2030. Hence the annual reduction in the fuel emissions is 2282 Gg/annum, which results in 30.76% reduction in the fuel emissions.

### 6.3 Scenario III- Desirable Scenario

In the desirable scenario, the growth rate values of MTCB, TW and CR has been altered as per the Government policies which targets for a 75:25 modal split between public and personalized transport modes for the horizon year 2030. The forecasting process of the SD simulation built model is carried out for each class of vehicle on the basis of their incremental growth rate values which is shown in Figure 2 (b). To achieve the target of 75:25 modal split between public and personalized transport modes, the growth rate of the MTCB has been increased to reach 17.34% and on the same time, the growth rate of TW and CR is restrained to be 2.33% & 3.19% respectively. Meanwhile, the growth rates of the other modes of transport like the AR, TX, LCV, HCV, PB and MB is assumed to be the same as that in the do-minimum scenario since the model split process is carried out between the public and personalized transport system only. The forecasted vehicle population for each class of vehicle-based on the above-mentioned growth rates are shown in Table 10.

#### Table 10. Results from scenario III – Forecasted vehicular population

| Year | MTCB (Lakh) | AR (Lakh) | TX (Lakh) | LCV (Lakh) | HCV (Lakh) | PB (Lakh) | MB (Lakh) | TW (Lakh) | CR (Lakh) |
|------|-------------|-----------|-----------|------------|------------|-----------|-----------|-----------|----------|
| 2018 | 4257        | 73854     | 1628      | 41248      | 49124      | 3043      | 2575      | 35.09     | 6.87     |
| 2019 | 4812        | 78211     | 1939      | 49126      | 50057      | 3442      | 2858      | 35.48     | 6.98     |
| 2020 | 5440        | 82826     | 2309      | 58510      | 51008      | 3892      | 3173      | 35.88     | 7.09     |
| 2021 | 6149        | 87713     | 2750      | 69685      | 51978      | 4402      | 3522      | 36.28     | 7.21     |
| 2022 | 6951        | 92888     | 3276      | 82995      | 52965      | 4979      | 3909      | 36.69     | 7.33     |
| 2023 | 7857        | 98368     | 3901      | 98847      | 53972      | 5631      | 4339      | 37.10     | 7.44     |
| 2024 | 8882        | 104172    | 4646      | 117726     | 54997      | 6369      | 4816      | 37.51     | 7.57     |
| 2025 | 10040       | 110318    | 5534      | 140212     | 56043      | 7203      | 5346      | 37.93     | 7.69     |
| 2026 | 11349       | 116827    | 6591      | 166993     | 57107      | 8147      | 5934      | 38.36     | 7.81     |
| 2027 | 12829       | 123719    | 7850      | 198888     | 58192      | 9214      | 6587      | 38.79     | 7.94     |
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| Year | MTCB | AR | TX | LCV | HCV | PB | MB | TW (Lakhs) | CR (Lakhs) |
|------|------|----|----|-----|-----|----|----|------------|------------|
| 2028 | 14502 | 131019 | 9349 | 236876 | 59297 | 10421 | 7312 | 39.22 | 8.07 |
| 2029 | 16393 | 138749 | 11135 | 282119 | 60424 | 11787 | 8116 | 39.66 | 8.20 |
| 2030 | 17584 | 145731 | 12657 | 294184 | 61204 | 12149 | 9075 | 40.48 | 8.36 |

It could be observed from Table 10 that if the desirable efforts are applied based on the Government’s policy and by altering the growth rate of existing trend, the number of TW and CR would reach to 40.48 lakh and 8.36 lakh in scenario III from 46.06 lakh and 11.18 lakh, respectively (scenario II) and from 92.41 lakhs and 19.89 lakhs respectively (scenario I) in the horizon year 2030. While the public transportation vehicles constituting the MTCB would increase only to a fleet size of around 17584 from 13217 (scenario II) and from 7155 (scenario I) in the horizon year 2030. This happens so because of the consideration of the hypothesis that 40 TW and 20 CR can be replaced by one single MTCB. This decrease in the vehicle population with respect to the number of TW and CR happens due to a modal split value of 75:25 among public and personalized transport modes in the transportation system. This has lead to a decrease in fuel consumption and fuel emissions also which is shown in Table 11 and 12 respectively.

