IMPACT OF TRANSPORTATION DEMAND MANAGEMENT STRATEGIES – A CASE STUDY OF ODD-EVEN POLICY IN DELHI, INDIA

RANJANA SONI

TRANSPORTATION RESEARCH AND INJURY PREVENTION CENTRE
INDIAN INSTITUTE OF TECHNOLOGY DELHI
JULY 2025

Impact of Transportation Demand Management Strategies–A Case Study of Odd-Even Policy in Delhi, India

by

Ranjana Soni

Transportation Research and Injury Prevention Centre (TRIPC)

Submitted

In fulfillment of the requirement of the Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2025

Dedicated to

Mrs. Vipan Arora (My mother in heaven)

whose love, values, and blessings continue to inspire me every day

With sincere appreciation for

Prof. Geetam Tiwari (My supervisor)

for her invaluable guidance, constant encouragement, and belief in me

I owe special thanks to

Mr. K.K. Arora *(My father)*

(for always being my guiding light and constant source of strength)

Mr. Krishan Soni*(My husband)*

and

Hrisheek *and* ***Akshaj*** *(My lovely kids)*

(Your unwavering support and encouragement made this journey possible)

Certificate

This is to certify the thesis entitled "**Impact of Transportation Demand Management Strategies on Pollution, Congestion, and Mobility –A Case Study of Odd-Even Policy in Delhi, India**" being submitted by **Ms. Ranjana Soni** to the Indian Institute of Technology Delhi, India, for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of original bonafide research work carried out by her. Ms. Ranjana Soni has worked under our guidance and supervision. To our knowledge, the thesis has reached the requisite standard. The material in this thesis has not been submitted, in part or in whole, to any other University or Institute for the award of any degree or diploma.

Prof. Geetam Tiwari
Professor (Emeritus)
Transportation Research and Injury Prevention Centre (TRIPC),
Indian Institute of Technology,
New Delhi, India

Dr. Manoj M
(Professor)
Department of Civil Engineering,
Indian Institute of Technology,
New Delhi, India

Acknowledgement

I consider myself truly fortunate to have had the opportunity to pursue PhD at TRIPC after a long sabbatical. I am deeply grateful to Almighty and the universe for guiding me towards such an enriching academic journey that blessed me with the most supportive supervisors and an institute of great repute.

I am grateful to my supervisor, **Prof. Geetam Tiwari,** for her guidance, dedication, constant encouragement, and immense patience throughout my PhD journey. Her support and belief in my abilities helped me navigate some of the challenging phases of this academic pursuit. I remain deeply indebted to her for her motivation and mentorship during my tenure at IIT Delhi. Working under her supervision has been an enriching and transformative learning experience.

I am grateful to my second supervisor, **Prof. Manoj M,** for his consistent guidance, valuable time, and insightful feedback, which enriched my doctoral journey. His observations and suggestions were instrumental in shaping the direction and clarity of my research.

This study is a part of the project under the "Woman Scientist Scheme (WOS-A)" funded by the Department of Science and Technology (DST) under the Ministry of Science and Technology, New Delhi. I would like to extend my gratitude to **DST** for providing the opportunity and support to undertake this research.

I would also like to express my sincere thanks to all the faculty members of TRIPC and the Department of Civil Engineering, whose valuable feedback, particularly during progress presentations, played a vital role in improving the quality of my research. I am grateful to my SRC members, **Prof. Puneet Mahajan, Prof. Nomesh Bolia**, and **Prof. Gazala Habib** for their thoughtful inputs and suggestions, which helped me move forward in my work.

