ABSTRACT

Chennai is the fourth largest metropolitan city of India which covers an area of 426 sq.km and recorded a population of 46.81 lakhs in 2011. The Chennai Metropolitan Area which extends over an area of 1189 sq.km recorded the population of 86.96 lakhs in 2011 and the density is 11,000 per sq.km. The population of Chennai in 1639 was 40,000 and today the city is estimated to have a population of 7.5 million, which gives a population density of about 6482 per sq. km. This rapid increase in population leads to traffic congestion and imbalanced supply and demand of transport facilities. Thus it is important to develop a dynamic model which would exhibit the invention of various transportation facilities in Chennai and to estimate the travel demand for both present and future situation. Hence in this study, it is intended to make an attempt to develop the System Dynamics model using STELLA simulation software. Model is developed for population, transport demand and supply individually. Also a micro level model is developed to define the V/C ratio of the different hierarchy of roads. After developing the model collected data are fed into the model and initial calibration was done. The model has been tested for different scenarios after it is validated. Hence, from the model results to suggest appropriate course of actions in a phase-wise manner towards achieving sustainable transportation planning for Chennai city.

Keywords: System Dynamics; Simulation Model; Public Transport; Mode Share; Sustainable planning.

1. INTRODUCTION

1.1 General

The sustainable development of urban transportation system is a key point to strike the resource-saving, environment-friendly, and people-oriented society. The conception of sustainable urban transportation comprises four aspects, namely, economic sustainability, environmental sustainability, social sustainability, and transportation sustainability. Urban transportation system is a complex system with multiple variables and feedback loops between subsystems and influencing factors. It is not appropriate to use the ordinary linear quantitative approach to describe the
characteristics of this complex system. Therefore, system dynamics (SD) approach is used in this study to simulate the evolution of urban transportation system; specifically the existing and future trips performed in the city and the demand and supply of the city.

1.2 Objectives of the Study
- To study and appreciate the trend of transport development in Chennai with regards to Transportation Demand and Supply.
- To build a Macro level system dynamics simulation model for the existing and predicted period.
- To build micro level model to evaluate the service volumes for various hierarchies of roads as well.
- To suggest appropriate course of actions in a phase-wise manner towards achieving sustainable transportation planning for Chennai city.

2. SYSTEM DYNAMICS

2.1 Principles of System Dynamics
System dynamics has a long history as a modelling paradigm with its origin in the work (Forrestor 1969), who developed the subject to provide in understanding of strategic problems in complex and dynamic systems. System dynamics model, by giving insight feedback processes, provide system uses with a better understanding of the dynamic behaviour of systems. Areas of application of system dynamics have always been very wide, however, with an emphasis on socio-economic applications.

2.2 Building Blocks of Model
The system dynamics model has four basic building blocks as listed below:

- Stocks
  Stocks or levels are used to represent anything that accumulates. An example of stock would be population level at one point of time.

- Flows
  Flows or rates represent activities that increase and decrease stocks. An example of flow includes birth rate or death rate.

- Connectors
  Connectors are used to establish the relationship among variables in the model. The software represents them graphically as arrows. They carry information, which can be a quantity, constants, an algebraic relationship or a graphical relationship.

- Converters
  Converters transform input into output. Converters can accept input in the form of algebraic relationships, graphs and Tables.

2.3 Model Development Life Cycle
The model development process is summarized in the schematic diagrams of a model life cycle in figure 2.1.
2.4 Phases of Model Building Process

It is the process of defining a problem out of a situation, developing various relationships quantitatively, testing the model with several policy options and analyzing the behaviour of the model. The various phases in model building process are:

- Problem definition
- System conceptualization
- Model representation
- Model behaviour
- Model evaluation
- Policy analysis and model use

3. METHODOLOGY

Primary data like volume count, road geometrics and secondary data including different modes of transport supply provided by the government are collected from the respected departments / institutions like CMDA, Metropolitan Transport Corporation (Chennai) Ltd, MRTS Division, Southern Railway, Chennai. Causal loop diagrams are developed in order to found the relationship between different components related to transportation. And then System Dynamics STELLA model is developed for population, transport demand and supply individually. Also a sub model is also developed to define the V/C ratio of the different hierarchy of roads. After developing the model collected data are fed into the model and initial calibration was done. The model has been run for different scenarios and it is validated. From the model results a desirable scenario is suggested in order to attain sustainability in terms of transportation.
4. DATA COLLECTION

4.1 Primary Data Collected

On all the three roads hourly flow is calculated based on the collected data. In that Rajiv Gandhi salai towards Adyar from Tidel Park, the vehicle flow is more (7705.1) during 6pm to 7pm. The other hourly flow variations on all the three roads (with respect to time) are discussed in the table 4.1.

4.2 Secondary Data Collected

Some of the secondary data which are collected for the scenarios analysis are number of private and public trips, average daily passengers carried by both train and bus, future project details like Metro and BRT etc. These details are collected from the respective departments/ institutions and have been used in the model.