Table 11. Results from scenario III – Forecasted fuel consumption by each class of vehicle

| Year | MTCB | AR | TX | LCV | HCV | PB | MB | TW (Lakhs) | CR (Lakhs) |
|------|------|----|----|-----|-----|----|----|------------|------------|
| 2018 | 1.48 | 3.37 | 0.059 | 1.50 | 6.23 | 1.06 | 0.065 | 8.65 | 10.98 |
| 2019 | 1.67 | 3.57 | 0.070 | 1.78 | 6.35 | 1.20 | 0.072 | 8.74 | 11.16 |
| 2020 | 1.89 | 3.78 | 0.084 | 2.13 | 6.47 | 1.35 | 0.080 | 8.84 | 11.34 |
| 2021 | 2.14 | 4.00 | 0.010 | 2.53 | 6.60 | 1.53 | 0.089 | 8.94 | 11.52 |
| 2022 | 2.42 | 4.24 | 0.011 | 3.02 | 6.72 | 1.73 | 0.094 | 9.04 | 11.74 |
| 2023 | 2.74 | 4.49 | 0.014 | 3.60 | 6.85 | 1.96 | 0.106 | 9.14 | 11.90 |
| 2024 | 3.09 | 4.76 | 0.016 | 4.28 | 6.98 | 2.22 | 0.122 | 9.25 | 12.10 |
| 2025 | 3.50 | 5.04 | 0.020 | 5.10 | 7.11 | 2.51 | 0.139 | 9.35 | 12.30 |
| 2026 | 3.95 | 5.34 | 0.024 | 6.08 | 7.25 | 2.84 | 0.158 | 9.45 | 12.50 |
| 2027 | 4.47 | 5.65 | 0.028 | 7.24 | 7.39 | 3.21 | 0.167 | 9.56 | 12.70 |
| 2028 | 5.05 | 5.98 | 0.034 | 8.62 | 7.53 | 3.63 | 0.180 | 9.67 | 12.91 |
| 2029 | 5.71 | 6.34 | 0.040 | 10.27 | 7.67 | 4.11 | 0.205 | 9.78 | 13.13 |
| 2030 | 6.36 | 6.98 | 0.046 | 10.87 | 7.95 | 4.42 | 0.216 | 10.56 | 14.25 |

In accordance with the alteration of growth rate in the number of vehicles between the public and personalized transportation, the consumption of fuel by each class of vehicle in the transportation system gets varied correspondingly. The fuel consumed by TW decreases to 10.56 lakh litres per day in scenario III from scenario II’s 17.85 lakh litres per day and from scenario I’s 21.57 lakh litres per day similarly the fuel consumed by CR decreases to 14.25 Lakh litres per day from scenario II’s 17.85 lakh litres per day and from scenario I’s 30.32 Lakh litres per day. The fuel consumed by MTCB increases to 6.36 lakh litres per day from scenario II’s 4.94 lakh litres per day and from the scenario I’s 2.49 lakh litres per day. The total fuel consumption by the personalized transportation is 24.81 lakh litres per day whereas that of public transportation has been just 6.36 lakh litres per day.

From the above results it can be said that the fuel consumption of MTCB has seen to increase, but when we take the values of fuel consumption per person travelling in MTCB into account with respect to that of persons using TW and CR combinedly, it can be said that the fuel consumption of the former mode of transport is seen to be much lesser than that from the latter one. When these resultant values are compared with the scenario II & I results, it can be seen that the total fuel consumed by all the vehicles in scenario III decreases to 225.03 Crore litres per annum from 239.92 Crore litres per annum.
annum and from scenario I’s 309.72 Crore litres per annum in the horizon year 2030, which shows a reduction of 14.89 Crore litres per annum and 84.69 Crore litres per annum of fuel consumption by all the vehicles in the scenario III. Hence the annual saving in the fuel consumption results in 6.61% and 37.63% reduction in fuel consumption.

The variation of growth rate in the number of vehicles and the consumption of fuel by each class of vehicle between the public and personalized transportation in the transportation system has a direct impact of fuel emissions correspondingly. This can be seen in Table 12.