This thesis would not have been possible without the support and encouragement of my colleagues and well-wishers. I am thankful to **Deotima** for her guidance, **Neba** for helping me with formatting. I also made many good friends during my tenure at IIT. Heartfelt thanks to

Aishwarya, Rashmeet, Srishti, Asha, Akanksha, **Preeti, Ashley, Richa and Ruchi** for their support and chit chats. I am indebted to **Mr. Mahesh Gaur** who always rendered a helping hand whenever I needed. I am thankful to **Ms. Hema** for being with me as a supportive friend through thick and thin. I express gratitude to **Ms. Suman** for readily offering help whenever I needed. I truly appreciate everyone's patience, encouragement, and cooperation throughout my journey at IIT. I am also thankful to all the helping staff of IIT who made sure that we worked on a clean desk and a clean room.

My special thanks to **Mr. Hari Chand** for taking care of the smallest things. Special thanks to all the students who contributed to the data extraction process, whose efforts were integral to the completion of this work. I would like to extend my thanks to **Mr. Ashok Srinivasan**, who is always a pleasure to talk to in our department.

This journey would not have been possible without the unwavering love and support of my family. I am deeply indebted to my **mother** and **father** for always believing in me and standing by me throughout my life. My mother would proudly tell everyone that her daughter was pursuing a PhD from IIT Delhi. I am sure she is watching from heaven, smiling at this accomplishment. I am thankful to my father for instilling in me the perseverance to keep going despite the odds. It is he who taught me the value of resilience, hard work, and integrity. I am also thankful to my father for reading my thesis and sharing his feedback which helped me improve my work.

I am grateful to my husband, **Mr. Krishan Soni,** for his constant support and patience throughout this journey. His cooperation in sharing the responsibilities at home and with the children made this journey much smoother and balanced. In fact, it was he who planted this thought of pursuing PhD in my mind many years back. I also extend my thanks to my **in-laws (Mr. Mehar Chand Soni and Mrs. Sunita Soni)** for their help at home. Their contributions behind the scenes played an important role in helping me navigate the demands of both

academic and family life. I am thankful to my dear brother, **Mr. Ashish Arora,** for his unwavering encouragement and faith in my abilities. He has always been my pillar of strength.

This journey would not have been possible without the support of my two little champs, **Hrisheek** and **Akshaj**, who grew up alongside my PhD. I cherish their sweet contributions in the little ways they could help their mother fulfil her dream. Watching them become independent and responsible during these years has been one of the most rewarding parts of this journey.

Finally, I am thankful to my friends and other close family members who, in their own meaningful ways, contributed to the successful completion of this journey.

Last but not least, I would like to acknowledge **myself** for having the courage to return to academics after a long break, for not giving up despite the challenges, and for truly embracing this enriching journey at IIT Delhi!

Ranjana Soni
(July 2025)

Abstract

The reliance on motorized vehicles and inadequate infrastructure planning has led to a significant increase in congestion and pollution levels. Conventionally, the transportation planners predicted transport growth trends based on demographic changes and provided road facilities to match this growth. However, the traditional "predict and provide" approach could not cater to the present situation's needs. The need arose for better transport system management, after which the "Transport Demand Management (TDM)" was introduced. Therefore, the alternative solution to supply was to manage the travel demand and induce a behavioural change in commuters by introducing some policies. The impact of TDM strategies affected a small portion of total travel, but their cumulative impacts were found to be significant. Some of the TDM policies implemented worldwide are Congestion charging, car-free day, and the odd-even policy. The odd-even policy was implemented in the National Capital Territory (NCT) of Delhi thrice, each time between 8 am and 8 pm: January 2016 (phase I), April 2016 (phase II), and 4^{th} to 15^{th} of November 2019 (phase III). The scheme was introduced under stage 4 of GRAP (Graded Response Action Plan), an incremental emergency measure that kicks in to prevent further deterioration of air quality. Under this policy, odd-numbered cars drive on odd dates, and even-numbered cars drive on even dates of the month. Some of the exemptions announced during the policy were motorized two-wheelers (M2W), vehicles of the President and Prime Minister, emergency vehicles, vehicles carrying school children, women traveling alone, and electric cars, equalling twenty-nine categories.

