A SYSTEM DYNAMICS MODEL FOR ASSESSING LAND-USE TRANSPORT INTERACTION – CASE STUDY OF PUNE CITY

Submitted in partial fulfillment of the requirements of the degree of Bachelor of Planning

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CERTIFICATE

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REPORT APPROVAL

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is approved for the degree of

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Of

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DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

Rapid urbanization is dangerous to the development of society as it hinders development and makes urban living more difficult. This research aims to develop a system dynamics model for land use transportation. Design/methodology/approach are the parameters of urbanization can be simulated using a system dynamics model. In this case study various parameters, such as population, land use, trip rate, Volume/Capacity (V/C), are simulated for three different years: 2024, 2034, and 2044. Three scenarios are simulated: the Business As Usual Scenario (existing trend), and the proposed scenario (where all the proposed models are implemented). The results show that the proposed desirable model is highly effective. Originality of this study has been performed in the Indian city of Chennai, where such studies are rare. This study could help to analyse how the land use affects the traffic situation and make improvements in the transportation to ease the urbanization issues. This research could also help to analyse the future traffic situation and make improvements to ease urbanization-related issues. Moreover, when the desirable scenario is followed in real-time, it could solve future problems that may arise from traffic congestion.

Keywords:
urbanization; **system dynamics**; **transport demand and supply**; **trip generation**; **population**

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ABBREVIATIONS

INI-POP	Initial population
PVT	Private vehicle
PT	Public transportation
2W	Two Wheeler
C	Car
SD	System Dynamics
CLD	Causal Loop Diagram
BR	Birth Rate
DR	Death Rate
VO	Vehicle Ownership
HHS.	Household Size
AvgTr	Average Trip Rate
TT	Total Trips
TTC	Total Trips by Car
TT2W	Total No. of Trips made by Two Wheeler
TPT	Total No. of Trips made by Public Transportation
TN2W	Total No. of Two Wheelers
TNC.	Total No. of Cars
TNPT	Total No. of Public Transportations
2WOC	Two Wheeler Vehicle Occupancy
COC	Car Vehicle Occupancy
PTOC	Public Transportation Vehicle Occupancy
PCU/hr	Passenger Car Unit Per Hour
V/C	Volume/Capacity

CHAPTER 1 INTRODUCTION

1.0 PREAMBLE

A human settlement is a living organism. It has origin, growth, decay and, re-growth. It is a dynamic entity, subject to various types of forces, such as, physical, physiological, social, economic, technological, etc. These forces are mainly responsible for rapid pace of urbanisation of human settlement. Rapid urbanization is dangerous to the development of society as it hinders development and makes urban living more difficult. When urbanization takes place the population of that area also increases causing traffic issues and transportation demand in that area also increases leading to haphazard land use. This chapter briefly discusses the implication of urbanization and motorization of the transport sector and, ultimately, urban areas.

1.1 BACKGROUND

The urban environment is riddled with space constraints related to residential, commercial, and industrial activities. The inefficient use of urban space may not be evident immediately, but would become apparent in the future. Hence, there must be careful urban planning, with analysis of different scenarios for long-term cases to prevent deterioration of land. In most developing countries, especially India, sustainable urban development has often been neglected, leading to overcrowding and overuse of resources in urban areas. Efficient development requires solving urbanization issues, such as transportation, land use, and population control. Of all the resources, land use for transportation is concerning since the land and buildings use up much of the available space. Unchecked development has rapidly converted agricultural and other vacant land types into unapproved structures for residential and commercial applications. Such unapproved urbanization means that traffic volume often exceeds capacity, resulting in congestion and, as a consequence, causing time delays and pollution.

It is essential to study the suburban areas and analyse their growth patterns, to project future growth levels and their impacts on transportation facilities. Suburban areas experience significant physical and socioeconomic changes as cities continue to sprawl. Unregulated growth, low- quality housing, and inadequate infrastructure facilities are significant problems in the suburban areas. In the metropolitan region, settlements are growing rapidly due to urban sprawl. However, the development of these settlements is not of the same order. Some settlements are growing more than others; however, the road network does keep up with the same development, resulting in plethora of issues

All these issues emerged out of rapid urbanization and motorization needs to be tackled with prime focus. Looking into the qualitative and quantitative aspect of transport issues and complex interaction among them, there is a need of a baseline structure to quantify and resolve the issues. The basic behind all these needs inculcate the need and motivation of the study as discussed in the next section.

1.2 NEED OF STUDY

Most cities in India are experiencing unplanned development because of urbanization. Higher demand for transportation results from both the massive migration of people from rural to urban regions, and natural growth. Indian cities are experiencing worrisome growth in their human and vehicle populations, yet their road networks are not designed to handle the volume of traffic seen today.

Economic and transportation systems are mutually dependent on one another due to the interdependence of their supply and demand. The main component of a transportation system is the infrastructure that grants access to a certain degree of transportation supply. A number of models have been developed to assess the availability of transportation, and the enabling or restricting implications it has on mobility.

Thus, unplanned urbanization leads to the mixing of industrial and residential locations in a single region, which endangers human lives. Unplanned urbanization does not mean illegal construction. However, delays in setting specific guidelines by city corporations may lead to residential houses and commercial industries being built in the same region, especially in suburban regions outside large cities such as Chennai. Once the houses and industries are built, relocating the residents or companies from the regions is deemed impossible due to the significant capital costs involved. Demolition can be an option in case of illegal construction. However, since the buildings are often not illegal, no mitigating action can be taken once problems emerge.

There are lack of system dynamics-based studies specific to Indian cities. Due to the unique nature of urban expansion in Indian cities, it is necessary to analyse these factors in the Indian context. This is also necessary to make predictive analyses for the future. Hence, this paper analyses the various factors of urban expansion and how these factors affect the transportation sector and traffic in Indian cities. This paper aims to determine the impacts of land uses on the transportation system. The paper also predicts the future growth levels of traffic, and studies their impact on the transportation sector.

1.3 AIM

To assess the impacts of land use on transportation and develop a framework of evaluation for the transport system using system dynamics

1.3 OBJECTIVES OF THE STUDY

1. To identify the various parameters affecting the land use transportation
2. To develop a system dynamics models using the identified parameters affecting the land use transport system
3. To recommend policies for the Proposed Framework of Evaluation of land use and transportation system

1.4 SCOPE OF THE STUDY

It is identified that this model would be highly effective in controlling the population and other parameters. In the land use sector, a desirable density is achieved by restricting the population growth trend and augmenting the intensification of land use. With respect to transportation, the growth of private transport is reduced by introducing better public transportation facilities . The variables that are used as parameters for the calculation predict the traffic volume in the future and enable informed planning for future traffic demand.

1.5 ORGANIZATION OF THE REPORT

CHAPTER 1 (Introduction) : this chapter discusses the influence of rapid urbanization and exponential vehicle growth in India. The need for the study. The definition and theories related to the study. The objectives and scopes of the study.

Chapter 2 (Literature review) : This chapter covers a detailed literature review. The first section covers the definition and theories of the system dynamics in land use transportation

Chapter 3 (Methodology) : Detailed methodology adopted for the study is discussed in this chapter. The division of entire work to reach to the goal of framework development is divided into steps and discussed in detail including the scope of the work in that step.

Chapter 4 (Case study area and data collection) : importance of study area delineation and the approach used for study area delineation is discussed in this chapter. Importance of study area delineation and the approach used for study area delineation is discussed in this chapter. The other important aspects like questionnaire development for data collection, techniques used for data collection, sample size determination, and descriptive statistics of collected responses are also discussed in this chapter.

Chapter 5 : (Data Analysis) : this chapter discuses on how the collected data is analysed using system dynamics.

Chapter 6 : (Policy Recommendations) : This chapter discusses a procedure that is designed and followed for policy testing for proposed framework.

Chapter 7: (Conclusion) : This chapter summarizes the findings of the entire study.

CHAPTER 2 : LITERATURE REVIEW

2.0 PREAMBLE

The literature review's primary objective is to articulate the studies and work conducted in the study's scope. A literature review has majorly four objectives (i) It surveys the literature in the selected research area of study (ii) It synthesizes the information into a summary (iii) It critically analyses the information gathered by identifying gaps, shows limitations of theories; help to formulate area for further research and reviewing areas (iv) It presents the literature in an organized way. In the current study the first part is about the use of system dynamics in various aspects of transportation The second part discusses the theories and definition about system dynamics in land use transportation and the third part discusses the gap analysis of the literature review

2.1 USES OF SYSTEM DYNAMICS IN VARIOUS ASPECTS OF TRANSPORTATION

System dynamics can be used in many transportation aspects some of them are mentioned in the study. The study of prioritizing public transportation using system dynamics model. In this paper it provides a modelling framework based on the system dynamics approach by which policy makers can understand the dynamic and complex nature of the policies on prioritizing public transportation within a transportation socioeconomic system. Since the government has implemented the policies on prioritizing public transportation, a framework that helps policy makers to understand the impacts of such policies is currently quite relevant. Within this framework, 6 basic subsystems: population, economic development, environmental influence, public transport development, private cars development and priority polices, focuses on the short- and long-term system behaviours. The objective of this paper is to provide a modelling framework based on the system dynamics (SD) approach by which the policy makers can understand the dynamic and complex nature of the policy influence within a transportation socioeconomic system representation of a metropolitan area. This framework offers policy makers an assessment platform that focuses on the short and long-term system behaviours arising from the policies on prioritizing public transportation. This can lead to the understanding of the dynamic long-term behaviour of key variables in the transportation socioeconomic system with or without policies on prioritizing public transportation being implemented. Since many cities in China have already implanted the public transport priority policy and more are about to do so, a framework that helps policy makers to understand impacts of the policy is currently very relevant.

The second aspect is urban transportation planning using system dynamics. In this an urban transportation planning is done through the use of system dynamics simulation model. This planning includes congestion mitigation through demand and capacity management, the improvement of public transport sector, and the urban mobility improvement. System dynamics simulation model was used to test and evaluate some alternative policies for urban transportation planning. Simulation results show that mobility depends on travel time, the fulfilment ratio of public transport supply and demand, the effectiveness of public transport

transfer distance and transfer time, as well as the access time. Traffic congestion is influenced by the internal factor and external events. This study was conducted at Surabaya, East Java, Indonesia, which is the fourth most congested city in the world. The original scientific contributions of this research include model formulation and development of the daily traffic, urban mobility, and congestion; predictive analysis of the future daily traffic; scenarios development to increase mobility and reduce congestion by considering the internal and external factors. Similarly Kanyakumari has also made a transportation plan using the system dynamics. The transportation system in Kanyakumari District has met the grim situation over the years due to numerous parameters like increasing population, increasing economic activity, increasing vehicular population, negligence from the administrative officials, unethical practices of the locals, etc.; led it to a pathetic condition, especially on National Highway-47. The study aims at analysing the impact of road transportation and developing plausible policy decision for sustainable development in Kanyakumari District. Survey research method has been adopted for this investigation. The methodology of the study consist primary household surveys and secondary data collection from various literature and competent government authority. Relevant statistical methods such as descriptive statistics correlation and regression have been used in the study. Systems theory and system dynamics modelling have been applied to the present investigation for comprehensive inclusion of diverse and dynamic behaviour of the system with respect to transportation indicators

The third aspect for the use of System dynamics for making sustainable plans. Towards the end of 20th century, ever-increasing pressures for the need of sustainable development have re-shaped our way of thinking in which sustainability is now widely accepted as a top priority. Most of the economic and social activities are provided via transportation. Thus, it is of great importance to achieve sustainable transportation for sustainable development, especially from the point of energy and carbon dioxide emission reduction. However, transportation systems are complex and involve social, economic and environmental aspects which call for employing a holistic approach rather than conventional methods. System dynamics (SD) is such a holistic methodology for studying and managing complex systems in order to make integrated assessments and policy decisions. While its conception and early applications have been mainly related to industrial applications (frequently referred to “industrial dynamics”), it has also been used recently for the analysis of transportation systems. The aim of this study is to explore the feasibility of SD for transportation-related energy consumption, CO2 emissions, health impacts and economics.

