POST-CRASH ACCESSIBILITY
TO
CARE: THE CASE OF DELHI, INDIA

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INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

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CERTIFICATE

This is to certify that the thesis entitled "**Post-Crash Accessibility to Care: The Case of Delhi, India**" submitted by **Ms. Richa Ahuja** to the **Indian Institute of Technology, Delhi,** is a record of the bona-fide research work carried out by her under our supervision. The thesis, in our opinion, is worthy of consideration for the award of the degree of **Doctor of Philosophy** in accordance with the regulations of the Institute. The results embodied in the thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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Date:

Place: New Delhi

Dedicated to God, my family, and all the road safety warriors.

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"The dream begins with a teacher who believes in you, who tugs and pushes and leads you to the next plateau, sometimes poking you with a sharp stick called truth." – Dan Rather

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Richa Ahuja

ABSTRACT

Road traffic crash injuries are the eighth leading cause of death in India (World Health Organization, 2015). About 50-75 % of the Indian population does not have access to an ambulance. Accessing care after a road traffic crash reduces the chances of injury aggravation and improves recovery time. Information about the existing system plays an important role in provisioning an efficient system. The annual operation cost of one ambulance is nearly $53,000. Most low and middle-income countries (LMICs) cannot afford to establish and maintain such expensive systems. Half of the world's population resides in such LMICs where definitive care services operate with limited Health care infrastructure. The limited post-crash care resources necessitate optimum use of available resources. Ideally, post-crash transport must be done by an ambulance. But in resource-constrained countries, bystanders have prominently emerged as the first responders. Theoretically, access to care is a multi-dimensional term that includes aspects such as (a) availability, (b) accessibility (geographic), (c) accommodation, (d) affordability, (e) acceptability, and (f) awareness. Past attempts at estimating post-crash access and measuring emergency responders' performance have focused primarily on spatial and temporal aspects of access. Very few studies focussed on holistic evaluation consider the role of formal (ambulance) and informal responders (police and others) and such system wide operation of post-crash mechanisms of accessing care. There was a need to give due attention to all these factors, which eventually enable post-crash access to care. This thesis has attempted to bridge this research gap. It was demonstrated as a case study of Delhi. The work was developed with five objectives: the first objective was an in-depth qualitative assessment which gave a systems perspective of post-crash access to care in Delhi. The next four objectives were guided by insights from Objective 1. As identified from the literature review and behavioural theories of accessing care, these

emergency decisions were taken under duress and thus there wasn't any mode choice and hospital utilization model available in the context of post-crash access to care. The second objective derived the factors leading to these decisions through elaborate interviews with stakeholders and victims. These factors were used to model the post-crash utilization of care by different modes of transport. The third objective of this thesis estimated relative spatial access to one of the nearest hospitals or the trauma care system. It addressed the divided stakeholder views and policies about appropriate points of care for a crash victim and helps in deciding the on-site triage. In the fourth objective, the existing multi-modal post-crash operations were assessed using scenario analysis. An inclusive simulation-based framework was developed to accommodate the multi-modal nature of formal-informal response dynamics alongside the multi-dimensionality of accessibility in the current post-crash chain of events. It was demonstrated in the case of Delhi's Emergency Response Services. In the fifth objective, the use of already available commercial taxi resources was proposed to strengthen the existing ambulance operations in accordance with the international performance benchmarks.

Methodologically, this study used a mixed-methods approach. First, the literature review of the post-crash response system, synthesis of the available accessibility indicators, field observations, and informal conversations with stakeholders helped in identifying research gaps and developing a methodology for this thesis. It also formed the basis of qualitative research guides in the first objective, which was analysed using thematic analysis. In the second objective, post-crash mode choice and hospital care utilization were modelled using the structural constructs of Andersen's access to care framework and qualitative understanding from stakeholder interviews. The data was collected using a primary survey at the trauma centre. In the third objective, spatial access was assessed using four-year fatal crash data, and hospital information and travel time were calculated

