

**HIGHER ORDER CONTINUUM  
MODELLING METHODOLOGY FOR  
NON-LANE BASED HETEROGENEOUS  
TRAFFIC ENVIRONMENT**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI  
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LANE BASED HETEROGENEOUS  
TRAFFIC ENVIRONMENT**

**by**

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# CERTIFICATE

This is to certify the thesis entitled “*Heterogeneous Continuum Modelling Methodology for Non-Lane Based Heterogeneous Traffic Environment*” being submitted by **Mr. Hari Krishna Gaddam** to the Indian Institute of Technology Delhi India, for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of original bona-fide research work carried out by him. Mr. Hari Krishna Gaddam has worked under my guidance and supervision. To the best of my knowledge, the thesis has reached the requisite standard. The material contained in this thesis has not been submitted, in part or in full to any other University or Institute for the award of any degree or diploma.

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**Hari Krishna Gaddam**

# ABSTRACT

A large number of studies have been carried out to represent the traffic flow on homogeneous car following traffic environment using macroscopic continuum models. These models are either phenomenological in nature or derived from car following theories. The main assumption behind these theories is that the vehicles strictly travel at the centre of the lane and they assign leadership fully to the front vehicle. The follower vehicle response strictly depends on relative distance and a relative speed between the leader and follower vehicles and lane changing is strictly prohibited. However, in developing countries such as India, vehicles do not follow lane discipline, and they always deviate from its centre- line positions. Moreover, each vehicle has multiple leaders ahead, and disruptive lane changing can also be observed. Further, complexity increases due to the presence of slow and fast moving vehicles and their wide range of physical and dynamical characteristics. Therefore continuum models developed from the lane based car following models will poorly represent the dynamics of non-lane heterogeneous traffic (NLHT) and cannot be applied directly. Even though few researchers attempted to model the traffic in NLHT environment, they are successful only to some extent. The drawbacks of the existing modelling methodologies such as: independent conservation of vehicle momentum of each vehicle class; absence of effect of vehicles off-centeredness; interaction between slow moving and fast moving vehicles motivated the present research. A comprehensive modelling methodology has been proposed to represent the traffic behaviour in non-lane based heterogeneous traffic environment.

As an initial step, the research focuses on evaluating existing single regime models using two criteria. One is fitting empirical speed-density data and the other is about properties of fundamental diagrams. Limitations of the existing speed-density models in satisfying all the

mathematical properties of fundamental diagrams encouraged us to develop new speed-density functional forms. The new speed-density functional form along with the developed conservation of momentum equation will be helped in predicting the traffic flow patterns in non-lane heterogeneous traffic stream more accurately.

An improved two-sided lateral gap car following theory and statistical inferences from field data are used in developing a new non-lane based heterogeneous continuum model. To capture the complex vehicular interactions, the proposed model considers class specific lateral separation distance factor, frictional clearance term and density dependent disturbance propagation speed which are absent in other non-lane continuum models. The lateral separation distance factor represents the overtaking behaviour of vehicles on both sides of the leader, frictional clearance term represents the effect of slow moving vehicles on traffic stream. The proposed model is able to replicate complex traffic phenomenon such as local clusters, phantom traffic jams and dissipation of queues etc. Further, the proposed model is effective in suppressing traffic jams even at high density conditions compared to other continuum models. Analytical results proved that new model improves the stability region of traffic flow thereby increases the throughput of traffic stream. The current research presented two classical and evolutionary optimization algorithms such as hybrid search and generalised pattern search to find model parameters for non-lane based heterogeneous traffic present on urban arterials in India. Performance of these algorithms have been compared with other commonly used global search algorithms such as genetic algorithm and simulated annealing. The robustness of proposed model in representing the real traffic behaviour is validated using traffic accident evaluation and platoon dispersion characteristics of vehicles. Finally, the proposed model is applied to evaluate the effect of alternative transport policy measures i.e. odd-even car rule. It is anticipated that the new model provides the basis for evaluating alternative transport policy measures and helps in analyzing the system performance in the future.