The fourth aspect is the application of system dynamics in understanding the satisfaction level of the citizens for the use of public transportation. The main objective of this research is to evaluate how the transport sector affects the satisfaction of citizens. The model developed aims both at assessing the satisfaction of citizens and using it as a tool to measure the change in citizens’ satisfaction resulting from new mobility practices or policies. The developed scenarios are based on the principles of sustainability and the action plans concern: better accessibility conditions for alternative means of transport; improving travel safety; reducing air pollution, greenhouse gas emissions and energy consumption; increasing efficiency and effectiveness in the movement of people and goods; and enhancing the attractiveness and

quality of the urban environment. The results reveal that it is necessary for local decision makers to take further measures to increase the overall satisfaction of citizens with the aim of prosperity and happiness of citizens within their city, and the proposed model can support the decision-making process. Utilizing the developed system dynamics model, it is possible to make simulations with new data and at the same time to evaluate the change they bring to the individual sectors and to the overall satisfaction of the citizens.

The last one a system dynamic model for assessing the land use transportation. In this paper, the unchecked urbanization of Southern Chennai is considered as a case study; various parameters, such as population, land use, trip rate, Volume/Capacity (V/C), and Demand/Supply (D/S), are simulated for three different years: 2011, 2021, and 2031. Three scenarios are simulated: the Do-Min scenario (existing trend), partial scenario (some models are implemented), and the desirable scenario (all the proposed models are implemented). Findings—the simulation is performed using the Stella simulation tool. The results show that the proposed desirable model is highly effective in controlling both the population and other parameters. Originality/value—this study has been performed in the Indian city of Chennai, where such studies are rare. This study could help to analyse the traffic situation and make improvements to ease the urbanization issues. This research could also help to analyse the future traffic situation and make improvements to ease urbanization-related issues. Moreover, when the desirable scenario is followed in real-time, it could solve future problems that may arise from traffic congestion in Chennai.

Table 2.1: Summary of areas explored using SD

Sr No	Author & Year	Remark
1.	Paul Pfaffenbichler, Günter Emberger, and Simon Shepherd. 2010	• They did a review on system dynamics model for land use transportation using MARS model. • The paper introduces the concepts behind the MARS model, deals with validation and transferability between cities and provides example applications.
2..	Xinminao yang, kunda li 2013	• Did a review of system dynamic approach for evaluating policies on prioritizing public transportation • The subsystems considered were economic, population, environment, transportation

3..	Tejas Rawal, Varunvel Devdas 2015	• Prepared transportation plan using system dynamics model in Kanyakumari, Tamil Nadu. • The various subsystems of the urban system are physical, social, economic, ecological, environmental, infrastructure, institution, etc. to build the model
4.	Nunu Noviandia, P. Pradonob, Muhammad Tasrifc, Iwan P Kusumantorod. 2016	• This paper discusses the development of a model for understanding the dynamics complexity of the interaction between land use and transport in Greater Jakarta suburb.
5.	Hamad Bin Khalifa 2017	• Did a Review of System Dynamics Applications in Sustainable Urban Transportation. • The subsystems considered were environment, transportation etc.
6..	Suryani, E, Hendrawan, Adipraja, & Indraswari, 2020	• This paper aims to develop an urban transportation planning through the use of system dynamics model in Indonesia which is the fourth most congested city.
7..	Mylonakou M,Chassiakos A, Karatzas S Liappi, 2023	• The main objective of this research is to evaluate how the transport sector affects the satisfaction of citizens. • System dynamic model was used to identify the new policies which will develop the transportation sector as well as make the citizens satisfied. • The subsystems considered were economy, environment, society and transportation
8..	Devi Priyadarisini K and G. Umadevi 2023	• This studied the land use transportation using system dynamics models. • The subsystems considered were population, transportation.

2.2 DEFINITIONS & THEORIES IF SYSTEM DYNAMICS IN LAND USE TRANSPORTATION

A) Land use transportation model :

Land use models can be integrated with travel demand models to reflect the interactions between the transportation system and land use development. Both households and businesses prefer locations with -everything else being equal- higher accessibilities, and therefore, are influenced by travel times that are an output of transportation models. The location choices of households, businesses and developers, in turn, influences the location and scale of travel demand that is calculated by the travel demand model. The integration of land use with transportation models has proven to improve the model sensitivities in scenario analyses. Common design principles show how different elements of land-use models work together.

The transportation and land use systems closely interact, as illustrated by the land use/transport feedback cycle (Wegener 2004).

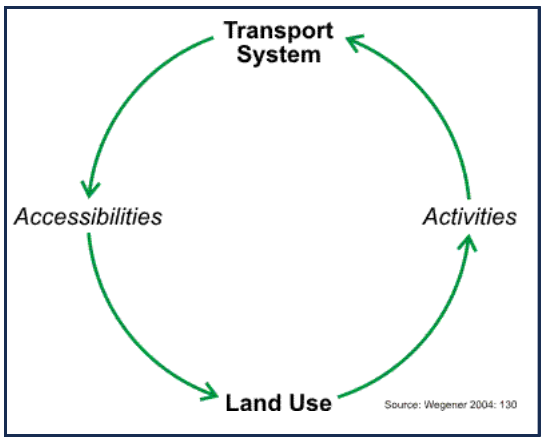


Fig 2.1 Land Use Transport Cycle

Starting at the bottom of the cycle (Land Use), the locations of population and employment determine the origins and destinations of most trips in travel models (Activities). After the Transportation Model was run, and travel times were updated, Accessibilities can be calculated. Accessibilities describe for every zone how well accessible all other zones are. Accessibility shapes land use, as both households and businesses search for locations that are - among other location factors - well accessible.

The connection between transportation and land use is a fundamental concept in transportation. Everything that happens to land use has transportation implications and every transportation action affects the land use. Land development generates travel and travel generates the need of new facilities which in turn increase accessibility and attracts future development

B) System dynamics

A system functions as a whole with the interaction of several subsystems. All the sub-systems of the system are interconnected, and interdependent to each other, and form a system. If one of the sub-systems of the system is defunct or functions with higher degree (taking lead role during its function) or partly function, its effects can be visualised in the entire system over a

period of time. In some cases, the system may not function at all, while in some cases the system may function, but with many disturbances or smooth functions of the system may be paralysed.

1) System characteristics

The various major characteristics of a system as postulated by various Scholars are:

- A system is a complex grouping of human beings and machine.
- A system may be broken down in to sub-systems, the amount of sub-systems detail depending on the problem being studied.
- The outputs from the given sub-system provide the inputs to the other sub-systems. Thus, a given sub-system interacts with the other sub systems and hence cannot be studied in isolation.
- The system being studied will usually form part of a hierarchy of such-systems. The systems at the top are very important and exert considerable influence on the systems lower down.
- To function, a system must have an objective, but this is influenced by the wider system of which it forms a part. Usually, systems have multiple objectives, which are in conflict with one another, so that an overall objective is required which affects a compromise between these conflicting objectives.
- To function at maximum efficiency, a system must be designed in such a way that it is capable of achieving its overall objective in the best possible ways.

Thus, all living systems maintain steady state dynamic equilibrium keeping an orderly balance among its sub-systems with respect to its super system and the environment. However, if an element of a system fails to handle a stress, other elements come forward and share this excess stress

2) Systems theory

Various forms of systems theories have been proposed over the years. The important ones among them are General System's theory, Cybernetics, Systems Approach, and System Dynamics approach.

General System theory has its genesis in the original research of Ludwig Von Bertalanffy on study of biological organism (1920s and 1930s) and theory of open systems, which was both supported and criticised by many Scholars. The broad objectives of the theory are to investigate the isomorphic of concepts, laws and models in various fields and to help in useful transfers from one field to another, to encourage the development of adequate theoretical models in areas which lack them, to eliminate the duplication of theoretical efforts in different fields and to promote the unity of science through improving communication between specialists. However, this theory has not properly emerged due to lack of methods capable of implementing it.

Cybernetics is proclaimed to be a theory of communication and control in animals, society, and machines. The elements of the theory are feedback, self- regulation, control, and information transmission. It uses the concept of entropy in communication theory and uses this as a measure of disorder, uncertainty or variety of systems. This theory has inspired to analyse the problems arise in social systems; however remain largely verbal, and often graphical rather than mathematical.

Systems Theory is an outgrowth of the concepts of General Systems Theory and cybernetics. It is more of a practical philosophy of solving problems in societal systems. It suggests a holistic approach in defining the problem, defining the objectives of the system, designing the change, and evaluating the design and known as design methodology. The characteristics of this theory are:

- The problem of a system is defined in relation to super-ordinate systems to which a community of objectives relates it.
- The objectives of the system must be viewed in relation to these super-ordinate systems or the whole system. Present design must be evaluated in terms of opportunity costs or the extent of divergence of the system from the optimum design.
- The optimum design cannot usually be found incrementally nearby present adopted forms. It involves planning, evaluation, and implementation of new alternatives, which offer innovative and creative departures from the whole system.
- System design involves processes of thinking, such as, induction and synthesis, which differ from deductive and reductive methods used in the scientific method of system improvement.
- Planning is conceived as a process where Planner assumes the role of a leader rather than that of a follower, so those problems are prevented from occurring rather than solved when
- It is universally accepted that it is one of the most potent ways of undertaking a systematic inquiry. However, it does not recommend any specific methodology, which guides the actual employment of approach.

The System Dynamics approach amalgamates ideas developed in various System Theories and is a result of cross-fertilisation of ideas from traditional management, cybernetics, and computer simulation. It is a theory of structure and behaviour system. It presents a very easy to use intuitively appealing and yet use mathematically sophisticated methodologies while undertaking practical systems enquiry. Moreover, System Dynamics has its genesis to Industrial Dynamics, where it is said to be the study of information and feedback characterisation of industrial enterprises to show the interaction of structure, amplification and time delay to influence successes of an enterprise, and is adopted for investigating dynamic behaviour of feedback systems It is applicable to other complex social systems other than industrial systems with problems of controllability such as, urban systems, world systems, tourism systems, which deal with socio-economic systems and management.

3) Application of system dynamics theory

System Dynamics Theory has been employed to a wide range of problem domains. It includes works in corporate planning and policy design economic behaviour, public management and policy, biological and medical modelling , energy and environment, theory development in the natural and social sciences, dynamic decision modelling, complex non-linear dynamics, software engineering, supply chain management, tourism system dynamic model, and integrated tourism dynamic model

4) System dynamic modelling

System Dynamic modelling is one approach that can help the Urban Planners and Managers to meet the challenges of decision-making and policy formulation for the development of a system. It represents the key feedback structures in the system. Simulating the model shows the effect of the system structures on policy interventions. It is a problem evaluation approach based on the premise that the structure of a system, that is the way essential components are connected, generates its behaviour. It is well suited to analysis of problems whose behaviour is governed by feedback relationships, has a long- term time horizon, and not suited to one-time decisions. The process of creating a simulation model helps clarify the resource management problem and makes modeller assumptions about the way the system works explicitly. The most important advantage of this model is once the model is built; it can be used to simulate the effect of proposed actions on the problem and the system as a whole. In this regard, Forrester (1987) noted that this kind of tool is necessary because, while people are good at observing the local structure of the system, they are not good at predicting how the complex and interdependent the system will behave.

System Dynamics proceeds through several major steps and these are the same steps followed in any problem solving process. This is also an iterative process and results at any stage can feed back to previous steps. The various steps for developing and employing the System Dynamic models are:

- Define the problem
- Describe the system
- Develop the model
- Build confidence in the model (Validation)
- Use the model for policy analysis
- Use the model for public outreach.

Building a model for decision support within an organisation may use only first five steps and using the model for public communication includes the next one.