using Google Maps API. The fourth objective used the Delhi-based ambulance and police operations data, taxi trajectory data, mode choice, hospital choice decision probability, etc. These inputs were used in the proposed framework based on the system-wide understanding of post-crash operations as described in Delhi through chapters one and two. The developed simulation framework assessed the response time and coverage characteristics of multiple proposed scenarios, accounting for the post-crash dynamics of multi-modal transportation and hospital decisions. This indicated an operationally important role of taxis in delivering patients to care. The fifth objective thus proposed to supplement ambulance operations with taxis. This was done using simulation-optimization methodology with the existing ambulance and taxi operations data.

Results from the first objective gave insights into the policies, processes, practices, and aspects of post-crash access to care. Ambulances, bystanders, taxis, and police play essential roles in enabling access to care. They were individually governed and guided by multiple laws and policies. The second objective identified education, financial status, help callers (bystanders & relatives), and injury severity as essential determinants of the post-crash use of a trauma care facility. Private transport, financial Status, education, injury severity, and status of care at the private hospital were significant determinants of receiving hospital-based care. The mode choice model finds bystanders as the primary informant of police transportation. Ambulance transportation gets accompanied by police personnel to the hospital. Ironically, information about emergency responders and having health insurance does not necessitate ambulance-based transport of the victims. The third objective found that the post-crash decision of taking the victim to a trauma care facility or one of the nearest hospitals is essentially a 15-minute difference for 90% of cases. As the triaging personnel often need to decide the type of care, this decision may account if the patient would survive these 15 minutes for better care in a trauma centre. Scenario analysis in the fourth objective showed the

importance of informal transportation in the overall post-crash access mechanism. Empirically, taxis and police emerged as significant responders to crash victims. The fifth objective factored in the critical role played by privately engaged taxi responders as enablers of post-crash access. The optimum ambulance to taxi configuration for capacity building of existing ambulance operations in response to the road traffic crashes was observed to be 1:4. The thesis brings out comprehensive estimates of multiple aspects of accessing care after a road traffic crash. Systematic framework-based assessment of post-crash response operations highlights the vital role of private vehicles in providing timely access. Neglecting them would create biases in actual access to care. Privately owned vehicles could be a precious resource in LMICs. Limited resources can be systematically supplemented with privately-owned taxis. If managed and integrated correctly, taxis can become an asset to ambulance operations. Post-crash accessibility insights in this thesis would be valuable information for the policymakers, ambulance providers, and the general body of knowledge. It holistically covers the functional intricacies of the system in the case of a road crash emergency. These aspects may be considered while planning, developing, and operating an emergency response system in India.