## सार

मैक्रोस्कोपिक सातत्य मॉडल का उपयोग करते हुए यातायात पर्यावरण के बाद सजातीय कार पर यातायात प्रवाह का प्रतिनिधित्व करने के लिए बड़ी संख्या में अध्ययन किए गए हैं। ये मॉडल या तो घटनात्मक हैं या सिद्धांतों का पालन करते हुए कार से निकले हैं। इन सिद्धांतों के पीछे मुख्य धारणा यह है कि वाहन लेन के केंद्र में सख्ती से यात्रा करते हैं और वे सामने वाले वाहन को पूरी तरह से नेतृत्व प्रदान करते हैं। अनुयायी वाहन की प्रतिक्रिया सख्ती से रिश्तेदार की दूरी पर निर्भर करती है और नेता और अनुयायी वाहनों और लेन बदलने के बीच एक रिश्तेदार गति को सख्त वर्जित है। हालांकि, भारत जैसे विकासशील देशों में, वाहन लेन अनुशासन का पालन नहीं करते हैं, और वे हमेशा इसकी केंद्र रेखा के पदों से विचलित होते हैं। इसके अलावा, प्रत्येक वाहन के आगे कई नेता होते हैं, और विघटनकारी लेन बदलने को भी देखा जा सकता है। इसके अलावा, धीमी और तेज गति से चलने वाले वाहनों की उपस्थिति और भौतिक और गतिशील विशेषताओं की उनकी विस्तृत श्रृंखला के कारण जटिलता बढ़ जाती है। इसलिए निरंतर मॉडल लेन आधारित कार से विकसित मॉडल निम्नलिखित मॉडल खराब लेन विषम यातायात (एनएलएचटी) की गतिशीलता का खराब प्रतिनिधित्व करेंगे और सीधे लागू नहीं किया जा सकता है। भले ही कुछ शोधकर्ताओं ने एनएलएचटी वातावरण में यातायात को मॉडल करने का प्रयास किया, लेकिन वे केवल कुछ हद तक सफल हैं। मौजूदा मॉडलिंग विधियों की कमियां जैसे: प्रत्येक वाहन वर्ग के

वाहन की गति का स्वतंत्र संरक्षण; ऑफ-सेंटेडनेस वाहनों के प्रभाव की अनुपस्थिति; धीमी गति से और तेजी से आगे बढ़ने वाले वाहनों के बीच बातचीत ने वर्तमान शोध को प्रेरित किया। गैर-लेन आधारित विषम यातायात वातावरण में यातायात व्यवहार का प्रतिनिधित्व करने के लिए एक व्यापक मॉडलिंग पद्धति का प्रस्ताव किया गया है।

प्रारंभिक चरण के रूप में, शोध दो मानदंडों का उपयोग करके मौजूदा एकल शासन मॉडल का मूल्यांकन करने पर केंद्रित है। एक अनुभवजन्य गति-घनत्व डेटा फिटिंग है और दूसरा मौलिक आरेख के गुणों के बारे में है। मौलिक आरेखों के सभी गणितीय गुणों को संतुष्ट करने में मौजूदा गति-घनत्व मॉडल की सीमाओं ने हमें नए गति-घनत्व कार्यात्मक रूपों को विकसित करने के लिए प्रोत्साहित किया। गति के समीकरण के विकसित संरक्षण के साथ नए गति-घनत्व कार्यात्मक रूप को गैर-लेन विषम यातायात धारा में ट्रैफिक प्रवाह पैटर्न की अधिक सटीक रूप से भविष्यवाणी करने में मदद मिलेगी।

एक बेहतर दो तरफा लेटरल गैप कार के बाद थ्योरी और स्टैटिस्टिकल इंफॉर्मेशन ऑफ द फील्ड डेटा का इस्तेमाल एक नए नॉन-लेन बेस्ड हेटेरोसिनस कंटीनम मॉडल को विकसित करने में किया जाता है। जटिल वाहनों की पारस्परिक क्रियाओं को पकड़ने के लिए, प्रस्तावित मॉडल वर्ग विशिष्ट पार्श्व पृथक्करण दूरी कारक, घर्षण निकासी अवधि और घनत्व निर्भर अशांति प्रसार गति पर विचार करता है जो अन्य गैर-लेन सातत्य मॉडल में अनुपस्थित हैं। पार्श्व पृथक्करण दूरी कारक नेता के दोनों तरफ वाहनों के ओवरटेकिंग व्यवहार का प्रतिनिधित्व करता है, घर्षण निकासी शब्द ट्रैफिक स्ट्रीम पर धीमी गति से चलने वाले वाहनों के

