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Urban Freight Regulations: Cost of restricting freight transport in a city

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Master of Planning
(Transport Planning and Logistics Management)

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Thesis submitted in partial fulfillment of the requirements for the award of the degree of

Master of Planning
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By

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Declaration

I **Ashutosh Malviya**, Scholar No. **2022MTPLM010** hereby declare that the thesis titled **"Urban Freight Regulations: Cost of restricting freight transport in a city"** submitted by me in partial fulfilment for the award of **Master of Planning**, at School of Planning and Architecture, Bhopal, India, is a record of bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

Signature of the Student
Date: _______________

Certificate

This is to certify that the declaration of **Ashutosh Malviya** is true to the best of my knowledge and that the student has worked under my guidance in preparing this thesis.

RECOMMENDED

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Signature of the Guide
Dr. Mayank Dubey

ACCEPTED

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Dr. Saurabh Popli
Head, Department of Transport Planning

April 2024

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Abstract

Urban freight transportation is a vital component of the larger supply chain and a major driver of urban development and economic viability. This dynamic system generates a strong ecosystem that supports many livelihoods in the metropolitan environment while also enabling the effective transportation of products. On the other hand, intrinsic difficulties such freight flow bottlenecks cause serious problems for inhabitants, customers, and the cost of goods. This essay examines the complex effects of urban freight restrictions, concentrating on the most widely used policy strategies used by Indian cities, which restrict freight movements based on weight or time limits. The urban freight ecosystem has a profound impact on all aspects of city life, including employment prospects and economic activity. Many different types of people, including small business owners, logistics specialists, truck drivers, and warehouse employees, depend on the complex web of freight movements for their livelihoods. Comprehending the interdependent nature of this relationship is crucial in order to appreciate the wider implications of policies designed to control the movement of freight in cities.

Imposing restrictions on freight movements is a typical governmental strategy in Indian cities, where urbanisation is fast accelerating. When it comes to addressing issues like traffic congestion, environmental degradation, and safety problems, the two most common ways are weight limitations and time constraints. There is a need for a thorough investigation of the consequences of these regulatory initiatives because, in spite of their popularity, there is still a dearth of scholarly research in this area.

This essay makes a basic assumption: in order to enhance living conditions in cities, there is often a need for a shared responsibility, meaning that when freight movement is restricted, city people themselves must shoulder some of the expense.

Keywords: Urban Freight Movement, Freight Regulations, Quality of Life, Cost of Living

सारांश

शहरी मालवाहन परिवहन, बड़ी आपूर्ति श्रृंग का एक अत्यंत महत्वपूर्ण घटक है और यह शहरी विकास और आर्थिक संभावनाओं का मुख्य आधारभूत है। यह गतिशील सिस्टम कई आजीविकाओं का समर्थन करने वाला एक मजबूत पारिस्थितिकि उत्पन्न करता है जो महानगरीय पर्यावरण में कई लोगों को समर्थन करता है जबकि यह उत्पादों की प्रभावी परिवहन को भी संभावित बनाए रखता है। दूसरी ओर, जैसे ही ऐसी मालवाहन बोटलनेक्स उत्पन्न होती हैं, वह निवासियों, उपभोक्ताओं और माल की मूल्य की समस्याएं उत्पन्न करती हैं। यह निबंध शहरी मालवाहन प्रतिबंधों के जटिल प्रभावों का परीक्षण करता है, जिसमें भारतीय शहरों द्वारा उपयुक्त नीति रणनीतियों पर केंद्रित किया गया है, जो भार के या समय सीमाओं के आधार पर मालवाहन गतिविधियों को प्रतिबंधित करती हैं। शहरी मालवाहन पारिस्थितिकि से शहरी जीवन के सभी पहलुओं पर गहरा प्रभाव डालता है, जैसे कि रोजगार के अवसर और आर्थिक गतिविधि। इस रिश्ते की इसकी अंतरदृष्टि को समझना, शहरों में मालवाहन के गतिविधियों को नियंत्रित करने के नीतियों के व्यापक प्रभावों को समझने के लिए महत्वपूर्ण है। मालवाहन गतिविधियों पर प्रतिबंध लगाना भारतीय शहरों में सामान्यतः सरकारी रणनीति है, जहां शहरीकरण तेजी से बढ़ रहा है। जब यातायात जनसंख्या, पर्यावरण की क्षति और सुरक्षा समस्याओं जैसे मुद्दों का सामना करने की बात आती है, तो वजन सीमाओं और समय सीमाओं ये दो सबसे सामान्य तरीके हैं। इन विधियों के परिणामों की गहन जांच की आवश्यकता है क्योंकि, इनकी लोकप्रियता के बावजूद, इस क्षेत्र में अब भी विद्वान अनुसंधान की कमी है। यह निबंध एक मौलिक मानदंड का परिभाषा करता है: शहरों में जीवन की गुणवत्ता में सुधार के लिए अक्सर साझा जिम्मेदारी की आवश्यकता होती है, अर्थात, जब मालवाहन गतिविधि पर प्रतिबंध लगाया जाता है, तो शहरवासी खुद को कुछ खर्च उठाना होता है।

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CHAPTER 1: INTRODUCTION

1.1 Background

Urban areas serve as bustling hubs where production and consumption activities thrive, shaping the heartbeat of modern civilization. The intricate web of freight and passenger transport networks that crisscross these urban landscapes serves as the lifeblood of economic vitality, facilitating the movement of goods and people within and between cities. From the moment a product is manufactured to its ultimate destination on a store shelf or in a consumer's home, it navigates through a labyrinth of logistical pathways that intersect with various urban nodes along the way. At the heart of these urban centres lie crucial facilities such as industrial plants, distribution centres, and retail outlets, each playing a pivotal role in the supply chain ecosystem. The bustling activity within these nodes is intricately intertwined with the constant flow of freight, as goods are sourced, processed, warehoused, and distributed to meet the demands of urban consumers. This symbiotic relationship between urban activities and freight movements underscores the indispensable role that transportation infrastructure plays in sustaining the dynamic urban landscape. However, the ever-expanding scale and complexity of freight transportation present a double-edged sword for cities. While it fuels economic growth and provides access to a diverse array of goods and services, it also poses significant challenges and impacts on urban life. The increasing volume of freight traffic strains existing transportation infrastructure, leading to congestion, pollution, and wear and tear on roadways. Moreover, the spatial footprint of freight-related activities, such as warehousing and distribution facilities, encroaches upon valuable urban land, potentially competing with other land uses and exacerbating land-use conflicts. As urban populations continue to swell and global trade networks expand, the pressure on cities to effectively manage freight movements and mitigate their adverse effects intensifies. Sustainable urban planning and transportation policies that prioritize efficiency, safety, and environmental stewardship are imperative to address the growing demands of freight transport while safeguarding the liveability and resilience of urban communities. Only through holistic and collaborative efforts can cities navigate the complexities of freight transportation and harness its potential as a catalyst for prosperity and sustainable development.

The freight transport also impacts the car travel, which harms urban transportation systems in a number of ways, including air pollution, traffic accidents, and congestion (Rocky Mountain Institute, 2019). Urban centres seek to reduce one of the most prevalent issues of the modern era: the high congestion index, which is caused by a growing number of automobiles on the road, dense populations, inadequate street infrastructure, and unstable public transportation. One of the biggest issues affecting people living in metropolitan areas is traffic. Environmental deterioration, a rise in accidents, and noise pollution are some of its effects. Resolving the public's complaints about traffic while satisfying their want for consumption is one of the primary difficulties facing today's governments. People desire reduced pollution and traffic, among other problems, and they want industrialised goods to be accessible and delivered quickly (Bontempo, Cunha, Botter, & Yoshizaki, 2014).

1.2 Aim

To identify the costs of regulating urban freight movement and its impact on the inhabitants.

1.3 Objective

- To understand the current scenario of urban freight regulations – The current scenario of policy environment, challenges faced and the process of freight restriction is largely undocumented. Thus, it becomes evident to understand existing scenario of urban freight restrictions.
- To understand the current condition of way side amenities supporting freight ecosystem – Currently, as the truck operators are forced to stay outside the city during peak hours, an entire ecosystem is under function to support these activities. Or the truck operators are stopping in the areas where these activities are happening. Unregulated amenities give rise to other problems such traffic congestion, improper facilities, no answerability, etc.
- To identify the various costs incurred due to the freight regulations – It is a fact that there is always a cost affiliated with things that are comparative in nature. In this scenario, as the truck operators' movements are restricted,

their cost of waiting should be outweighed by the ease of mobility provided to the other users of the city. If it does not happen in this manner, then it can be said that the model is in disequilibrium.

- To develop a transport model which allows for a more efficient application of regulations – After studying the existing scenarios and other challenges in the urban freight restriction, a model proposing a more efficient application of regulation will be developed.

1.4 Methodology

This methodology discusses the process of selection of theme till the end outcome. This thesis is heavily inspired by the social suffering of people involved in the freight transport ecosystem especially the urban freight. Selecting the theme was thus, easier. The topic of finding the cost of restricting the freight transport in a city is unique in itself because it has never been discussed in detail in the existing research papers which discuss the urban freight mobility and their restrictions.

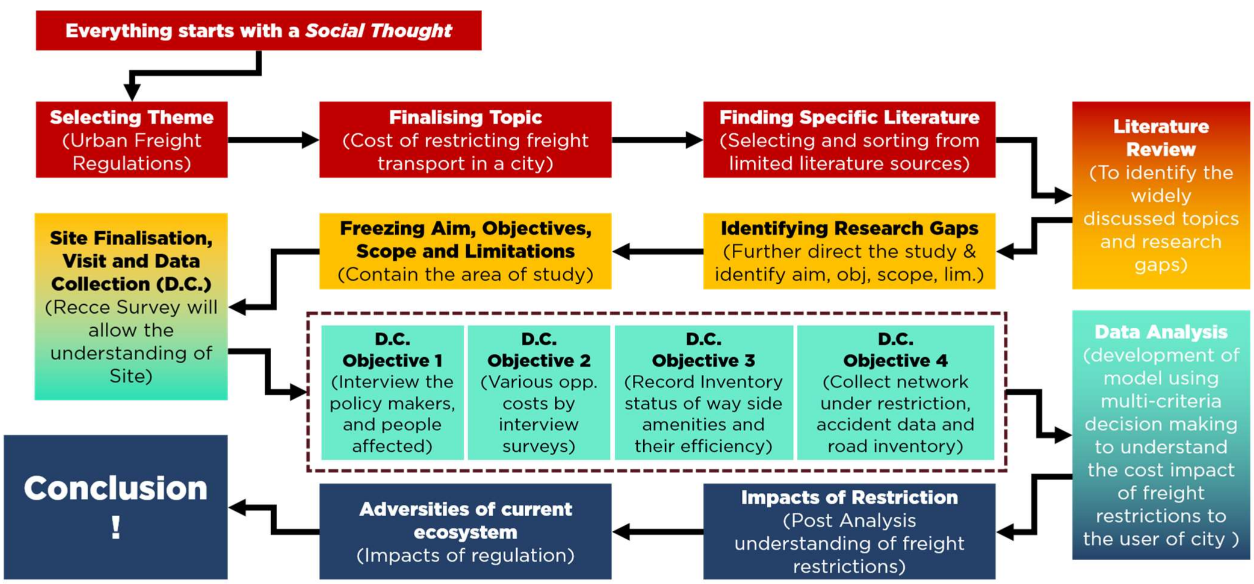

Figure 1 Methodology showing the process that is undertaken to complete the thesis

Furthermore, due to the limited availability of literature done on the specific topic it was challenging to find the detailed literature pertaining to freight mobility restrictions. Identifying the research gaps freezing aim, objectives, scope and limitations and finalising site are the further steps of this process.

The process of data collection for this study was meticulously structured, divided into four distinct parts to fulfil the objectives efficiently. The initial challenge lay in selecting the most suitable city or region for comprehensive analysis, considering the time constraints and the expansive nature of the task at hand. To address this, a reconnaissance survey was conducted across four cities: Kanpur, Ghaziabad, Indore, and Bhopal. After careful consideration, Indore emerged as the prime candidate for this exercise due to its status as one of India's fastest-growing cities, particularly notable as the swiftest developing urban centre in Madhya Pradesh.

Indore's strategic geographical positioning further solidified its selection, serving as a focal point for trade, commerce, and overall development in the region. Its pivotal location facilitates the smooth flow of goods not only within Madhya Pradesh but also extends to neighbouring states such as Maharashtra, Karnataka, Chhattisgarh, Gujarat, Rajasthan, and Uttar Pradesh. This centrality positions Indore as a key player in the economic landscape of central India, making it an ideal subject for in-depth scrutiny.

Data collection relied on a combination of secondary and primary sources to ensure a comprehensive understanding of the city's dynamics. Secondary sources included the Comprehensive Mobility Plan, offering insights into traffic characteristics and travel patterns, and the Central Motor Vehicle Rules (CMVR), providing details on the types of vehicles traversing Indore's roads. Additionally, the Indore Development Plan shed light on the city's growth trajectory and urban planning initiatives. Road Accident Data from 2022 furnished crucial information regarding road safety concerns and accident patterns.

Supplementing these secondary sources, a primary survey was conducted through interviews with key stakeholders, including Traffic Inspectors and Truck Drivers. These interviews provided invaluable first-hand accounts of the current state of way-side amenities, challenges encountered by truck drivers due to restrictions, and insights into their willingness to pay for improved services. This qualitative data enriched the study, offering nuanced perspectives that complemented quantitative findings.

To extrapolate and analyse the collected data, advanced tools like PTV VISUM were employed. PTV VISUM facilitated the development of a macro-model, enabling the assessment of delay caused by heavy vehicles and its impact on Level of Service (LOS). By simulating two scenarios—one where heavy vehicle enters the city during peak hours and another where they do not—the software generated valuable insights into traffic flow dynamics and congestion patterns.

Post-analysis, the traffic data underwent thorough scrutiny to determine the cost of time incurred due to delays. This analysis considered the broader implications, including the impact on the value of commodities, costs borne by drivers, and overall economic repercussions. Armed with these insights, conclusions and recommendations were formulated, addressing key findings and offering actionable strategies to mitigate traffic congestion, enhance road safety, and optimize logistical operations.

In essence, the data collection process served as the cornerstone of the study, laying a robust foundation for informed decision-making and policy formulation. By leveraging a combination of secondary research, primary surveys, and advanced modeling techniques, the study provided a comprehensive overview of Indore's transportation landscape, paving the way for targeted interventions aimed at fostering sustainable growth and development.

1.5 Scope

Urban freight restriction measures are increasingly necessary due to several factors, primarily stemming from the challenges posed by rapid urbanization and the resultant strain on transportation networks. Let's delve into the evaluation of these restrictions and their relationship with spatial growth, along with an assessment using parameters such as per capita income, value of time, emissions, and more.

1.5.1 Need for Urban Freight Restrictions

Traffic Congestion: As cities grow, so does vehicular traffic, leading to congestion that impacts both passenger and freight transportation. Freight vehicles contribute significantly to congestion, affecting the efficiency of urban logistics.

Environmental Concerns: Urban freight transportation is a major contributor to air pollution and greenhouse gas emissions. Restricting freight movements can help mitigate these environmental impacts and promote sustainability.

Infrastructure Strain: Urban infrastructure, including roads and bridges, faces strain due to heavy freight traffic. Restrictions can help in preserving and maintaining infrastructure, reducing maintenance costs and extending their lifespan.

Safety: High volumes of freight traffic in urban areas can pose safety risks to pedestrians, cyclists, and other road users. Restrictions can enhance safety by reducing the number of large vehicles navigating through densely populated areas.

1.5.2 Role of Spatial Growth:

Urban Expansion: Spatial growth patterns influence the distribution of economic activities and transportation demand within urban areas. As cities expand, new logistics hubs and distribution centres emerge, affecting the flow of goods and the need for freight restrictions.

Land Use Planning: Effective land use planning can help designate areas for industrial activities and freight distribution, thereby minimizing conflicts with residential and commercial zones. Strategic spatial growth planning can facilitate the implementation of targeted freight restrictions in sensitive areas while ensuring efficient goods movement.

