

PEDESTRIAN SAFETY NEAR BUS STOPS: A CASE STUDY IN DELHI

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by

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to the



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Dedicated to

All my beloved teachers

CERTIFICATE

This is to certify the thesis entitled “*Pedestrian Safety near Bus Stops: A Case Study in Delhi*” being submitted by **Ms. Deotima Mukherjee** 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 her. Ms. Deotima Mukherjee 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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ABBREVIATIONS

RTI : Road Traffic Injury

VRU : Vulnerable Road Users

OECD : Organisation for Economic Co-operation and Development

ADT : Average Daily Traffic

GPS : Global Positioning System

TCT : Traffic Conflict Technique

AHP : Analytical Hierarchical Process

FIR : First Information Report

NCT : National Capital Territory

GIS : Geographic Information System

API : Application Programming Interface

χ^2 : Chi square statistic

GOF : Goodness-of-fit

AIC : Akaike Information Criterion

BIC : Bayesian Information Criterion

KDE : Kernel Density Estimation

OR : Odds ratio

CI : Confidence interval

ANOVA : Analysis of variance

FOB : Foot-over-bridge

DOF : Degrees of freedom

PAC : Percentage accuracy in classification

ROC : Receiver Operating Characteristic

AUC : Area under the curve

SPF : Safety Performance functions

HSM : Highway Safety Manual

AASHTO : American Association of State Highway and Transportation Officials

PMF : Probability mass function

NB : Negative Binomial

CMF : Crash Modification Factor

PDO : Property damage only

r_{day} : Correlation coefficient (day-time) between bus commuter and number of buses

r_{night} : Correlation coefficient (night-time) between bus commuter and number of buses

SD : Standard deviation

PCA : Principal Component Analysis

SFP : Safety perception

BEP : Built-environment perception

SQP : Service quality perception

KMO : Kaiser-Meyer-Olkin

ABSTRACT

The main objective of this research was to assess the risk faced by pedestrians near bus stops considering the interactions between pedestrians and other road users as well as existing built-environment near the bus stops. The assessment was conducted using four discrete approaches: (i) evaluating impact of built-environment around bus stops on pedestrian safety, (ii) developing crash prediction models for high risk bus stops, (iii) deriving crash modification factors and (iv) evaluating safety perception of the pedestrians at high risk bus stops. The scope of the research included identification of high risk bus stops with pedestrian fatalities in the study area; select an appropriate sample of bus stops that can be a good representative of the entire population; develop a checklist including potential factors that contribute to pedestrian fatalities near a typical bus stop; conduct a robust video-graphic survey and built-environment audit at all sites and analyse the data and identify significant attributes pertinent to pedestrian fatalities at such locations.

The study was based on the police reported traffic fatalities (from First Information Report data) for the time period of 2014-2016 that occurred in the NCT. Apart from the FIR data, other sources of secondary data were Open Street Maps for obtaining the coordinates of existing bus stops, shape files of administrative districts and road network of Delhi classified as trunk, primary, secondary and tertiary roads. The study area was divided into 18 zones, based on the administrative districts of Delhi and distance from the Central Business District (CBD), that encountered multiple pedestrian fatalities. A total of 185 bus stops were selected from these zones with 103 fatal and 82 non-fatal sites. Fatal bus stops thus indicated bus stops with more than one pedestrian fatality within the buffer radius around each location while non-fatal indicate bus stops with no pedestrian fatality within buffer radius in the period of 2014-2016. This database was segregated into multiple subsets to create separate databases as per requirement of the research. The entire study was conducted in two separate formats, namely

day-time and night-time, and the fatal locations were segregated based on the time of fatality for that particular bus stop. Video-graphic survey and built-environment audits were conducted to capture road user factors and infrastructure attributes around the sites for possible identification of influencing factors. Moreover, average traffic speed was obtained using an API system for all locations. Correlation and independency tests were conducted for identifying strong association amongst the predictors. Furthermore, model estimations were followed by Goodness-of-fit tests using Akaike Information Criterion and Bayesian Information Criterion values.