4.3 Metro Details

The Chennai Metro is a mass-transit rail system in the Indian city of Chennai. The metro rail work split in to 7 corridors and presently work is under construction in Corridor 1 & 2.

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>HOURLY FLOW</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IT Corridor(towards)</td>
<td>Sardar Patel Road (towards)</td>
<td>LB Road (towards)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adyar</td>
<td>IT</td>
<td>Adyar</td>
<td>Rajbhavan</td>
</tr>
<tr>
<td>3.30 - 4.30</td>
<td>2696</td>
<td>4284.15</td>
<td>2981.95</td>
<td>3176.9</td>
</tr>
<tr>
<td>3.45 - 4.45</td>
<td>2759.75</td>
<td>4518.35</td>
<td>3183.3</td>
<td>3291.05</td>
</tr>
<tr>
<td>4.00 - 5.00</td>
<td>2805.8</td>
<td>4501.95</td>
<td>3487.25</td>
<td>3400.5</td>
</tr>
<tr>
<td>4.15 - 5.15</td>
<td>2919.15</td>
<td>4530.7</td>
<td>3613.9</td>
<td>3501</td>
</tr>
<tr>
<td>4.30 - 5.30</td>
<td>3123.3</td>
<td>4764.45</td>
<td>3719.4</td>
<td>3589.7</td>
</tr>
<tr>
<td>4.45 - 5.45</td>
<td>3420.7</td>
<td>5169.3</td>
<td>3772.9</td>
<td>3668.85</td>
</tr>
<tr>
<td>5.00 - 6.00</td>
<td>3590.5</td>
<td>5127.75</td>
<td>3668.05</td>
<td>3721.45</td>
</tr>
<tr>
<td>5.15 - 6.15</td>
<td>4226.95</td>
<td>5244.5</td>
<td>3808.05</td>
<td>3770.8</td>
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<tr>
<td>5.30 - 6.00</td>
<td>4967.55</td>
<td>5002.6</td>
<td>3871.8</td>
<td>3747.35</td>
</tr>
<tr>
<td>5.45 - 6.45</td>
<td>6139.85</td>
<td>4705.95</td>
<td>3855.35</td>
<td>3741.35</td>
</tr>
<tr>
<td>6.00 - 7.00</td>
<td>7705.1</td>
<td>4511.7</td>
<td>3899.15</td>
<td>3742.75</td>
</tr>
<tr>
<td>6.15 - 7.15</td>
<td>7326.45</td>
<td>4264.1</td>
<td>3813.95</td>
<td>3593.6</td>
</tr>
<tr>
<td>6.30 - 7.30</td>
<td>6322.05</td>
<td>3986.35</td>
<td>3682.8</td>
<td>3539.95</td>
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</table>

Table No 4.2 MTC Strength Details

<table>
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<tr>
<th>S. No</th>
<th>Different Components of MTC</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Depots</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>Fleet</td>
<td>3257</td>
</tr>
<tr>
<td>3</td>
<td>Route</td>
<td>622</td>
</tr>
<tr>
<td>4</td>
<td>Passengers per day</td>
<td>43.55 Lakhs</td>
</tr>
<tr>
<td>5</td>
<td>Collection per day</td>
<td>181.58 Lakhs</td>
</tr>
</tbody>
</table>

Source: Metropolitan Transport Corporation (Chennai) Ltd.
Table No 4.3 Types of Bus Services

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of Service</th>
<th>Number of Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single floor</td>
<td>2253</td>
</tr>
<tr>
<td>2</td>
<td>Semi low floor buses</td>
<td>874</td>
</tr>
<tr>
<td>3</td>
<td>Vestibule buses</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Volvo A/C buses</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Total</td>
<td>3257</td>
</tr>
</tbody>
</table>

Source: Metropolitan Transport Corporation (Chennai) Ltd.

Table No.4.4 MRTS Details

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Length</td>
<td>25 km</td>
</tr>
<tr>
<td>2</td>
<td>No. of stations</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>No of Runs(Up and Down)</td>
<td>62 Pairs</td>
</tr>
<tr>
<td>4</td>
<td>Frequency</td>
<td>20 minutes</td>
</tr>
<tr>
<td>5</td>
<td>Average number of persons used daily</td>
<td>80,000</td>
</tr>
</tbody>
</table>

Source: MRTS Division, Southern Railway, Chennai.

4.4 Model Development

The most crucial part of the study is the model development. The Steps involved in the development of model are the following:

- Formation of Causal loop diagram
- Identification of key variables involved in the process.
- Model Development
- Calibration of Model
- Validation of model
- Simulation of various scenarios
- Model results

4.4.1 Formation of causal loop diagram

A causal loop diagram shows the cause and effect of each variable with respect to other variables. Usually a positive effect is indicated using the ‘+’ sign and negative effect with ‘–’ effect. The causal loop diagrams are represented separately for the individual sectors and as a whole and depict the fig 4.1 and fig 4.2.

![Causal Loop Diagram for Population Sector](image)
4.4.2 Identification of key variables

The key variables are necessary for development of the model. The following are some of the key variables identified for model development.