Define the Problem

The first step in System Dynamic modelling is to identify the key variable whose behaviour over time defines the problem. The consequence of a system of interactions among large numbers of variables needs study through modelling to recognise a problem. The interactions of these variables operate on feedback mechanisms and generate the dynamics of the system. In the identification stage, it is important to interpret the problems and the causes thereof from the past behaviour of the system. In a social complex system, it is difficult to build a reference mode and identify a problem. In such situations, the problem is identified through discussions with experts, interviews, questionnaire surveys, Delphi, etc., study for building up a rich picture of the situation and record multiple perspectives for a problem situation looking at the interactions from different angles.

Describe the System

Describing the system involves identifying the system structure that appears to be generating problematic trend. This entails extracting the essential elements and connections from the real system that produces the anticipated or observed behaviour. At this stage, fixing model aggregate and boundary is of paramount importance and should be free from any mental fixate or obsession. All the factors relevant to the description of the problem phenomena under investigation are to be included, therefore a large number of variables those influence the system are brought within the system boundary for comprehensiveness. The final representation of important variables and causal links called dynamic hypothesis, which is the system structure, is thought to explain the dynamic behaviour of the system.

Develop the Model

A detailed model is developed based on the dynamic hypothesis, by representing through flow diagrams, which takes into account the physical resources and information linkages at the time of their construction. Further, the variables are presented in different forms to identify them as Stocks or Levels (accumulation), Rates (decisions), Auxiliaries (algebraic subdivision of rates) or Converters and parameters. Model assumptions are also incorporated while developing the model.

Model Validation

In System Dynamic modelling, the ultimate objective of the validation process is to establish the structural validity of the model with respect to the modelling purpose. It is critical because the purpose of a system dynamic study is to evaluate alternative strategies, or policies to improve the behaviour. Accuracy of the model behaviour is meaningful only if there is sufficient confidence in the structure of the model. Validation needs to be applied at every stage of modelling. It is required to be validated against the observed or anticipated trend and sometimes individual tests, such as, structure oriented behaviour tests (extreme condition, behaviour sensitivity and phase relationship tests are used for detection structural flaws in the

model. If the model reproduces the trend and represents the real system as it actually works, then the model leads to accurate behaviour or else the second step must be revisited to revise the dynamic hypothesis or model structure.

2.3 GAP ANALYSIS OF THE LITERATURE REVIEW & SUMMARY

- Most of the studies conducted with system dynamics are for sustainable transportation, public transportation, or transportation planning.
- Only Chennai has done a research of system dynamics model on land use transportation interactions. Hence in this thesis System dynamics will be used to prepare the land use transport interactions in the PMC region.
- Literature review can be presented in the form of global distribution on world map. It helps to cover no of studies with authors in different parts of the world. This chapter attempts to brief different transport planning studies covered with different objectives and with different approaches. The discussed literature review highlights some major findings with respect to the Indian urban transport system like (i) lack of guidelines for assessing the transport system according to the local travel characteristics of area (ii) need of a well-defined analytical method or approach structure for comprehensive evaluation of transport system in an area

CHAPTER 3: RESEARCH METHODOLOGY

3.0 RESEARCH METHODOLOGY

This section introduces the framework of the methodology adopted for the present research work. A stepwise methodology adopted for the study is illustrated in Figure 3.1. Identification of the real-world problem is the first step of any research work. Based on the literature review conducted and research gaps identified, objectives are finalized for the proposed framework. For the desired research outcomes in an effective way, a stepwise methodology is developed. The following subsections provide a broad description of steps adopted in methodology.

3.1 PROBLEM IDENTIFICATION

The first phase of research starts with problem identification. It is the most basic and essential step of any research work. "A problem is an interrogative sentence or statement that asks: what relation exists between two or more variables." (Kerlinger, 1986). In the step of problem identification, a broad area is selected and further narrowed down to a specific one problem. The study's problem statement is drafted as assessing the land use transportation in the metropolitan area using policy formulated by system dynamics

3.2 LITERATURE REVIEW

The second stage is comprised of a comprehensive literature review. It forms the nucleus of any research and help to interpret of old literature in the light of new developments. It also helps to identify the gaps which can be further explored for research. It is important to understand previous studies made in that area, relevant theories, and methods applied to the field and gaps in the existing research. This comprises of 3 stages i) analysing the application of system dynamics in various approaches of transportation ii) understanding the concept of system dynamics and land use transportation iii) gap analysis of the literature review

3.3 STUDY AREA DELINEATION

The next stage, followed in the prescribed methodology, is the study area delineation. The selected area for this study is Pradhikaran, Nigdi.

3.4 DATA COLLECTION AND ANALYSIS

The holding capacity of the roads was one of the main factors influencing traffic congestion. The holding capacity was determined by considering traffic volume as primary data while demography, land use and, norms on basic infrastructures was secondary data.

The primary data collection involved local trips bounded in the study area. It will be achieved by conducting traffic volume surveys.

1) Trip rate

The trip rate is the number of trips a person makes across a given area. The number of trips that each person takes over a certain time was also considered, and various parameters were used to measure this variable.

2) Land use

Land use was defined as the management and modification of existing land into a different type of land. In this case, it is the conversion of agricultural, forested, and wasteland into urban land. The conversion of land use must be productive in a planned urban region, given the limited land available for urban use

Secondary data : such as The demography data for rural and urban areas should be collected

3) Trip generation

The frequency of trips that start and terminate in each region is modelled as trip generation. The goal of trip generation is to simulate the total number of anticipated trips to each zone within the research area. The trip generation, or trip rate, can be calculated from the land use and population data

4) V/C calculation

The selection of an appropriate exposure measure is a critical issue in traffic accident investigation. Currently, traffic volume is employed as a metric of visibility. The number of accidents per million vehicle kilometres is used to measure the risk of using a certain stretch of road. Assuming that traffic accidents grow in proportion to traffic flow is an oversimplified assumption that is incorrect as a rule. Using the same traffic volume on various capacity road sections provides varied operation circumstances and, hence, variable accident possibilities. A more effective measure of exposure may be the volume-to-capacity (V/C) ratio, which is one of the characteristics that affect the level of service, since there is a limit in the vehicle capacity of a particular road. V/C is a ratio that compares the actual volume of the vehicles to the maximum vehicle capacity. Ideally, This ratio should be low to ease the flow of traffic. The volume of each model of vehicle is calculated by computing the percentage modal share of each vehicle, and the occupancy ratio of the respective vehicle. The model for the V/C sector is built by accounting for the present vehicular volume and the capacity of the corridor six-lane road, as per government regulations, to determine the V/C ratio. The ratio is predicted from two different parameters—land use and population. The desirable V/C ratio from the land use and population is very small, and this ratio must be maintained in the future projection

5) Implications

The study will create three scenarios, in which the Do-Min, partial and desirable proposals are implemented. For the Do-Min scenario, the existing trend is allowed to continue with no improvements. In the partial scenario, some new proposals implemented; however, most

proposed models are ignored, hence, it is known as partial implementation of the model. The desirable scenario is the complete proposed model, in which all the proposals are implemented.

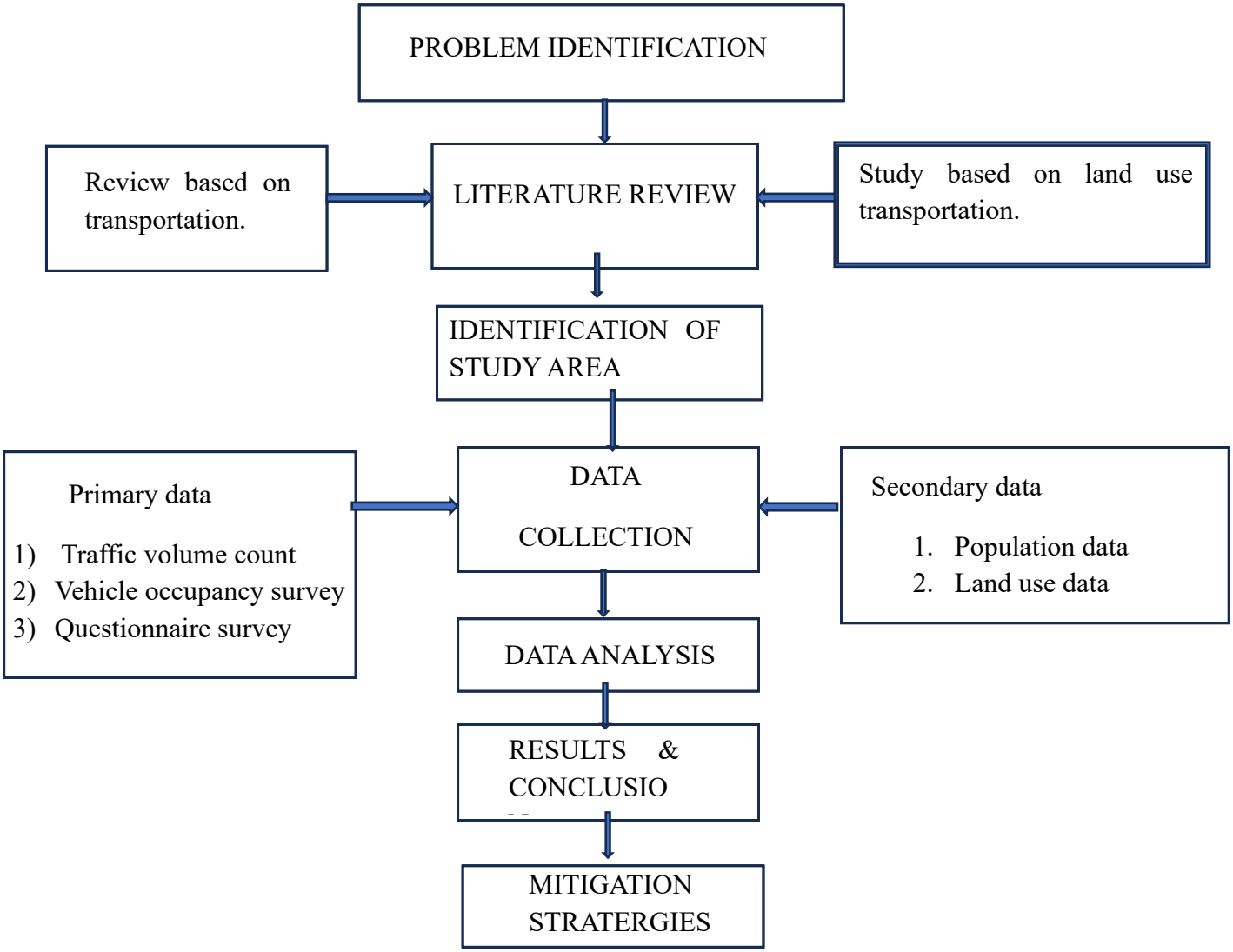


Fig 3.1 Research Methodology

CHAPTER 4: STUDY AREA DELINEATION & DATA COLLECTION

4.1 Study Area

The selected area for the case study i.e. Pradhikaran falls in the PCMC region which has a total population of is 26485 and area is 2.9sq. Km Fig 4.1 shows the map of the study area. The Administration office of Pradhikaran is PMRDA and PCMC which is located within the area.