1.5.3 Assessment Through Various Parameters:

Income: Higher income levels may correlate with increased demand for goods, leading to more significant freight volumes. However, affluent neighbourhoods may advocate for stricter freight restrictions to maintain quality of life and aesthetics.

Value of Time: Time-sensitive industries, such as e-commerce and perishable goods, may prioritize timely freight deliveries over stringent restrictions. Balancing the value of time with the need for congestion mitigation and environmental protection is crucial.

Emissions: Urban freight vehicles contribute to air pollution and carbon emissions. Assessing the environmental impact of freight restrictions involves analyzing emission reduction potential and evaluating alternative transportation modes, such as electric or low-emission vehicles.

Public Health: Freight-related emissions have direct implications for public health, particularly in densely populated urban areas. Evaluating the health benefits of freight restrictions involves considering factors such as reduced air pollution exposure and associated health care costs.

In summary, the need for urban freight restrictions is multifaceted, driven by concerns related to congestion, environmental sustainability, infrastructure strain, and safety. Spatial growth patterns influence the distribution of freight activities within urban areas, shaping the rationale for implementing and enforcing restrictions. Assessing the impact of these restrictions requires a comprehensive analysis of economic, environmental, and social parameters to ensure a balance between the efficient movement of goods and the well-being of urban communities.

1.6 Limitations

The assessment of urban freight restrictions in this report is constrained by several limitations, primarily stemming from the lack of comprehensive data availability and the absence of detailed pre and post-restriction studies. One significant limitation is the reliance on calculating only the time delay costs associated with freight transportation, as other critical parameters such as environmental impacts, economic efficiency, and social welfare considerations are not fully explored due to data constraints. Without detailed pre-restriction studies, it is challenging to establish baseline conditions and accurately quantify the potential benefits of implementing freight restrictions. Similarly, the absence of post-restriction evaluations hinders the ability to assess the actual effectiveness of the measures in alleviating traffic congestion, reducing emissions, and improving overall transportation system performance. Furthermore, the limited availability of empirical data complicates the validation of modelling results and introduces uncertainties in estimating the impacts of urban freight restrictions. These limitations underscore the need for enhanced data collection efforts, stakeholder collaboration, and methodological advancements to overcome data constraints and provide more robust assessments of urban freight management strategies.

CHAPTER 2: LITERATURE REVIEW

Understanding the existing framework and policy ecosystem is crucial to identify the cause, challenges, public response and drawbacks of urban freight restrictions. As observed in various cities, the current practice of freight restriction involves time access restriction and weight access restriction practices commonly followed. Apart from the existing practices there are other parameters on which these restrictions are done.

2.1 Urban Freight Regulation

Urban Freight Regulation encompasses a complex set of policies and measures aimed at governing the movement of freight vehicles within urban areas. While such regulations are within the constitutional rights of states, their implementation without a solid scientific basis can lead to unintended negative consequences. This essay explores the critical importance of ensuring smooth and efficient freight transport within urban environments, highlighting its pivotal role in sustaining economic growth and enhancing the overall quality of life for urban residents. Drawing from empirical evidence and scholarly research, including studies by (Cui, Dodson, & Hall, 2015), we argue for a reconsideration of urban freight regulations and a shift towards prioritizing infrastructure development to support freight mobility.

The movement of goods within urban areas is essential for sustaining economic activity and ensuring the smooth functioning of supply chains. Urban freight plays a crucial role in facilitating trade, supporting local businesses, and meeting the daily needs of urban residents. Research has consistently shown that efficient urban freight systems contribute significantly to economic growth, job creation, and overall prosperity.

(Cui, Dodson, & Hall, 2015) emphasize the positive correlation between urban freight movement and economic development, underscoring the need to recognize and support the vital role of freight transport in urban economies. Despite its importance, urban freight movement faces numerous challenges, many of which are exacerbated by regulatory measures that fail to consider the complex dynamics of freight transportation. Ill-conceived regulations can lead to increased congestion, longer delivery times, and higher operating costs for businesses.

Moreover, arbitrary restrictions can hinder the efficient flow of goods, negatively impacting businesses, consumers, and the overall economy. The lack of a scientific approach to urban freight regulation has often resulted in policies that are ineffective, counterproductive, and detrimental to economic growth. In light of the significant benefits associated with urban freight movement, there is a growing recognition of the need to reassess existing regulatory frameworks. Rather than viewing freight regulations as a means of constraining economic activity, policymakers should adopt a more nuanced approach that balances the need for regulation with the imperative of supporting economic growth. While certain regulations may be necessary to address legitimate concerns such as safety and environmental impact, they should be based on sound evidence and tailored to specific urban contexts.

Moreover, regulations should be designed in consultation with stakeholders, including businesses, freight operators, and community representatives, to ensure that they effectively address key concerns while minimizing unintended consequences. A critical component of re-evaluating urban freight regulation is the recognition of the importance of infrastructure development. Historically, infrastructure investment has predominantly focused on passenger mobility, leading to inadequate support for freight transportation. This oversight has hampered the development of efficient freight networks and constrained the capacity of urban areas to accommodate growing freight volumes.

To address these challenges, there is an urgent need for increased investment in freight infrastructure, including the development of dedicated freight corridors, intermodal terminals, and last-mile delivery solutions. (Cui, Dodson, & Hall, 2015) By prioritizing infrastructure development, policymakers can create an enabling environment for freight mobility, fostering economic growth and enhancing urban liveability. In rethinking urban freight regulation, policymakers should adopt a holistic approach that considers the broader economic, social, and environmental implications of regulatory measures. (Rocky Mountain Institute, 2019)

This requires conducting thorough cost-benefit analyses to assess the potential impacts of regulations on businesses, consumers, and the economy as a whole. Additionally, policymakers should prioritize investments in infrastructure projects that enhance the efficiency and sustainability of urban freight transportation. This may include measures such as expanding road capacity, improving freight rail networks, and promoting the use of clean energy technologies. Furthermore, policymakers should actively engage with stakeholders to solicit input and feedback on proposed regulatory changes, ensuring that regulations are pragmatic, effective, and widely supported.

2.2 Freight Restriction

Regulations serve as the backbone of governance, shaping policies and decisions that orchestrate the functioning of societies. Within this framework, freight restrictions stand as stringent measures aimed at managing the movement of freight vehicles across urban networks. In countries like India, where rapid economic growth intersects with burgeoning urbanization, the impact of such restrictions reverberates throughout the transportation landscape. This essay delves into the multifaceted implications of freight restrictions on Indian roads, exploring their significance, challenges, and the delicate balance they strike between alleviating congestion and sustaining economic vitality (Bontempo, Cunha, Botter, & Yoshizaki, 2014). Freight restrictions play a pivotal role in urban transportation management, particularly in densely populated areas like India's bustling cities. With the exponential growth of individual car ownership, urban road networks often grapple with congestion, posing challenges to efficient movement of goods and people alike. In this context, restrictions on large trucks emerge as a pragmatic solution to mitigate congestion, offering immediate relief to strained infrastructure and enhancing road safety. By limiting the influx of freight vehicles during peak hours or in designated zones, these regulations aim to optimize traffic flow and curb environmental pollution, thereby fostering a more sustainable urban environment (Chitresh Kumar, 2018), (Quak & Koster, 2005).

Despite their intended benefits, freight restrictions pose a set of challenges and give rise to several ill impacts, particularly in the context of Indian roads. One of the primary concerns revolves around the intricate web of logistics and supply chains, which rely heavily on seamless freight movement for timely delivery of goods. Imposing restrictions on large trucks can disrupt this delicate ecosystem, leading to logistical bottlenecks, delayed deliveries, and increased operational costs for businesses. Moreover, the diversion of freight traffic onto alternative routes or modes of transport may exacerbate congestion in peripheral areas, undermining the efficacy of restriction measures and perpetuating traffic woes.

Furthermore, the enforcement of freight restrictions often encounters hurdles related to regulatory compliance and infrastructure capacity. In many cases, the lack of robust monitoring mechanisms and inadequate infrastructure for alternative transportation modes hampers the effective implementation of restriction policies. Additionally, the socio-economic implications of such measures cannot be overlooked, especially concerning the livelihoods of individuals employed in the freight and logistics sector. For many, the imposition of restrictions translates into reduced job opportunities and economic hardships, amplifying social inequalities and engendering resistance against regulatory interventions (Chitresh Kumar, 2018).

Navigating the complexities of freight restrictions necessitates a nuanced approach that strikes a delicate balance between urban mobility and economic growth. While curbing congestion remains a paramount objective, policymakers must adopt a holistic perspective that considers the broader ramifications of restriction measures on the economy, society, and environment. One avenue for achieving this balance lies in the adoption of innovative transportation solutions and infrastructural upgrades that enhance the efficiency of freight movement without resorting to blanket restrictions.

For instance, investments in smart logistics technologies, such as real-time tracking systems and route optimization algorithms, can optimize freight operations while minimizing congestion and environmental impact. Similarly, incentivizing the adoption of cleaner and more sustainable modes of transport, such as electric trucks and freight trains, can mitigate the carbon footprint of freight transportation while ensuring the uninterrupted flow of goods. Moreover, fostering multi-stakeholder collaborations between government agencies, businesses, and civil society can facilitate the co-creation of tailored solutions that address the unique challenges of each urban context.

In conclusion, freight restrictions wield significant influence over the dynamics of urban transportation in India, shaping the contours of mobility, commerce, and sustainability. While they offer a pragmatic response to congestion and environmental concerns, their implementation entails a careful balancing act that weighs the imperatives of economic growth against the imperatives of urban liveability. By embracing a holistic approach that integrates technological innovation, policy coherence, and stakeholder engagement, India can chart a path towards a more resilient and inclusive transportation ecosystem—one where freight restrictions serve not as impediments, but as catalysts for sustainable urban development.

2.3 Parameters of freight restriction

"Many local authorities do not have an extensive freight transport policy. And, partly caused by a lack of information, their freight policies tend to be based on a reaction to problems and negative impacts, rather than taking a proactive position."

(Quak & Koster, 2005) initially recognised the two crucial parameters governing the freight restrictions, namely, *time access restriction* and *vehicle weight access restriction*. These parameters have remained unchanged in the newer study as well, proving its importance in the dynamics of the urban freight restriction. Including the existing practices there are several parameters according to which the freight restrictions are applied. The study by (Bontempo, Cunha, Botter, & Yoshizaki, 2014), identifies some parameters as elucidated thus,

2.3.1 Area-based restrictions

Restricting the entry of trucks into designated areas, such as historic quarters or pedestrian zones, embodies a comprehensive approach to addressing a diverse array of environmental, cultural, and societal concerns. These regulations, enforced through the establishment of cordon boundaries, exemplify a deliberate endeavour by policymakers to reconcile economic activities with the imperative of safeguarding natural and cultural heritage.

At its core, this strategy is driven by the imperative to mitigate the ecological impact stemming from heavy vehicular traffic. By curbing truck access to regions characterized by fragile ecosystems, including wildlife habitats or conservation enclaves, governments strive to curtail the adverse effects of air and noise pollution, thereby fostering ecological resilience and promoting biodiversity conservation. This proactive stance not only fosters the preservation of natural landscapes but also cultivates healthier environments conducive to human well-being.

In addition to ecological considerations, the imposition of truck restrictions serves as a means to enhance the quality of life for inhabitants and visitors alike. By alleviating noise pollution and reducing emissions in densely populated locales, authorities endeavour to create more habitable urban environments characterized by tranquillity and cleanliness. Such initiatives hold the potential to yield tangible health benefits, as reduced exposure to pollutants contributes to improved respiratory health and overall wellness among residents (Bontempo, Cunha, Botter, & Yoshizaki, 2014).

Furthermore, the regulatory measures are underpinned by a commitment to safeguarding the architectural and cultural heritage intrinsic to designated zones. Historic quarters often harbour invaluable landmarks, architectural marvels, and archaeological sites that serve as repositories of collective memory and cultural identity. By precluding the ingress of heavy vehicles into these precincts, policymakers aim to shield these cherished assets from the perils of potential damage wrought by vehicular activity, ensuring their preservation for posterity and fostering a deeper appreciation of cultural heritage.

The delineation of cordon boundaries to govern truck access underscores an appreciation for the intricate interplay between economic vitality, environmental sustainability, and cultural stewardship. Through judicious planning and implementation, these regulations facilitate the cultivation of resilient communities that flourish harmoniously amidst their natural and cultural environs (Kučas, Balciauskas, & Lavalle, 2023). By embracing a holistic approach that considers ecological, cultural, and societal imperatives, policymakers lay the groundwork for a more sustainable and harmonious urban fabric, characterized by the coexistence of vibrant economic activity and the preservation of natural and cultural treasures.

2.3.2 Time-based restrictions

In the analysis of urban traffic dynamics, researchers have identified specific timeframes marked by surges in vehicular movement, commonly referred to as peak hours (Kadiyali, 1999).During these peak periods, cities face significant challenges in managing traffic flow due to the heightened demand on transportation infrastructure. To address this issue, a variety of strategies have been adopted in major urban centres. These strategies encompass sophisticated approaches such as congestion pricing, advanced traffic management systems, data-driven decision-making methodologies, and optimization of traffic signal timings, among others.

Among these strategies, there persists a longstanding practice of restricting heavy vehicles during peak hours. This approach, rooted in traditional traffic management principles, aims to alleviate congestion by regulating the movement of large vehicles that occupy considerable space on roadways (Quak & Koster, 2005). By imposing restrictions on heavy vehicles during periods of peak traffic flow, urban planners seek to optimize road space utilization and improve the overall efficiency of transportation networks.

The rationale behind this restriction is two-fold. Firstly, it aims to enhance traffic flow by minimizing the presence of vehicles that inherently impede the movement of other road users due to their size and manoeuvrability constraints. Secondly, it serves to prioritize the allocation of road space during peak hours, ensuring that it is utilized most effectively to accommodate the maximum volume of traffic.

While this measure is widely regarded as a pragmatic approach to managing urban congestion, its effectiveness and broader implications warrant continual evaluation and refinement. As cities evolve and transportation trends shift, the optimization of traffic management strategies remains a dynamic and ongoing endeavour.

2.3.3 Vehicle size and weight limits

Vehicles responsible for bringing large quantities of essential and non-essential commodities to the cities from warehouses, APMCs' or factory are large vehicles (Quak & Koster, 2005) which are put under the class N3 by ((MoRTH), 1989), goods carrying vehicle having carrying capacity of more than 12 tonnes. Due to their enormous size and limited manoeuvrability these vehicles are restricted from entering the city. These vehicles are thus, force to load or unload outside the municipal premises. ((iRAP), (gTKP), & (GRSF), 2021) in the Road Safety Toolkit discussed the importance of monitoring the freight vehicles in order to prevent the road accidents and reduce the probability of vehicle conflicts. The impact of heavy vehicles on pavement quality is a critical consideration for transportation authorities and urban planners.

- *Surface wear and tear:* Heavy vehicles exert greater pressure on the pavement surface due to their weight distribution, leading to accelerated wear and tear. This results in surface distress such as cracking, rutting, and potholes, which compromise the integrity of the pavement and create safety hazards for road users.

- *Structural damage:* Beyond surface deterioration, heavy vehicles can also cause structural damage to the pavement layers beneath the surface. This includes deformation of the pavement layers, loss of stability, and reduced load-bearing capacity, which can necessitate costly repairs or reconstruction.
- *Visibility and aesthetics:* The movement of heavy vehicles can result in the accumulation of debris, dust, and tire marks on the pavement surface, diminishing its visibility and aesthetic appeal. This not only affects the overall appearance of the roadway but also poses challenges for road marking visibility and traffic safety.
- *Noise pollution:* Heavy vehicles often generate higher levels of noise compared to light vehicles, contributing to noise pollution in urban areas. Pavement deterioration caused by heavy vehicle traffic can exacerbate noise levels due to increased surface roughness and irregularities, impacting the quality of life for nearby residents.
- *Economic implications:* Pavement maintenance and rehabilitation activities incur significant costs for transportation agencies and municipalities. By restricting heavy vehicle access to certain areas or implementing weight limits, authorities can mitigate pavement deterioration and extend the service life of road infrastructure, thereby reducing the need for frequent repairs and associated expenses.
- *Preservation of investment:* Roads and pavements represent substantial investments in infrastructure development. By implementing restrictions to protect pavement quality from the adverse effects of heavy vehicle traffic, authorities ensure the longevity and sustainability of these investments, maximizing their economic and social benefits over time.

