RESEARCH ARTICLE OPEN ACCESS

Modelling Intercity Public Transport Using a System Dynamics Approach

Ahsan Tariq*
*(National Institute of Urban Infrastructure Planning, University of Engineering & Technology, Hayatabad Peshawar, Pakistan, Email: ahsantariq.niuip@uetpeshawar.edu.pk)

Abstract:

The paper presents a study on modeling the complex intercity public transportation system, addressing its multifaceted challenges. With a focus on Pakistan, it explores the intricate interplay between variables like population, economy, travel demand, and service quality. Employing system dynamics modeling, it intricately examines the system's dynamics, considering factors such as bus availability, traffic congestion, and investment attractiveness. The model showcases the direct and indirect relationships between variables, elucidating how population growth impacts transport demand, service quality influences public transport attractiveness, and traffic congestion affects travel time. It scrutinizes revenue aspects, including fare structures, ridership, operational costs, and external influences, providing insights into financial performance. By analyzing these sectors, the paper aims to guide policy formulation for an efficient, sustainable intercity public transportation system, emphasizing the need for integrated strategies and stakeholder collaboration to optimize service quality, manage traffic, and enhance economic viability.

Keywords — **Public Buses, Private transport, Travel Delay, Service quality, Intercity Transport, Public Transport, System Dynamics, Transport Policy**

I. INTRODUCTION

The introduction highlights how important mobility is to modern civilization since it links communities, makes trade and business easier, and promotes economic progress. Different modes of transportation have specific advantages and disadvantages based on factors such as distance, speed, comfort, and environmental impact. The paper highlights the significance of public transportation in addressing challenges such as traffic congestion, air pollution, and energy consumption. It discusses the impact of transportation infrastructure on road transport systems, emphasizing the need for sustainable transportation policies. The research also delves into the intercity bus transport industry in Pakistan, analyzing its economics, market control, and the impact of government policies. Additionally, the paper touches upon the efficacy and impact of intercity public transportation buses, suggesting that system dynamic modelling and optimizing fare systems are essential for addressing complexities and making informed decisions. The paper ultimately emphasizes the importance of sustainable and effective transportation in shaping urban economies and connectivity.

II. LITERATURE REVIEW

The choice of transportation method can greatly influence the environment, social equality, and economic development. Selecting to use a private vehicle can increase greenhouse gas emissions, air pollution, and traffic congestion. On the other hand, using public transit can improve urban mobility in a more environmentally friendly way. [1]

Due to urbanization and population growth, it is more necessary than ever to find efficient and sustainable ways to move people and goods.

Reaching this aim will be essential to ensuring that everyone has a sustainable future. [2] Public transportation reduces traffic congestion, leading to faster travel times and decreased greenhouse gas emissions. It provides affordable access to jobs and services for those unable to afford or drive cars, making it an economical choice. Intercity public transit offers quicker, safer travel compared to driving, with dedicated lanes and priority features enhancing efficiency.[3] In major cities with over one million residents, congestion is common due to growing motorization and inadequate infrastructure. Increased vehicle ownership exacerbates challenges such as traffic congestion, infrastructure requirements travel time and fare cost.[4] Addressing these issues requires developing efficient public transportation and promoting alternative modes of transport Infrastructure. [5] Intercity public transportation faces stiff competition from private options. [6] The safety, security, and accessibility remain crucial concerns. [7], [8] Additionally, the environmental impact of transportation underscores the need for eco-friendly policies.[9] Overall, addressing these challenges is essential for effective public transportation, which plays a pivotal role in shaping urban economies and connectivity.[10] Transportation infrastructure, along with social, economic, and environmental factors, significantly impacts the road transportation system, which operates as a complex system with various variables and feedback loops.[11] Limited resources and environmental constraints necessitate system improvements, particularly in anticipation of technological advancements and evolving regulations.[12] The proliferation of vehicles and urbanization's adverse effects underscore the urgent need for sustainable transportation policies.[13], [14] With over half of the global population residing in cities and cities accounting for a significant portion of greenhouse gas emissions, addressing issues like traffic congestion and air pollution is critical.[15], [16]

Evaluating current public transportation policies in select Pakistani cities can identify flaws and inform the development of sustainable, environmentally friendly transportation policies. [17]

Projects that connect cities are in great demand for investment. Better economic performance, which is currently a primary focus for policymakers and is attained through increased production, jobs, and productivity, justifies these measures.[17] Public transit is provided by companies that are either privately or owned by the government. Each institution's boundaries are established by its official or informal rule systems. organizations are the participants in the system; institutions control it. [12]