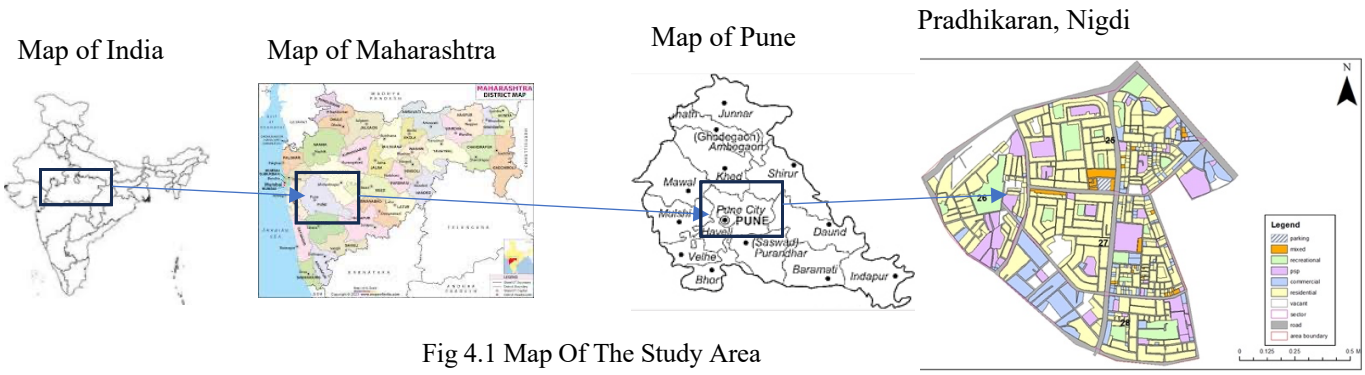


Fig 4.1 Map Of The Study Area

4.2 Data Collection

Data collection is the procedure of collecting, measuring, and analysing accurate insights for research using standard validated techniques. The approach for data collection is different for different types of studies, depending on the required information. The most important aspect of data collection is ensuring information-rich and reliable data should be collected so that data-driven decisions can be made for research. So a comprehensive data on travel behaviour, transport network performance, associated land-use characteristics, and travel preferences will be essential in decision-making and policy formulation. A travel survey is the most widely used tool in this process. Travel surveys are used to collect information about demographic, socioeconomic, and trip making characteristics of individuals and households. They are also used for understanding travel for location, choice, and scheduling of daily activities. It enhances the ability to predict changes in daily travel patterns in response to currently observed trends. To comprehend all the study objectives, a household (HH) survey form is designed, and a survey is conducted in the described study area.

4.2.1 Questionnaire development

A well-designed questionnaire is a crucial aspect of any planning exercise. It helps to understand a user's travel behaviour. In developing countries, questionnaire survey faces

many problems, and some of them are; illiteracy, unfamiliar terms associated with language, lack of sample frame, therefore, respondent selection, social-religious-cultural norms, suspicious about the purpose of the survey, response reliability and achieving users

understanding without interviewer bias (Jones, 2003). At the same time, a well-designed questionnaire survey can reduce errors to specified acceptable levels of precision. It also helps to record the behaviour in a predefined situation. In the present study, the first part, Part A, is comprised of details like HH size, gender, age, education, occupation, monthly income, vehicle ownership, transport expenditure, etc. It also includes daily travel details like trip purpose, travel time, travel cost, etc. Part B, the second part of the questionnaire, is about the behavioural change of user-tested through expected mode attributes, transport system satisfaction for different types of user, policy measure choice.

4.2.2 Data Collection Method

Data collection is a process of information collected from all the relevant sources to find answers to the research problem and evaluate outcomes. Data is usually collected for two categories (i) Primary data and (ii) Secondary Data. In the present study, secondary data is collected from authorized government reports, published books, journal papers, etc. Government report comprised of City Development Plans (CDP), Comprehensive Mobility Plans (CMP), etc. Primary data is collected through the HH survey, whereas the questionnaire developed is discussed above. In the present study, the data collection done is 1)face to face household survey 2)Traffic volume count 3)vehicle occupancy.

4.2.3 Household Survey

1. Survey form and estimation of sample size

A survey form was prepared based on travel behaviour, transport network performance, associated land-use characteristics, and travel preferences that will be essential in decision-making and policy formulation.

The sample size is an important factor in the sample design. It affects the precision, cost, and duration of the survey more than other factors (like the method of survey, duration, etc.). Three factors significantly affect the determination of sample size, variability of a population, degree of precision, and population size. The sample size is calculated using the formula for estimating a population proportion i.e. Equation (1) as given below:

$$S = \frac{z^2\, P(P-1)}{E^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

Where,
S = Required sample size;

z= Z-score corresponding to the desired confidence level (for 95% of confidence level, approximately 1.96)

P= estimated proportion of the population (80%)

E= margin of error (5%)

The value of the sample size achieved using the above formula is 206. The samples are collected from different sectors from the face-to-face HH survey.

2. Socio-Demographic Characteristics

In this area , 44% of respondents are observed with private service and business and 28% are involved in the educational field. 56% of trips are observed for work purposes and 32% of observed trips are for education purpose. So, 88% trips are observed as compulsory trips in the study area.

3. Travel characteristics

Travel characteristics studied through the HH survey helps to analyse how a user participates in the transport system. User participation can better be studied through choices made for travel. It also helps to analyse how choices made affect the transport system. Further, it can be utilized to understand the gaps that exist in the transport system. The same objective, mode share, average trip length, and average speed are studied through descriptive statistics.

4.Mode share and trip length

Mode share is an essential component in the planning process of a land use transport system. It reveals the preferred mode of transport in an area. Modes in the study area are classified into four categories, namely: TW, FW, PT. The study area is observed with a 67% TW mode share, while the car mode share is 20%. For PT, 3W and NMT mode share is observed as 5%. The average trip length is considered based on the highest kilometres travelled using that mode of transport.

4.2.4 Traffic Volume Count And Vehicle Occupancy Survey

Traffic volume is the number of vehicles crossing a section of road per unit time at any selected period. Traffic volume survey is used in planning, traffic operation and control of existing facilities and also for planning and designing the new facilities. This survey is also used in the analysis of traffic patterns and trends. It also helps to determine the traffic flow or traffic in the peak hour. The methods used for traffic volume counts are Manual count, Mechanical count, Combination of manual and mechanical methods, Automatic devices(pneumatic tube, photo electric cells, magnetic detectors and radar detectors), Photographic methods. In this study manual count method is used. In this method it employs a field team to record traffic volume on the prescribed record sheets. The number of observers needed to count the vehicles during the peak hour and it depends upon the number of lanes in the road on which the count is to be taken and the type of information. In this study the TVC was conducted in Sant Dnyaneshwar chowk during the evening peak hour between 7:00pm to 8:00pm on all the four arms. Vehicles were separated by type and counted for analysis. The two wheelers and cars had the highest proportion of the total vehicle volume, at around 67% and 20%, respectively. Buses, which consisted of private, institutional, and public transportation, made up only 4% of the total vehicles. Environmentally friendly vehicles, such as bicycles, made up a mere 1% of the total number of vehicles. The Fig 4.2 shows the graph of the percentage mode share obtained during the TVC.

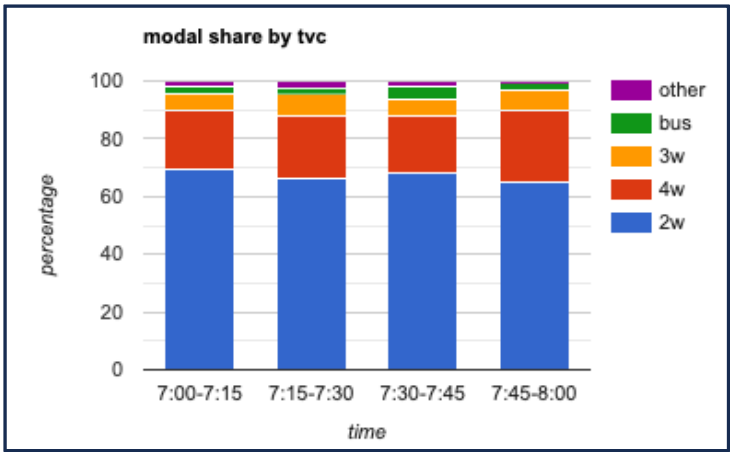


Fig 4.2 Mode Share of TVC in Sant Dnyaneshwar Chowk, Nigdi Pradhikaran, Pune

Vehicle occupancy survey is a survey in which the number of occupants using that particular vehicle is observed. It was conducted in the same intersection. Based on the observed occupancy the vehicle occupancy factor was calculated. The equation (2) gives the vehicle occupancy factor.

$$V_{o=}\frac{\text{Sum of all observed vehicle occupancy}}{\text{Total occupant capacity}}$$

Hence the vehicle occupancy factor of 2W=1.2, 4W=3.5, 3W=3, bus=48. These values are used in the stock and flow diagram.

CHAPTER 5 ANALYSIS OF THE DATA COLLECTED

5.1 System Dynamics

A system is nothing but a well-organized structure comprising interrelated components that influence one another directly or indirectly. Continuous interaction of these components generates dynamism in the system, further making the process more complicated. A transport system is one such system where the continuous interaction of different transport system components has resulted in different complexities. So, there is a need for an approach that will help to make better decisions when encountered with complex issues. It should provide a viewpoint and tool to model and analyse the system capturing the dynamism involved. SD is one such a computer-aided concept used for policy analysis and design (Richardson, 1996). It provides a technique and tool to investigate current decision making and future behaviour of the system using simulation. It is useful for systems characterized by interdependent systems majorly observed with mutual interaction, causal effects, and feedback structure. It can relate a system's behaviour to the underlying structure.

The first stage, a Causal Loop Diagram (CLD) is developed to represent the complexity and interactions among the land use and transportation. In the second stage, a stock and flow diagram is developed based on a causal loop diagram. Later, in the third stage of the study, scenario-based (futuristic) demonstrative analysis is performed by applying the developed model. This all is done using the software Vensim

5.2 Methodology

SD is a conceptual tool that enables understanding of the structure and dynamics of a complex system. It is a rigorous modelling method that enables building formal computer simulations of complex systems and uses them to design policies that are more effective for organizations (Sterman, 2000). With all these advantages, the user's dynamic mode choice and its consequent impact on congestion level are studied in the present study using the SD approach. The methodology adopted for appraisal of the urban transport system consists of four stages, as shown in Figure 5.1

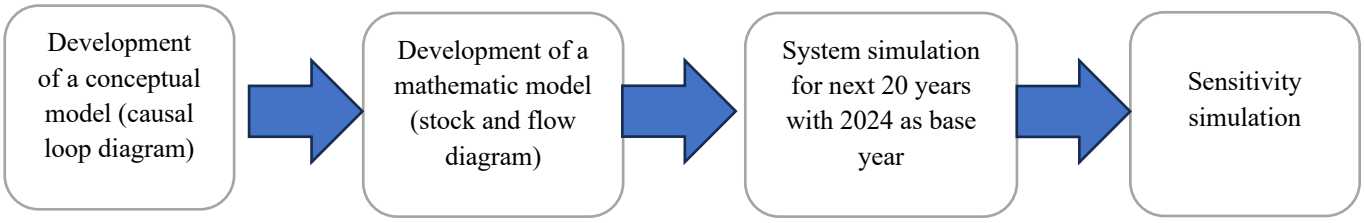


Fig 5.1 Methodology for the appraisal of Land Use Transportation

The flowchart reflecting the methodology adopted for the study. The first phase of the methodology consists of problem identification. Key players of the system leading to problem generation are framed in the phase of model development. For the developed model, data is validated to verify how models perform according to their design objectives. If it does not validate, then the model is revised, and if the model is validated, further analysis of data is conducted to evaluate the system and understand the causal effects of variables on the system.

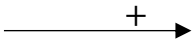
Model simulation and sensitivity analysis further help to improve the performance of the transport system. The conceptual and mathematical model of proposed land use transport dynamic system is developed using @Vensim software. @Vensim is simulation software and it provides a graphical interface with Stock and Flow Diagram and CLD. It includes a method of behaviour interactive tracing through causal links in model structure.

5.3 Causal Loop Diagram For Land Use Transport

The first phase of the SD analysis is the Causal Loop Diagram (CLD). It is also called a feedback loop where the transmission and return of information occur (Richardson and Pugh, 1981). In other words, it is a system with a closed sequence of causes and effects. It is used to display the behaviour of cause and effect from a system‘s standpoint. It helps in visualizing how different variables in a system are interrelated through nodes and edges. Nodes represent the variables, and edges are the links that represent a connection or a relation between the two variables. A link marked positive indicates a positive relationship, and a link marked negative indicates a negative relation. A positive causal link means the two nodes change in the same direction, i.e., if the node in which the link starts decreasing, the other node also decreases.