To sum up restrictions on heavy vehicle access in urban areas play a crucial role in preserving pavement quality, ensuring road safety, enhancing aesthetics, mitigating noise pollution, and optimizing the long-term sustainability of transportation infrastructure. These measures are essential for maintaining the functionality and resilience of urban road networks, thereby facilitating efficient and safe mobility for all road users (Bhandari, Luo, & Wang, 2022).

2.3.4 Permits and fees

Permits play an important part in the legalised transport of goods and commodities. Permits also allow for better scrutiny and reduce the no. of crime that are related with goods transportation. When a freight vehicle departs from a warehouse, factory outlet or a mandi, their weight and the commodity that is loaded is monitored and a slip is issued to the driver and/ or conductor. This slip is checked by the officials when the vehicle enters a municipal boundary of a city. Due to certain goods and commodities being essential and others being non-essential for the city and its inhabitants, certain restrictions are placed on the vehicles to allow for a more efficient movement of goods and commodities (Chitresh Kumar, 2018).

Certain restrictions are placed on the permits of vehicles on the basis of type of fuel too. When cities are over polluted due to high saturation of particulate matter suspended in air, certain fuel types especially diesel are restricted to enter in the city. Vehicles older than certain version of emission stage, for example vehicles older than BS IV diesel vehicles were banned in Delhi when GRAP was implemented (Commission for Air Quality Management in National Capital Region and Adjoining Areas).

2.4 Rationales and Intended Effects

Studying the rationales behind freight restrictions is crucial for conducting a critical evaluation of the policies or decisions implemented. These rationales serve as the foundation upon which policies are built, providing insight into the objectives, motivations, and anticipated outcomes of the restrictions. By understanding these rationales, evaluators can effectively assess the effectiveness, feasibility, and potential shortcomings of the policy, thereby facilitating informed decision-making and policy refinement.

- ***Foundation for Implementation***: Rationales elucidate the underlying goals and intentions behind the implementation of freight restrictions. They provide a framework for policymakers to develop strategies and interventions aimed at addressing specific challenges or achieving desired outcomes in the transportation sector. By examining these rationales, evaluators can gain clarity on the overarching purpose of the restrictions and how they are intended to contribute to broader policy objectives, such as safety, efficiency, or environmental sustainability.

- ***Identification of Limitations***: Studying rationales enables evaluators to identify potential limitations and challenges associated with freight restrictions. By scrutinizing the underlying assumptions, evidence, and logic supporting the policy, evaluators can pinpoint areas where the policy may fall short or encounter obstacles in practice. This critical assessment helps to uncover gaps in the rationale or implementation approach, informing opportunities for improvement or adjustment to enhance the policy's effectiveness and relevance.
- ***Evaluation Criteria***: Rationales provide a basis for establishing evaluation criteria and performance metrics to assess the impact and efficacy of freight restrictions. By clearly articulating the intended outcomes and objectives of the policy, rationales guide evaluators in determining the criteria against which the policy's success or failure can be measured. This systematic evaluation process allows stakeholders to gauge whether the restrictions are achieving their intended purposes, as well as to identify areas for recalibration or refinement based on empirical evidence and feedback from stakeholders.
- ***Policy Coherence and Consistency***: Understanding the rationales behind freight restrictions enables evaluators to assess the coherence and consistency of the policy within the broader regulatory framework. By examining how the restrictions align with existing laws, regulations, and policy objectives, evaluators can identify potential conflicts, overlaps, or inconsistencies that may undermine the effectiveness or legitimacy of the policy. This analysis helps to ensure that freight restrictions are integrated into a cohesive and harmonized policy framework that maximizes synergies and minimizes unintended consequences.
- ***Stakeholder Engagement and Transparency***: Rationales provide a basis for engaging stakeholders in the policymaking process and fostering

transparency and accountability in decision-making. By clearly communicating the reasons behind freight restrictions, policymakers can solicit input, feedback, and collaboration from affected stakeholders, including industry representatives, advocacy groups, and the public. This participatory approach helps to build consensus, mitigate resistance, and enhance the legitimacy and acceptability of the policy among diverse stakeholders. Thus, studying the rationales behind freight restrictions is essential for conducting a thorough and critical evaluation of the policy, enabling evaluators to identify limitations, assess effectiveness, establish evaluation criteria, ensure policy coherence, and engage stakeholders in a transparent and inclusive manner. By interrogating the underlying motivations and objectives of the policy, evaluators can contribute to evidence-based policymaking and iterative policy refinement that advances the goals of safety, efficiency, and sustainability in freight transportation.

2.4.1 Alleviating Traffic Congestion

The challenge of congestion in urban areas, causing inefficiencies in transportation, increased fuel consumption, and economic burdens.

Implementation of Restrictions: Imposing restrictions on the presence and size of freight vehicles during specific hours or designated zones to alleviate congestion, especially during peak periods.

Smoother Traffic Flow: By regulating freight vehicles during peak hours, the aim is to facilitate smoother traffic for both commercial and general transportation.

Expedited Delivery Times: Reduced congestion provides delivery vehicles the opportunity to navigate urban areas more efficiently, resulting in faster and more dependable deliveries.

2.4.2 Ensuring Safety

The interaction between large freight vehicles, pedestrians, and smaller vehicles in urban settings poses safety risks.

Implementation of Restrictions: Measures include assigning specific routes for freight vehicles, establishing dedicated loading/unloading zones, or implementing time constraints to minimize interactions with pedestrians and smaller vehicles.

Pedestrian Safety: Regulating the movement of freight vehicles aims to create safer pedestrian environments, lowering the risk of accidents and collisions.

Reduced Traffic Conflicts: Segregating freight traffic during specific times or in designated areas helps minimize conflicts, enhancing overall road safety.

In summary, restrictions on urban freight are instituted with a holistic strategy to address congestion, air quality, and safety challenges in urban environments. The expected outcomes include improved traffic flow, reduced emissions, and heightened safety for pedestrians and other road users, contributing to the development of more sustainable and liveable urban spaces

2.4.3 External Costs

External costs, often referred to as externalities, encompass the unintended and uncompensated outcomes stemming from economic activities, impacting individuals or entities not directly involved in the transaction. These costs remain unaccounted for in the pricing mechanism of the activity, thereby existing external to the conventional market exchange. Externalities manifest in both negative and positive forms: negative externalities, such as pollution adversely affecting nearby communities, and positive externalities, such as the enhancement of property values resulting from the establishment of a public park. The presence of external costs precipitates inefficiencies within markets, as the genuine expenses associated with production or consumption aren't fully acknowledged, leading to excessive production or consumption of goods accompanied by negative externalities. To rectify these market inefficiencies, various policy instruments, including taxation, subsidies, and regulatory frameworks, are implemented to internalize externalities. Through such measures, producers are held accountable for the incurred costs or are required to compensate affected parties, thereby fostering improved resource allocation and societal welfare (Mankiw, 1997).

As stated by (Qingyu, Zhicai, Baofeng, & Hongfei, 2007) and (Izadi, Nabipour, & Titidezh, 2020) the external costs associated with congestion encompass four primary components. To begin, it's essential to define the scope of our analysis. For measuring the overall external costs of congestion within specific urban areas, the entirety of the traffic network is considered. These costs are intricately linked with environmental impact and the value of human life, making them challenging to quantify precisely within market frameworks. Consequently, various methods have been developed for evaluation, including travel cost measurement, willingness-to-pay approaches, expenditure defences, stated references, and dose-response methodologies. Each of these techniques faces hurdles in gathering practical data.

Considering these challenges, the core principles of these methods has been tailored to the unique characteristics of congestion-related external costs. This synthesis has led to the formulation of specific equations. For instance, additional travel time costs can be calculated using the average regional value of time. Environmental pollution costs can be assessed by determining the proportion of pollution attributable to congestion compared to total transportation-related pollution. Traffic accident costs can be estimated based on accident probabilities, while fuel consumption costs can be derived from the increased fuel consumption resulting from congestion. In essence, by integrating insights from various evaluation methodologies and aligning them with the nuances of congestion's external costs, we aim to develop more robust formulas for accurately assessing the economic impact of congestion on society.

2.5 Congestion Cost

As explained in *section 2.4.3*, external costs are unintended and uncompensated costs not considered in the direct calculation of cost benefit analysis. Congestion Cost is one such type of cost. When the density of vehicle starts increasing on the network, certain detrimental impacts can be seen such as more fuel consumption, increased travel times, more emissions and increased probability of accidents.

(Qingyu, Zhicai, Baofeng, & Hongfei, 2007) provides ways to calculate the various congestion cost in urban traffic. These costs are also named external cost as they are usually not accounted for while implementing restrictions.

- *Extra Time Cost* – The additional expenses incurred due to extra time, referred to as C_{time}, are determined by multiplying the constant value of time, denoted as u, by the additional travel time, t_{extra}, and the number of travelers, P_c. The average income of a city, I_a, divided by the average working time, T_a, equals u. The extra travel time, t_{extra}, can be computed by comparing the decrease in average travel speed, denoted as v_c, with the normal average travel speed, denoted as v_0, over the average travel distance, l, under congested conditions. The formula is

$$t_{extra} = l \times \left(\frac{1}{v_c} - \frac{1}{v_0}\right) \qquad (i)$$

$$C_{time} = t_{extra} \times u \times P_c = l \times \left(\frac{1}{v_c} - \frac{1}{v_0}\right) \times \frac{I_a}{T_a} \times P_c \qquad (ii)$$

- *Environmental Pollution Cost* – Environmental pollution encompasses various forms such as air pollution, noise pollution, and water pollution. Determining the environmental pollution costs C_{envi} attributable to congestion is challenging due to their entanglement with the overall pollution costs C_{te} incurred by transportation. However, the ratio of congestion-related pollution costs to transportation-related pollution costs can be seen as equivalent to the ratio of congestion time to total travel time, denoted as p_t. Moreover, vehicles operating at low speeds or in a rush during congestion tend to emit higher levels of pollution compared to other scenarios. To illustrate this variation in pollution intensity, ξ_e is introduced.

$$p_t = \frac{t_{extra}}{t_{total}} = \frac{\frac{l}{v_c} - \frac{l}{v_0}}{\frac{l}{v_c}} = 1 - \frac{v_c}{v_0} \qquad (iii)$$

$$C_{envi} = C_{te} \times \xi_e \times p_t = C_{te} \times \xi_e \times \left(1 - \frac{v_c}{v_0}\right) \qquad (iv)$$

- *Traffic Accident Cost* – Assessing the damages caused by accidents is frequently employed when determining the costs associated with traffic accidents, denoted as C_{acci}. This can be understood as the outcome of multiplying the overall traffic accident costs, C_{ta}, by the likelihood of accidents occurring due to congestion, referred to as p_a. The effects of speed and traffic density on congestion-related accidents differ: lower speeds decrease the probability of accidents, while higher traffic density increases it. To account for these variations, a parameter, ξa, is introduced. The probability of accidents, pa, is calculated as the product of ξa and pt.

$$p_a = \xi_a \times p_t \qquad (v)$$

$$C_{acci} = C_{ta} \times p_t = C_{ta} \times \xi_a \times \left(1 - \frac{v_c}{v_0}\right) \qquad (vi)$$

- *Fuel Consumption Cost* – Travelers are typically aware of their total fuel expenses but struggle to discern the specific portion attributed to overuse during congestion. Essentially, they are cognizant of their own fuel costs but haven't accounted for the additional burden they impose on others during congested periods. Consequently, the excess fuel consumption costs incurred during congestion are considered external costs. This surplus fuel consumption often arises from congested vehicles engaging in activities such as accelerating, braking, moving at low speeds, or racing. These costs can be calculated by comparing fuel consumption rates during congestion and non-congested conditions. There exists a relationship between the fuel consumption during congestion, denoted as C_{fuel}, and the total fuel consumption for transportation, denoted as C_{tf}, as expressed in Equation (*vii*).

$$\frac{C_{fuel}}{C_{tf}-C_{fuel}} = \frac{v_0}{v_c} \quad (vii)$$

$$C_{fuel} = C_{tf} \times \frac{v_0}{v_0+v_c} \quad (viii)$$

- *Total Congestion Cost* – Total congestion cost becomes the total of extra time cost, environmental pollution cost, fuel consumption cost and traffic accident cost.

$$C_E = C_{time} + C_{envi} + C_{acci} + C_{fuel} = \left(l \times \left(\frac{1}{v_c} - \frac{1}{v_0}\right) \times \frac{I_a}{T_a} \times P_c\right) + \left(C_{te} \times \xi_e \times \left(1 - \frac{v_c}{v_0}\right)\right) + \left(C_{ta} \times \xi_a \times \left(1 - \frac{v_c}{v_0}\right)\right) + \left(C_{tf} \times \frac{v_0}{v_0+v_c}\right) \quad (xi)$$

According to the 2022 Road Accident data compiled by the Ministry of Road Transport and Highways (MoRTH), it has been determined that, on average, the major cities with populations exceeding ten million inhabitants collectively represent a 4.6% share of the total reported accidents for that year. This finding is detailed in Table 1, which not only presents the accident figures for these prominent cities but also outlines their respective percentage contributions to the overall accident tally. Furthermore, the table offers insights into the annual variations in accident percentages spanning from 2018 to 2022. It's worth emphasizing that these top-tier cities, despite accounting for just a fraction of India's total land area, play a significant role in road safety dynamics, collectively attributing approximately half of the country's reported accidents.

Table 1 Million Plus Cities and Accident share percentage. Source: Road Accidents 2022 by MoRTH

S.no.	Million Plus Cities	2018	2019	2020	2021	2022
1	Delhi	6,515	5,610	4,178	4,720	5,652
	Share % in total	7.64	6.78	7.11	7.01	7.36
2	Indore	3,434	3,383	3,036	3,676	4,680
	Share % in total	4.02	4.09	5.17	5.46	6.10
3	Jabalpur	3,419	3,397	3,226	3,855	4,046
	Share % in total	4.01	4.10	5.49	5.73	5.27
4	Bengaluru	4,611	4,684	3,233	3,213	3,822
	Share % in total	5.40	5.66	5.50	4.77	4.98
5	Chennai	7,580	6871.00	4,389	5,034	3,452
	Share % in total	8.88	8.3	7.47	7.48	4.5
6	Bhopal	3,508	3,287	2,295	2,616	3,313
	Share % in total	4.11	3.97	3.91	3.89	4.32
7	Mallapuram	2,423	2,562	1,784	2,147	2,991
	Share % in total	2.84	3.09	3.04	3.19	3.9
8	Jaipur	2,781	4,271	1,940	2,165	2,687
	Share % in total	3.26	5.16	3.3	3.22	3.5
9	Hyderabad	2,846	2,900	2,064	2,273	2,516
	Share % in total	334	3.50	3.51	3.38	328
10	Kochi	2,411	2,290	1,437	1,781	2,432
	Share % in total	2.83	2.77	2.45	2.65	3.17
Total top 10		**39,528**	**39,255**	**27,582**	**31,480**	**35,591**
% share in Total		**46.33**	**47.42**	**46.96**	**46.77**	**46.37**
All Cities Total		**85,318**	**82,781**	**58,736**	**67,301**	**76,752**

CHAPTER 3: SITE STUDY

3.1 Process of Site Selection

In the preliminary stages of selecting a site for our research, an extensive reconnaissance survey was undertaken across four diverse cities. The overarching goal was to gain a comprehensive understanding of the complex dynamics surrounding urban freight restrictions, which vary significantly across different states and city sizes in India. These restrictions, particularly the prohibition of freight vehicles during daytime hours, are critical considerations for urban planners and policymakers aiming to manage congestion, improve air quality, and enhance the overall efficiency of goods movement within urban areas. Moreover, the chosen cities were characterized by their substantial industrial presence, attracting a significant influx of heavy vehicles for commercial and manufacturing activities.