- Existing Population
- Population Growth rates
- Immigration Trends
- Per Capita Trip Rate
- Mode Share of Trips
- Demand and supply of transportation

4.4.3 Model development

After the identification of important variables, the model is developed. The model is divided into three major sectors namely

- Population Sector
- Transport Demand Sector
- Transport Supply Sector

4.4.4 Calibration of Model

There is no universal model that can run for all conditions with an unaltered set of parameters. Parameters must be checked and adjusted within the known range to avoid unrealistic projections.

4.4.5 Validation of Model

The Validation is an important step in model development, which determines the realistic feature of model. The model is validated for the demand and supply of transportation facilities using the previous data.

4.3.6 Simulation of various scenarios

The various scenarios for which the model was run are as follows:

- Do-minimum Scenario
- Completion of current projects – As per plan Scenario
- Project Delay Scenario
- Achievement of Desirable Demand Supply Scenario.
4.5 Description of the Model

4.5.1 Population Sector
In this sector, population of the base year, birth rate, death rate, immigration and outmigration are considered. The size of the population is influenced by both the net birth rate and net migration rate. The net birth rate equals the total number of births per year minus the total number of deaths. Similarly, the net migration rate equals the number of immigrants minus the number of out migrants. However, the number of births and deaths as well as net immigrants can be defined as a yearly percentage of the population. It is represented in the figure 4.3.

4.4.1 Transport Demand and Supply Sector
The main sector is the total trips sector in which the total trips, motorised trips and non-motorised trips are calculated. The sub sectors include the motorised trips sector, non motorised trips sector and public transport supply sector.

In the total trips sector, the total number of trips generated from the area is calculated from the population and the per capita trip rate. The motorised and non-motorised trips are calculated simultaneously from the total trips with the help of respective trip fractions.

![Fig 4.3 Population Model](image)

![Fig 4.4 Transport Demand Sector Model](image)
In the non motorised trips sector the walk trips and cycle trips are estimated. In the motorised trips sector the personal vehicle trips, IPT (Intermittent Para Transit) trips and bus trips are estimated. In the scenarios, the supply sector is used to calculate the supply of public transport against the demand of the area i.e. the supply-demand ratio is calculated. The model is shown in figures 4.4 and 4.5.

5. RESULTS

The following are the summary of results obtained from the analysis of the models through various scenarios.

- In the do minimum scenario of the city model, population reaches only 53 lakhs due to the reduction in the birth rate.
- Birth rate is decreased from 0.23 in the base year to 0.15 in the projected year.
- Demand supply ratio for the do minimum scenario decreases from 1.71 to 1.45 even if the existing trend continues.
- But in the second scenario, demand supply ratio further drops to 1.21 due to the execution major projects like Metro and BRT because the two alone would take 20% of the vehicular travel demand.
- In the project delayed scenario, if the proposed projects get delayed by 3 years then it again increases the demand supply ratio to 1.34.
- The ideal demand supply ratio should be arrived from the desirable scenario. Here bus augmentation is increased from 0.1 to 0.2 and MRTS is augmented at the rate of 0.15 with the likes of Metro and BRT, the demand supply ratio reached the desirable value of 0.73
- In the do minimum scenario for the CMA model, the population crosses the 1 crore nos. during the projected period. As differ from the city model, instead of decreasing in demand supply ratio, here it headed in increasing trend. It reaches almost 2 at the final year.
- In the desirable scenario, mode share of motorized trips is decreased from 54% to 40%, bus augmentation is increased by 0.01 and MRTS by 0.05 rate then the demand supply ratio decreased to 0.80
- Bus augmentation rate, MRTS augmentation rate and per capita trip rate are the three sensitive variables in the city model
- V/C ratio gets increased in all the roads, if the existing trend in mode share continues upto the projected year. It reaches 2.55 in Sardar Patel road, 1.90 in Rajiv Gandhi Salai and 1.80 in LB road.
- In order to reduce the V/C ratio, the mode share of the vehicles are taken as per the master plan i.e. 70% public mode and 30% of private mode. Now the mode share is decreased to 0.7
6. RECOMMENDATIONS

The following are the conclusions and recommendations made by this study.

- Demand for transport facilities keeps on increasing both in City and CMA region due to significant improvement in socioeconomic factors of the people.
- Per capita trip rate is accelerating at much faster rate.
- Existing supply of transport facilities by the government doesn’t meet with the requirements of public demand.
- To bring down the demand supply ratio to 1, government should augment the existing facilities at a higher rate than normal.
- Government should encourage the public to use the public transport by providing more supply in terms of both quantity and quality.
- When the desired public private share of 70:30 is achieved, congestion on the roads reduces drastically, thereby reducing the travel time of passengers.
- Transportation alone contributes 80% of air pollution in urban areas.
- If the desirable mode share is achieved as per the plan, air pollution will reduce significantly.
- It not only makes the environment good, but also it saves more energy resources.
- Thus increase in public transport facilities will provide a sustainable solution to urban transportation problems.

7. REFERENCES

5. Second Master Plan for Chennai Metropolitan Area 2026, Chennai Metropolitan Development Authority.