Similarly, if the node in which the link starts increasing, the other node increases as well. A negative causal link means the two nodes change in opposite directions, i.e., if the node in which the link starts increasing, the other node decreases and vice versa. Table 5.1 enlists the symbols used in the construction of CLD.

Table 5.1 Symbols used in the construction of CLD

SR NO	SYMBOL	DESCRIPTION
1.		It is used to show Causation
2.		It indicates that if tail increases head increases and if tail decreases head decreases.
3.		It indicates an inverse relationship. If tail increases head decreases and if tail decreases head increases.
4.		The symbol found in the middle of the loop indicates the loop continues going in the same direction. It is called “positive” or “reinforced” feedback loop. Often shows systematic growth or decline.
5.		The symbol found in the middle of the loop indicates the loop changes direction. It shows the system to fluctuate or to move towards equilibrium. It is called “counteracting” or “negative” feedback loop

A conceptual model is developed using, as shown in Fig 5.2. It explores the causal loop of increased land demand and its impact on the transport system. Closed cycles in the diagram are important feature of the CLD. The model consists of three balancing loops (B1 & B2,). A negative, or balancing, feedback loop seeks a goal. A balancing loop is a cycle in which the effect of a variation in any variable propagates through the loop and returns to the variable; a

deviation opposite to the initial one, i.e., if a variable value increase in a balancing loop, the effect through the cycle will return a reduction to the same variable and vice versa.

Loops and interaction among all the loops are as discussed below:

-B1 loop: this loop starts with the exogenous variables (population and employment opportunities), these variables increase the land demand which in turn influences the travel demand and increases the vehicular traffic volume and congestion. Thus, this emphasizes the need to improve the accessibility. Accessibility then has impacts on the land use, land value and land demand.

-B2 loop: Second closed loop starts at vehicular traffic volume, increasing the travel time and travel cost. It further increases household transport expenditure, decreases affordability, and affects area's economic growth. It then leads to decrease in land use and land value.

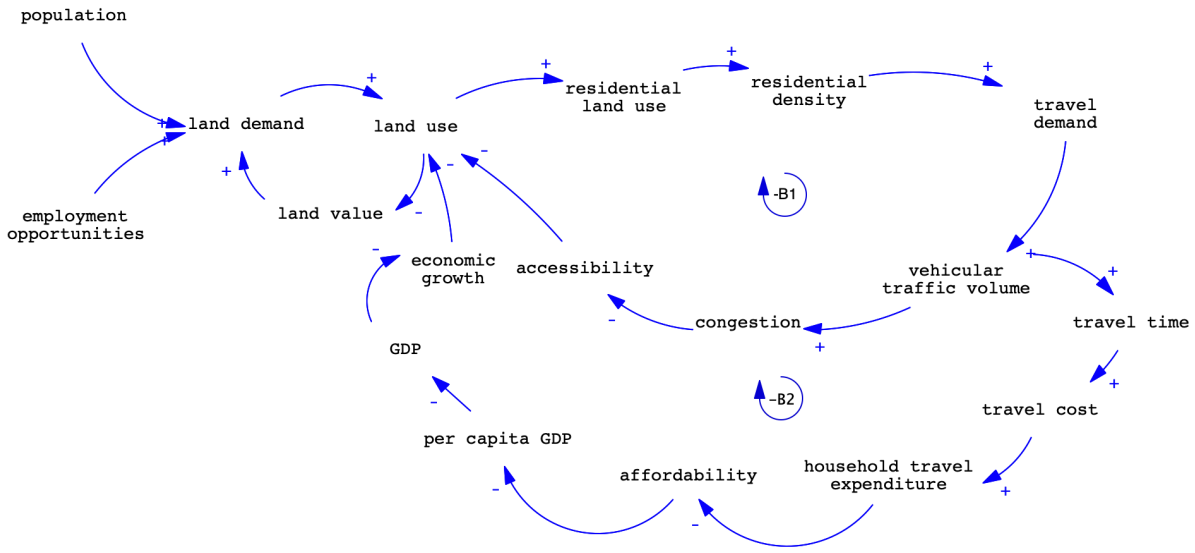


Fig 5.2 Casual Loop Diagram for Land Use Transport Interactions

The quantification of the conceptual model can be well-illustrated with the help of stock and flow diagram, the mathematical version of conceptual model. Next section comprises of details of stock and flow diagram formulation and results obtained.

5.3 Stock And Flow Diagram

The next phase of the analysis is to understand how the variables and the system will behave over a period of time. It can better be comprehended through the stock and flow diagram. It works as a medium between system dynamics and simulation. Stock and flow diagrams contains specific symbols and components representing the structure of a system. Stocks are things that can accumulate. Flows represent rates of change. It is the phase of mathematical expression. The stock and flow diagram developed for the land use transportation system is shown in Figure 5.3. The mathematical model is divided into three sub-models: (i) Population model, (ii) Mode choice behaviour model (iii) congestion level model.

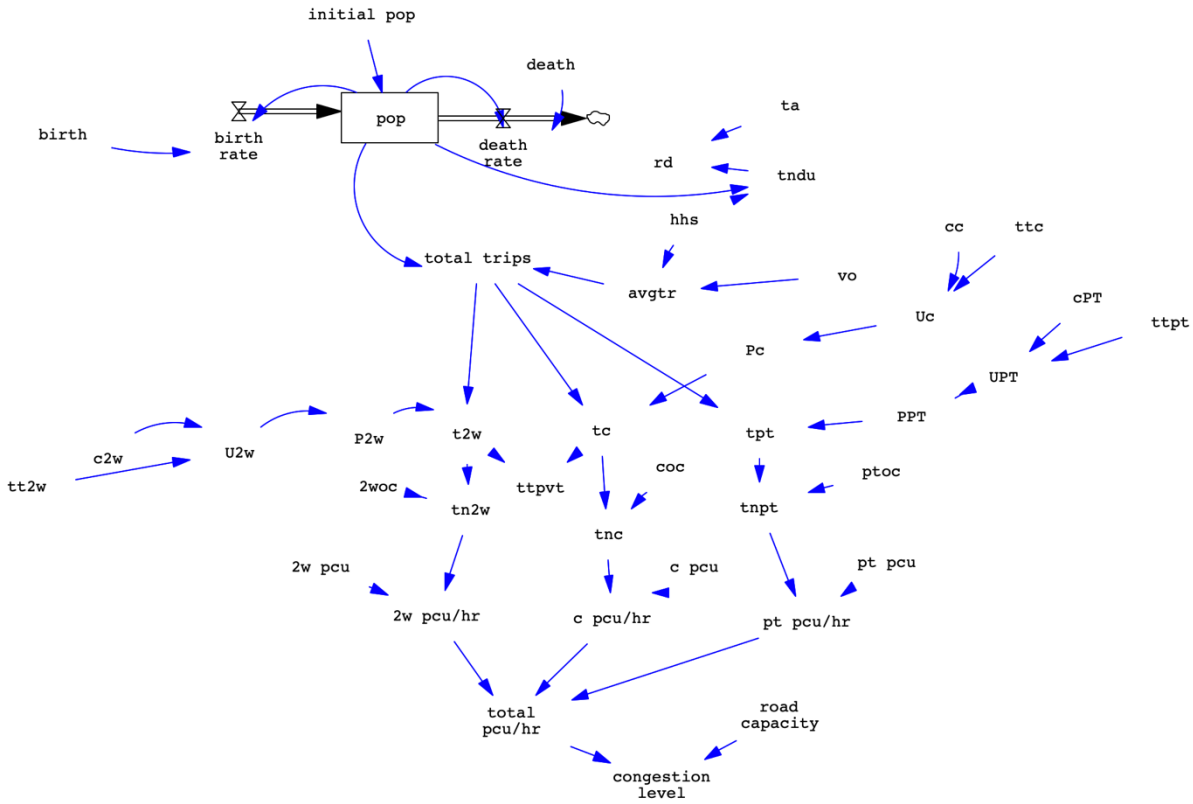


Fig 5.3 Stock and flow Diagram for Land Use Transport Interactions

Population model: - Population model represents the demographic growth of the city for which migration, birth, and death rate are taken as exogenous factors. In this sub-model, the initial population (IP), birth rate (Br), death rate (Dr), are taken as constant. The Net increment (Net-Incr) is taken as a rate variable. The estimated total population is also used for the initiation of the mode choice behaviour model.

Mode choice behaviour model: Total population (Tot-pop), a flow variable, is used to initiate mode choice analysis. Mode choice helps to analyse and predict the choices that individuals or groups make in selecting the mode used for a particular trip. Mode attractiveness is analysed with the probability of choosing a mode under a given set of conditions. The same choice-based model is considered in the study. Choice model permits comparison of two or more than two alternatives and the importance of attributes of alternatives. One such model, the mode choice Logit model, is used in the current study. It is widely used for transportation forecasting in various forms. The mode choice Logit model is used for the prediction of the probability of occurrence of an event. The probability of choosing a mode by trip maker is defined by Equation 1.

$$P_i = \frac{EXP\ U_i}{\sum_{i=1}^{n} EXP\ (U_i)} \quad \ldots\ldots(1)$$

$0<Pi<1$ where $\forall i, j \in N \rightarrow Ui, Uj \in [0,1]$ and $Pi = 1-j \sum_{i=1}^{n} P_i$

where Pi or Pj is the probability of choosing alternative mode i or j, respectively, and Ui or Uj is the value of utility function for the alternative mode. Travel Time (TT) and Travel Cost (TC)

are two parameters considered for the utility function. The output of this sub-model consists of (i) trips by car, TW, and public transport (PT) (Tc, T2w, Tpt)

Congestion level model : the traffic congestion level is given by the V/C ratio where V is the traffic volume and C is the road capacity. The traffic volume is estimated by using the total trips made by 2W, c, and Pt, vehicle occupancy rate of 2w, c, and Pt, and the total PCU/hr of all the vehicles. The road capacity is taken from the IRC standards.

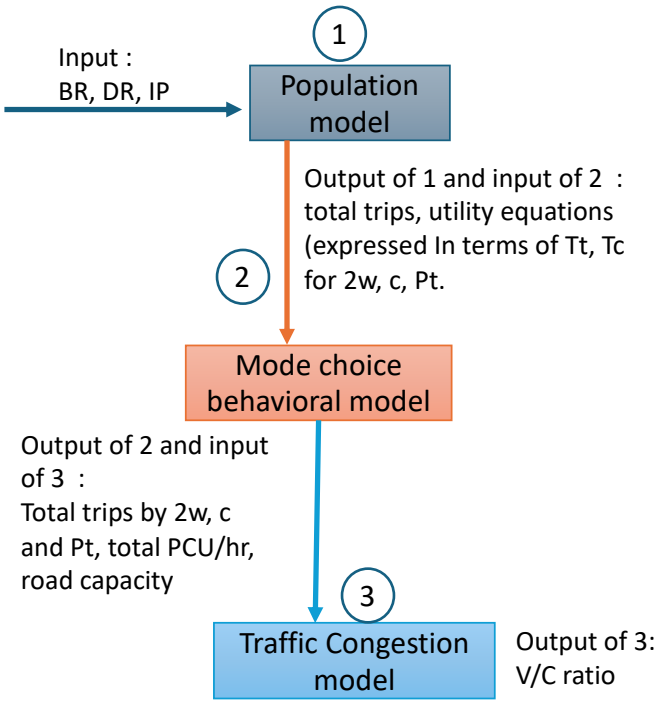


Fig 5.4 Submodels of the Stock and Flow Diagram

Table 5.2 Formulae for Stock and Flow Diagram of Land Use Transport

Sr no	**Variables**	**Type of variable**	**Formulae**
1.	INI-POP	Constant	From secondary data
2.	BR	Rate	Birth/population*1000
3.	DR	Rate	Death/population*1000
4.	Total Population	Level	(Birth Rate-D Rate)*initial pop
5	Total Area	Constant	From Land use data
6.	Total no of dwelling units	Auxiliary	Total Population/HHS
7.	Residential Density	Level	Total No. of Dwelling Units/Total Population