The four cities selected for this survey—Bhopal, Ghaziabad, Indore, and Kanpur—were chosen deliberately for their unique attributes and strategic importance. Despite sharing commonalities in their approach to freight regulations and industrial landscapes, each city possessed its own distinctive characteristics, contributing to its individual flavour and identity.

Bhopal, the capital of Madhya Pradesh, stands out for its blend of historical heritage and modern development. Its strategic location in central India makes it a vital hub for trade and commerce in the region. The city's industrial sector, encompassing manufacturing and commercial enterprises, generates substantial demand for freight transportation services, necessitating effective urban freight management strategies.

Ghaziabad, situated in the National Capital Region (NCR), is renowned for its rapid urbanization and industrial growth. As an integral part of the NCR, Ghaziabad serves as a crucial link between Delhi and other neighbouring cities. The city's burgeoning manufacturing sector and proximity to major transportation arteries make it an ideal candidate for studying urban freight dynamics and logistical challenges.

Indore, known as the commercial capital of Madhya Pradesh, boasts a thriving business ecosystem and a robust industrial base. Its strategic location along key transportation corridors position it as a key player in the regional economy. With a diverse array of industries ranging from textiles to pharmaceuticals, Indore experiences significant freight movement, necessitating effective urban freight management policies to mitigate congestion and ensure smooth goods distribution. Kanpur, located in the northern state of Uttar Pradesh, is renowned for its rich industrial heritage and vibrant commercial activities. The city's historical significance as a major centre for leather and textile industries has contributed to its status as an economic powerhouse in the region. However, rapid urbanization and industrialization have posed significant challenges in terms of traffic congestion and air pollution, underscoring the need for sustainable urban freight solutions.

In addition to their industrial prowess and urban freight dynamics, all four cities feature dedicated Transport Nagars, specialized areas designed to facilitate the efficient loading and unloading of goods from heavy vehicles to Light Commercial Vehicles (LCVs). These Transport Nagars play a pivotal role in optimizing the distribution process and minimizing disruptions caused by freight movements within urban areas. The selection of these cities was guided by several criteria, including their size, economic significance, and proximity to national or state capitals. Importantly, cities ranking among the top 10 in terms of Gross Domestic Product (GDP) were intentionally excluded from consideration. This deliberate omission was motivated by the desire to focus our research efforts on cities that may have been overlooked in previous studies but hold immense potential for future economic growth and development. By conducting the research in these selected cities, the aim is to generate valuable insights into the complexities of urban freight management and contribute to the formulation of effective policy interventions aimed at enhancing the efficiency, sustainability, and resilience of urban freight systems in India. Through collaboration with local stakeholders, government agencies, and industry partners, we endeavour to develop innovative solutions tailored to the unique challenges and opportunities presented by each city, ultimately fostering economic prosperity and improving quality of life for urban residents.

3.2 Site Selection

Indore, a city located in the Indian state of Madhya Pradesh, offers several advantages for the study of urban freight transport:

3.2.1 Economic Capital of Madhya Pradesh

Indore is one of the major economic contributors in the GDP of Madhya Pradesh. Overall, the combination of a diverse urban environment, robust transportation infrastructure, smart city initiatives, and academic expertise makes Indore an excellent location for studying urban freight transport networks and addressing the associated challenges and opportunities.

3.2.2 Diverse Urban Environment

Indore provides a diverse urban setting with a mix of residential, commercial, and industrial zones. This diversity allows researchers to analyse various aspects of freight transport, including last-mile delivery challenges, distribution patterns, and traffic congestion issues.

3.2.3 Rapid Urbanization

Like many other Indian cities, Indore has been experiencing rapid urbanization, leading to significant changes in its transportation infrastructure and logistics networks. Studying the city's freight transport system can provide valuable insights into the impacts of urbanization on logistics operations and supply chain management. In the past decade the city has witnessed a population of growth of 130% as per (Indore Development Plan, 2021).

3.2.4 Transportation Infrastructure

Indore boasts a well-developed transportation infrastructure, including road networks, railways, and air connectivity. This infrastructure facilitates the movement of goods within the city and across different regions, making it an ideal location for studying the efficiency and effectiveness of urban freight transport, (UMTC, 2023).

3.2.5 Smart City Initiatives

Indore has been at the forefront of implementing smart city initiatives aimed at improving urban infrastructure and transportation systems. These initiatives often involve the use of technology and data analytics to optimize freight movements, reduce congestion, and enhance sustainability. Studying Indore's smart city projects can offer valuable insights into innovative approaches to urban freight management.

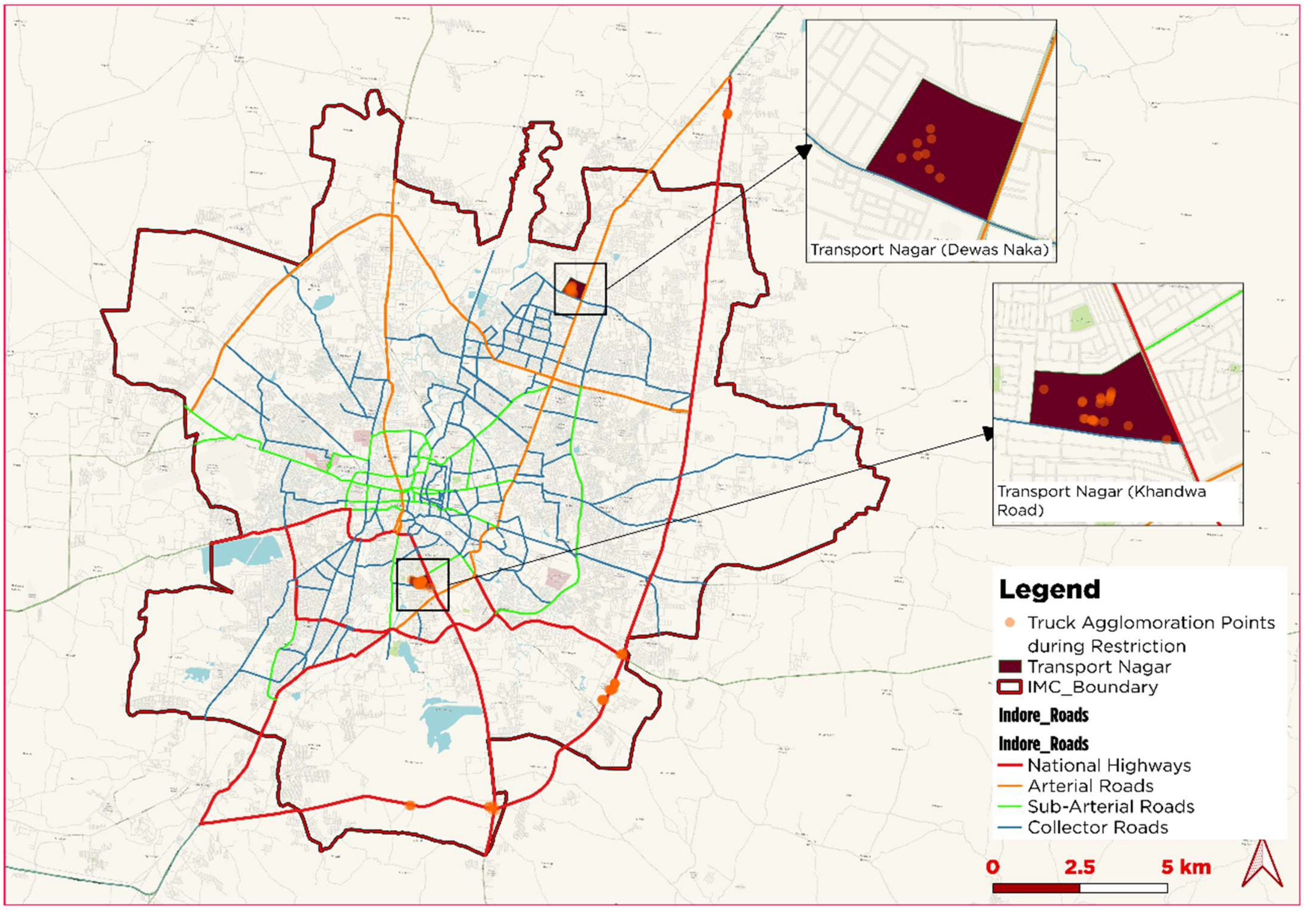

Figure 2 Map showing locations of Transport Nagar and Major Road Hierarchies in Indore

The major road network is shown in Figure 2 alongwith the location of two Transport Nagar operating in Indore. Figure 2 also shows the major Truck Agglomeration Points in the city of Indore. The area of Transport Nagar (Dewas Naka) is 26.9 ha and the area of Transport Nagar (Khandwa Road) is 17.66 ha. These Transport Nagars are located at the north and south entry points of city to cater majority of the freight traffic during restriction time. As discussed in section 3.1 these Transport Nagar play a vital role in accommodating the freight traffic as per the current flow. Although not the only answer to freight traffic restriction, these are one of the most crucial solution.

3.3 Site Characteristics

Figure 3 Pavement Quality of a Transport Nagar in Indore

Figure 3 shows the pavement quality in a Transport Nagar in Indore. This road section is made of concrete and thus, still survives the brutalities of heavy vehicles, the asphalt road sections are not as durable and are prone to breakage. Another thing that can be seen in Figure 3 is the absence of road marking and retroreflective studs. All the Transport Nagars in Indore have no lane marking which makes it difficult to manoeuvre in the dark. As mentioned in (IRC SP:30, 2009), (Kadiyali, 1999) and (IRC 35, 2015) lane markings and retroreflective studs improve the driving conditions and provide better visibility at night. This is true for both fast-moving and slow-moving roads.

On the other hand, in Figure 5 the pavement quality of a major road adjacent to transport nagar is shown. This road section has proper lane marking and is much cleaner than compared to the road section in Figure 3. Another change that can be seen is the material of the pavement, the road is built from Asphalt bitumen and not concrete and is yet in good condition. This shows that the movement of trucks deteriorate the pavement quality and similar can be seen in Indore.

Figure 5 Pavement Quality of other major road of Indore

Figure 4 Truck parked at roadside

In Figure 4, it can be seen that due to unavailability of parking and proper loading/ unloading areas in the city, truck drivers park their vehicles on the side of the road, occupying carriageway space. This leads to vehicle collisions, accidents and in worst scenarios fatalities. Trucks have larger blind spot areas when compared to other vehicles as illustrated in Figure 6.

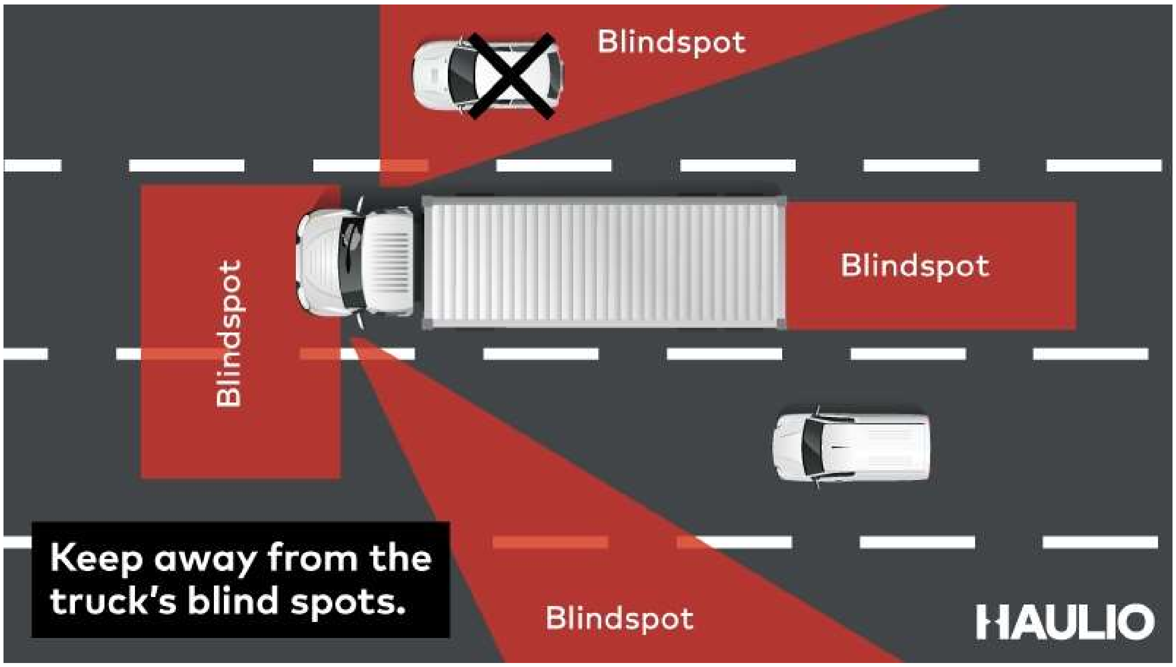

Figure 6 Blind Spots in a Truck. Source: Haulio - Road Safety

These blind spots become a more dangerous zone when the trucks move on the city roads and park alongside. A worse scenario is seen in Figure 7 where the trucks is parked alongside the road and there is movement of traffic creating potential chances of traffic collision.

In Figure 8, the condition of Transport Nagar (Dewas Naka) is shown. There is an informal tea stall, which has cigarettes, and gutka along with biscuits. These tea stalls are the most common points where groups of truck driver sit down and spend a quality time with their community, i.e. the truck drivers. People had placed woven beds for seating and other chairs of similar material. This image also shows the dilapidated condition in which the truck drivers have to live, whenever they are stopped in the restriction time. There is also a time when extreme summers and winters are witnessed by the people, the hardships become worse in these times.

Figure 7 Truck Movement on Ring Road in Indore

Figure 8 Transport Nagar (Dewas Naka) with wayside amenities

3.4 Stakeholders responsible for Enforcing the regulations

Stakeholders play a crucial role in the decision-making process that shapes urban freight policies and regulations. Among these stakeholders, law enforcement agencies, particularly the police, are tasked with establishing the fundamental principles governing the necessity of limiting freight movement within cities. Through a series of interviews with traffic inspectors from Bhopal and Ghaziabad, it became evident that determining the rationale behind freight limitations and making informed choices regarding these restrictions are dynamic processes. The responsibility of enforcing freight restrictions often falls under the purview of the police department. Traffic inspectors, who are at the forefront of managing vehicular movement within urban areas, are intimately involved in this process. Their daily interactions with traffic conditions on the ground provide valuable insights into the challenges posed by freight movement and the potential solutions to address them.

In interviews conducted with traffic inspectors, it was observed that the decision-making process surrounding freight limitations is not static but rather responsive to evolving circumstances. Factors such as traffic congestion, road safety concerns, air pollution levels, and the overall impact on urban mobility are carefully considered in determining the necessity and extent of freight restrictions. Moreover, the input provided by police officers, based on their direct observations and experiences, serves as a crucial source of information for policymakers and urban planners. On the ground, there are essentially two types of implied restrictions on freight movement within cities. The first type involves explicit regulations imposed by local authorities, such as time-based restrictions on the entry of freight vehicles into certain areas during peak traffic hours. These restrictions are typically enforced through the issuance of permits and the deployment of surveillance mechanisms, including CCTV cameras and mobile patrols. The second type of implied restrictions is more informal in nature and may not be explicitly codified in official regulations. These restrictions often arise as a result of practical considerations and informal agreements between stakeholders. For example, certain routes or areas within the city may be deemed unsuitable for heavy vehicle traffic due to narrow streets, residential areas, or historical sites. While not formally enforced by regulations, these implicit restrictions are widely recognized and adhered to by freight operators and drivers to avoid potential conflicts and disruptions. In addition to enforcing existing regulations, police officers also play a proactive role in identifying emerging challenges and proposing innovative solutions to improve urban freight management. Their close collaboration with other stakeholders, including government agencies, transport authorities, industry associations, and community groups, facilitates the development of holistic strategies that balance the needs of various stakeholders while addressing the broader goals of sustainable urban development. Overall, the involvement of law enforcement agencies, particularly the police, is indispensable in shaping the policies and regulations governing urban freight movement. By leveraging their expertise, experience, and on-the-ground insights, police officers contribute to the development of effective and responsive strategies that enhance the efficiency, safety, and sustainability of urban freight systems, ultimately benefitting both residents and businesses alike.