This thesis evaluated the effectiveness of the odd-even policy implemented in the NCT of Delhi, focusing on its impact on traffic volume, commuter behaviour, congestion, and pollution levels. The study examined variations in traffic volume, speeds, and car occupancy rates between the policy and non-policy periods. It analyzed mode and route shifts among commuters and explored the changes in the daily travel behaviour in the short and long-term. The second choice of public transport commuters was also interpreted. Most of the metro users

chose M2W as their second mode choice, and bus users chose the metro as their second mode choice. Comparisons between policy and non-policy days provided insights into the policy's role in altering travel patterns. The study also aimed to assess the policy's influence on reducing pollution and congestion. Additionally, it analyzed the implications of the policy on observed changes in pollution levels in Delhi and surrounding cities, where the policy was not applicable.

Data for this study was collected using both primary surveys and extracted from secondary sources for the policy and non-policy periods. Traffic volume data was obtained through observational counts and videography at ten locations in Delhi. Car occupancy data was collected in 15-minute intervals at the same locations during morning, afternoon, and evening peak hours. Speed data was extracted using the Google API for 39 origin-destination pairs, every 30 minutes. The travel behaviour data was collected, firstly through an online survey, secondly through a road car survey, and thirdly on-board metro and bus commuters. Pollution data were extracted from the Central Pollution Control Board (CPCB) archives for the pollutants. $PM_{2.5}$ and PM_{10}, SO_2 and NO_2. The data about the meteorological parameters' temperature, wind direction, wind speed, and humidity were also extracted from CPCB. This data was extracted for Delhi and nearby cities: Sonipat, Noida, Gurugram, Ghaziabad, and Rohtak. The data analysis was done using descriptive, statistical analysis, and the development of models.

The results showed that the policy led to a reduction in the total traffic volume. Car usage decreased across all locations, which aligned with the policy's aim to reduce reliance on private vehicles. An increase in M2W was observed across all locations, indicating a modal shift. The impact on the other modes was mixed, indicating an increase and a decrease across locations. The policy had a limited effect on improving vehicular speeds between policy and non-policy areas. Speeds were higher on longer road segments, intercity roads and slower on short length roads. The car occupancy rates did not improve during the policy period. Location-

wise, the car occupancy rates showed variations. The online survey showed that 41 % of the commuters shifted their modes. The car commuters survey observed that most of the commuters shifted to the metro during the restricted days of their car. The commuters stated a potential shift towards public transport if the policy were to continue in the long run. The policy did not have much impact on route shifts, with most car commuters maintaining their usual travel routes. The travel distance remained the same for men, but their travel time and cost increased. The policy contributed to a temporary reduction in emissions due to decreased car usage. $PM_{2.5}$ and PM_{10} reduced in the during and the after period, and SO_2 and NO_2 did not show much change. The impact of the policy on pollution, considering neighbouring cities, showed that pollution between Delhi and nearby cities changed during different policy periods, and meteorological factors could have had an impact. The congestion reduced at some locations during the policy period. In summary, the thesis indicated a mixed impact of the odd-even policy. The insights from the thesis could inform policymakers in refining existing policies for future implementation.