9.	VO	Constant	From Primary data
10.	HHS	Constant	Land use data
11.	AvgTr	Auxiliary	-a+(xp)+(yv)……(where x and y are the coefficient)
12.	TT	Auxiliary	AvgTr *Total Population
14.	TTC, TT2W, TTPT	Constant	From primary data
15.	TCC, TC2W, TCPT	Constant	From primary data
16.	UC, U2W, UPT	Auxiliary	aTT+bTC……(where a and b are coefficients from CMP)
17.	PC, P2W, PPT	Auxiliary	e^U/((e^-u)+(e^u))
18.	TC, T2W, TPT	Auxiliary	P*TT
19.	2WOC, COC, PTOC	Constant	From primary data
20.	TN2W, TNC, TNPT	Auxiliary	Total Trips by mode share/oc by mode share
21.	2WPCU, CPCU, PTPCU	Constant	From IRC
22.	2WPCU/hr, CPCU/hr, PTPCU/hr	Auxiliary	PCU*TN
23.	Traffic congestion level	Auxiliary	Total PCU/hr/Road Capacity

5.5 Parameter estimation and model simulation

The very first stage in the analysis is the parameter estimation. It is the process of using simple available data to estimate the parameters for analysis followed by simulation. The next stage is to simulate obtained parameters to understand the eventual effects of alternative conditions and courses of action. The values of constants in the model are refereed from various reports of selected cities like city development plan reports; comprehensive mobility plans, and primary survey

5.6 Model Validation

Validation is the accuracy check process by determining the degree to which a simulation model and its associated data represent the real world from the model's intended uses. Among the different methods of model validation, a method of comparison is used. Simulation results are compared with the known results of the analytical model. For the validation purpose, two variables, population, and total trips, are selected. Projected Population values are validated using population projection methods: Geometric increase. In this the increment is determined for each decade from the past population, and the average value is added to the present population and the average rate of increase. So, it helps to generate a range of population increase. The total trips are calculated using the 4 stage modelling.

The projected population of Pradhikaran by geometrical method is 48286 while current model simulated values is 47863 with 1 % error. In case of total trips, forecasted four step modelling value for Pradhikaran is 49626 and the simulated value is 48494 with 1.02% of error. According to the results, the error (%) of total population and vehicle population are less than 5% showing that the model is accurate enough for simulation. Values listed in Table 7.11 for population and total trips validate the model output for further analysis. Accordingly, the simulation process is further used for other variables to evaluate the transport system under different scenarios as explained in the next sections.

5.7 System Simulation

Simulation is an approximate imitation of a process's operation or a system representing its operation over time (Banks et al., 2001). The advantage of using simulation is to show the eventual real effects of alternative conditions and course of action. The present study used the simulation concept to understand the land use transport system's response in the future under prevailing conditions. It will help to understand the behaviour over a period of time and the probable consequences. Outcomes of the model will help to understand the behavioural limits of key parameters for future years and will be used to comprehend the changes in each variable of the land use transport system. The simulation graph shows simulated values: X-axis – Times in years and Y-axis corresponding values of variable aggregated for the respective year.

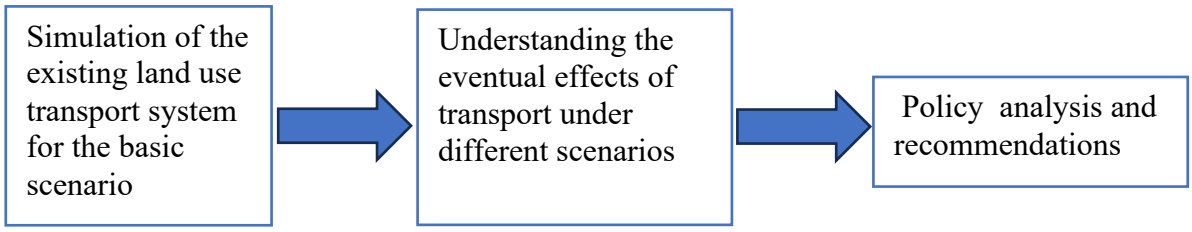
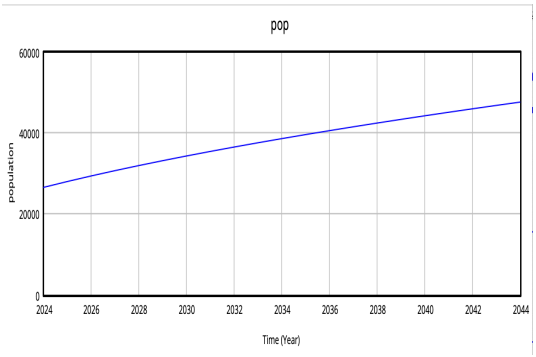


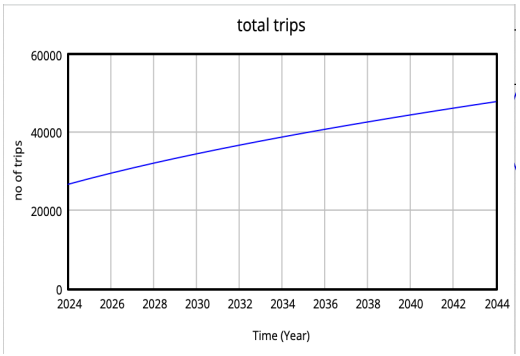
Fig 5.5 Stages of SD

As previously explained, the model is developed with two objectives of (i) studying the impact of land use on transportation (ii) understanding the existing and future transport system under different scenarios through simulation. Simulation is performed for all the selected set of variables. Simulation is conducted for 20 years while taking 2024 as the base year. Outcomes of the model will help to understand the behavioural limits of key parameters for future years and will be used to comprehend the changes in each variable of the land use transport system. Figures 5.6 illustrates the simulation result for some of the variables under Business As Usual

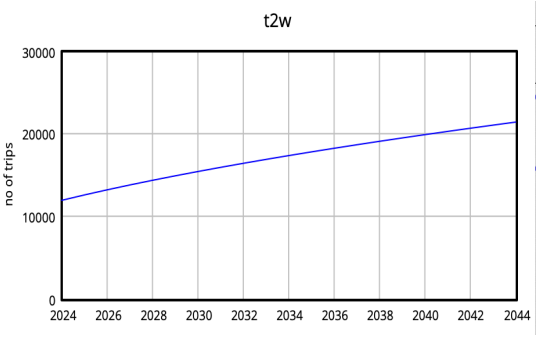
Scenario (BAU). The simulation graph shows simulated values: X-axis – Times in years and Y-axis corresponding values of variable aggregated for the respective year.



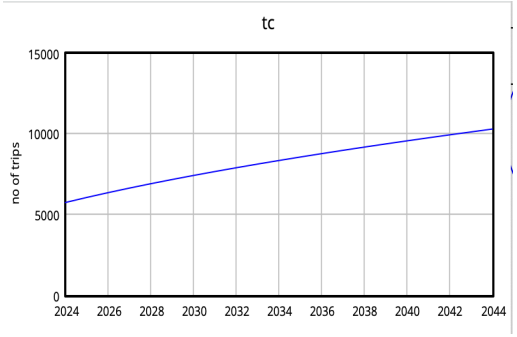
a) Population



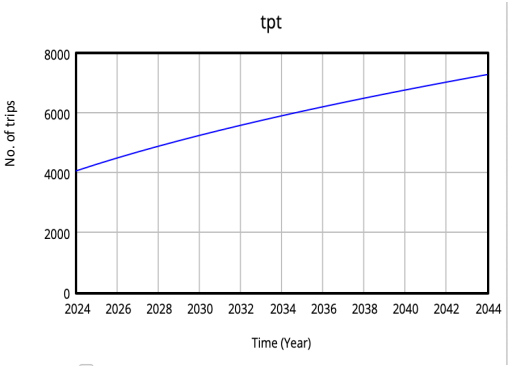
b) Total Trips



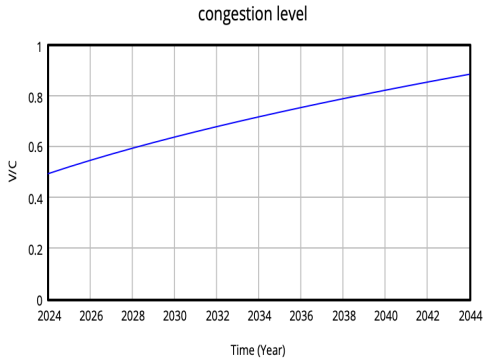
c) Trips made by 2W



c) Trips made by Car



d) Trips made by PT



e) Congestion Level

Fig 5.6 Simulated values for selected variables in BAU scenario

Table 5.3 Model validation

Sr No.	Variable	Calculated value (2044)	Simulated value (2044)	Error (%)
1.	Population	48286	47863	1%
2.	Total trips	49494	48494	1.02%

Table 5.4 Simulated values for 2044 with 2024 as base year

Sr No.	Variables	Simulated Values for 2024	Simulated Values for 2044
1.	Total population	26,485	47,544
2.	Total trips	27,014	48,494
5.	No. of trips by 2w	15,670	24,747
6.	No. of trips by C	3,880	10,668
7.	No. of trips by PT	4,322	7,759
8.	Congestion level	0.4	0.88

The simulation graph shows an increasing trend for variables for Pradhikaran, and the simulated values are summarized in Table 7.11The simulation graph shows an increasing trend of variables for Pradhikaran, and the simulated values are summarized in Table 10. where the simulated values for X-axis is the Times in years and Y-axis is the corresponding values of variable aggregated for the respective year. The results of the simulation reveal the future scenarios in Pradhikaran area. It shows that population has a decadal growth rate of 33% and the number of trips made by PVT has a decadal growth of 34% and the number of trips made by PT has a 7.5% of decadal growth rate . Hence it is observed that the trips made by PVT is 81% and the PT is 19% for the year 2044.Therefore the congestion level in the area for 2044 increases to 0.88 with a LOS level E. According to IRC LOS E indicates unstable flow ie low speed with considerable delays and the volumes are at or slightly over the capacity. Hence a decrease in economic growth can be seen due to increased delays and excessive fuel consumption(according to Wesley E. Marshall1 · Eric Dumbaugh 2020). This negative economic growth affects the land use and land value (according to ampofo 2020).

Simulation with 10% increase in the values of VO, travel time and travel cost is done to understand the adverse effect on the future trends. A 10% increase in influencing variables leads to increase in the number of trips and increase in value of the congestion level in 2044 which is increasing from 0.88 LOS E to 1.2 LOS F. This 10% increase in each variable provides the need to adopt the appropriate measures to enhance the land use transport system's performance by addressing the traffic congestion level. Approaches for these measures should help to visualize and analyse the proposed measures.