3.5 Vehicle Weight Access Restriction

Vehicle weight restrictions are a common regulatory measure implemented by governments to ensure the safety and integrity of road infrastructure, protect public safety, and mitigate environmental impacts. These restrictions typically impose limits on the maximum weight that vehicles can carry, encompassing both the vehicle's own weight and the weight of the cargo it is transporting. The rationale behind weight restrictions lies in preventing excessive wear and tear on roads and bridges, reducing the risk of accidents caused by overloaded vehicles, and minimizing environmental damage, particularly in terms of pavement deterioration and emissions.

3.6 Time Access Restriction

Time access restriction in urban freight transport refers to the implementation of policies or regulations that limit or control the times at which freight vehicles are allowed to access certain areas or routes within urban environments. As mentioned in *section 2.3.2* these restrictions are typically aimed at mitigating traffic congestion, reducing emissions, improving road safety, and enhancing the overall efficiency of freight operations in urban areas. Several approaches to time access restriction in urban freight transport include. Cities may establish specific time-of-day delivery zones where freight vehicles are permitted to operate and make deliveries during off-peak hours. This helps to alleviate congestion during busy periods while still facilitating the movement of goods. Some cities impose bans on freight vehicle access during peak traffic hours to reduce congestion and improve traffic flow. During these restricted periods, freight vehicles may be prohibited from entering certain areas or using specific routes.

Municipalities may incentivize off-peak deliveries by offering reduced tolls, parking fees, or other financial incentives to freight operators who schedule deliveries during less congested times of the day. Congestion pricing schemes charge vehicles a fee for entering certain areas or using specific routes during peak hours. These fees can vary based on factors such as vehicle type, time of day, and level of congestion, encouraging freight operators to schedule deliveries during off-peak times. Advanced logistics technologies enable freight operators to optimize delivery routes and schedules in real-time based on current traffic conditions, helping to avoid congested areas and comply with time access restrictions. Collaborative freight consolidation initiatives bring together multiple shippers to consolidate their shipments and reduce the number of individual freight vehicles traveling into urban areas, thereby minimizing congestion and the need for time access restrictions. Innovative last-mile delivery solutions, such as micro-depots, cargo bike deliveries, and drone deliveries, can bypass traditional roadways and congestion-prone areas, providing alternative options that may not be subject to time access restrictions.

By implementing time access restrictions in urban freight transport, cities can better manage traffic flow, reduce environmental impacts, and enhance the overall liveability of urban environments while ensuring the efficient movement of goods and supplies.

3.7 Truck Drivers and Operators

In order to comprehend the challenges faced by truck drivers and operators, a willingness to pay survey was carried out. In retrospect, it was believed that the freight regulations are taking advantage of the truck drivers. Truck drivers find it exceedingly difficult to follow the rules when there are few basic amenities available, yet they are compelled to do so because of the high challan. Additionally, it is noted that these truck drivers struggle greatly and are from the lowest socioeconomic classes in society.

Their monthly income ranges between 4000-6000 rupees, plus an extra 200-400 rupees for daily meals. This meal allowance covers food, truck parking fees, other incidental expenses, and their stay at a hotel, motel, or inn (if applicable). The results of the primary study showed that the drivers' companions, their assistance, are seen via the criminal's eyes. It is nearly absurd to even operate trucks in these current conditions. The urban freight laws exacerbate the situation further. Drivers and assistants are left without basic facilities to maintain themselves, and they are always at risk from a variety of dangers, including theft of personal belongings, diesel theft, and life threats.

When questioned about their need for the bare minimum of amenities, drivers all stated that their socioeconomic level prevented them from being willing to pay exorbitant prices for them. They were prepared to spend between 50 and 100 rupees on such facilities.

3.8 General Public

There are just two ways in which these restrictions impact the general population. First, when they are commuting through the city, they observe fewer trucks and lorries operating on the roads. People feel psychologically satisfied since they think that the large cars are a nuisance on the roadways. Conversely, a number of scholars who have studied driving behaviour have made the opposite claim. Over the previous five years, traffic accidents in Indore have increased at a lethal rate of 12.5% each year, despite fewer trucks and lorries operating on urban roadways (Road Accidents in India, MoRTH, 2022).

Second, throughout the day, trucks and lorries that are prohibited from entering the city line along the regional corridor as far as the conveniences such as the petrol station, the closest toll booth, unofficial truck parking, roadside dhabas, etc. Since the majority of the unofficial wayside amenities are located right next to the roadways, they are forced to park their truck on the carriageway. The incoming traffic that travels at high speeds on these roads—typically 80–100 kmph, or 2.6 times higher than the rates in cities—is at risk of collisions because of these parked trucks.

Another type of loss that practically everyone involved in the supply chain of any given product experiences is loss of delay.

3.9 Delays

Apart from the understanding of the participation of stakeholders, the delays faced by the truck operators were also inquired about. The primary reason for doing this exercise was to comprehend the various delays that act as challenges in the whole supply chain of the delivery of a commodity. After conducting initial recci surveys it was identified that primarily the delay is due to restriction in the city. This restriction however creates several bottlenecks, like, *bottlenecks while entering the city* – when there are all the queued-up trucks trying to enter the city, the limited capacity of the existing network creates a bottleneck which gives rise to other problems like accidents, conflicts amongst drivers, etc. The data was collected by asking the truck drivers, how much time on an average do they face on each of these steps.

The various bottlenecks in the supply chain with respect to the city restriction were classified broadly into three categories – City Entry, Queueing before Loading/ Unloading, Tired truck drivers.

CHAPTER 4: DATA COLLECTION AND ANALYSIS

The process of gathering and analysing data was meticulously carried out to thoroughly examine and understand the multitude of challenges that truck drivers face in their line of work. Surveys, as outlined in Annexure 1, were an integral part of this process, as they were used to collect data from a sample of 108 truck drivers. The focus of these surveys was to explore the obstacles posed by city restrictions that truck drivers often encounter during their daily operations. In addition to identifying the challenges that truck drivers face due to city restrictions, the study also sought to evaluate the availability and quality of necessary amenities for highway traffic and rest breaks. These essential amenities included access to sanitary restrooms, drinking water, rest and sleep areas, laundry services, cooking facilities, auto repair workshops, designated areas within TUZs for truck-related activities, ample parking, warehousing and logistical support, fuelling stations, and dining options such as food courts or dhabas. The comprehensive data collection and analysis aimed to provide a deep and nuanced understanding of the problems encountered by truck drivers, including both operational and infrastructural issues. By examining the current state of facilities and amenities available to support their operations, the study sought to assess the level of comfort and safety truck drivers experience during long-distance journeys. Through the extensive data gathered, the research offered an overview of the existing infrastructure supporting truck drivers, while also highlighting gaps and areas that require improvement. The goal was to use this information to propose informed solutions that can enhance the overall experience for truck drivers, making their journeys more efficient and safer. In conclusion, the in-depth analysis and evaluation of the data collected from truck drivers aimed to contribute to a comprehensive understanding of the diverse challenges they face, the adequacy of the existing infrastructure, and the range of amenities available to support their operations. This research holds the potential to inform better policies and practices that can positively impact the lives and work of truck drivers, ensuring their comfort and safety during long-distance travels.

4.1 Primary Data Collection

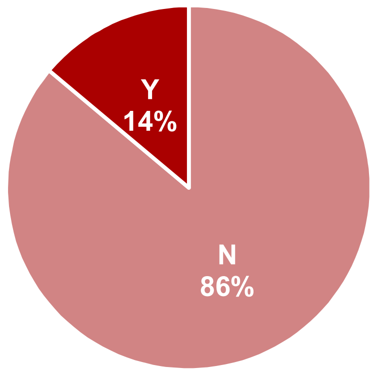

Figure 9 Availability of Dormitories, Self-Laundry/ Cooking, Source: Primary Survey

Dormitories, Self Laundary/ Cooking are important when a person has to stay overnight in an unknown place. Surprisingly, when asked from the truck drivers and conductors whether they have this facility or not 86% drivers said that they don't have dormitories or self-laundry available shown in Figure 9. If they want to rest or sleep, they only find nearby dhabas who have limited space available, once this space gets filled the drivers and conductors have to spend their entire time in the cabin of the vehicle. In extreme temperatures this becomes horrendous to live in. When asked about how they wash their clothes, the drivers explained that they have to carry their own soap, hangers and ropes and use the wind while driving the truck to dry their clothes. This creates another hazard for the traffic moving on the road.

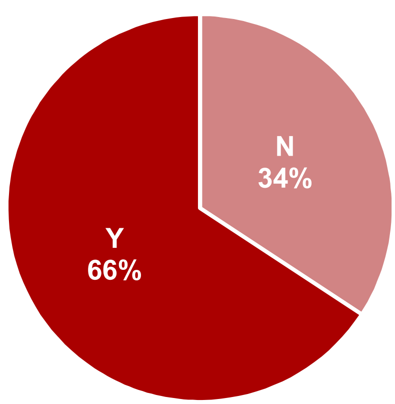

Figure 10 Availability of Clean Washrooms and Drinking Water, Source: Primary Survey

Clean Washrooms and pure drinking water are the most essential requirement of everybody when travelling. After inquiring from the truck drivers, it was found that

66% of the truck drivers said that they have clean drinking water and washrooms available, Figure 10. Surprising thing is that 34% of the truck drivers still didn't find these amenities. They said that due to certain social stigmas, people don't allow them to fill the water from their mud pots, thermos or water tanks. Weirdly truck drivers are also not allowed to use toilets in the nearby retail outlets and it is not possible for them to leave the truck and go to special complex. The Sulabh complexes are not conveniently located for them, thus, this increases the intensity of the problem.

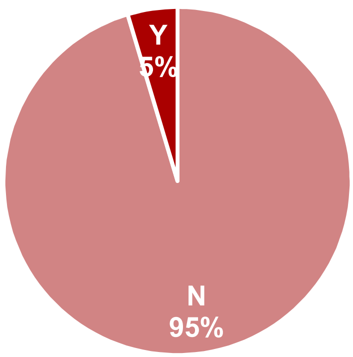

Figure 11 Availability of Truck User Zone & Parking, Source Primary Survey

In Figure 11, the availability of Truck User Zone & Parking is shown. Only 5% of the drivers said that they were able to find parking. This is the case because these drivers worked for companies that had the warehouses or parking reserved for their trucks. Apart from these driver others didn't have any parking available for their trucks and this number is as large as 95%. The parking that is provided in the Transport Nagar is almost never free and always occupied. In addition to this the majority of the loading and unloading areas are far away from these Transport Nagar, thus, this becomes a serious problem. As shown in Figure 4 and Figure 7 it is clearly found similar to the result.

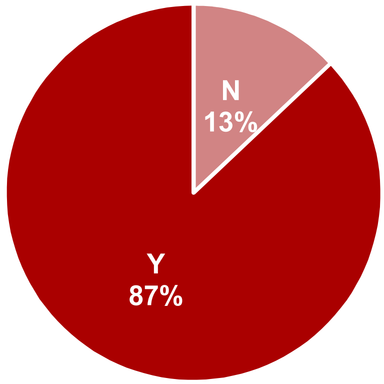

Figure 12 Availability of Auto Workshops, Source: Primary Survey

It is clearly evident from the site visit that the Transport Nagar and other Truck Agglomeration Points in the city as shown in Figure 2 have sufficient amount of Auto Workshops. The identical observation is obtained from primary data, Figure 12. 87% of the truck drivers and operators could easily find the truck repair workshops when standing outside due to the restrictions. These workshops are necessary as they provide crucial support in the operation of the trucks. Although drivers themselves are somewhat educated when it comes to repairing vehicle, the mechanics can ease the process and do the same work more efficiently. This also prevents the drivers from getting extra fatigue which reflects on their driving. Auto Workshops are usually found near by petrol pumps in Indore or dhabas. When not allowed in the city, trucks can undergo maintenance (if any required) making the best use of time.

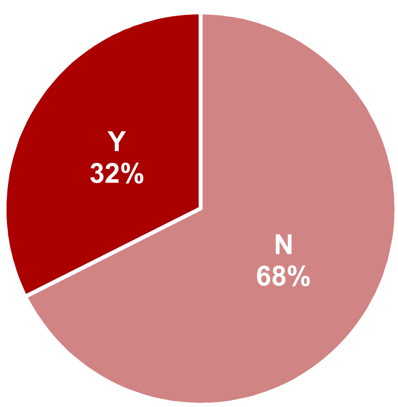

Figure 13 Availability of Warehousing & Logistics Facility, Source: Primary Survey

Warehouses are an indispensable service which allow for seamless transfer of goods from one mode to another and also play a vital role in value-addition. Warehouses are also important in long hauls of commodities as they act as an interchange of modes in the same journey. There are various times when the connecting truck is not available readily and there is a time lag in the transport of goods, in such conditions the goods are stored in a warehouse. Upon interviewing the truck drivers, as shown in Figure 13, only 32 % of the drivers had the facility of warehouse available. Other drivers had to unload their goods directly at the outlet. This might initially seem demand-oriented supply, but, when the trucks have to stay at the periphery of the municipal boundary due to restriction, warehouses can be used to shift the goods and transferred to a smaller vehicle.

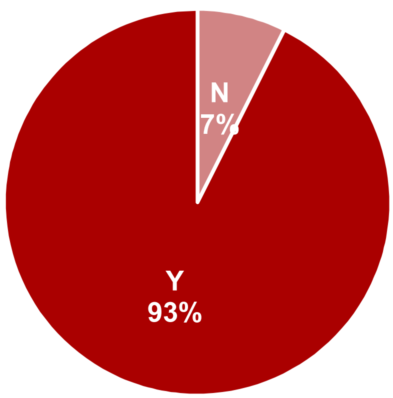

Figure 14 Availability of Fuel Stations, Source: Primary Survey

Fuel Stations are another major amenity on required by the truck drivers. In the current scenario, 97% truck drivers are able to find the fuel stations in the vicinity, Figure 14. It is also seen that the fuel stations are not just the providers of fuel and related services, but also provide parking, toilet and clean water to the truck drivers. This is the reason, why the truck drivers favour to stop nearby the fuel stations exclusively.

Apart from inquiring about the availability of various way side amenities, the time delay caused due to restriction was also asked, shown in Table 2. These delays were selected after having a preliminary conversation from the truck drivers and the challenges that they faced.

Table 2 Various delays as observed from site

Delays caused	Time
Delay due to restriction	17 hrs.
Delay due to bottleneck at entry	1.5-2.5 hrs.
Delay before loading/unloading	1-2 hrs.
Delay due to tired truck drivers	3 – 5 hrs.

It is found that the delay due to restriction is 17 hours. This is so, because the restriction in Indore is from 6:00 in the morning to 23:00 in the night. From (UMTC, 2023) it was found that the incoming flow of heavy vehicles is not constant throughout the day, thus, queuing theory (IIT Bombay, 2023) is used to determine the average inflow of heavy vehicles.

4.2 Road Accident

The 2022 analysis of road accident data in Indore has provided insightful observations about the impact of freight transport on road accidents. According to the data recorded by the Ministry of Road Transport and Highways (MoRTH), there were a total of 639 fatalities due to road accidents in Indore during the year. When we delve into the specifics, it is revealed that only 3.8% of the accidents were caused by trucks and lorries, with these heavy vehicles accounting for 24% of the fatalities in such incidents. This data suggests that while trucks and lorries do contribute to road accidents and fatalities in Indore, their impact is relatively minimal compared to other types of vehicles. Two-wheelers, such as motorcycles and scooters, play a much more significant role in road accidents in the city. Over 35% of the road accidents in Indore involve two-wheelers as the crime vehicles, indicating that these smaller, more agile forms of transport are far more prone to being involved in collisions and mishaps.