For assessing the impact of built-environment attributes around bus stops on pedestrian safety, firstly hotspot analysis was conducted. The purpose of this was to compare fatal and non-fatal bus stops that although belonged from similar high to medium risk clusters (based on number of pedestrian fatalities per square-km) incurred different outcomes. Kernel Density Estimation was used to identify 177 bus stops, within the fatality-prone clusters, from the total shortlisted sample sites. This dataset consisted of 103 fatal and 74 non-fatal bus stops. Logistic regression was used for modelling the data and only categorical attributes were included for this study. Some of the important outcomes indicated that presence of zebra marking at the crosswalks near bus stops reduces the chances of fatal crashes by 23% for the night-time fatal locations. During the day, a broader sidewalk enhances pedestrian safety while at night, sidewalk height greater than 300 mm has resulted in 28% decline in fatalities. Also, the presence of bus bays and on-street parking increases the likelihood of pedestrian crashes by about three and four times respectively.

For developing Safety Performance Functions, separate day and night datasets were prepared with a total of 148 bus stops such that the proportion of the fatal to non-fatal locations in the sample datasets were equivalent to the proportion of the same in the actual population. Negative Binomial and Hurdle regressions were applied to account for excess ‘sampling’

zeroes in the dataset. Model estimations showed that bus stops with higher bus commuter frequency report occurrence of more number of fatalities. For the night-locations, midblock crossings are safer as compared to intersection crossing. Also, at-grade crosswalks with proper zebra marking reduces crash probability as compared to grade-separated and unmarked at-grade crossings. Besides, proper lighting conditions at shelters reduces chances of collision for waiting pedestrians. Model comparison indicated Hurdle NB models to be more suitable for similar datasets with excess 'sampling' zeroes.

A matched case-control study was carried out as an alternative for obtaining Crash Modification Factor for pedestrian safety near bus stops. Eighty-two pairs of cases (fatal) and controls (non-fatal) were matched based on study zones and similar road type. Conditional Logistic regression was applied for modelling the data. Results from the fitted models indicated that presence of foot-over-bridge or subways near bus stops increases the odds of fatality by about 30 times. Also, a well-lit bus shelter offers a safer waiting environment for pedestrians at night, reducing risk of pedestrian-vehicular collisions by approximately 16 times.

To understand the safety perception of pedestrians, top 10 high-crash bus stops were selected and a questionnaire survey was conducted to collect the commuters' personal details. It was followed by a set of Likert scale-based questions and the participants were asked to rate their opinion about the existing facilities. A total of 70 participants were interviewed, seven from each location and targeting every third or fourth pedestrian irrespective of age and gender.

Preliminary data analysis indicates that majority of the pedestrians were unwilling to opt for foot-over-bridges, unless they have elevators. Females and younger pedestrians were more willing to use subways as compared to others. They were also considered safety near bus stops as a more important attribute than comfort and convenience. Furthermore, the crossing facility at most of the bus stops scored significantly low, which means that an emphasis needs to be laid on improving the convenience and safety of pedestrians while crossing. Application

of Principal Component Analysis and linear mixed-effects model showed pedestrian age, travel frequency, trip purpose, median type, sidewalk quality and number of lanes as impacting parameters on the perception of pedestrians who access such high-risk bus stops.

Overall, the research highlighted the existing condition of the road infrastructure near bus stops in Delhi NCT and the attributes that require immediate attention in order to reduce pedestrian fatalities in future.