सारांश

मोटर चालित वाहनों पर बढ़ती निर्भरता और अपर्याप्त बुनियादी ढांचे की योजना ने जाम और प्रदूषण के स्तर में उल्लेखनीय वृद्धि की है। पारंपरिक रूप से, परिवहन योजनाकार "पूर्वानुमान और उपलब्धता" दृष्टिकोण अपनाते थे—जिसमें जनसंख्या संबंधी रुझानों के आधार पर परिवहन की मांग का अनुमान लगाकर सड़क अवसंरचना का विस्तार किया जाता था। हालांकि, यह तरीका वर्तमान शहरी परिवहन समस्याओं से निपटने में अपर्याप्त साबित हुआ है। इसके परिणामस्वरूप ध्यान परिवहन मांग प्रबंधन की ओर गया, जिसका उद्देश्य केवल आपूर्ति बढ़ाने के बजाय यात्रा की मांग को नियंत्रित करना है। रणनीतियाँ यात्रियों के व्यवहार में परिवर्तन लाने के लिए विभिन्न नीतियों के माध्यम से उन्हें अधिक कुशल और सतत यात्रा विकल्प अपनाने के लिए प्रेरित करती हैं। यात्रा की कुल मात्रा में परिवहन मांग प्रबंधन रणनीतियों का प्रभाव सीमित हिस्से पर ही पड़ा, लेकिन इन रणनीतियों का संचयी प्रभाव महत्वपूर्ण पाया गया। दुनिया भर में लागू की गई कुछ नीतियों में कंजेशन चार्जिंग, कार-फ्री डे और ऑड-ईवन नीति शामिल हैं। ऑड-ईवन नीति राष्ट्रीय राजधानी क्षेत्र दिल्ली में तीन बार लागू की गई—हर बार सुबह 8 बजे से रात 8 बजे तक: जनवरी 2016 (चरण I), अप्रैल 2016 (चरण II), और 4 से 15 नवंबर 2019 (चरण III)। यह योजना ग्रेडेड रिस्पांस एक्शन प्लान के चरण 4 के तहत शुरू की गई थी, जो वायु गुणवत्ता के और अधिक बिगड़ने से रोकने के लिए अपनाया जाने वाला एक क्रमिक आपातकालीन उपाय है। इस नीति के तहत, विषम नंबर वाली कारें महीने की विषम तिथियों पर चलती हैं, और सम नंबर वाली कारें सम तिथियों पर चलती हैं। इस नीति के दौरान कुछ श्रेणियों को छूट दी गई थी, जैसे मोटर चालित दोपहिया वाहन, राष्ट्रपति और प्रधानमंत्री के वाहन, आपातकालीन सेवाओं के वाहन, स्कूल बच्चों को ले जाने वाले वाहन, अकेली यात्रा कर रही महिलाएं, और इलेक्ट्रिक वाहन। कुल मिलाकर, ऐसी छूट वाली श्रेणियों की संख्या उनतीस (29) थी।

इस शोध में राष्ट्रीय राजधानी क्षेत्र दिल्ली में लागू की गई ऑड-ईवन नीति की प्रभावशीलता का मूल्यांकन किया गया, जिसमें इसका प्रभाव यातायात की मात्रा, यात्रियों के व्यवहार, जाम की स्थिति और

