

**ESTABLISHING RELATIONSHIP BETWEEN
ELEMENTS OF HIGHWAYS ON FATAL
CRASHES ON NATIONAL HIGHWAYS
IN INDIA**

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by

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Submitted in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



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Dedicated to my family

CERTIFICATE

This is to certify that the thesis entitled “**Establishing Relationship between Elements of Highways on Fatal Crashes on National Highways in India**” submitted by **Mr. Hasan Mehdi Naqvi** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of original bonafide research work carried out by him under my supervision and guidance.

The thesis work 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 award of any degree or diploma.

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(Hasan Mehdi Naqvi)

ABSTRACT

National Highways (NHs) in India traverse the length and breadth of the country connecting national and state capitals, and so forth. NHs in India represent less than 2% (114,158 km) of total road length (5.89 million km as on March 2017), and carry almost 40% vehicular traffic. During the last one decade, numbers of NHs are upgraded from single- to two-lane, two- to four-lane and four- to six-lane by the concerned authorities. The improvement in road infrastructure with respect to increase in number of lanes, riding quality, and so on has helped to reduce travel time between cities, improved productivity of freight transport and so on. However, on the other side increase in traffic crashes (number of road fatalities on NHs are observed to be to the tune of 34-39% during 2000 to 2017) has partially nullified the positive impact of NHs development. The other motivation is due to lack of adequate research on highway safety for developing countries in general and specially in India. Some of the results of research studies on highway safety or road safety strategy adopted for developed (high-income) countries are less relevant owing to significant variation in local circumstances. Hence, there is an urgent need to study fatal crashes pattern on NHs to identify factors.

It is in this context, an attempt is made to identify factors contributing to fatal crashes for short-listed NHs through statistical techniques such as, logistic regression and generalized linear modeling. Three NHs having varying lanes configuration: two-lane paved shoulder NH-8, four-lane NH-24 and six-lane NH-1 are short-listed for in-depth study of fatal crashes for past 4-5 years. Total 1,534 fatal crash first information reports (FIRs) are collected from the respective police stations for three NHs, and are examined for the study.

Based on data analysis, fatal crashes/km/year is found to be highest (3.08) on six-lane NH-1, followed by 2.42 on four-lane NH-24, and 0.72 on two-lane NH-8. The distribution of victims' mode by striking vehicles in fatal crash shows that on two-lane NH-8, share (%) of striking vehicle as truck and car against the respective victims' vehicle (motorcycle) is 44%, and 21% respectively. Similarly, fatal crash analysis is done for four-lane NH-24 and six-lane NH-1. The distribution of fatal crashes by collision type shows that share of fatal crashes involving pedestrians is highest (45%) on six-lane NH-1, followed by 34% on four-lane NH-24 and 19% on two-lane NH-8. High share of pedestrians in fatal crashes on four-

lane (NH-24) and six-lane (NH-1) could be attributed to densely populated land use, as part of these two NHs fall in close proximity to Delhi.

As per the logistic regression models developed, the likelihood of motorcycle fatal crash versus non-motorcycle fatal crash model showed that 'collision type': 45-times, 30-times and 25-times higher for 'rear-end', 'sideswipe' and 'head-on' than 'hit pedestrian' respectively. Similarly, factors contributing to fatal crashes on NHs are estimated for other dependent (fatal pedestrian versus fatal non-pedestrian crash and fatal truck-involved versus fatal non-truck involved crashes) and independent variables.

The results of the safety performance functions (SPFs) showed that out of seven explanatory variables examined for each NH (segments), the significant explanatory variable is found to be 'segment length' in km for all three models of NHs (segments). Other significant variable is 'land use' along NHs for both two-lane NH-8 and six-lane NH-24. The response variables 'presence of service road' and 'terrain type' are found significant for four-lane NH-24 and two-lane NH-8 respectively. ADT is not found significant variable, hence it is taken as an offset variable owing to its importance in SPFs.