सार

इस शोध का मुख्य उद्देश्य बस स्टॉप के पास पैदल चलने वालों द्वारा सामना किए जाने वाले जोखिम का आकलन करना था, पैदल चलने वालों और अन्य सड़क उपयोगकर्ताओं के साथ-साथ बस स्टॉप के पास मौजूदा निर्मित वातावरण के बीच बातचीत पर विचार करना। मूल्यांकन चार अलग-अलग दृष्टिकोणों का उपयोग करके किया गया था: (i) पैदल यात्री सुरक्षा पर बस स्टॉप के आसपास निर्मित वातावरण के प्रभाव का मूल्यांकन, (ii) उच्च जोखिम वाले बस स्टॉप के लिए क्रैश भविष्यवाणी मॉडल विकसित करना, (iii) क्रैश संशोधन कारक प्राप्त करना और (iv) मूल्यांकन करना हाई रिस्क बस स्टॉप पर पैदल चलने वालों की सुरक्षा की धारणा। अनुसंधान के दायरे में अध्ययन क्षेत्र में पैदल यात्रियों की मौत के साथ उच्च जोखिम वाले बस स्टॉप की पहचान शामिल थी; बस स्टॉप का एक उपयुक्त नमूना चुनें जो पूरी आबादी का एक अच्छा प्रतिनिधि हो सकता है; संभावित कारकों सहित एक चेकलिस्ट विकसित करना जो एक विशिष्ट बस स्टॉप के पास पैदल चलने वालों की मृत्यु में योगदान देता है; सभी साइटों पर एक मजबूत वीडियो-ग्राफिक सर्वेक्षण और निर्मित पर्यावरण लेखा परीक्षा आयोजित करना और डेटा का विश्लेषण करना और ऐसे स्थानों पर पैदल चलने वालों के लिए महत्वपूर्ण विशेषताओं की पहचान करना।

यह अध्ययन एनसीटी में हुई 2014-2016 की समयावधि के लिए पुलिस द्वारा रिपोर्ट की गई यातायात दुर्घटनाओं (प्रथम सूचना रिपोर्ट डेटा से) पर आधारित था। प्राथमिकी डेटा के अलावा, द्वितीयक डेटा के अन्य स्रोत मौजूदा बस स्टॉप के निर्देशांक प्राप्त करने के लिए ओपन स्ट्रीट मैप्स, प्रशासनिक जिलों की आकार फाइलें और दिल्ली के सड़क नेटवर्क को ट्रंक, प्राथमिक, माध्यमिक और तृतीयक सड़कों के रूप में वर्गीकृत किया गया था। दिल्ली के प्रशासनिक जिलों और केंद्रीय व्यापार जिले (सीबीडी) से दूरी के आधार पर अध्ययन क्षेत्र को 18 क्षेत्रों में विभाजित किया गया था, जिसमें कई पैदल यात्री मारे गए थे। इन क्षेत्रों से 103 घातक और 82 गैर-घातक स्थलों के साथ कुल 185 बस स्टॉप का चयन किया गया था। घातक बस स्टॉप इस प्रकार इंगित करता है कि प्रत्येक स्थान के चारों ओर बफर त्रिज्या के भीतर एक से अधिक

पैदल यात्री की मौत के साथ बस स्टॉप है, जबकि गैर-घातक संकेत बस स्टॉप 2014-2016 की अवधि में बफर त्रिज्या के भीतर कोई पैदल यात्री मृत्यु नहीं है। अनुसंधान की आवश्यकता के अनुसार अलग डेटाबेस बनाने के लिए इस डेटाबेस को कई सबसेट में अलग किया गया था। संपूर्ण अध्ययन दो अलग-अलग स्वरूपों में आयोजित किया गया था, अर्थात् दिन-समय और रात-समय, और घातक स्थानों को उस विशेष बस स्टॉप के लिए घातक समय के आधार पर अलग किया गया था। प्रभावित करने वाले कारकों की संभावित पहचान के लिए साइट के आसपास सड़क उपयोगकर्ता कारकों और बुनियादी ढांचे की विशेषताओं को पकड़ने के लिए वीडियो-ग्राफिक सर्वेक्षण और निर्मित पर्यावरण ऑडिट आयोजित किए गए थे। इसके अलावा, सभी स्थानों के लिए एपीआई प्रणाली का उपयोग करके औसत यातायात गति प्राप्त की गई थी। भविष्यवक्ताओं के बीच मजबूत जुड़ाव की पहचान के लिए सहसंबंध और स्वतंत्रता परीक्षण किए गए। इसके अलावा, मॉडल अनुमानों का पालन अकाइक सूचना मानदंड और बायेसियन सूचना मानदंड मूल्यों का उपयोग करके अच्छाई-की-फिट परीक्षणों द्वारा किया गया था।