Research is being done on the institutional dynamical elements of public transit. The problems with a dispersed institutional framework for public transport services have been covered in earlier studies. [18] Since local government operations and urban development strategies are not integrated with Mobility Plans, the implementation of sustainable urban mobility is still far from critical. [18] The development of the road infrastructure, its ongoing modernization, and the evolution of automotive technology have all contributed to the fleet growth of private intercity buses.[19]

Nonetheless, buses, minibuses and wagons make up the current intercity public transportation fleet in Pakistani cities. Rather than taking the lead in rail-based public transit, government authorities tried to improve bus systems in accordance with World Bank principles since buses are more flexible and less expensive. [17] The government has long pushed for promoting the private sector to run public transit in line with World Bank guidelines. As a result, more systematized and comprehensive policies for intercity transportation which are more complicated than those for public transportation within cities are needed.[20], [21]

It is recommended that future research look at the impacts of numerous other variables on the effectiveness of new bus lines in reducing traffic congestion, including population density, the fare system, and travel demand.[22], [23] However, if they are environmentally friendly, intercity buses are safe and release relatively little carbon dioxide into the atmosphere.[24] Intercity bus service companies are expanding at a rapid pace due to increased urbanization and demand.[25] Competition from other modes of transportation has increased in recent years for intercity and interstate bus operators, necessitating the development of an appropriate policy, management system, and modelling technique to capture the intricacies among them. [26] Furthermore, maximising public transport fare systems is necessary to achieve objectives such as maximising public transport demand, revenue, expenditure, profit, or social welfare, which will help the investor assess the company's economic and financial position for investment. [27] As a result, system dynamics models can provide more reliable short-to-mid-term forecasts than statistical models, allowing for better decisions and understanding the causes of industry behaviour, early detection of changes in industry structure, and identification of factors to which forecast behaviour is sensitive. It also allows for the determination of reasonable scenarios as inputs to decision and policy making. [28]

III. PROBLEM STATEMNT

The intercity transportation system is complex due to its many interacting variables, including the economy, population, travel demand, and transportation factor. Often, such system complexity gets ignored while developing sector policy. Instead, taking a linear approach that ignores the interdependence of the system variables results in unforeseen outcomes. Therefore, System dynamic approach is being used for modelling the intercity public transportation model for Peshawar & Nowshera cities of Khyber-Pakhtunkhwa.

IV. OBJECTIVE

Development of the causal relationship among the complex variables & Modelling of stock and flow.

Development of different scenarios complex variable of inter-city transport system

Suggest the best policy for the inter-city public transportation system.

V. SCOPE OF WORK

The study aims to investigate the impact of fare controls and traveling costs on intercity public bus transport. It aims to describe the institutional structure and analyse current intercity public transport strategies in order to improve the public bus system. Additionally, the study aims to assess private company investments by analysing revenue, net profit, and expenditures influenced by various factors. The research paper also contains a model for estimating travel delays as a fraction of free flow journeys, free flow velocity, time burdens induced by congestion, and travel time to destinations. Overall, the study addresses key factors influencing intercity public bus transport and proposes methods for evaluating and improving the system.

VI. MATERIALS AND METHODS

The research methodology involves a comprehensive review of intercity public transportation, utilizing literature, policies, and regulations to identify variables. A causal loop diagram is created to depict variable interconnectedness. Data on public and private bus routes, financial performance, and previous studies are gathered. In the absence of data, logical analysis and empirical estimation are employed. Model validation is conducted using collected data, with scenarios analysed to identify trends and variable impacts. Suggestions for policies to control unnecessary bus additions and model improvements are provided based on the analysis.

These factor which are identified as listed as under

Table 1

1. Population	2. Economy
3. Private transport demand	4. Public transport demand
5. Service provider competition	6. Public transport service quality
7. Travel time	8. Route permit
9. Public transport support	10. Investment attractivenes s
11. Traffic Congestion	12. Number of buses
13. Population	14. Economy
15. Private transport demand	16. Public transport demand
17. Number of buses	18. Addition of Buses