Spatial analysis of fatal crashes on NHs (two-lane NH-8, four-lane NH-24 and six-lane NH-1) has been carried out employing spatial autocorrelation, kernel density estimation method, and hot spot analysis using Getis-ord G_i^* through ArcGIS. The fatal crash analysis at the intersection influence area showed that intersection(s) is/are observed to be one of the most dangerous spot (about 15% of fatal crashes) on NHs having two-, four- and six-lane configuration, and the study results suggest that due care need to be taken while designing and executing works of intersections and non-intersection segments at NHs including safety measures for pedestrians movement. The study results for spatial autocorrelation showed that the spatial pattern of fatal crashes (all modes) on studied NHs are found to be clustered, and statistically significant at $P = 0.00$, and for only fatal pedestrian crashes the pattern is observed to be 'clustered' for four-lane NH-24 and 'random' for two-lane NH-8 and six-lane NH-1. The spatial analysis (KDE and Getis-ord G_i^*) of fatal crashes on NHs is found to be very effective technique for highway engineers to identify accident prone locations for short- and long-term remedial measures.

Finally, the screening of studied NHs segments for fatal crashes employing empirical Bayes (EB) method has helped to define and prioritize blackspots for each NHs. Through EB method, screening of the three NHs segments for fatal crashes was carried out, and it revealed that for two-lane NH-8, of the total 5 segments caught in the 10 or more fatal crashes net, 3 segments are expected to 'correct positive'. Similarly, for four-lane NH-24 of the total 1 segment caught in the 9 or more fatal crashes net, 0 segment is expected to 'correct positive'. For six-lane NH-1, of the total 9 segments caught in the 16 or more fatal crashes net, 5 segments are expected to 'correct positive'. Furthermore, review of identified NHs segments with correct positive obtained through EB method at Google Earth map and corresponding NHs segments with hot spots map using KDE is done to appreciate the EB results and the review showed matching pattern of recurrence of fatal crashes with respect to both cited figures.

Key words: National Highways, fatal crashes, logistic regression, negative binomial regression, spatial analysis, empirical Bayes.

सार

भारत में राष्ट्रीय राजमार्ग (NH) देश की लंबाई और चौड़ाई को देश और राज्यों की राजधानियों और महत्वपूर्ण जिले से जोड़ते हैं। भारत में NHs कुल सड़क की लंबाई का 2% (114,158 किमी) (मार्च 2017 को 58.9 लाख किमी) से कम का प्रतिनिधित्व करते हैं, और लगभग 40% वाहनों का आवागमन करते हैं। पिछले एक दशक के दौरान, संबंधित अधिकारियों द्वारा एनएच की संख्या को एक से दो-लेन, दो- से चार-लेन, और चार- से छह-लेन में अपग्रेड किया गया है। सड़क बुनियादी ढाँचे में सुधार जैसे कि लेन की संख्या में वृद्धि, सवारी की गुणवत्ता, इत्यादि, के कारण शहरों के बीच यात्रा के समय को कम करने, माल परिवहन की उत्पादकता में सुधार हुआ है। हालाँकि, दूसरी तरफ सड़क दुर्घटना में (2000 से 2017 के दौरान NHs पर 34 - 39% पर घातक दुर्घटनाओं) ने आंशिक रूप से NHs विकास के सकारात्मक प्रभाव को कम कर दिया है। अन्य प्रेरणा सामान्य रूप से और विशेष रूप से भारत में विकासशील देशों के लिए राजमार्ग सुरक्षा पर पर्याप्त शोध की कमी के कारण है। विकसित (उच्च आय) देशों के लिए अपनाई गई राजमार्ग सुरक्षा या सड़क सुरक्षा रणनीति पर शोध अध्ययन के कुछ परिणाम स्थानीय परिस्थितियों में महत्वपूर्ण भिन्नता के कारण कम प्रासंगिक हैं। इसलिए, कारकों की पहचान करने के लिए NHs पर घातक दुर्घटना पैटर्न (pattern) का अध्ययन करने की तत्काल आवश्यकता है।