पैदल यात्रियों की सुरक्षा पर बस स्टॉप के आसपास निर्मित पर्यावरण विशेषताओं के प्रभाव का आकलन करने के लिए, सबसे पहले हॉटस्पॉट विश्लेषण किया गया था। इसका उद्देश्य घातक और गैर-घातक बस स्टॉप की तुलना करना था, हालांकि समान उच्च से मध्यम जोखिम वाले समूहों (प्रति वर्ग किलोमीटर पैदल चलने वालों की संख्या के आधार पर) से अलग-अलग परिणाम हुए। कुल शॉर्टलिस्ट किए गए नमूना साइटों से, घातक-प्रवण समूहों के भीतर, 177 बस स्टॉप की पहचान करने के लिए कर्नेल घनत्व अनुमान का उपयोग किया गया था। इस डेटासेट में 103 घातक और 74 गैर-घातक बस स्टॉप शामिल थे। डेटा मॉडलिंग के लिए लॉजिस्टिक रिग्रेशन का उपयोग किया गया था और इस अध्ययन के लिए केवल श्रेणीबद्ध विशेषताओं को शामिल किया गया था। कुछ महत्वपूर्ण परिणामों ने संकेत दिया कि बस स्टॉप के पास चौराहे पर ज़ेबरा मार्किंग की उपस्थिति रात के समय घातक स्थानों के लिए घातक दुर्घटनाओं की संभावना को 23% कम कर देती है। दिन के दौरान, एक व्यापक फुटपाथ पैदल चलने वालों की सुरक्षा को बढ़ाता है, जबकि रात में 300 मिमी से अधिक की फुटपाथ की ऊंचाई के कारण मृत्यु

दर में 28% की गिरावट आई है। इसके अलावा, बस बे और ऑन-स्ट्रीट पार्किंग की उपस्थिति से पैदल चलने वालों के दुर्घटनाग्रस्त होने की संभावना क्रमशः लगभग तीन और चार गुना बढ़ जाती है।

सुरक्षा प्रदर्शन कार्यों को विकसित करने के लिए, कुल 148 बस स्टॉप के साथ अलग-अलग दिन और रात के डेटासेट तैयार किए गए थे, ताकि नमूना डेटासेट में घातक से गैर-घातक स्थानों का अनुपात वास्तविक जनसंख्या में उसी के अनुपात के बराबर हो। डेटासेट में अतिरिक्त 'नमूनाकरण' शून्य के लिए नकारात्मक द्विपद और बाधा प्रतिगमन लागू किए गए थे। मॉडल अनुमानों से पता चला है कि बस स्टॉप अधिक बस कम्प्यूटर फ्रीक्वेंसी रिपोर्ट के साथ अधिक संख्या में मौत की घटना होती है। रात के स्थानों के लिए, चौराहे क्रॉसिंग की तुलना में मिडब्लॉक क्रॉसिंग अधिक सुरक्षित हैं। साथ ही, ग्रेड-सेपरेटेड और अचिह्नित एट-ग्रेड क्रॉसिंग की तुलना में उचित ज़ेबरा मार्किंग के साथ ग्रेड क्रॉसवॉक दुर्घटना की संभावना को कम करता है। इसके अलावा, आश्रयों में उचित प्रकाश व्यवस्था की स्थिति में पैदल चलने वालों के लिए टक्कर की संभावना कम हो जाती है। मॉडल की तुलना ने बाधा एनबी मॉडल को अधिक 'नमूनाकरण' शून्य वाले समान डेटासेट के लिए अधिक उपयुक्त होने का संकेत दिया।