List of variable used in Causal Loop Diagram

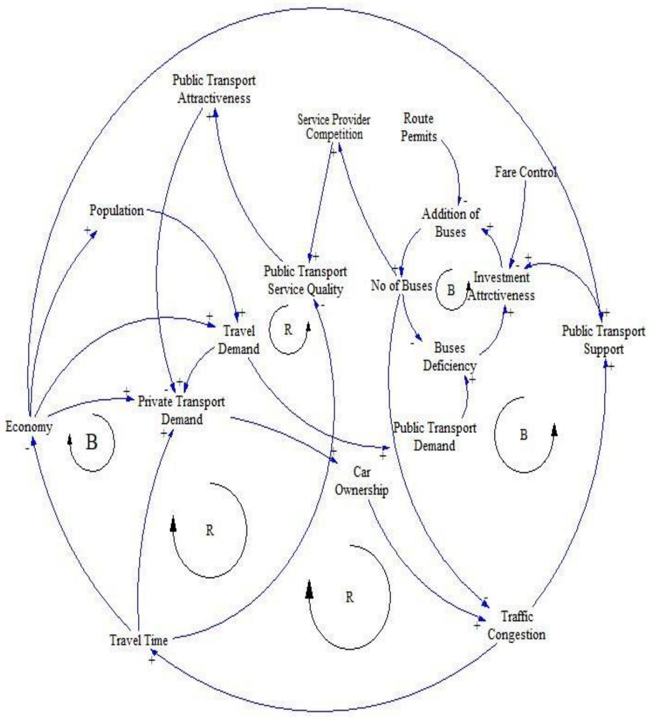

Fig. 1 Causal Loop Diagram for Intercity Public Transportation SD Modelling

Figure 1 depicts the causal loop diagram used in this study. Population growth directly influences travel demand, split between private and public transport. Bus shortages create investment opportunities, influenced by factors like fare control and public transport subsidies. Investment attractiveness drives bus additions, regulated by route permits. More buses contribute to traffic congestion, impacting travel time. Service provider competition affects service quality, influencing public transport attractiveness and reducing private transport demand. Travel time links with service quality and the economy; shorter travel times enhance service quality and reduce economic losses. Economic activity correlates with population growth, income, and transport demand, encouraging public transport support and investor interest in the transportation sector.

VI. MODELING APPROACH

The modelling approach examines the effect of public transportation on factors like travel time, fare cost, and traffic bottleneck. It uses converter, stocks, and flow variables to show their relationships systematically. Emphasizing population and commuter fraction, the model illustrates public bus transportation demand. It's structured into sectors such as commute, transportation, traffic flow, delay, and revenue, providing a framework to assess urban mobility and infrastructure effects.

VII. COMMUTER SECTOR

The figure 2 outlines components of the commuter sector used to forecast transportation demand from 2022 to 2047.

The population growth rates are sourced from the Pakistan Bureau of Statistics. The methodology involves estimating travel demand as 10% of the total population using intercity transportation. Within this, 75% are bus users and 25% are private vehicle travellers. Public transport utilization is influenced by factors like proximity to services, route frequency, and service quality.[29] The closeness to public transportation utilization, the number of bus routes, service frequency, and service quality all have an impact on the number of bus users.[30]

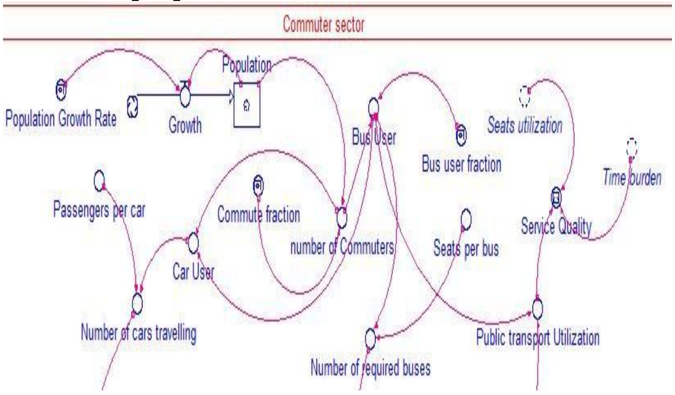

Fig. 2 Commuter Sector

VIII. TRANSPORTATION SECTOR

The figure 3 depicts the transportation sector, comprising stocks, flows, and converters. Stocks represent the number of private vehicles and buses on the road annually. Flows indicate the rate of increase of vehicles and buses annually, assumed to have negligible decrements. Stocks are converted into Passenger Car Units (PCUs), with 1 PCU for normal vehicles and 3.5 PCUs for buses. Peak hour PCU factors are determined based on traffic flow data. Travel delay is influenced by the number of PCUs per lane and lane capacity, represented graphically. Level of serviceability (LOS) aims for a value of 1 (free flow), while maximum traffic densities are defined graphically according to HCM2000 guidelines. Lane capacity represents the maximum number of PCUs a road can carry.[10]