यह इस संदर्भ में है, सांख्यिकीय तकनीकों जैसे लॉजिस्टिक प्रतिगमन (logistic regression) और सामान्यीकृत रैखिक मॉडलिंग (generalised linear modelling) के माध्यम से चुने एनएच के लिए घातक दुर्घटनाओं में योगदान करने वाले कारकों की पहचान करने का प्रयास किया है। अलग-अलग लेन विन्यास (configuration) वाले तीन एनएच: दो लेन वाले पक्के कंधे (paved shoulder) एनएच -8, चार-लेन एनएच -24 और छह-लेन एनएच -1 पिछले 4-5 वर्षों से घातक दुर्घटनाओं के गहन अध्ययन के लिए सूचीबद्ध हैं। तीन एनएच के लिए संबंधित पुलिस स्टेशनों से कुल 1,534 घातक दुर्घटना पहले सूचना रिपोर्ट (एफआईआर) एकत्र की हैं, और अध्ययन के लिए जांच की है।

डेटा विश्लेषण (data analysis) के आधार पर, घातक दुर्घटनाओं / किमी / वर्ष छह-लेन एनएच -1 पर उच्चतम (3.08) पाया जाता है, इसके बाद चार-लेन एनएच -24 पर 2.42, और दो-लेन एनएच -8 पर 0.72। घातक दुर्घटना में मारने वाला वाहनों द्वारा पीड़ितों की विधा के वितरण से पता चलता है कि संबंधित पीड़ितों के वाहन (मोटरसाइकिल) के खिलाफ ट्रक और कार के रूप में दो-लेन एनएच -8, शेयर (%) क्रमशः 44% और 21% है।। इसी तरह, चार-लेन एनएच -24 और छह-लेन एनएच -1 के लिए घातक दुर्घटना विश्लेषण किया जाता है। टक्कर प्रकार से घातक दुर्घटनाओं के वितरण से पता चलता है

कि पैदल चलने वालों में घातक दुर्घटनाओं का हिस्सा उच्चतम स्तर (45%) छह लेन एनएच -1 पर है, इसके बाद चार-लेन एनएच -24 पर 34% और दो-लेन एनएच- पर 19% है। 8। चार-लेन (NH-24) और छह-लेन (NH-1) पर घातक दुर्घटनाओं में पैदल चलने वालों के उच्च हिस्से को घनी आबादी वाले भूमि उपयोग के लिए जिम्मेदार ठहराया जा सकता है, क्योंकि इन दो NH का एक हिस्सा दिल्ली से निकटता में है।

जैसा कि लॉजिस्टिक रिग्रेशन मॉडल विकसित किया गया है, मोटरसाइकिल घातक दुर्घटना बनाम गैर-मोटरसाइकिल घातक दुर्घटना मॉडल की संभावना से पता चला है कि 'टक्कर प्रकार': 'रियर-एंड-rear-end', 'साइडस्पाइप-sideswipe' के लिए 45 गुना, 30 गुना और 25 गुना अधिक है। और 'हेड-ऑन-head on' क्रमशः 'हिट पैदल यात्री-hit pedestrian' से। इसी तरह, NH पर घातक दुर्घटनाओं में योगदान करने वाले कारकों पर अन्य आश्रितों (घातक पैदल यात्री बनाम घातक गैर-पैदल यात्री दुर्घटना और घातक ट्रक-शामिल बनाम घातक गैर-ट्रक शामिल क्रैश) और स्वतंत्र चर (variable) के लिए अनुमान लगाया जाता है।