The high incidence of accidents involving two-wheelers could be attributed to various factors such as the vulnerability of these vehicles on the road, the behaviour of their riders, and the general road conditions in Indore. In contrast, heavy vehicles such as trucks and lorries, though large and imposing, are less frequently involved in accidents, possibly due to stricter regulations, better-trained drivers, and lower speeds. Nonetheless, their presence in the accident data should not be dismissed entirely, as they do contribute to a portion of fatalities and road safety challenges. From this analysis, we can draw the conclusion that heavy vehicles like trucks and lorries are not the primary culprits when it comes to road accidents in Indore. While they do have a presence in the statistics, their share is not as substantial as that of two-wheelers. This insight is crucial as it shifts the focus from solely blaming large freight vehicles for road safety issues to considering the risks associated with other types of vehicles, particularly two-wheelers.

The emphasis should be on improving safety measures for two-wheelers and their riders to decrease the high percentage of accidents. This might include better education for two-wheeler riders on safe practices, stricter enforcement of traffic rules, and possible infrastructure improvements to accommodate these vehicles more safely on the roads. Moreover, while heavy vehicles like trucks and lorries aren't the primary cause of accidents, their large size and weight mean they can cause significant damage when they are involved. So, it's essential to maintain a level of vigilance around these types of vehicles and ensure that drivers receive proper training and adhere to safety regulations.

4.3 Demand Generation

To assess the impact on Level of Service, it's crucial to develop a demand model. In this study, a vehicle matrix is created using PTV VISUM software. This involves generating vehicle trips by establishing various zones at major demand generation points. The traffic flow data is correlated with findings from (UMTC, 2023), and a trip matrix is generated based on the weighted traffic flow data. *Table 3* demonstrates the demand generation process and relative traffic flows.

From the weighted Trip Production, trip matrices are constructed and utilized for trip assignment. Although these trip matrices include some induced error, they still yield results within a 10% margin of error, making them suitable for the final analysis. Both the trip production and trip matrices are calculated in two categories: Restricted and Non-Restricted Modes. Since the data is extrapolated from the PCU (Passenger Car Units) counts, the trip values represent PCU values, ensuring uniformity in comparisons.

Table 3 Relative Demand Generation for producing demand model

TAZ	Traffic Flow	Relative Traffic Flow	Trip Production (passenger)	Trip Production (freight)	Trip Production (Heavy)
10	55000	8%	19156.5	4409.9	1624.7
20	93400	14%	40162	7488.812	2759.036
30	38000	6%	16340	3046.84	1122.52
40	64200	10%	27606	5147.556	1896.468
50	18000	3%	7740	1443.24	531.72
60	70000	11%	30100	5612.6	2067.8
70	50000	8%	48100	9139	3367
80	74500	11%	71669	13617.11	5016.83
90	35000	5%	15050	2806.3	1033.9
100	40000	6%	38480	7311.2	2693.6
110	15400	2%	14814.8	2814.812	1037.036
120	60000	9%	57720	10966.8	4040.4
130	40000	6%	38480	7311.2	2693.6

Table 4 Direction of Trips on OCP and SL

Direction of Trips (As per Indore CMP 2023)	Passenger Vehicles	Freight Vehicles
I-E	43%	38%
E-I	42%	39%
E-E	14%	20%
I-I	1%	3%

In the **Restricted Mode**, the dataset includes PCU counts of heavy vehicles such as trucks and multi-axle vehicles (MAVs). According to data from (UMTC, 2023), out of the total vehicles (PCU) operating on Indore's roads, only 7% are heavy vehicles entering the city. This heavy mode is subject to restrictions between 6:00 am and 11:00 pm.

In the **Non-Restricted Mode**, the dataset comprises all other modes permitted to travel within the city during the time restrictions. Indore has about 12% of freight traffic within the city, excluding freight traffic itself. As discussed in section 3.1, the heavy influx of traffic flow is one of the reasons this city was chosen for the study. To expand on the analysis, additional simulations and assessments were carried out to understand how different scenarios affect Level of Service across various zones in the city. By using advanced modeling techniques, the study examines how traffic flow, vehicle types, and time of day impact congestion and the overall efficiency of the road network.

For each zone, specific trip patterns were identified and analyzed to determine the root causes of congestion or bottlenecks. The data was then processed to create detailed trip matrices that depict the movement of different vehicle types throughout the city. These matrices are critical in predicting how traffic will behave under various conditions, allowing for the exploration of potential solutions to improve Level of Service. This includes assessing the impact of new infrastructure, road widening, or changes to traffic signals.

Moreover, the study considered alternative transportation modes and their potential role in reducing congestion. For example, public transit options and non-motorized transportation were evaluated for their effectiveness in mitigating traffic challenges and promoting sustainable mobility.

4.4 Analysis of Trip Assignment

The trip assignment result show that the central portion of the city is receiving maximum traffic after the bypass road. The bypass road receives more traffic because of the way the demand model is generated, every trip is either going towards the bypass or coming from bypass. It should be also accounted that very small roads do not have much traffic assigned to them as the model has calibrated many trips on roads with higher capacity.

Figure 15, shows the Road Network which allows the movement of restricted freight vehicles in the restriction period. The distribution of Truck Agglomeration Points along the network is also seen in **Error! Reference source not found.**. This map highlights the importance of a bypass road in the through transportation of traffic. If this road had not been there, it would cause extreme congestion and traffic conflicts in the interior roads of the city. This observation can be further strengthened by the traffic model generated in Figure 16. It shows the movement of restricted and non-restricted traffic in Indore and the most preferred route taken by them. The trip Assignment model displayed in Figure 16 is also crucial to understand the load on various networks.

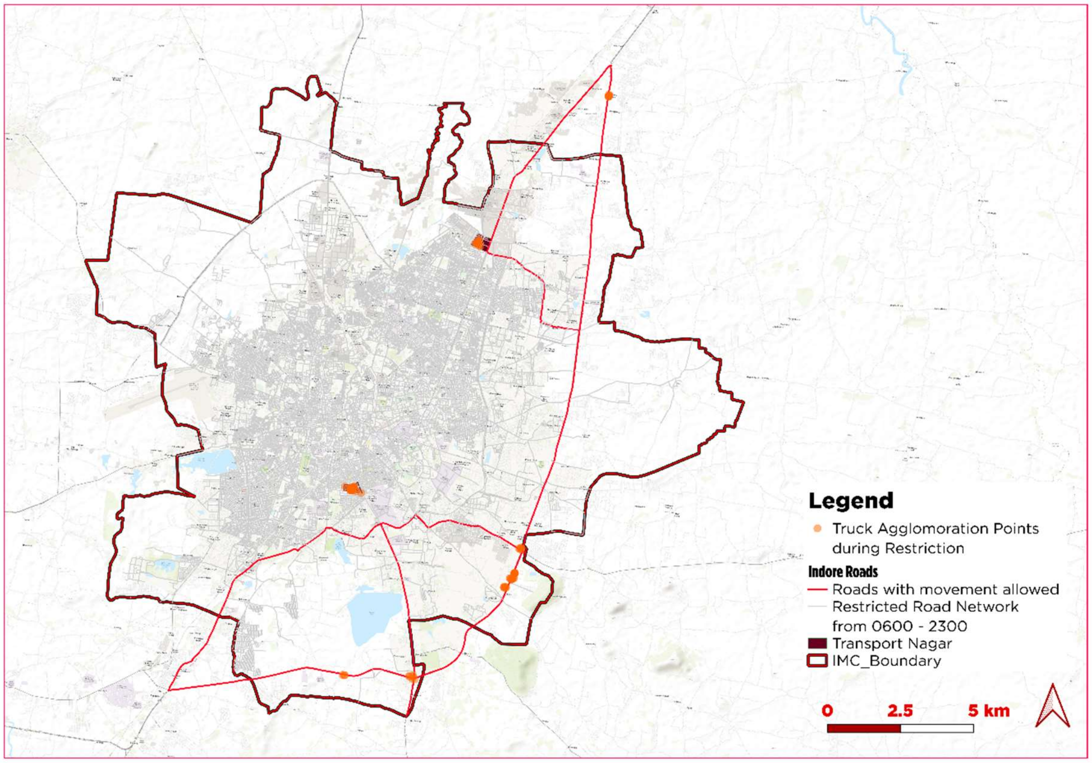

Figure 15 Truck Agglomeration nodes and Roads open to Truck in Restricted Time

The trip assignment shown in Figure 16 is Average Daily Traffic data computed from (UMTC, 2023). It can be clearly seen that majority of the traffic is on the bypass road (a), AB Road (b), Ujjain Road (c) and MR 10 (d).

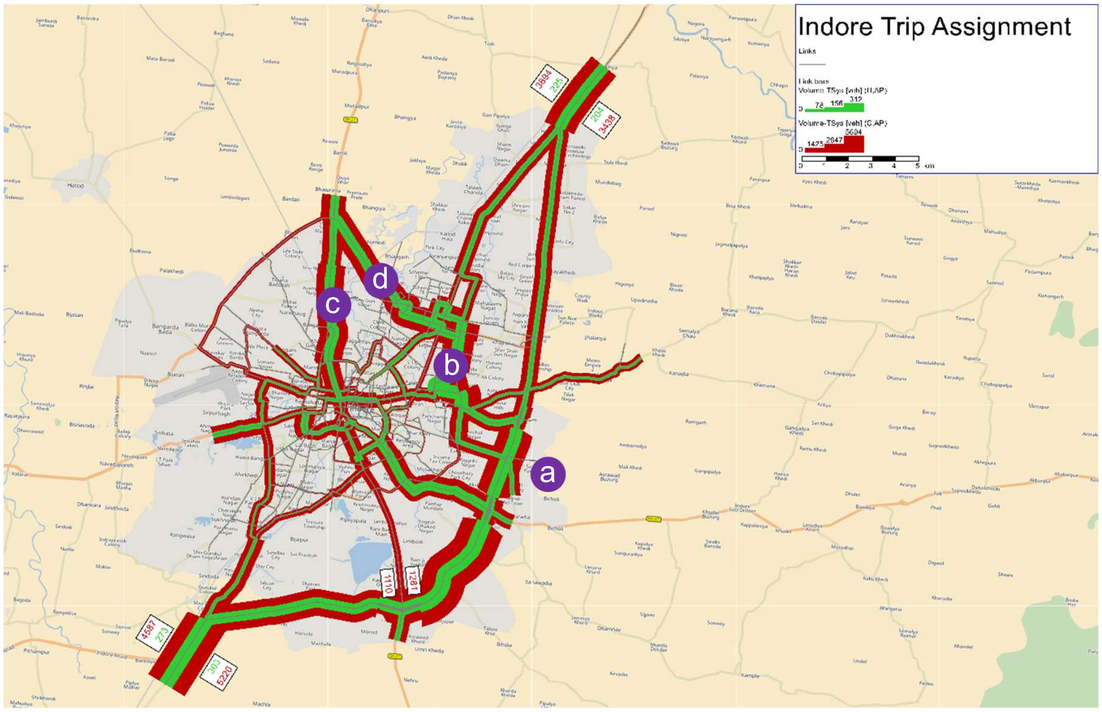

Figure 16 Trip Assignment of ADT combined modes

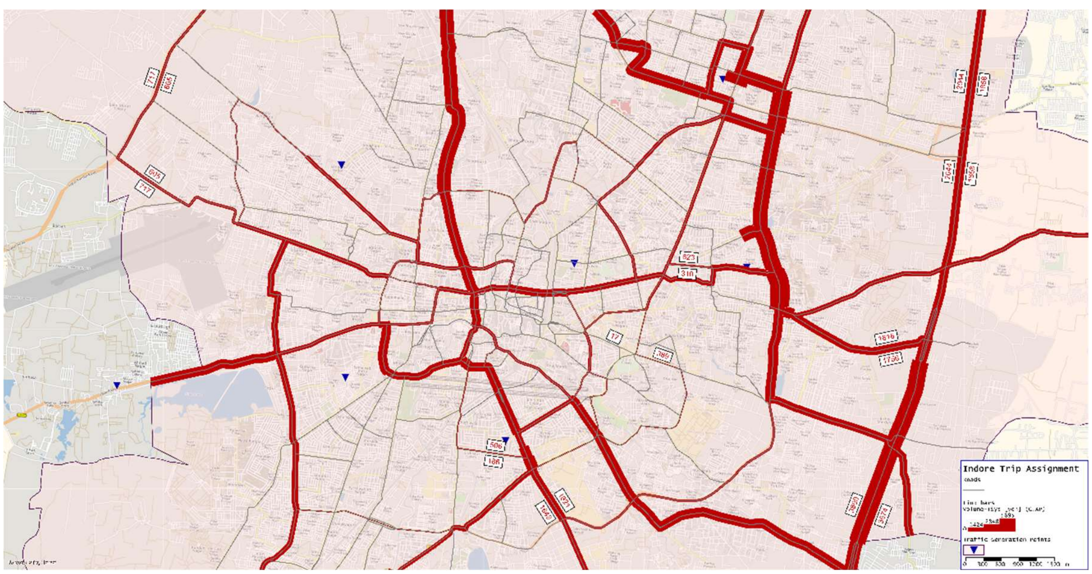

Figure 17 Non-Restricted Mode Trip Assignment, Peak Hour

Figure 17 shows the Trip Assignment of Non – Restricted mode in Peak Hour. It can be inferred from the above image that the flow of Non-Restricted Vehicles behaves similarly to that of restricted mode, the only difference is seen the reduced load on the network due to the reduction of heavy vehicles. This allows for a free movement of traffic as there is more space available on the road network. There is however, one discrepancy in this analogy, as the traffic is a like stream of water, it fills the remaining space and it is not possible to quantify the amount of space saved, thus, trip production of both restricted and non-restricted modes is done simultaneously as shown in Figure 18. This shows that some road network is used exclusively highly by the heavy vehicles due to either the availability of space on the road or faster road available. The trip pattern of the heavy vehicles also differs from the other modes as they are also having a regional leg of trip which is not found in majority of the internal trips. The freight trip usually terminates to common points, having high density of establishments.

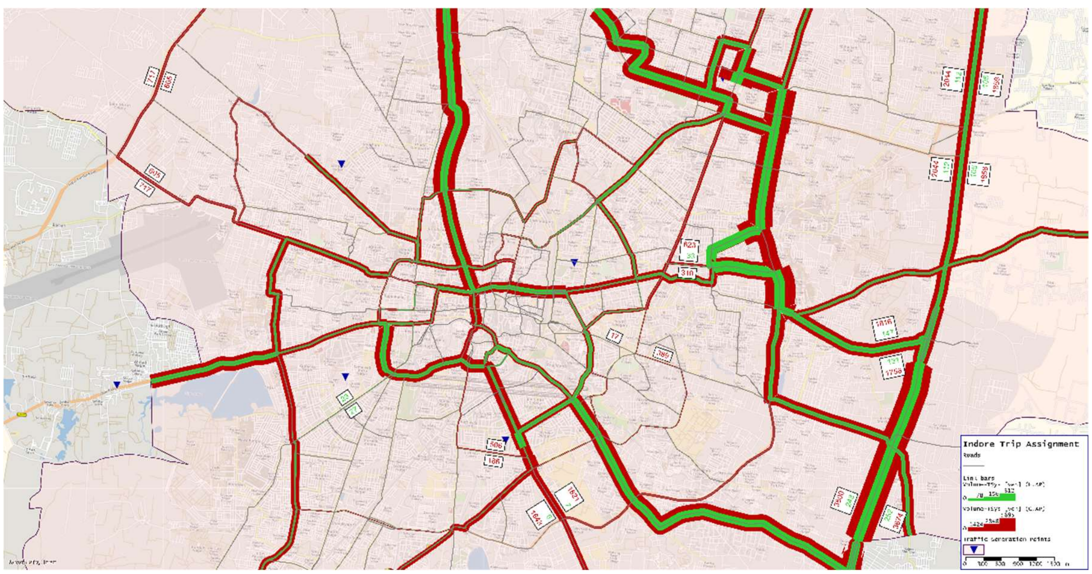

Figure 18 Both Non-Restricted and Restricted Mode Peak Hour

For obtaining a better understanding of the impact on the road network by restricting certain modes, volume to capacity ratios have been calculated as per the (IRC 106, 1990). For the two scenarios one in which the restriction is there and the other in which no restriction is implied. Figure 19 shows the Level of Service with restrictions in place, Figure 20 on the other hand shows the road network with no restriction. It is seen that there is a 10% decrement in the Level of Service by allowing the freight vehicles. This changes the LOS from C to D on some road networks and from B to C on other, but largely, the LOS remains unchanged.