**Table 12. Results from scenario III – Forecasted fuel emission for each class of vehicles**

| Year | MTCB (in Gg/day) | AR | TX | LCV | HCV | PB | MB | TW | CR |
|------|------------------|----|----|-----|-----|----|----|-----|-----|
| 2018 | 0.343            | 0.477 | 0.008 | 0.923 | 1.185 | 0.180 | 0.030 | 1.936 | 3.732 |
| 2019 | 0.395            | 0.502 | 0.008 | 0.956 | 1.253 | 0.188 | 0.031 | 2.034 | 3.922 |
| 2020 | 0.455            | 0.530 | 0.008 | 0.990 | 1.324 | 0.196 | 0.032 | 2.138 | 4.121 |
| 2021 | 0.523            | 0.558 | 0.009 | 1.026 | 1.400 | 0.205 | 0.033 | 2.246 | 4.330 |
| 2022 | 0.602            | 0.588 | 0.009 | 1.063 | 1.479 | 0.214 | 0.033 | 2.361 | 4.550 |
| 2023 | 0.693            | 0.620 | 0.009 | 1.101 | 1.564 | 0.224 | 0.034 | 2.480 | 4.781 |
| 2024 | 0.798            | 0.653 | 0.010 | 1.141 | 1.653 | 0.233 | 0.035 | 2.606 | 5.024 |
| 2025 | 0.918            | 0.689 | 0.010 | 1.182 | 1.747 | 0.244 | 0.036 | 2.739 | 5.279 |
| 2026 | 1.057            | 0.726 | 0.011 | 1.225 | 1.847 | 0.254 | 0.037 | 2.878 | 5.547 |
| 2027 | 1.217            | 0.765 | 0.011 | 1.269 | 1.952 | 0.266 | 0.038 | 3.024 | 5.829 |
| 2028 | 1.401            | 0.807 | 0.012 | 1.314 | 2.063 | 0.277 | 0.039 | 3.178 | 6.125 |
| 2029 | 1.612            | 0.850 | 0.012 | 1.362 | 2.181 | 0.290 | 0.040 | 3.340 | 6.436 |
| 2030 | 1.856            | 0.896 | 0.013 | 1.411 | 2.305 | 0.302 | 0.041 | 3.509 | 6.763 |

In the scenario III the fuel emission by TW decreases to 3.509 Gg/day from scenario II’s 4.942 Gg/day and from scenario I’s 7.789 Gg/day similarly the fuel emission by CR decreases to 6.763 Gg/day from scenario II’s 9.203 Gg/day and from scenario I’s 13.199 Gg/day while the fuel emission by MTCB increases to 1.856 Gg/day from scenario II’s 1.207 Gg/day and from scenario I’s 0.616 Gg/day. The total fuel emissions incurred by personalised transportation is 10.272 Gg/day whereas that of public transportation is just 1.856 Gg/day.

From the above results it is evident that though the fuel emissions for MTCB has increased, yet when we take into account the fuel emissions per capita travelling in MTCB with respect to that of persons using TW and CR combinedly, it can be said that the fuel emission of the former transportation mode is much lesser than that from the latter one. When these resultant values are compared with the Scenario II & I results, it can be seen that the total fuel emission incurred by all the vehicles in scenario III decreases to 6240 Gg/annum from scenario II’s 7417 Gg/annum and from scenario I’s 9699 Gg/annum in the horizon year 2030. Hence the annual reduction in the fuel emissions is 1177 Gg/annum and 3459 Gg/annum, which results in 18.86% and 55.43% reduction in the fuel emissions in scenario III for the horizon year 2030.

### 7. Conclusion and recommendations

This study recommends stringent legislative policy as similar to the one implemented in the New Delhi Capital city of India: Odd-Even concept of plying of vehicles on the road on alternate days of a week. Similar stringent legislative policies are to be framed and implemented with immediate effect that curbs the usage of the personalised modes of transport. This will not only reduces the plying of
the personalized mode of transport vehicles on the city roads but also enhances the usage of the public mode of transport vehicles including sub-urban rails, metro rails, etc. On the other hand, the fleet size of the public transport like the MTCB has to be increased not only with greater efficiency and reliability but also with promising mobility, accessibility and connectivity, to achieve the above-mentioned policies of the government. These policies will eventually lead to a considerable reduction in fuel consumption, fuel cost and fuel emissions in the city. This makes the city a place with reduced economic losses due to lesser fuel imports from overseas and thereby achieving a sustainable transportation system that has considerable contributions towards achieving the globally adopted Sustainable Development Goals (SDG).

This study also recommends that besides implementing the conventional measures of 4E’s - Engineering, Enforcement, Education and Emergency action to the overall transportation system, it is always advisable and better to add an additional E also i.e, the Equity while framing policies for a sustainable city. Finally, it could be suggested from this research work that not only the quantitative indicator like the vehicular population, fuel consumption, fuel cost, fuel emissions and GDP of the city have to be considered for representing the sustainable growth of the city, but also the qualitative indicators like the value system and quality of life of the people is also to be considered for representing the real sustainable growth and prosperity of the city for achieving SDG.

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