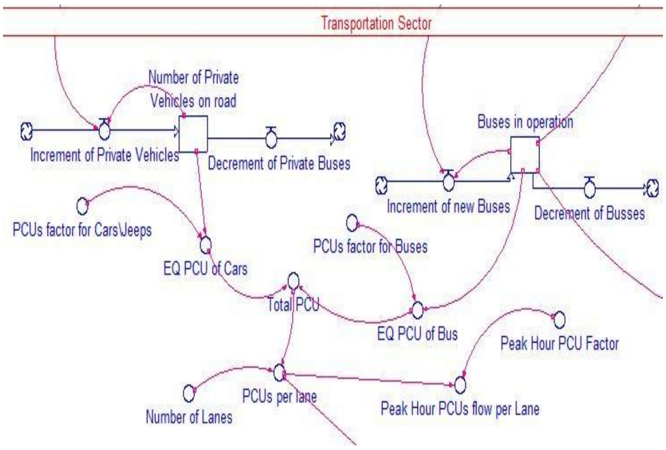

Fig. 3 Transportation Sector for Intercity Public Transport SD Model

IX. TRAFFIC FLOW AND DELAY SECTOR

The primary component of this sector is the flow of traffic study at free flow speed, level of serviceability, and delay analysis. The trip delay is calculated by the number of PCUs travelling on the roadway. There is an immediate connection between the number of PCUs per lane and lane capacity, that specifies the travel delay. According to HCM2000 guidelines, this range of travel delay varies with time, hence it appears as a graphical function. Mathematically, it is the ratio of PCUs to lane capacity.

Furthermore, level of serviceability (LOS) is the converter in this framework that represents a value of 1 (free flow) that was necessary to be obtained in this framework, whereas LOS max traffic densities have been defined as a graphical function that shows the extent to which the highest possible level of serviceability is being achieved by the data inputs which have been defined so far. These are defined based on HCM2000 ranges. The lane capacity represents the maximum number of PCUs that a road can carry, as represented by a converter.

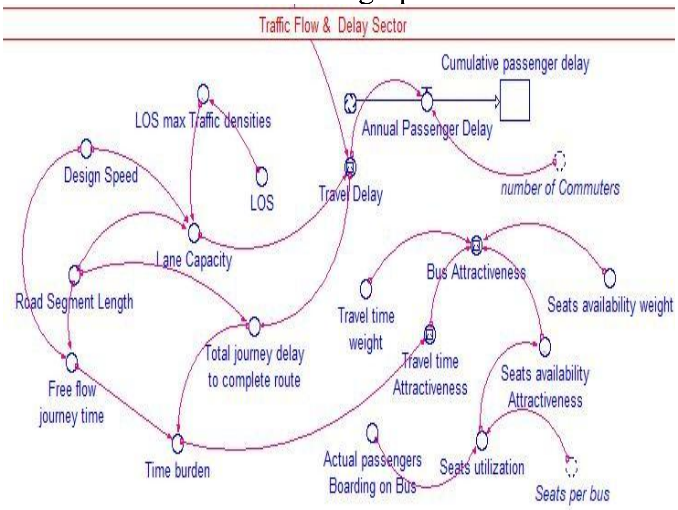

Fig. 4 Traffic Flow & delay Sector

X. REVENUE SECTOR

Figure 5 outlines the revenue sector of the intercity public bus transportation system in the system dynamics model, focusing on financial aspects. It considers fare structures, ridership, service frequency, and operational costs, including fuel, labour, maintenance, and administrative expenses. External factors such as fuel prices, subsidies, and market competition are also analysed. The model helps understand revenue sources, expenditure, and profit margins, considering variables like fare costs, number of trips, and road length. By simulating these dynamics, stakeholders can make informed decisions to optimize revenue generation and service quality. [31]