सुरक्षा प्रदर्शन कार्यों (एसपीएफ) के परिणामों से पता चला है कि प्रत्येक एनएच (सेगमेंट) के लिए जांचे गए सात व्याख्यात्मक चरों में से एनएच (सेगमेंट) के सभी तीन मॉडलों के लिए किमी में महत्वपूर्ण व्याख्यात्मक चर 'खंड लंबाई' पाया जाता है। अन्य महत्वपूर्ण चर दोनों-लेन NH-8 और छह-लेन NH-24 के लिए NHs के साथ 'भूमि उपयोग' है। प्रतिक्रिया चर 'सर्विस रोड की उपस्थिति' और 'इलाके प्रकार' क्रमशः चार-लेन एनएच -24 और दो-लेन एनएच -8 के लिए महत्वपूर्ण पाए जाते हैं। ADT को महत्वपूर्ण चर (significant variable) नहीं पाया जाता है, इसलिए इसे SPF में इसके महत्व के कारण ऑफसेट चर (offset variable) के रूप में लिया जाता है।

NHs पर घातक दुर्घटनाओं का स्थानिक विश्लेषण (दो-लेन NH-8, चार-लेन NH-24 और छह-लेन NH-1) स्थानिक autocorrelation, कर्नेल घनत्व आकलन (kernel density estimation) विधि, और गेटिस-ऑर्ड (Getis-ord G_i^*) का उपयोग करके हॉट स्पॉट (hot spot) विश्लेषण को नियोजित किया गया है। ArcGIS के माध्यम से G_i^* । चौराहे प्रभाव क्षेत्र में घातक दुर्घटना विश्लेषण से पता चला है कि चौराहा(ओं) को दो चार-, और छह लेन वाले एनएच पर सबसे खतरनाक जगह में से एक माना जाता है, और अध्ययन के परिणामों से पता चलता है कि उचित देखभाल की जरूरत है पैदल यात्रियों के आवागमन के लिए सुरक्षा उपायों सहित एनएच पर चौराहों और गैर-चौराहों खंडों के कामों को डिजाइन (design) और निष्पादित करते समय लिया जाएगा। स्थानिक निरंकुशता के लिए अध्ययन के परिणामों से पता चला है कि अध्ययन किए गए एनएच पर घातक दुर्घटनाओं (सभी वाहन Mode) के स्थानिक पैटर्न को क्लस्टर किया गया है, और $P = 0.00$ पर

सांख्यिकीय रूप से महत्वपूर्ण है, और केवल घातक पैदल चलने वालों के लिए पैटर्न 'क्लस्टर' (cluster) होने के लिए मनाया जाता है। चार-लेन एनएच -24 के लिए और 'लेन' के लिए टू-लेन एनएच -8 और छह-लेन एनएच -1। एनएच पर घातक दुर्घटनाओं के स्थानिक विश्लेषण (केडीई-KDE और गेटिस-ऑर्ड जीई*-Getis-ord Gi*) को राजमार्ग इंजीनियरों के लिए लघु और दीर्घकालिक उपचारात्मक उपायों के लिए दुर्घटना संभावित स्थानों की पहचान करने के लिए बहुत प्रभावी तकनीक के रूप में पाया जाता है।