बस स्टॉप के पास पैदल यात्रियों की सुरक्षा के लिए क्रेश मॉडिफिकेशन फैक्टर प्राप्त करने के विकल्प के रूप में एक मिलान केस-कंट्रोल अध्ययन किया गया था। अध्ययन क्षेत्रों और इसी तरह की सड़क के प्रकार के आधार पर अस्सी-दो जोड़े मामलों (घातक) और नियंत्रण (गैर-घातक) का मिलान किया गया। डेटा मॉडलिंग के लिए सशर्त लॉजिस्टिक रिग्रेशन लागू किया गया था। फिट किए गए मॉडलों के परिणामों से संकेत मिलता है कि बस स्टॉप के पास फुट-ओवर-ब्रिज या सबवे की उपस्थिति से मृत्यु की संभावना लगभग 30 गुना बढ़ जाती है। इसके अलावा, एक अच्छी तरह से प्रकाशित बस शेल्टर रात में पैदल चलने वालों के लिए एक सुरक्षित प्रतीक्षा वातावरण प्रदान करता है, जिससे पैदल-वाहनों की टक्कर का जोखिम लगभग 16 गुना कम हो जाता है।

पैदल चलने वालों की सुरक्षा धारणा को समझने के लिए, शीर्ष 10 उच्च दुर्घटना बस स्टॉप का चयन किया गया और यात्रियों के व्यक्तिगत विवरण एकत्र करने के लिए एक प्रश्नावली सर्वेक्षण किया गया। इसके बाद

लिकर्ट स्केल-आधारित प्रश्नों का एक सेट दिया गया और प्रतिभागियों को मौजूदा सुविधाओं के बारे में अपनी राय देने के लिए कहा गया। कुल 70 प्रतिभागियों का साक्षात्कार लिया गया, प्रत्येक स्थान से सात और उम्र और लिंग के बावजूद हर तीसरे या चौथे पैदल यात्री को लक्षित किया गया।

प्रारंभिक डेटा विश्लेषण इंगित करता है कि अधिकांश पैदल यात्री फुट-ओवर-ब्रिज का चयन करने के इच्छुक नहीं थे, जब तक कि उनके पास लिफ्ट न हो। महिलाएं और छोटे पैदल यात्री दूसरों की तुलना में सबसे का उपयोग करने के लिए अधिक इच्छुक थे। उन्हें बस स्टॉप के पास सुरक्षा भी आराम और सुविधा से अधिक महत्वपूर्ण विशेषता के रूप में माना जाता था। इसके अलावा, अधिकांश बस स्टॉप पर क्रॉसिंग सुविधा का स्कोर काफी कम है, जिसका अर्थ है कि क्रॉसिंग करते समय पैदल चलने वालों की सुविधा और सुरक्षा में सुधार पर जोर देने की आवश्यकता है। प्रिंसिपल कंपोनेंट एनालिसिस और लीनियर मिक्स्ड-इफेक्ट्स मॉडल के अनुप्रयोग ने पैदल चलने वालों की उम्र, यात्रा की आवृत्ति, यात्रा के उद्देश्य, माध्य प्रकार, फुटपाथ की गुणवत्ता और गलियों की संख्या को ऐसे उच्च जोखिम वाले बस स्टॉप तक पहुंचने वाले पैदल चलने वालों की धारणा पर प्रभावित करने वाले मापदंडों के रूप में दिखाया।

कुल मिलाकर, अनुसंधान ने दिल्ली एनसीटी में बस स्टॉप के पास सड़क के बुनियादी ढांचे की मौजूदा स्थिति और भविष्य में पैदल चलने वालों की मौत को कम करने के लिए तत्काल ध्यान देने की आवश्यकता पर प्रकाश डाला।

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