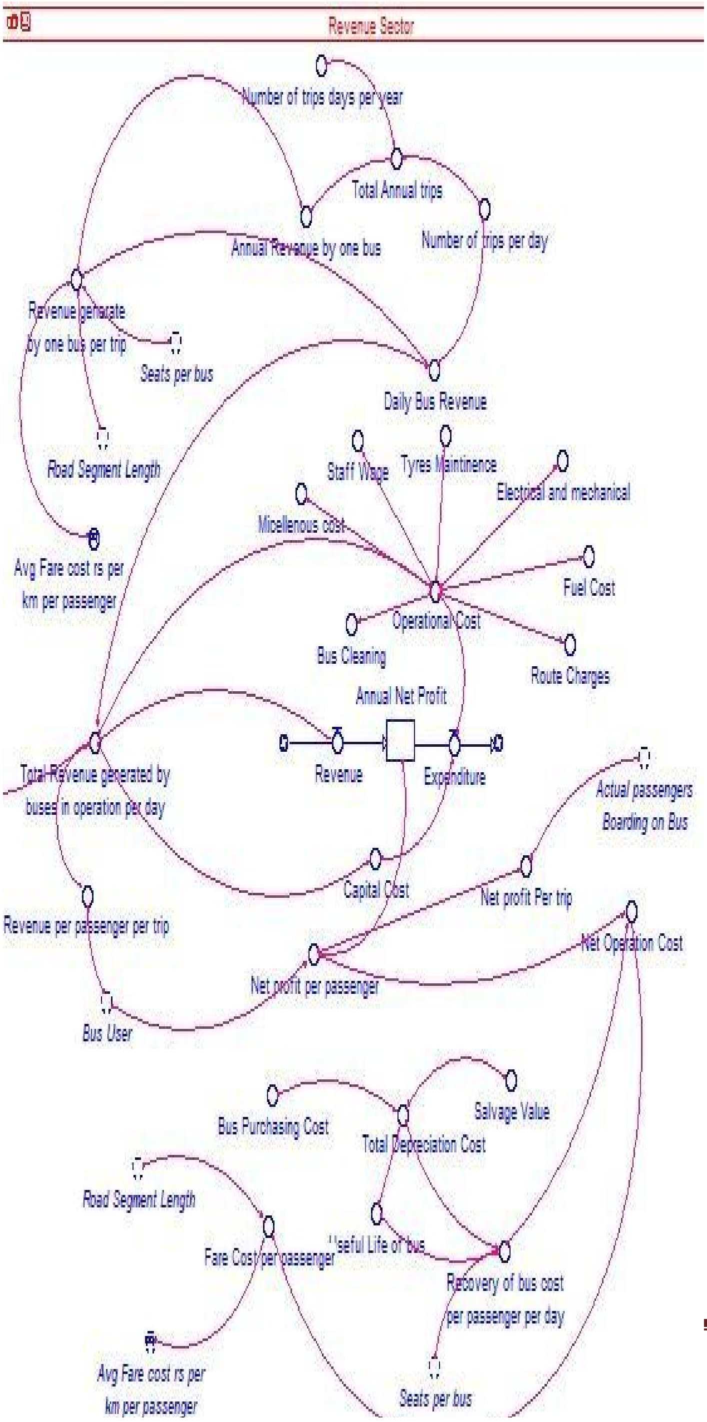

Fig. 5 Revenue Sector for Intercity Public Transport SD Model

XI. RESULTS

Multiple scenarios were studied to demonstrate the model structure's ability to help reduce traffic congestion and create a sustainable public transport system. There are two fundamental options based on the attractiveness of bus users and journey times. The table below describes the scenario in full.

Scenario	Detail
Scenario-1	Bus User fraction increment of 5% at the interval of duration of 25 years to check effect on annual net profit and service quality.
Scenario-2	Effect of travel time attractiveness to check bus attractiveness

Table 2 Scenarios Analysis of System Dynamic Model

Scenario 1: Effect of rate of increasing user bus fraction on net profit and service quality.

In this case, the bus user fraction was recognized as one of the important variables used to evaluate service quality and profit. Each increase in bus ridership has an impact on bus service quality, annual profit for service providers, and overall service quality. The potential outcomes were simulated for 25 years from the present time. The primary situations were then divided into sub-scenarios. These sub-scenarios depict the percentage of bus users ranging from 20% to 75% at 5% intervals. With the increase of numbers of bus users with respect to population the annual net profit behaves similar to rate of population increases.

The simulation results also show that the importance of improving service quality in response to an increased bus user percentage and growing customer expectations It suggests investing in fleet maintenance, customer service, on-time performance, comfort, and amenities can attract more passengers, resulting in a positive cycle of increased usage and higher service quality. It also highlights the negative impact of reduced service quality on passenger demand and operator revenue. Simulation results indicate that higher travel demand can lead to a slight depletion in bus service quality, particularly in cases of overcrowding.