अंत में, प्रयोगसिद्ध बे (empirical Bayes) विधि को नियोजित करने वाले घातक दुर्घटनाओं के लिए अध्ययन किए गए एनएच खंडों की स्क्रीनिंग (screening) ने प्रत्येक एनएच के लिए ब्लैकस्पॉट (blackspot) को परिभाषित करने और प्राथमिकता देने में मदद की है। ईबी विधि (EB method) के माध्यम से, घातक दुर्घटनाओं के लिए तीन एनएच खंडों (NH segments) की स्क्रीनिंग की गई, और यह पता चला कि 10 या अधिक घातक दुर्घटनाओं नेट में पकड़े गए कुल 5 खंडों में से दो-लेन एनएच -8 के लिए, 3 खंडों की उम्मीद है 'सही सकारात्मक' (correct positive)। इसी तरह, 9 या अधिक घातक दुर्घटनाओं नेट में पकड़े गए कुल 1 खंड के चार-लेन एनएच -24 के लिए, 0 सेगमेंट 'सही सकारात्मक' होने की उम्मीद है। 16 या अधिक घातक दुर्घटनाओं नेट में पकड़े गए कुल 9 खंडों में से छह-लेन एनएच -1 के लिए, 5 खंडों को 'सही सकारात्मक' होने की उम्मीद है। इसके अलावा, Google धरती के नक्शे (google earth map) पर EB विधि के माध्यम से प्राप्त सही सकारात्मक के साथ पहचाने गए NHs खंडों की समीक्षा की गई है और KDE का उपयोग करते हुए हॉट स्पॉट्स मैप के साथ NHs खंडों को EB परिणामों की सराहना करने के लिए किया गया है और समीक्षा में दोनों के संबंध में घातक दुर्घटनाओं की पुनरावृत्ति का मिलान पैटर्न दिखाया गया है उद्धृत आंकड़े।

मुख्य शब्द: राष्ट्रीय राजमार्ग, घातक दुर्घटनाएं, लॉजिस्टिक प्रतिगमन, नकारात्मक द्विपद प्रतिगमन (negative binomial regression), स्थानिक विश्लेषण (spatial analysis), अनुभवजन्य खाड़ी (empirical Bayes)।

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ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AIC	Akaike's Information Criterion
APM	Accident Prediction Model
BRO	Border Roads Organisation
CI	Confidence Interval
c/w	Carriageway
EB	Empirical Bayes
EMS	Emergency Medical Services
FB	Full Bayes
FCM	Fuzzy C-Means
FIR	First Information Report
FoB	Foot Over Bridge
ft	Foot
GIS	Geographic Information Systems
GLM	Generalized Linear Modeling
GLIM	Generalized Linear Interactive Modeling
GNP	Gross National Product
GoI	Government of India
hrs.	Hours
HTBR	Hierarchical Tree-Based Regression
HSM	Highway Safety Manual
IRC	Indian Roads Congress
IPC	Indian Penal Code
ITF	International Transport Forum
KDE	Kernel Density Estimation
Km	Kilometre
Km/hr	Kilometre per Hour
lb	Pound
LGV	Light Goods Vehicle
LOS	Level of Service
LVUP	Light Vehicle Underpass
m	Metre
MAAP	Micro-computer Accident Analysis Package
mi	Miles
ML	Maximum Likelihood
mm	Millimetre
mm/km	Millimetre per Kilometre
MoRTH	Ministry of Road Transport and Highways
MPLN	Multilevel Poisson-lognormal
MVM	Million Vehicles Miles
NCHRP	National Cooperative Highway Research Program
NCRB	National Crime Records Bureau
NHDP	National Highways Development Plan
NB	Negative Binomial
NS	Network Screening
NGO	Non-governmental Organization

NH(s)	National Highway(s)
NHAI	National Highways Authority of India
No.	Number
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Square
OR	Odds Ratio
PPA	Point Pattern Analysis
PRACT	Predicting Road Accidents
PS	Police Station
PTW	Powered Two Wheeler
PWD	Public Works Department
RISMET	Road Infrastructure Safety Management Evaluation Tools
RoW	Right-of-Way
SD	Standard Deviation
SH	State Highway
SPF	Safety Performance Function
SRs	Service Roads
SR	State Road
TAZ	Traffic Analysis Zone
TLA	Territorial Local Authority
TRB	Transportation Research Board
TV	Television
UN	United Nations
UP	Uttar Pradesh
VMT	Vehicle Miles Traveled
vpd	Vehicles per Day
VRUs	Vulnerable Road Users
WCTR	World Congress on Transport Research
WHO	World Health Organization
ZI	Zero-inflated
ZIP	Zero-inflated Poisson