Table 5.5 Simulated value for 2044 with 10% increase in all values

SR NO	VARIABLES	BAU	10% INCREASED
1.	Total No. of trips	47,544	53,249
2.	No. of Trips by PVT	35,415	48,988
3.	No. of Trips by PT	7759	13844
4.	Congestion level	0.88	1.5

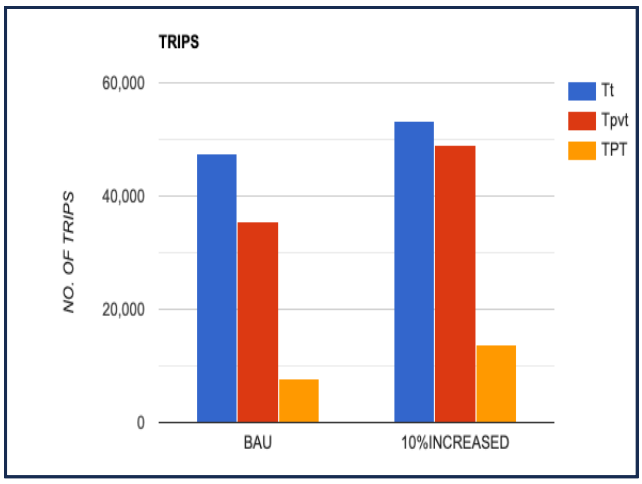


Fig 5.7 Graph of total trips and mode choice for 2024 in BAU and 10% increased value

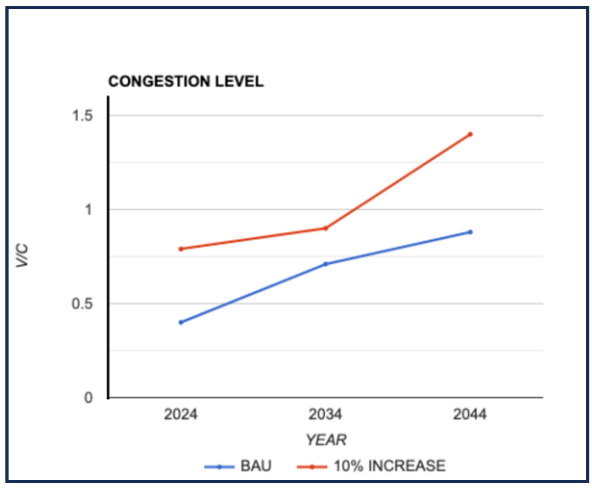


Fig 5.8 Graph of congestion level for 2024 in BAU and 10% increased value

CHAPTER 6 : TESTING OF POLICIES FOR PROPOSED FRAMEWORK

6.1 Policy testing for proposed framework of evaluation

Considering the nature of problem and the target area, policies to be tested are decided. The proposed set of solution in terms of policy testing will provide decision-makers a basis for improving land use transport system . Figure 8.1 shows the considered framework for policy testing.

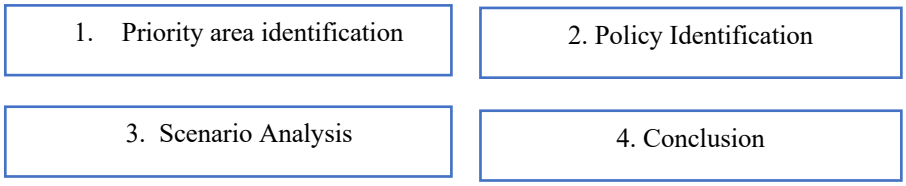


Fig 6.1 Stages of Policy Testing

6.2 Priority area identification policy testing

The very first stage of policy testing is to identify priority area. The identified area is taken up as the major focused policy area. It is observed that the congestion level of the area is to be addressed. The increased congestion is the outcome of excessive use of private vehicles. The majorly used mobilities are TW and FW which also result in major issue like air pollution. So, from the policy testing point of view, the study focuses on mitigation measures for traffic congestion through mobility management.

6.3 Policy Identification

The second stage is policy identification. The smart city plan of Pune has focused on many areas for achieving sustainable transportation. Considering the current mobility system the smart city plan Pune has focused on increasing the public transportation usage trips.

The smart city plan focuses on increased share of public transport by 2030 from 19% to 30% as a result of completing the 96kms BRTS network and 2 metro corridors measuring 31 kms, together with augmented bus fleet. NMT share also increases with the development of compact mixed-use development, further improving the traffic situation.

It also focuses on making public transportation percentage to 50% from current 19% through 100 e- buses, 26 km BRT route, 54 bus stop overhaul and 100 e-rickshaws; take NMT to 8% from 1% through 27 km bicycle tracks, 60 km footpath redesign, etc

Affordable, clean Mass transit option complemented by augmented, refurbished bus fleets (¬3500 buses) with feeder (¬500 Mini Buses) by 2021, better route planning, premium options and systems of information dissemination. Policy changes to make parking expensive with

stricter enforcements. Procurement of 2,500/ ITMS enable buses. Depot and terminal development. Public bicycle sharing system. Smart Redesign of 50 km of streets Redesign of 75 Junctions. Full rollout of BRT Network, metro and 2 Ring Roads to be completed.

6.4 Scenario Analysis

Scenarios are consistent and coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present, and future developments, which can serve as a basis for action (Van Notten, 2005). Scenarios are effective tool to evaluate proposed actions towards sustainability. It should answer (a) what will happen? (b) What can happen? (c) How a specific target can be reached? The very first stage of scenario analysis is defining strategies. Strategies on increasing the public transportation.

Due to rapid urbanization in metro cities the number of private vehicles have increased. Strategies are defined to demonstrate how strategies of increased public transportation will affect the traffic level congestion. For the same, concept of SD; demonstrated earlier; is used for the considered scenarios. Simulation results obtained through SD.

The second stage of scenario analysis is defining the best action. It gives a relatively detained and quantitative indication of how the system will change behaviour under assumptions. Looking to the scope, objectives, methods used, and results obtained in the study, scenarios are developed. The study's main aim is to define a comprehensive framework for measuring the traffic congestion of the land use transport system. For the same scenario, consideration is done following the Smart City Plan Pune. Based on this scenario analysis is done. SD is used to simulate the land use transport system's behaviour over a time period. The land use transport system's behaviour is tested for mode share and traffic congestion level using the concept of SD.

Table 6.1 Scenario analysis with different values

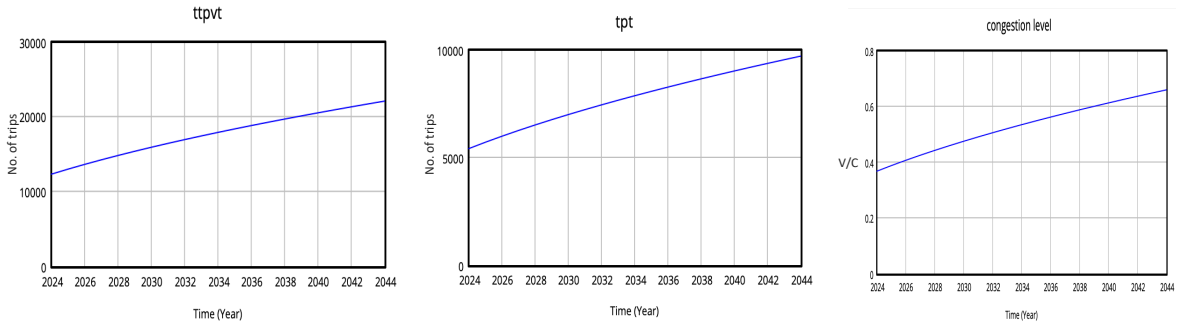
Sr No	**Scenarios**	**Mode share**	
		Private transportation	**Public transportation**
1.	S-1	-30%	+30%
2.	S-2	-40%	+40%
3.	S-3	-50%	+50%

In case of first scenario analysis, PVT and PT modes are considered in S-1 where PVT comprises of TW and Car. First scenario S-1 comprised of 30% decreased TW and Car in total PVT mode share while 30% increase of PT. S-2 comprised of 40% decreased TW and Car in total PVT mode share while 40% increase of PT. S-3 comprised of 50% decreased of TW and Car in total PVT mode share while 50%of increase PT. Three scenarios with S-1-±30%, S-2-±40%, and S-3- ±50% variation of TT and TC of PT and PVT have simulated the SD mode. The last stage of scenario analysis is estimating the impacts. The significant step a carried out for the same is 1) SD for simulating the mode share and traffic congestion for all scenarios.

Table 6.2 Simulated Values for 2044

Sr no.	Indicator	BAU	30%	40%	50%
1.	T2W	24747	14548	12123	5332
2.	TC	10668	6304	5334	12123
3.	TPT	7759	10668	11638	11638
4.	% Pvt	81	72	67	59
5.	% Pt	19	28	33	41
6.	Congestion level	0.88	0.59	0.5	0.5

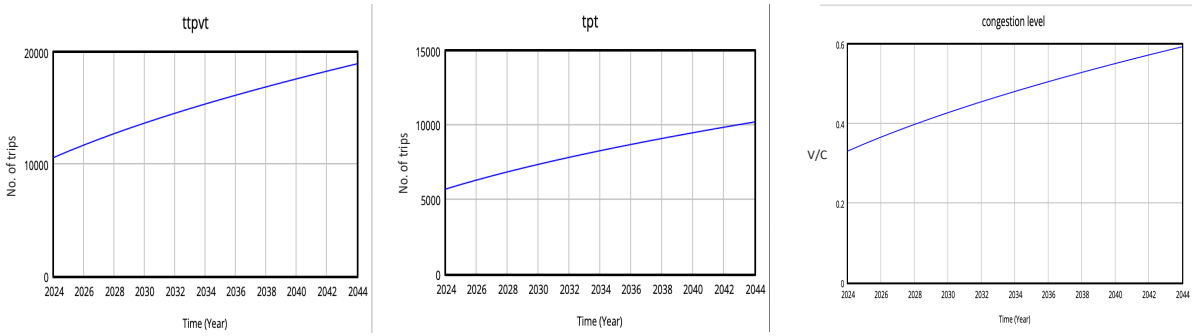
1) When public transportation trips is increased by 30% and 30% of private transportation trips are decreased then the congestion level is 0.65. fig 6.2 shows the graphs simulated by Vensim with 30% increase in PT trips and 30% decrease in PVT trips



c) Total trips by PVT a) Total trips by PT b) Congestion Level

Fig 6.2 Scenario analysis with different 30% increase in PT and 30% decrease in PVT

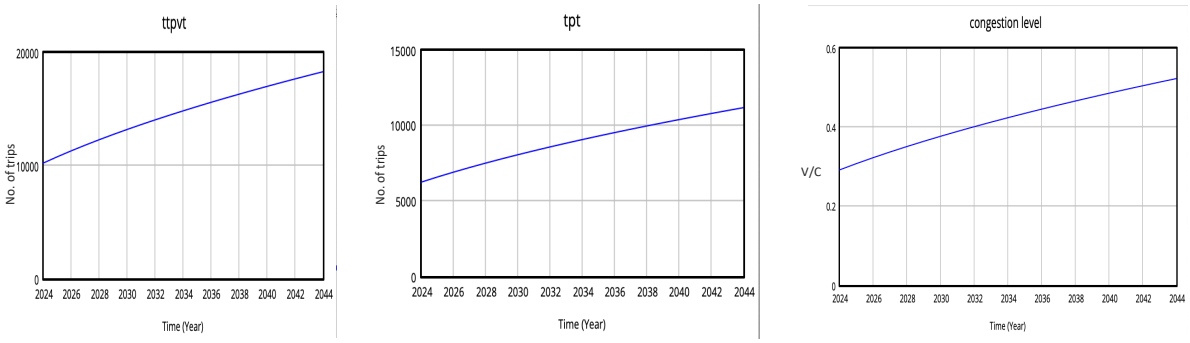
2) When public transportation trips is increased by 40% and 40% of private transportation trips are decreased then the congestion level is 0.59. fig 6.3 shows the graphs simulated by Vensim with 40% increase in PT trips and 40% decrease in PVT trips



a) Total trips by PVT b) Total trips by PT c) Congestion Level

Fig 6.3 Scenario analysis with different 40% increase in PT and 40% decrease in PVT

3) When public transportation trips is increased by 30% and 30% of private transportation trips are decreased then the congestion level is 0.65. fig 6.2 shows the graphs simulated by Vensim with 30% increase in PT trips and 30% decrease in PVT trips



b) Total trips by PVT c) Total trips by PT d) Congestion Level

Fig 6.4 Scenario Analysis with different 50% Increase in PT and 50% Decrease in PVT

Figure 6.5, 6.6 and 6.7 are the graphical representation of results obtained. Reduction of values for congestion level are observed. When 30% of public transportation is increased and 30% of private transport is decreased the mode share percentage for 2044 becomes PT-28% Pvt-72% and congestion level 0.65. When 40% of public transportation is increased and 40% of private transport is decreased the mode share percentage for 2044 becomes PT-33% Pvt-67% and congestion level 0.59. When 50% of public transportation is increased and 50% of private transport is decreased the mode share percentage for 2044 becomes PT-41% Pvt-59% and congestion level – 0.5. In short the simulation results from S-1 and S-2 and S-3 shows declining trend for simulated private vehicle mode share in all cases and It is observed that the congestion level for 2044 will be less only with S-3.