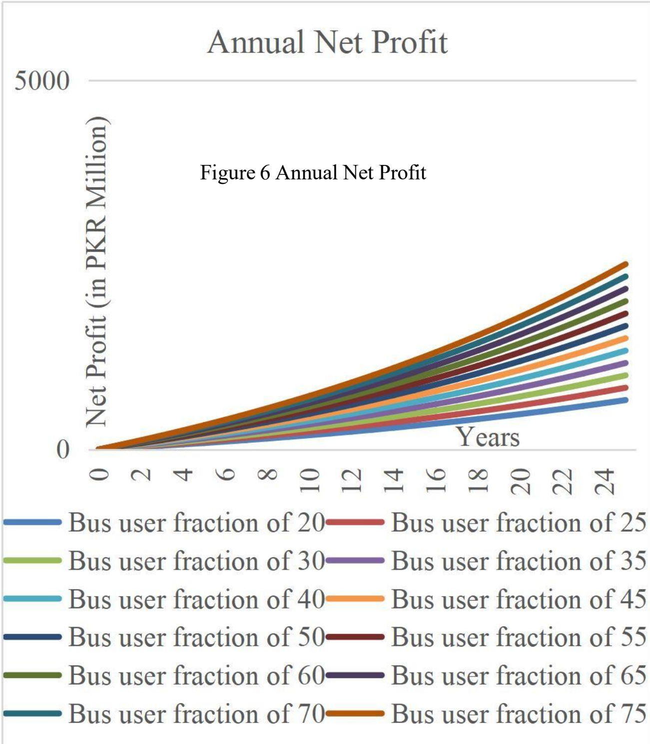

Figure 6 Annual Net Profit

The graphical representation showing the declining effect of increasing bus users on service quality and suggests that reaching 100% bus users may create difficulty in maintaining service levels. However, market-based competition drives bus service providers to strive for maintaining service quality, minimizing the impact of increasing bus users on service quality.

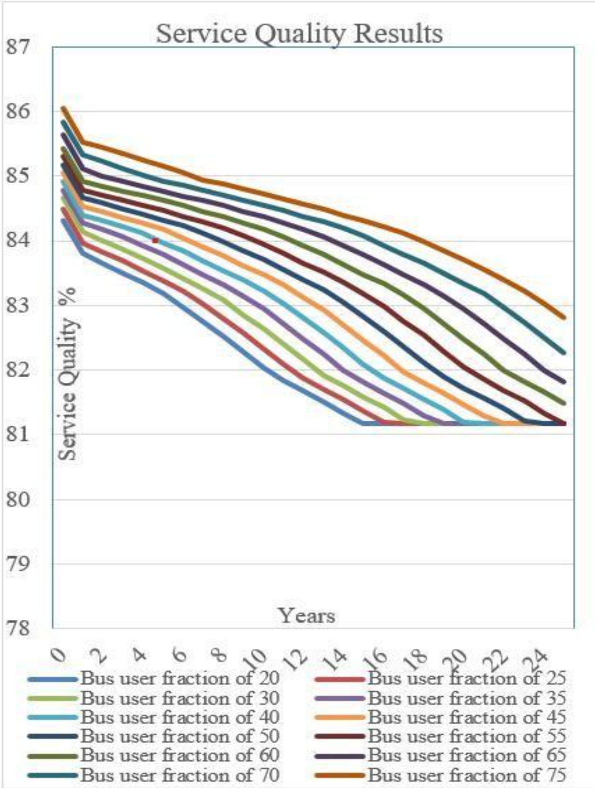

Figure 7 Service Quality Results

Scenario 2: Effect of travel time attractiveness to check the bus attractiveness.

The simulation shown that lower buses that are fully occupied have no influence on travel time, but this changes if the number of passengers surpasses the limit.

The duration of bus journeys influences their desirability for travel time. If buses can provide shorter journey times than other modes of transportation, they will appeal to passengers. Reduced journey time can lead to greater bus usage, since passengers see buses as a handy and time-saving means of transportation.