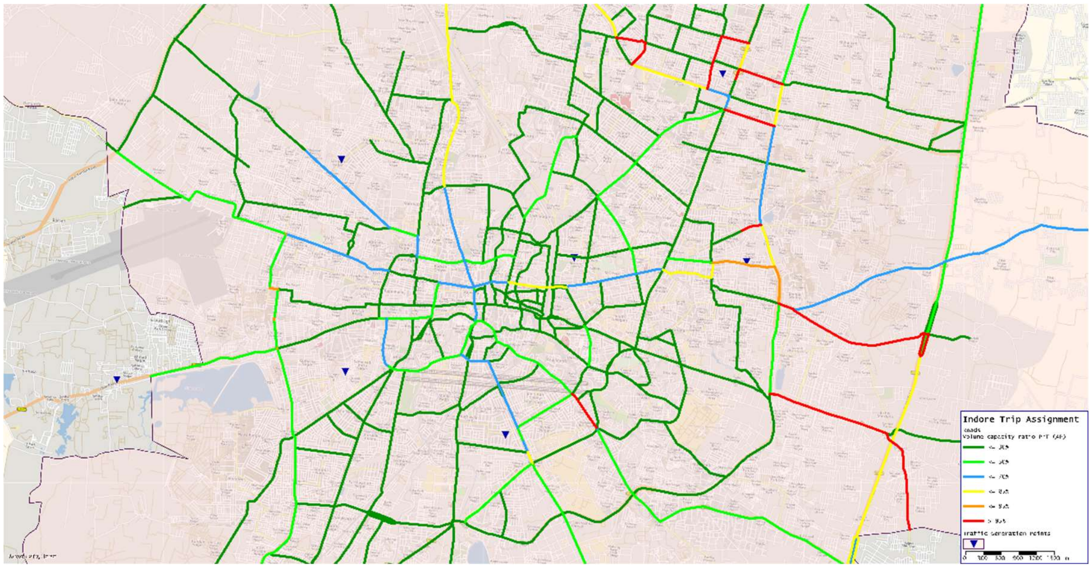

Figure 19 Level of Service with complete restriction

It is to be noted that some road networks show over-saturation, this is due to limited networks mapped in the model and a limited OD points used. For the sake of this study, the OD points were largely selected at major Outer Cordon Points and Major attraction points inside the city as explained in section 4.3.

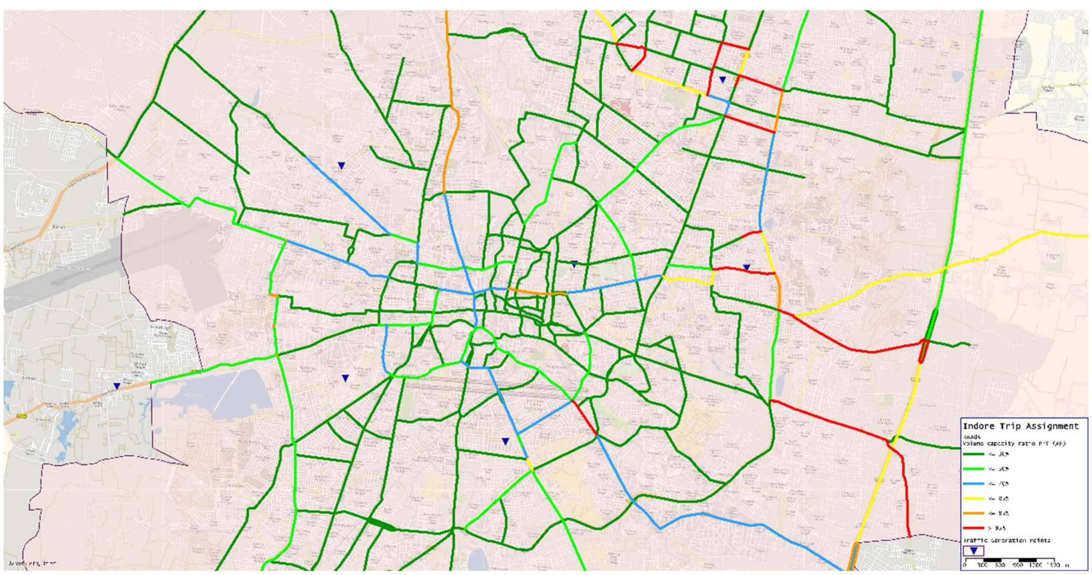

Figure 20 Level of Service with Heavy Vehicles allowed

4.5 Cost of Time Delay

On an average there is a drop of 10 % in the LOS in peak hour when both heavy vehicles and other modes ply on the road. This is much worse on Ujjain Road, Khandwa Road and Ring Road.

The depreciation of the level of service is 10% on an average on each road. This also helps to understand the Time cost of delay. As per (Qingyu, Zhicai, Baofeng, & Hongfei, 2007), time delay cost is expressed by the formula $c_{time} = t_{extra} \times u \times P_c$ where, c_{time} is to cost of time, t_{extra} is extra time caused due to congestion, u value of time and P_c is no of passengers affected. Time Delay calculated from the primary data is shown in Table 5.

Table 5 Delay caused to truck drivers. Source: Analysis from Primay Data

Delays caused	Time
Delay due to restriction	8.5 hrs.
Delay due to bottleneck at entry	2.5 hrs.
Delay while loading/unloading	2 hrs.
Delay due to tired truck drivers	4.5 hrs.

Delay caused to truck drivers for 1 day of restriction is 17.5 hrs. As their average income is ₹12000 pm, VOT comes out to ₹50 per capita per hr. ($\frac{12000}{30*8}$). No. of truck drivers affected 2285 (No. of trucks arriving in restriction * average occupancy of truck drivers). Total cost of delay due to restricting trucks = ₹ 19, 99, 200.

Whereas, cost of congestion due to heavy vehicles entering, avg delay time = 3.2 min (during restriction), VOT = ₹75 per capita per hour, total people affected = 35969. Total Cost of delay due to congestion = ₹1, 43, 876.

CHAPTER 5: CONCLUSIONS

The observation regarding the cost-benefit analysis of restricting freight transport against the backdrop of time delays unveils a complex interplay of factors that demand careful consideration in urban logistics management. This analysis underscores the delicate balance between regulatory measures aimed at curbing the influx of freight vehicles and the imperative to maintain an efficient and unhindered flow of goods within urban centres. While the depreciation in the Level of Service (LOS) due to such restrictions may seem relatively modest at around 10%, the financial implications of time delays present a compelling argument against stringent measures.

Indeed, the stark revelation that the monetary losses incurred solely from the additional expenses borne by drivers due to time delays exceed thirteen times the costs associated with freight restrictions underscores the economic imperative of ensuring smooth logistical operations. However, it is essential to recognize that the true cost of such restrictions extends beyond mere financial considerations. By incorporating a broader spectrum of parameters, including environmental impact, fuel costs, accident expenses, and other externalities, into the cost analysis, a more comprehensive understanding of the implications of freight restrictions can be achieved.

The findings of (Qingyu, Zhicai, Baofeng, & Hongfei, 2007) advocate for a holistic approach to assessing the costs of freight restrictions, thereby illuminating the multifaceted nature of urban logistics management. By accounting for these diverse factors, policymakers gain valuable insights into the true cost-benefit dynamics of regulatory interventions in freight transport.

Moreover, the context of Indore as a pivotal hub for the exchange of goods further accentuates the significance of proactive policy measures. With the city witnessing a surge in demand for goods and services, driven by rapid urbanization and economic growth, the need for strategic interventions to manage freight transport becomes increasingly pressing. In this regard, the delineation of a robust policy framework is paramount.

Such a framework should encompass a spectrum of measures aimed at optimizing freight flows while minimizing disruptions to the urban ecosystem. This includes strategies to regulate the influx of heavy vehicles into the city, enhance warehouse capacities to accommodate growing inventory levels, develop infrastructure for way-side amenities to facilitate efficient rest and refuelling for drivers, and promote the availability of smaller fleets for intra-city distribution.

By implementing these policy interventions, Indore can not only meet the burgeoning demand for freight transport but also alleviate supply chain delays and enhance overall urban liveability. Furthermore, the development of a successful policy framework has the potential to serve as a model for other cities grappling with similar challenges. Through knowledge sharing and collaborative learning, cities can leverage best practices and innovative solutions to optimize their logistical operations and foster sustainable urban development.

In essence, the discourse surrounding freight transport restrictions transcends mere economic considerations to encompass broader imperatives of environmental sustainability, urban liveability, and economic resilience. By adopting a holistic approach that integrates diverse perspectives and embraces innovative solutions, cities like Indore can chart a course towards a more efficient, equitable, and resilient urban future.

The proposal for establishing new Transport Nagar complexes in Indore presents a comprehensive solution to the city's traffic congestion issues, particularly along key corridors such as Bypass Road, Ujjain Road, and Dewas Road. These complexes are strategically positioned to serve as pivotal exchange points for vehicles, especially trucks, offering a range of amenities and services tailored to the needs of drivers and logistics operators. Each Transport Nagar complex will provide standardized facilities including potable water, sanitary facilities, driver accommodation, ample truck parking, convenience stores, automotive service centres, warehousing facilities, and additional amenities like rest areas and medical facilities. By offering these amenities, the complexes aim to not only alleviate traffic pressures but also enhance the well-being and convenience of drivers and passengers. Furthermore, the proposal emphasizes the importance of monitoring traffic data to effectively implement traffic restrictions and manage traffic flow. By analysing trends in traffic data, authorities can identify congestion hotspots and implement targeted measures such as lane closures, congestion pricing, and freight restrictions to mitigate traffic congestion and minimize economic losses to the city.

The development of freight corridors is also proposed to address challenges associated with the movement of both light and large freight vehicles. Special freight corridors with reserved carriageways for freight vehicles aim to streamline freight movement within the city, reducing delays, fuel consumption, and the probability of accidents. Additionally, shared goods drop-offs are suggested where right-of-way is not available, providing seamless loading and unloading facilities for local establishments while minimizing disturbance on the road. Intelligent Transportation Systems (ITS) are highlighted as a pivotal strategy for optimizing urban transportation. ITS modules can guide freight vehicles effectively, minimize the impact of freight traffic on urban roads, enforce regulations, and provide real-time traffic data for informed decision-making. Variable Messaging Systems (VMS) empower road users with real-time updates on traffic conditions, enhancing safety and efficiency.

The proposal also emphasizes the importance of an Integrated Warehousing System to address bottlenecks in goods transfer. Integrated warehouses linked via an application provide real-time information on warehouse availability, streamlining the booking process and improving operational efficiency. Automation, robotics, IoT, big data analytics, cloud computing, artificial intelligence, augmented reality, wearable technologies, and sustainability initiatives are highlighted as key components of an integrated warehouse, offering benefits such as streamlined inventory management, improved decision-making, and enhanced sustainability throughout the supply chain.

In summary, the proposal for establishing new Transport Nagar complexes, monitoring traffic data, developing freight corridors, implementing intelligent transportation systems, and integrating warehousing systems presents a comprehensive strategy to address traffic congestion and optimize logistics operations in Indore. By prioritizing driver welfare, operational efficiency, and sustainability, these initiatives aim to enhance the overall transportation infrastructure and contribute to the city's economic growth and development.

5.1 Establishing New Transport Nagar

The proposal aims to address the prevalent traffic congestion issues along key corridors in Indore by introducing multiple Transport Nagar complexes strategically positioned along these routes. These Transport Nagar hubs are envisioned as pivotal exchange points catering to the needs of vehicles, especially trucks, traversing the busy Bypass Road, Ujjain Road, and Dewas Road. In addition to alleviating traffic pressures, these complexes are designed to offer a suite of essential amenities and services crucial for the smooth functioning of transportation logistics.

Each Transport Nagar is slated to offer a standardized set of facilities tailored to the requirements of drivers and logistics operators. These amenities include:

- Provision of Potable Water: Ensuring access to clean and safe drinking water, essential for the well-being of drivers and passengers.

- Sanitary Facilities with Regular Upkeep: Maintaining hygienic restroom facilities through consistent cleaning and maintenance routines.

- Driver Accommodation: Providing dormitory-style lodgings capable of housing up to 200 drivers, complete with cooking provisions for self-prepared meals.

- Ample Truck Parking: Offering secure parking space for a minimum of 500 trucks, facilitating efficient vehicle storage and retrieval.

- Convenience Stores: Establishing on-site retail outlets stocked with household essentials, akin to compact grocery stores, for the convenience of drivers.

- Automotive Service Centers: Equipping workshops with a minimum of two truck service bays each, catering to repair and maintenance needs.

- Warehousing Facilities: Rentable warehouse spaces facilitating seamless goods transfer and storage, contributing to logistical efficiency.

- Additional Amenities: Incorporating supplementary services such as rest areas, medical facilities, and communication infrastructure to further support driver welfare

Moreover, these Transport Nagar complexes serve as vital waypoints during periods of traffic restrictions, effectively demarcating the onset of freight restrictions. To ensure future scalability and prevent overcrowding, these hubs are strategically positioned away from urban planning boundaries, allowing for potential expansion while maintaining operational efficiency. Overall, the proposed Transport Nagar complexes represent a comprehensive solution to Indore's traffic challenges, fostering enhanced logistics operations while prioritizing the welfare and convenience of drivers and passengers alike.

5.2 Monitoring Traffic Data

The traffic police department in integration with Indore Municipal Corporation and other stakeholders should monitor the trends of traffic data increase and the current data as per the latest CMP to provide a clearer picture of the latest traffic scenario in the city. This will help the traffic police department to implement traffic restrictions in a more effective manner. The inefficient implementation of restriction leads to economic loss to the city. There should be an upper cap on the influx of traffic movement, once the flow of traffic crosses the certain mark traffic management measures such as Lane Closures, Ramp Metering, Congestion Pricing, etc should be implemented along with some freight restriction instead of a complete ban on the freight vehicles.

Monitoring the traffic data will also help in identifying the potential road networks in Indore which are prone to accidents, the freight vehicles can be restricted only on those networks instead of the whole city.

5.3 Development of Freight Corridors

The freight traffic in Indore is of significant proportion. There are different challenges that area associated with the movement of the light freight vehicles such as increased load on the network, multiple bottlenecks due to loading and unloading points, erratic driving, etc. Identifying special freight corridors can solve both the problems, i.e. restriction on large vehicles and challenges related to smaller vehicles.

Where the ROW is available 7m of carriageway should be reserved exclusively for the movement of the freight vehicles in both directions, this will remove the hinderance caused to other modes of traffic. This will enable the freight vehicles to move freely inside the city, it will reduce the delay time caused due to congestion, it will reduce the excessive consumption of fuel, limit the probability of accident and reduce the overall logistics cost within the city.

Where the ROW is not available, goods drop-offs should be provided which are shared by multiple outlets. These drop-offs will make the loading and unloading process from the local establishment outlets seamless and reduce the disturbance on the road. The freight traffic can move amongst the normal traffic but will park in these goods drop-offs and load/unload the vehicle. These drop-offs should be large enough to accommodate full length lorry, i.e. 12m so that larger vehicles are also able to use the area. These drop-offs should be kept encroachment free in order to allow their functionality to prevail.

Ideal location in Indore for such drop-offs would be Chappan, Novelty Market Area, Vijaya Nagar Market, Rajwada, Saraffa Bazaar, etc. Whereas the carriageway reservation can be done on AB Road, Ujjain Road, Eastern Ring Road, etc.