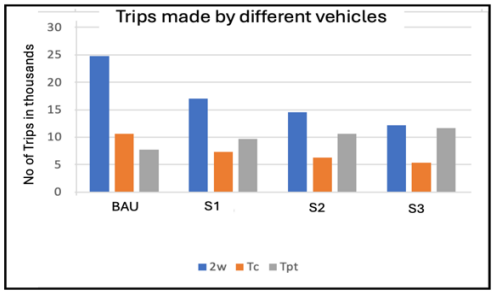


Fig 6.5 Trips made by different vehicles in different

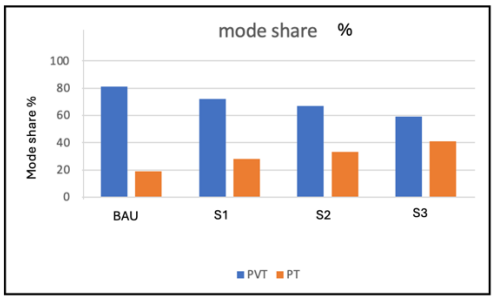


Fig 6.6 Mode share different vehicles in different

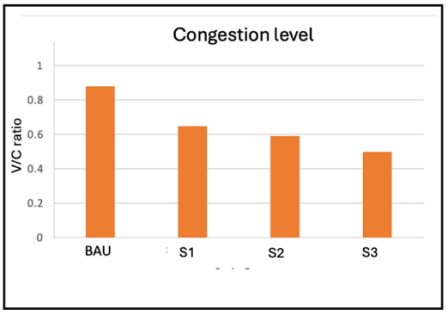


Fig 6.7 Congestion level in different scenarios

Proposals are more focused on reducing the traffic congestion level to reduce the negative impact of traffic congestion on land use. Hence the usage of public transportation trips is increased by 50% and this benchmark is taken from the smart city plan, Pune. In BAU the trips made by private vehicles are more considered to public transportation i.e. the percentage of private transport is 81% with the decadal growth rate of 34% while public transport is 19% with the decadal growth rate of 7.5% and hence the traffic congestion level for 2024 is 0.32 and when the same situation is followed till 2044 the traffic level congestion becomes 0.88 which is LOS E. With the proposed policy framework the public transportation in increased by 50% as per the smart city mission Pune and it is observed that the private transportation is decreased to 59% with decadal growth rate 30% and public transportation increases to 41% with annual growth rate of 32% giving a traffic congestion level of 0.5 which is LOS C. The Fig 6.8 and Fig 6.9 shows the percentage increase In mode share with and without the proposed framework.

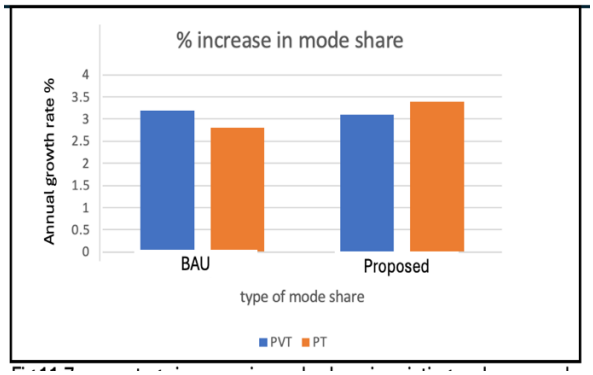


Fig 6.8 Increase in mode share in BAU and proposed framework

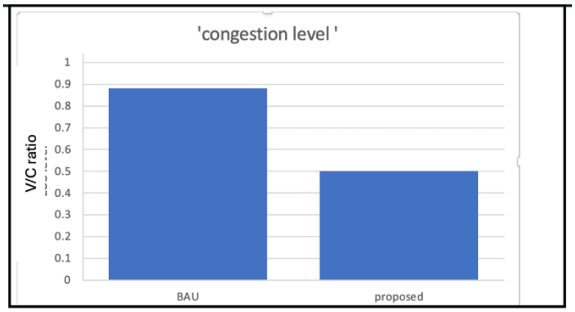


Fig 6.9 Congestion level in BAU and proposed framework

6.6) Proposal Framework

The last stage is the summarization of all strategies and scenarios with the results obtained. It would help to decide which scenario would be more effective for performance improvement.

Table 6.3 Proposal Framework

Policy Options Tested / Traffic Congestion	**GP1: Technology Promotion/Infrastructure Introduction (expected traffic congestion values)**
Traffic congestion level	50% Tt-Tc (0.5)
	40% Tt-Tc (0.59)
	30% Tt-Tc (0.65)

The three scenarios is put in a group namely GP1. Group 1 (GP1) is about technology promotion or transport infrastructure project introduction in the system. The option mainly centred on intended commencement of new technology or new infrastructure project in the system like : new BRT routes, bus stops, introduction of e-buses and e-rickshaws, Policy

changes to make parking expensive with stricter enforcement, Public bicycle sharing system and footpath redesigning.

6.7) Recommendations

These are the following policies recommended to increase public transportation and reduce private transportation

1) Recommendations to increase Public Transportations :

- Transit-Oriented Development (TOD) : TOD helps to promote pedestrian friendly infrastructure, compact and walkable neighbourhoods and easy access to public transportation.

- Digital Connectivity : digital connectivity can encourage people to use public transportation by providing mobile apps for passengers to access real time travel information, route planning and service updates and integrate digital platforms for ticket purchasing. This will help to reduce travel time

2) Recommendations to decrease Private Transportation

- Car Sharing / Car-Pooling : in this group of people travel together to work, school etc. this is done so that only one car is used at a time to reach the same destination. This will help to reduce private transportation

CHAPTER 7 CONCLUSION

The connection between transportation and land use is a fundamental concept in transportation. Transportation and land use are inexorably connected. Everything that happens to land use has transportation implications and every transportation action affects land use. Land development generates travel, and travel generates the need for new facilities, which in turn increases accessibility and attracts further development. Accessibility can be measured by the number of travel opportunities or destinations within a particular travel radius, measured in terms of either travel time or distance. Mobility is a measure of the ability to move efficiently between origins and the destinations. Mobility is directly influenced by the layout of the transportation network and the level of service it offers. Effective utilization of land stimulates urban activities, roads and other transportation facilities are maintained so as to follow for new transportation related activity. In this we studied the impact of land use on transportation i.e. how the residential density impacts the travel demand and how the increased travel demand affects the traffic congestion.

System dynamics is used to study the impacts of land use on transportation. The software used to create models are Vensim. The study began with the identification of parameters that affects the land use transportation and it was seen that parameters like population, residential area, trip rate, mode share and volume/capacity are the parameters that affect that land use transportation.

Based on the observed parameters Causal loop diagram and stock and flow diagram were prepared using Vensim software. Simulation was done for 20 years with base year 2044. Simulation graphs showed that as population increases the residential density also increases leading to increase in the total trips. The total trips then influences the trips made by different mode shares causing increase in the total number of vehicles. This leads to increase traffic congestion in the area. The simulated graphs show if the current scenario continuous then in the future the traffic congestion will have a LOS of E which states that the flow of traffic will be very low leading to increased delays which then affects the efficiency of land use. Hence to overcome this policies are evaluated and tested with different scenarios using SD effective scenarios.

In this study smart city plan Pune was considered where it was stated that they focused on making public transportation percentage to 50% by using various methods. Hence 3 scenarios were considered where it showed how the different mode shares affected the traffic congestion level and it was observed that 50% of the public transportation reduces the traffic level congestion in 2044 and is very effective. Hence the smart city plan Pune goals should be considered in this study area for effective use of public transportation.

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ANNEXURE I

1. Household Survey Format

COEP Technological University (COEP Tech)
A Unitary Public University of Government of Maharashtra
(Formerly College of Engineering Pune) Wellesley Road, Shivajinagar, Pune-411005, Maharashtra, India

Sample No._____ Date:_____ Time:_____ Origin:_____

PART A: HOUSEHOLD AND SOCIOECONOMIC INFORMATION

1. Family Structure: Joint Family ☐ Single Famil ☐
2. Members:

Members	Husband	Wife	Child1		Child2		Child3		Others 1 2 3
			S	D	S	D	S	D	
Age									

S- Son D-Daughter

3. Working Members: Husband Wife Son Daughter Others
   Occupation: ☐ ☐ ☐ ☐

4. Vehicle Ownership ☐ 2w. ☐ 4w ☐ bicycle

PART B: TRAVEL CHARECTERISTICS

5. Travel Details:

a) Work/education trip details

Member	Husband	Wife	Child 1	Child 2	Others
Trip mode					
Reasons for Public Transportation					
Reasons for private vehicle					
Trip length (km)					
Monthly travel expense					
travel time					
Trip frequency					
End location					

b. Shop end

Member	Husband	Wife	Child 1	Child 2	Others
Trip mode					
End location					
Trip length (km)					

Travel time					
Trip frequency					

c. Percentage share of family income spent for travel purpose (by all members) in a month _____

6. Do you use public transportation ? if no then What prevents you from using public transportation in your area?

A. language barrier. B. not within walking distance C. too confusing to use D. none available to me or in my area

E. Other_____

7. Public Transportation condition in the area . ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

8. How do you feel about the current transportation options in your area ?

A. Adequate b. inadequate

9. What according to you is the main cause of traffic congestion here ?

		1 Strongly Agree	2 Agree	3 Neither Agree nor Disagree	4 Disagree	5 Strongly Disagree
1	Inadequate road capacity					
2	Too many Private Cars					
3	Too many taxis					
4	Too many buses					
5	Presence of heavy vehicles					
6	Poor road congestion planning					
7	Poor traffic control management					
8	Poor road conditions					
9	Poor designed junction/roundabout					
10	Presence of construction activities					
11	Lack of road furniture					
12	Malfunctioning vehicles					
13	Poor Parking habits					
14	Poor driving habits					
15	Lack of parking facilities					
16	Lack of pedestrian facility					
17	Rainy weather					

10. To what extent do you agree or disagree with the following proposals to alleviating road congestion?

Member	Strongly agree	agree	Neither agree nor disagree	Strongly disagree	Others
Bus lane					
Increase parking facilities					
Improvement in network					
Alternate routes					
I would be will to use public transportation					

11. Please suggest any other measures that you think could reduce traffic congestion

Name of Enumerator(s): - Sign: -

ANNEXURE II

2. TVC Survey Format

Location Name :				Direction			Date :		
Surveyor Name :				**Straight**	**Left**	**Right**	Day :		
TIME	4 Wheleer	2 wheeler	Rickshaw/ Taxi	Mini Bus	Bus	LCV	2 Axel truck	Multiaxel trcuk	Cycle and Others

ANNEXURE III

3. Vehicle Occupancy Survey Format

College of Engineering Pune

Vehicles Occupency Surveys (गाडी मधील माणसे मोजने)

Road Name :- _____ Location . _____ Enumerator :-

Location No : Direction : towards कडे Date: / 12 /2017

Time	Passenger Vehicles										
15 mins	Cars/Vans/ Jeeps (Private)	PMPML Buses	S T Bus Pvt Travels Bus	BRT Bus	School / Office/ Company Bus	Mini Buses	2 Wheelers	3 Siter Auto	6 Siter Auto	Cycles Male / Female	
											
वेळ	कार व्हॅन जीप प्रायवेट	PMPML Buses	एस टी बस प्रायवेट बस	बिआरटी बस	स्कूल बस कंपनी बस	मिनी बस	बाईक	३ सीटर रिक्शा	६ सीटर रिक्शा	सायकल पुरुष	सायकल स्त्रिया
.00 to .15											
.15 to .30											
.30 to .45											
.45 to .00											