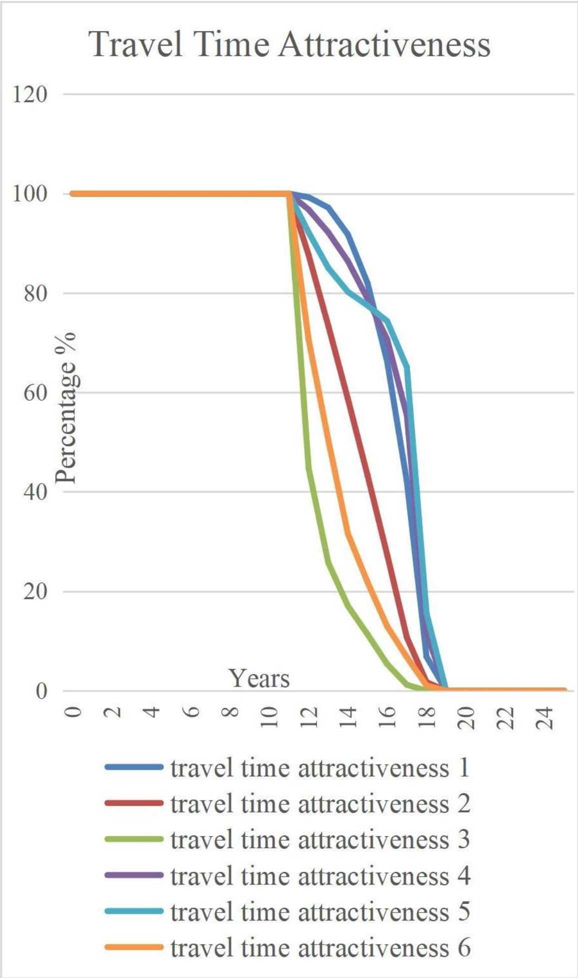

Figure 8 Travel Time Attractiveness Results

The findings reveal that when there is a brief delay, the attractiveness of travel time has little or no effect on it.

The passengers that ride within the bus may tolerate shorter time delays; but, if the delay begins to increase due to traffic congestion, travel pace, or other reasons, the attractiveness of the bus decreases at a low rate in the beginning. However, if journey time is further delayed, the endurance of waiting time becomes more annoying for the customer, which has a direct impact on the bus's appeal.

Furthermore, the simulation results show that there was no delay in travel from the first year to the eleventh year; however, as the number of private and public transport vehicles increases, the travel delay of traffic on roads begins to increase, reducing the level of serviceability of the road network that connects two cities. Due to the delay in reaching their location, travellers switch from public bus transit to their private vehicle. Therefore, the private vehicle modal shift causes additional traffic bottleneck which leads to complex problems in the future.

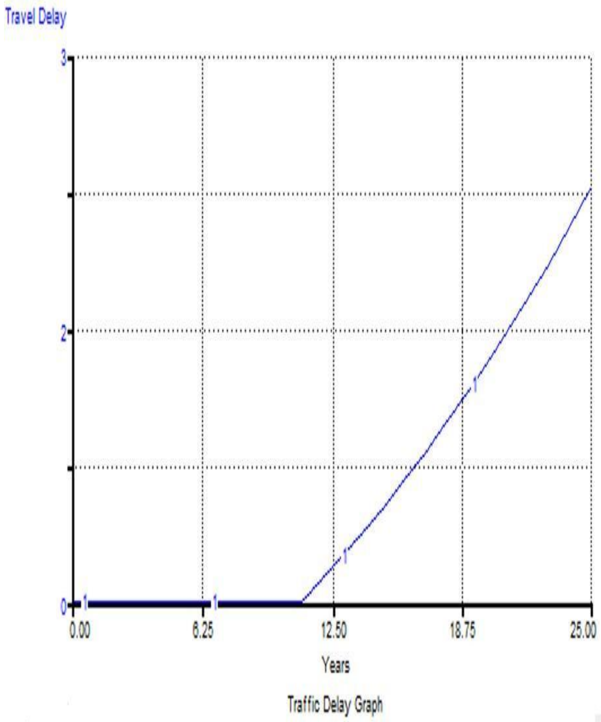

Figure 9 Travel Delay Results

In this scenario, bus attractiveness was calculated by weighting seat availability and trip time attractiveness equally. It has been noticed that until the eleventh year, the attraction of buses has remained consistent since they meet the needs of passengers travelling intercity. As the supply of buses exceeds the requisite demand, the attractiveness of buses for intercity transport begins to decline at varying rates. Thus, when the number of buses increases, more PCUs are on the road, leading to traffic congestion. when a result, the trip time attractiveness begins to drop, causing the overall bus attractiveness to reach 49.38%. It does not reach 0 due to the average proportion of seat availability attractiveness and travel time attractiveness, in which it is expected that the seats are fully utilized by the passengers.

The outcome of travel time attractiveness is zero, but the availability of seats in buses is completely utilized, which has little or no impact on seat attractiveness. Because bus attractiveness is calculated as the percentage average of travel time attractiveness and seat availability attractiveness, the final score remains 49.38%.