5.4 Use of Intelligent Transportation System

Intelligent Transportation Systems (ITS) modules represent the pinnacle of modern technology in addressing the multifaceted challenges of urban transportation. In cities like Indore, where burgeoning populations and rapid urbanization strain existing infrastructure, the deployment of ITS modules emerges as a pivotal strategy to mitigate congestion, enhance safety, and optimize freight management.

At the heart of ITS lies its ability to provide real-time data and actionable insights to both users and administrators. This real-time data forms the backbone of advanced traffic management systems, facilitating informed decision-making and dynamic response to changing conditions on the road. In Indore, where traffic congestion is a prevalent issue exacerbated by the city's rapid growth, the importance of such dynamic traffic management cannot be overstated.

One of the primary roles of ITS modules in Indore is to guide freight vehicles effectively, particularly at the city's periphery. By strategically placing modules at key entry points, freight vehicles can be directed towards designated routes and freight hubs, such as the Transport Nagar complex. This not only streamlines the movement of goods but also minimizes the impact of freight traffic on urban roads, reducing congestion and enhancing overall traffic flow. Moreover, ITS modules serve as enforcement tools to ensure compliance with regulations governing freight movement. Through advanced sensor technologies and automated monitoring systems, these modules can identify violations, such as unauthorized entry into restricted areas or non-compliance with weight restrictions. By issuing fines and penalties to violators, ITS modules incentivize adherence to regulations, thereby promoting safer and more efficient freight operations.

In the realm of traffic management, ITS modules offer unparalleled capabilities in monitoring and controlling traffic flow throughout the city. Real-time data on traffic conditions, obtained through sensors, cameras, and other monitoring devices, enables administrators to identify congestion hotspots and implement targeted interventions, such as adjusting signal timings or deploying temporary traffic controls. This dynamic approach to traffic management not only alleviates congestion but also enhances safety by reducing the likelihood of accidents and incidents on the road. Additionally, ITS modules play a vital role in disseminating information to road users, including both drivers and pedestrians. Variable Messaging Systems (VMS), equipped with dynamic displays, provide real-time updates on traffic conditions, road closures, and other relevant information, empowering users to make informed decisions about their travel routes and modes of transportation. This proactive communication fosters a culture of awareness and collaboration among road users, contributing to a safer and more efficient transportation environment.

5.5 Integrated Warehousing System

From the primary survey it was found that the absence of warehouse was at one of the root causes which created the bottlenecks in the transfer of goods to smaller modes. The warehouse in the Transport Nagar would not accommodate other transporter company's goods, this forced the truck drivers to either load/ unload on the road or to keep the goods in the truck and wait for the restriction. The larger group from the surveyed individual was waiting for the restriction to get over.

To solve this issue Integrated Warehouses should be introduced in the old and new Transport Nagar Complexes. These warehouses will be linked via an application which can be accessed by the freight operators. It will show in real-time, which warehouses are empty, which are being loaded and which are being unloaded. The emptied warehouses or warehouses to-be emptied can be booked via application which will save the time for finding the warehouses. These warehouses will have hourly rent starting from the time of booking and will be able to terminate once the loading/ unloading process is completed. An Integrated Warehousing System provides following benefits:

1. **Automation and Robotics**: Integrated warehouses heavily utilize automation and robotics to streamline various processes, such as inventory management, order picking, and packing. Automated guided vehicles (AGVs) and robotic arms work collaboratively to transport goods within the warehouse, minimizing manual intervention and reducing operational costs.
2. **Warehouse Management Systems (WMS)**: At the core of an integrated warehouse is a sophisticated Warehouse Management System (WMS). This software orchestrates all warehouse activities, including receiving, storage, picking, packing, and shipping. It optimizes inventory allocation, tracks stock levels in real-time, and provides insights for better decision-making.
3. **Internet of Things (IoT)**: IoT devices are strategically deployed throughout the warehouse to collect and transmit data about various parameters, such as temperature, humidity, and asset location. These sensors enable proactive monitoring, preventive maintenance, and optimization of resource utilization within the warehouse environment.

4. **Big Data and Analytics**: Integrated warehouses harness big data and analytics to derive actionable insights from the vast amount of data generated by warehouse operations. Predictive analytics algorithms anticipate demand patterns, optimize inventory levels, and identify areas for process improvement, leading to better decision-making and resource allocation.
5. **Cloud Computing**: Cloud-based platforms play a crucial role in enabling real-time connectivity and data sharing across different warehouse functions and locations. Cloud-based WMS solutions offer scalability, flexibility, and accessibility, allowing warehouse managers to access critical information from anywhere, at any time.
6. **Artificial Intelligence (AI)**: AI technologies, such as machine learning algorithms and natural language processing, are increasingly integrated into warehouse operations to automate repetitive tasks, optimize routes for order picking, and enhance demand forecasting accuracy. AI-powered chatbots provide responsive customer service and support to warehouse personnel.
7. **Augmented Reality (AR) and Wearable Technologies**: AR glasses and wearable devices equip warehouse workers with hands-free access to important information, such as picking instructions, inventory levels, and navigation guidance. This improves worker efficiency, reduces errors, and enhances safety by providing real-time alerts and warnings.
8. **Supply Chain Integration**: Integrated warehouses are seamlessly connected to broader supply chain networks, enabling end-to-end visibility and collaboration with suppliers, manufacturers, distributors, and retailers. Real-time data exchange facilitates agile responses to market changes, reduces lead times, and enhances overall supply chain resilience.
9. **Sustainability Initiatives**: Integrated warehouses incorporate sustainability initiatives, such as energy-efficient lighting systems, eco-friendly packaging materials, and optimized transportation routes, to minimize environmental impact and promote sustainable practices throughout the supply chain.

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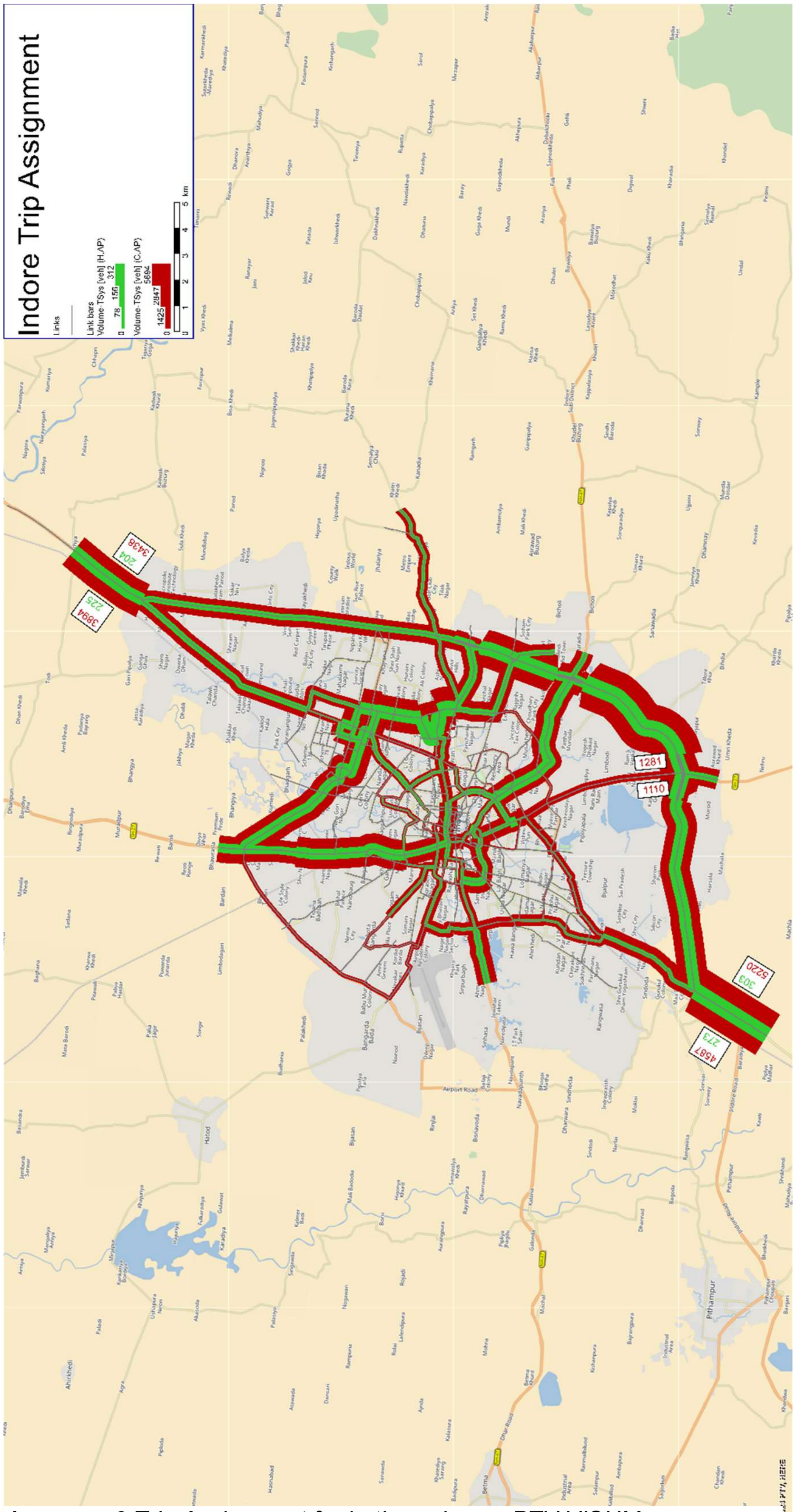
ANNEXURES

School of Planning and Architecture, Bhopal		Urban Freight Regulation Stakeholders Survey: Truck Drivers					Department of Transport Planning (Transport Planning & Logistics Management)		
Date/ Time -									
S. No.	**Questions**	**Results**							
1	Currently, how much is the No Entry Challan ?			Delay in entry		Delay in loading/unloading		Delay after exiting the city	
2	What are the problems faced by the No Entry regulation ?								
3	How much are you willing to pay to violate No Entry ?	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	₹150 - ₹200	₹200-₹250	₹250-₹300	>₹300
4	What wayside amenities are available ? Willingness to Pay for these facilities ?	Clean Washrooms & Drinking Water		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
		Dormitories, Self Laundary/Cooking		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
		Auto Workshops		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
		Truck User Zone & Parking		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
		Warehousing & Logistics Facility		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
		Fuel Stations		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
		Food Court Dhaba		Y/N ☐	<₹10	₹10 - ₹50	₹50 - ₹100	₹100 - ₹150	>150
5	If above mentioned amenities are provided, will it be more favourable for you to wait outside ?						Y/N ☐		
This survey is conducted solely as a part of academic exercise. The contents of the survey and all data extracted from it shall not be used otherwise.									

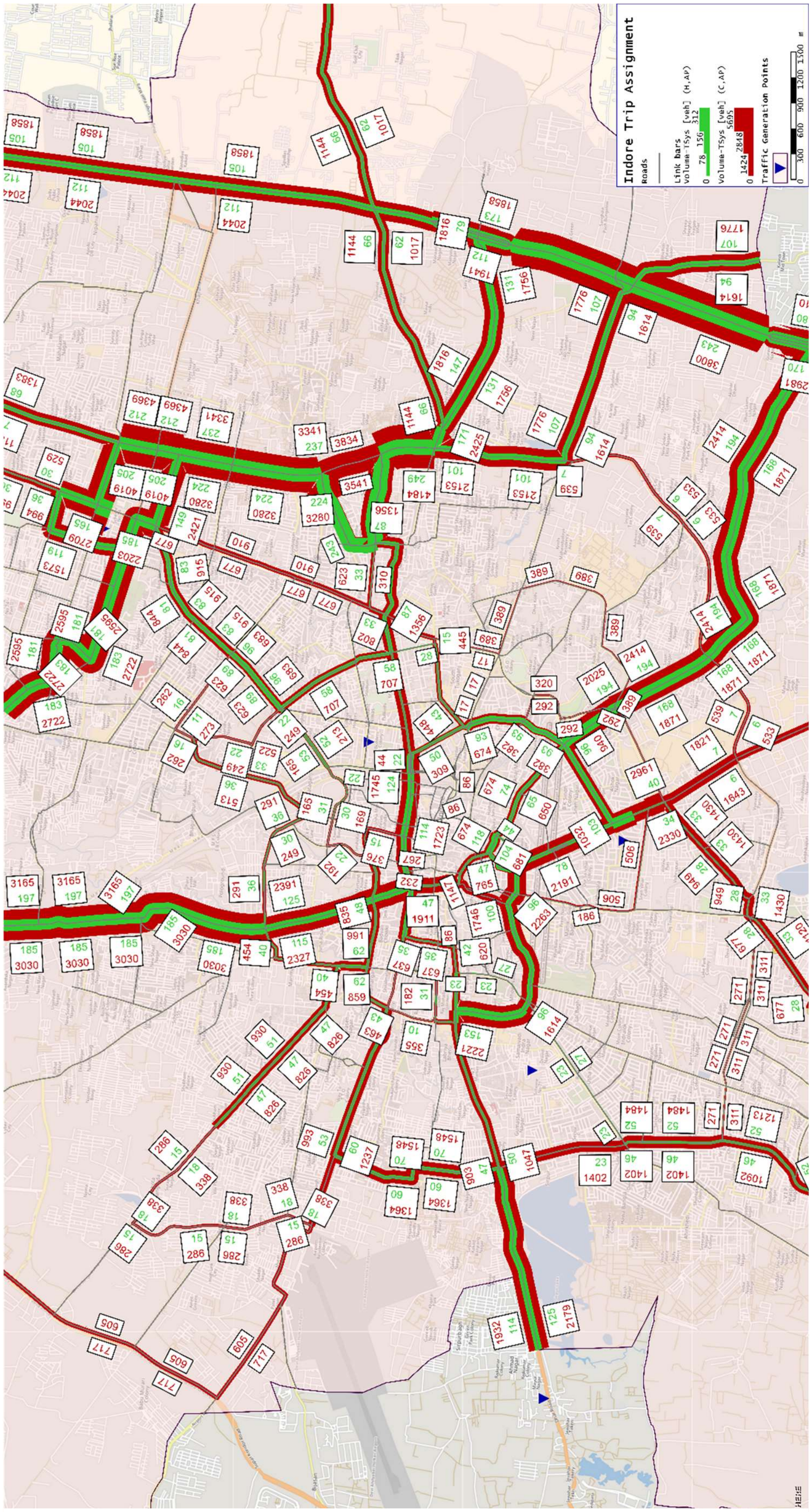
Annexure 1 Survey Format for Primary Survey

O/D	10	20	30	40	50	60	70	80	90	100	110	120	130
10	1983	4558	1855	3133	878	3416	3547	5284	1708	2837	1092	4256	2837
20	5201	6810	3593	6070	1702	6619	6606	9844	3309	5285	2035	7928	5285
30	2116	3593	1127	2470	692	2693	2688	4005	1346	2150	828	3225	2150
40	3575	6070	2470	3218	1170	4550	4541	6766	2275	3633	1399	5449	3633
50	1002	1702	692	1170	253	1276	1273	1897	638	1019	392	1528	1019
60	3898	6619	2693	4550	1276	3825	4951	7377	2480	3961	1525	5942	3961
70	4817	8181	3328	5623	1577	6131	4379	6525	3066	3504	1349	5255	3504
80	7178	12189	4959	8379	2349	9135	6525	9723	4568	5220	2010	7830	5220
90	1949	3309	1346	2275	638	2480	2476	3689	956	1981	763	2971	1981
100	3854	6545	2663	4499	1261	4905	3504	5220	2452	2803	1079	4204	2803
110	1484	2520	1025	1732	486	1888	1349	2010	944	1079	415	1619	1079
120	5781	9817	3994	6748	1892	7357	5255	7830	3679	4204	1619	6306	4204
130	3854	6545	2663	4499	1261	4905	3504	5220	2452	2803	1079	4204	2803

Annexure 2 Origin Destination Data Matrix used to generate the Trip Assignments



Annexure 3 Trip Assignment for both modes on PTV VISUM



Annexure 4 Trip Assignment for both modes with their traffic volume data