प्रभाव का प्रतिनिधित्व करता है। प्रस्तावित मॉडल जटिल ट्रैफ़िक घटना जैसे कि स्थानीय क्लस्टर, फ़ैटम ट्रैफ़िक जाम और कतारों के विघटन आदि को दोहराने में सक्षम है। इसके अलावा, प्रस्तावित मॉडल अन्य निरंतरता मॉडल की तुलना में उच्च घनत्व की स्थिति में भी ट्रैफ़िक जाम को दबाने में प्रभावी है। विश्लेषणात्मक परिणामों ने साबित किया कि नया मॉडल ट्रैफ़िक प्रवाह के स्थायित्व क्षेत्र में सुधार करता है जिससे ट्रैफ़िक स्ट्रीम का प्रवाह बढ़ता है। वर्तमान शोध ने भारत में शहरी धमनियों पर मौजूद गैर-लेन आधारित विषम यातायात के लिए मॉडल मापदंडों को खोजने के लिए हाइब्रिड खोज और सामान्यीकृत पैटर्न खोज जैसे दो शास्त्रीय और विकासवादी अनुकूलन एल्गोरिदम प्रस्तुत किए। इन एल्गोरिदम के प्रदर्शन की तुलना अन्य सामान्य रूप से उपयोग किए जाने वाले वैश्विक खोज एल्गोरिदम जैसे कि आनुवंशिक एल्गोरिथम और सिम्युलेटेड एनेलिंग के साथ की गई है। वास्तविक यातायात व्यवहार का प्रतिनिधित्व करने में प्रस्तावित मॉडल की मजबूती यातायात दुर्घटना मूल्यांकन और वाहनों के पलटन फैलाव विशेषताओं का उपयोग करके मान्य है। अंत में, प्रस्तावित मॉडल को वैकल्पिक परिवहन नीति के उपायों के प्रभाव का मूल्यांकन करने के लिए लागू किया जाता है अर्थात् विषम-सम कार नियम। यह अनुमान लगाया जाता है कि नया मॉडल वैकल्पिक परिवहन नीति उपायों के मूल्यांकन के लिए आधार प्रदान करता है और भविष्य में सिस्टम के प्रदर्शन का विश्लेषण करने में मदद करता है।

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## LIST OF NOTATIONS

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<b>Notation</b>	<b>Definition</b>
AO	Area Occupancy
AR	Aw and Rascle
ARE	Average relative error
BMW	Berg, Mason and Woods Model
CTM	Cell Transmission Model
CURE	Cumulative Residual
DE	Differential Algorithm
FD	Fundamental Diagram
GA	Genetic Algorithm
GPS	Generalized Pattern Search
GD	Gradient Descent
GKT	Gas-Kinetic Traffic flow
GNA	Gauss-Newton Algorithm
HS	Hybrid Search
HV	Heavy Vehicle
IOV	Improved Optimum Velocity
LCV	Light Commercial Vehicles
LH	Longitudinal Highways
LM	Levenberg-Marquardt
LP	Lateral Lane Position
LSD	Lateral Separation Distance
LWR	Lighthill-Whitham-Richards

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MTW	Motorised Two-Wheelers
MThW	Motorised Three-Wheelers
NLBCF	Non-lane based full velocity difference car following model
NLHT	Non-Lane based Heterogeneous Traffic
NLOPT	Non-Linear Optimization Library
NM	Nelder – Mead
OV	Optimum Velocity
OVM	Optimum Velocity model
PCE	Passenger Car Equivalency
PCU	Passenger Car Unit
PI	Performance Index
PW	Payne-Whitham
RMSE	Root Mean Square Error
SA	Simulated Annealing
SUV	Sports Utility Vehicle
TWU	Two wheeler units
$v_f$	Free flow speed
$k_j$	Jam density
$m$ and $n$	Shape parameters
$v_m$	Optimum speed
$\lambda$	Saturation flow parameter
$C_j$ and $c_0$	Kinematic wave speed of vehicles

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$E$ and $\theta$	Shape parameters
$v_b$	Average travel speed
$k_t$	Inflection point
$\theta_1$ and $\theta_2$	Scale parameter and lopsidedness of curve
$q, v$ and $k$	Flow, speed and density
$x$ and $t$	Space and time
$V_e$	Equilibrium speed
$P$	Traffic pressure
$\theta^e(k)$	Velocity variance
$\gamma$	Scaling factor
$\delta$	Lateral separation distance parameter at macroscopic level
$t_s$	Reaction time of vehicles at signals
$LS_{n, n+1}$	Lateral separation distance between vehicle n and vehicle n+1
$LS_{max}$	Maximum lateral separation distance
$\alpha$	sensitivity coefficient of a driver
$\kappa$	drivers response coefficient
$p_n$	Lateral separation distance parameter at microscopic level
$V_e(.)$	Equilibrium speed of vehicle

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$T$	Driver relaxation coefficient
$\tau$	Driver reactive coefficient
$x_n(t), v_n(t)$ and $a_n(t)$	Position (m), velocity (m/s) and acceleration (m/s <sup>2</sup> ) of the vehicle 'n' respectively
$\Delta x$	Longitudinal space headway
$\Delta v$	Speed difference
$\mu$	Friction factor

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