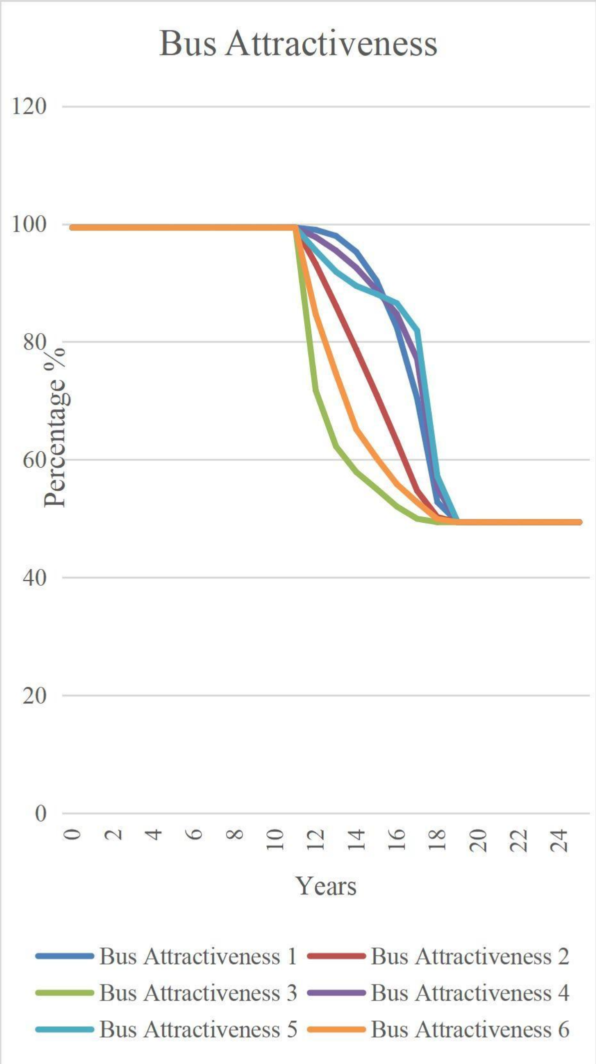

Figure 10 Bus Attractiveness Results

XII. DISCUSSION

The discussion focuses on the impact of population and the fraction of bus users on intercity public transportation systems. It highlights that the increase in population directly affects travel demand, which can be met by private vehicles or public transportation. The study emphasizes that the use of private vehicles contributes to traffic congestion and longer travel times and suggests that bus transportation or railway systems are preferable modes of travel. The paper also discusses the negative effects of unplanned launching of bus services, such as market disruption, strained infrastructure, financial challenges, regulatory issues, and potential innovation in the industry. Furthermore, it examines the potential effects on traffic congestion and travel delays, emphasizing the importance of proper planning, coordination with relevant authorities, and implementing improvement measures to minimize these negative effects. Overall, the section discusses the implications and challenges associated with the intercity public bus transportation system and suggests strategies for addressing them.

XIII. CONCLUSIONS

The objectives of this research were achieved by simulation tool which was developed to analyse the potential increase in public transportation, it’s time to time behaviour and its investment attractiveness for the intercity bus transportation industry and for the policy makers. Various scenarios were stimulated by increasing the population and number of commuters to understand the impact of modal shift from public transportation to private cars consider time travel and delays. The increase in private and public vehicle demand for new infrastructure may not be sustainable, thus the latest technology and legislation appear to have a significant influence on the ultimate results of the scenario simulations. If the number of buses with respect to time are increased on roads it will causes traffic congestion and simultaneously causes travel delays to reach the destination which will further leads to passenger’s dissatisfaction and thus modal shift will occurs causing the passenger to shift from public transportation to private vehicle. Under different condition on factors such as revenue generation, operational costs, fuel consumption, and fare levels for the bus service providers were also studied to determine whether to invest in public bus transportation industry. Furthermore, this tool helps to determine how will the road condition, transportation factors and economic factors gets effected by the increase in the number of bus service provider in long term.

The model results show that there is a high risk of over-use of buses in the research area, depending on the various future policy scenarios. The study also found that fuel consumption significantly affects the net annual profit of intercity travel and an efficient public bus system is essential for affordable fare systems. According to the scenario study, one of the biggest drivers of fare increases is an increase in fuel consumption expenses.

Uncontrolled bus purchasing and operations can lead to higher traffic congestion and lower attractiveness of intercity travel. The paper highlights the importance of sustainable infrastructure and the influence of technology and policies on future transportation outcomes. The study emphasizes the need for a flexible and integrated simulation tool to evaluate the effects of different policy scenarios and accommodate potential developments and new information.

Funding Source: No funding source was available from the public or commercial sector.
Conflict of interest: Author declares no conflict of interest.

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