प्रदूषण स्तर पर केंद्रित रहा। अध्ययन में नीति और गैर-नीति अवधि के बीच यातायात की मात्रा, गति और कार में सवारियों की संख्या में होने वाले बदलावों का विश्लेषण किया गया। इसमें यात्रियों के यात्रा साधनों और मार्गों में हुए परिवर्तनों के साथ-साथ उनकी दैनिक यात्रा आदतों में अल्पकालिक और दीर्घकालिक बदलावों की भी जांच की गई। सार्वजनिक परिवहन उपयोगकर्ताओं की द्वितीयक यात्रा विकल्पों की भी व्याख्या की गई। अधिकांश मेट्रो यात्रियों ने (मोटर चालित दोपहिया वाहन) को अपना दूसरा विकल्प चुना, जबकि बस यात्रियों ने मेट्रो को अपना दूसरा विकल्प चुना। नीति और गैर-नीति दिनों की तुलना ने यात्रा व्यवहार में नीति के प्रभाव को समझने में महत्वपूर्ण अंतर्दृष्टि प्रदान की। इस अध्ययन का एक उद्देश्य प्रदूषण और जाम की स्थिति में कमी लाने में नीति के प्रभाव का मूल्यांकन करना भी था। इसके अतिरिक्त, यह अध्ययन दिल्ली और आस-पास के शहरों में प्रदूषण स्तर में देखे गए बदलावों पर इस नीति के प्रभाव की भी जांच करता है, जहाँ यह नीति लागू नहीं की गई थी। इस अध्ययन के लिए डेटा संग्रहण प्राथमिक सर्वेक्षणों और द्वितीयक स्रोतों से नीति और गैर-नीति अवधियों के लिए किया गया। यातायात की मात्रा का डेटा दिल्ली के दस स्थानों पर प्रत्यक्ष अवलोकन और वीडियोग्राफी के माध्यम से प्राप्त किया गया। कार में सवारियों की संख्या का डेटा इन्हीं स्थानों पर सुबह, दोपहर और शाम के पीक घंटों के दौरान 15-15 मिनट के अंतराल पर एकत्र किया गया। गति से संबंधित डेटा 39 ओरिजिन-डेस्टिनेशन जोड़ों के लिए हर 30 मिनट पर Google API के माध्यम से निकाला गया।यात्रा व्यवहार संबंधी डेटा तीन तरीकों से एकत्र किया गया: पहला, ऑनलाइन सर्वेक्षण के माध्यम से; दूसरा, सड़क पर कार सर्वेक्षण; और तीसरा, मेट्रो और बस यात्रियों से ऑन-बोर्ड सर्वेक्षण के माध्यम से।प्रदूषण से संबंधित डेटा केंद्रीय प्रदूषण नियंत्रण बोर्ड के अभिलेखों से निकाला गया, जिसमें $PM_{2.5}$, PM_{10}, SO_2 और NO_2 जैसे प्रदूषक शामिल थे। इसके साथ ही, तापमान, हवा की दिशा, हवा की गति और आर्द्रता जैसे मौसम से संबंधित मापदंड भी CPCB से लिए गए। यह डेटा दिल्ली सहित आस-पास के शहरों — सोनीपत, नोएडा, गुरुग्राम, गाज़ियाबाद और रोहतक — से एकत्र किया गया।डेटा विश्लेषण वर्णनात्मक, सांख्यिकीय तकनीकों और मॉडल विकास की सहायता से किया गया।

परिणामों से पता चला कि नीति के लागू होने के बाद कुल यातायात मात्रा में कमी आई। सभी स्थानों पर निजी कारों का उपयोग घटा, जो नीति के उद्देश्य — निजी वाहनों पर निर्भरता कम करने — के अनुरूप था। सभी स्थानों पर मोटर चालित दोपहिया वाहनों में वृद्धि देखी गई, जो एक मोडल शिफ्ट (यात्रा साधन में बदलाव) का संकेत है। अन्य यात्रा साधनों पर प्रभाव मिला-जुला रहा, कुछ स्थानों पर वृद्धि तो कुछ पर कमी देखी गई।वाहन गति में नीति और गैर-नीति अवधि के बीच सुधार सीमित था। लंबी सड़क खंडों और अंतर-शहरी सड़कों पर गति अधिक रही, जबकि छोटी सड़कों पर गति धीमी रही। कार में सवारी दर नीति अवधि में नहीं बढ़ी, और यह स्थान-विशेष पर भिन्न रही।ऑनलाइन सर्वेक्षण से पता चला कि 41% यात्रियों ने अपना यात्रा साधन बदला। कार यात्रियों के सर्वेक्षण में पाया गया कि अधिकांश यात्रियों ने प्रतिबंधित दिनों में मेट्रो को अपनाया। कई यात्रियों ने कहा कि यदि नीति लंबे समय तक जारी रहती, तो वे सार्वजनिक परिवहन की ओर स्थायी रूप से स्थानांतरित हो सकते थे।

मार्ग परिवर्तन पर नीति का प्रभाव सीमित रहा, क्योंकि अधिकांश कार उपयोगकर्ताओं ने अपने सामान्य मार्गों को बरकरार रखा। पुरुष यात्रियों की यात्रा दूरी तो समान रही, परंतु यात्रा समय और लागत में वृद्धि हुई। नीति के चलते कार उपयोग में आई कमी के कारण उत्सर्जन में अस्थायी गिरावट दर्ज की गई।$PM_{2.5}$और PM_{10}के स्तर नीति के दौरान और बाद की अवधि में घटे, जबकि SO_2और NO_2में कोई विशेष बदलाव नहीं देखा गया। दिल्ली और उसके आस-पास के शहरों में नीति के दौरान प्रदूषण स्तर में बदलाव आया, जिसमें मौसमी कारकों की भूमिका हो सकती है। कुछ स्थानों पर नीति अवधि के दौरान भीड़भाड़ में कमी देखी गई।कुल मिलाकर, इस शोध में नीति का मिला-जुला प्रभाव सामने आया। हालांकि, इस शोध से प्राप्त अंतर्दृष्टियाँ भविष्य में नीति निर्माण और सुधार में नीति-निर्माताओं के लिए उपयोगी सिद्ध हो सकती हैं।

Contents

List of Figures

List of Tables

List of Abbreviations

AP	After Policy
ACO	Average car occupancy
AIC	Akaike information criterion
ANOVA	Analysis of Variance
API	Application Programming Interface.
AQI	Air Quality Index
Arc GIS	Arc Geographical Information System
ASCE	American Society of Civil Engineers
AT	Ambient Temperature
ATL	Average Trip Length
AV	Anand Vihar
BP	Before Policy
Con	Congested
CBD	Central Business District
CNG	Compressed Natural Gas
CO	Carbon monoxide
CPCB	Central Pollution Control Board
CRRI	Central Road Research Institute
CSV	Comma-separated values
CV	Commercial System
DP	During policy
Dec	Decrease in Volume
dof	Degree of freedom
DIMTS	Delhi Integrated Multi-Modal Transit System Limited
DTC	Delhi Transport Corporation
ERP	Electronic road pricing
FFPT	Free Fare Public Transport
FHWA	Federal Highway Administration
GRAP	Graded Response Action Plan
H_0	Null hypothesis

H_a	Alternative hypothesis
HCV	Heavy commercial vehicle HCV
HOV priority	Highway Occupancy Vehicles
Inc	Increase in Volume
IBTDM	Incentive-Based Traffic Demand Management
INR	Indian Rupees
IQR	Inter Quartile Range
JS	Jia Sarai
LCV	Light commercial vehicles LCV
LL_NP	Long length during non-policy
LL_P	Long Length during policy
LPRC	License Plate Restriction Charging
M2W	Motorized Two-Wheeler
M3W	Motorized Three-Wheeler
ML_NP	Medium length during non-policy
ML_P	Medium length during policy
MLAs	Member of Legislative Assembly
MNL	Multinomial Logistic Regression
NAMP	National Air Quality Monitoring Programme
Nagelkerke R2	Pseudo R-squared
NC	Non-congested
NCR	National Capital Region
NCT	National Capital Territory
NH	National Highway
NMT	Non-motorized transport
NO	Nitric oxide
NOx	Nitrogen oxides NOx
NP	Non-policy
O_3	Ozone
OD	Origin-Destination
ODPW	One day per week
OED	Odd even day
P	Policy

$PM_{2.5}$	Particulate Matter with PM below 2.5µm
PM_{10}	Particulate Matter with PM below 10µm
PT	Public Transport
PCTR	Per Capita Trip Rate
RH	Relative Humidity
SD	Standard Deviation
SL_NP	Short length during non-policy
SL_P	Short length during policy
SOV	Single-occupant vehicles
SPI	Speed Reduction Index SRI
SRI	Speed Reduction Index SRI
STMS	Short-term Mode Shift
TDM	Transport demand system
TDMS	Transportation Demand Management Strategies
TSI	Transport sustainability indicators
TSM	Transportation system management
VIPs	Very Important Persons
VKT	Vehicle kilometers travelled
VS	Very smooth
VTPI	Victoria Transport Policy Institute
VVIPs	Very Important Person
WFH	Work from Home
WHO	World Health Organization
WD	Wind Direction
WS	Wind Speed
CO_2	Carbon Dioxide
NO_2	Nitrogen dioxide
SO_2	Sulfur dioxide
SBM	Sai Baba Mandir