सार

सड़क यातायात दुर्घटना की चोटें भारत में मौत का आठवां प्रमुख कारण हैं (विश्व स्वास्थ्य संगठन, 2015)। लगभग 50-75% भारतीय आबादी के पास एम्बुलेंस तक पहुंच बहुत कम है। सड़क यातायात दुर्घटना के बाद देखभाल तक पहुँचने से चोट के बढ़ने की संभावना कम हो जाती है और ठीक होने में समय कम लगता है। कुशल प्रणाली के प्रावधान में मौजूदा प्रणाली के बारे में जानकारी एक महत्वपूर्ण भूमिका निभाती है। एक एम्बुलेंस की वार्षिक संचालन लागत लगभग $ 53,000 है। अधिकांश निम्न और मध्यम आय वाले देश (LMIC) इस तरह की महंगी प्रणाली को स्थापित करने और बनाए रखने का जोखिम नहीं उठा सकते हैं। दुनिया की आधी आबादी ऐसे देशों में रहती है जहां निश्चित देखभाल सेवाएं सीमित स्वास्थ्य देखभाल बुनियादी ढांचे के साथ संचालित होती हैं। सीमित पोस्ट-क्रैश देखभाल संसाधनों के लिए उपलब्ध संसाधनों के इष्टतम उपयोग की आवश्यकता होती है। आदर्श रूप से, दुर्घटना के बाद यात्रा एम्बुलेंस द्वारा होना चाहिए। लेकिन संसाधन-विवश देशों में, बाईस्टैंडर्स प्रमुख रूप से पहले उत्तरदाताओं के रूप में उभरे हैं। सैद्धांतिक रूप से, देखभाल तक पहुंच एक बहु-आयामी शब्द है जिसमें निम्नलिखित पहलू शामिल हैं: (ए) उपलब्धता, (बी) पहुंच (भौगोलिक), (सी) आवास, (डी) सामर्थ्य, (ई) स्वीकार्यता, और (एफ) जागरूकता .दुर्घटना के बाद पहुंच का आकलन करने और आपातकालीन प्रतिक्रियाकर्ताओं के प्रदर्शन को मापने के पिछले प्रयासों ने मुख्य रूप से पहुंच के स्थानिक और अस्थायी पहलुओं पर ध्यान केंद्रित किया है। इसके अलावा, औपचारिक (पुलिस, और अन्य) और अनौपचारिक (एम्बुलेंस) उत्तरदाताओं की भूमिका सहित देखभाल तक पहुंचने के बाद दुर्घटना तंत्र के सिस्टम संचालन को समग्र रूप से देखने वाले कई अध्ययन नहीं हैं। इन सभी कारकों पर उचित ध्यान देने की आवश्यकता है जो अंततः दुर्घटना के बाद देखभाल तक पहुंच को सक्षम बनाते हैं। इस शोध प्रबंध ने इस शोध अंतराल को भरने का प्रयास किया है। इसे दिल्ली के मामले का अध्ययन के रूप में प्रदर्शित किया गया था। काम को पांच उद्देश्यों में विकसित किया गया था: पहला उद्देश्य एक गहन गुणात्मक

मूल्यांकन था जिसने दिल्ली में देखभाल के लिए दुर्घटना के बाद पहुंच का प्रणाली परिप्रेक्ष्य दिया।। अगले चार उद्देश्य, उद्देश्य एक से अंतर्दृष्टि द्वारा निर्देशित थे। जैसा कि साहित्य समीक्षा और देखभाल तक पहुँचने के व्यवहार सिद्धांतों से पहचाना जाता है, दुर्घटना के बाद के संदर्भ में कोई भी विकल्प और अस्पताल उपयोग पद्धति नहीं थी, क्योंकि दबाव में आपातकालीन निर्णय लिए जाते हैं। दूसरा उद्देश्य हितधारकों और पीड़ितों के साथ विस्तृत साक्षात्कार के माध्यम से इन निर्णयों के लिए अग्रणी कारकों को प्राप्त करता है। इन कारकों का उपयोग परिवहन के विभिन्न साधनों द्वारा देखभाल के दुर्घटना के बाद के उपयोग को मॉडल करने के लिए किया गया इस थीसिस का तीसरा उद्देश्य निकटतम अस्पताल या ट्रॉमा केयर सिस्टम के सापेक्ष स्थानिक पहुंच का अनुमान लगाता है। यह दुर्घटना के शिकार व्यक्ति की देखभाल के उपयुक्त बिंदुओं के बारे में विभाजित हितधारक के विचारों और नीतियों को संबोधित करता है। चौथे उद्देश्य में, मौजूदा मल्टी-मोडल पोस्ट-क्रैश ऑपरेशंस का परिदृश्य विश्लेषण का उपयोग करके मूल्यांकन किया गया था। घटनाओं की वर्तमान पोस्ट-क्रैश श्रृंखला में पहुंच की बहु-आयामीता के साथ-साथ औपचारिक-अनौपचारिक प्रतिक्रिया गतिशीलता की बहु-मोडल प्रकृति को समायोजित करने के लिए एक समावेशी सिमुलेशन-आधारित ढांचा विकसित किया गया था। इसका प्रदर्शन दिल्ली आपातकालीन प्रतिक्रिया सेवाओं के मामले में किया गया था। पांचवें उद्देश्य में, पहले से उपलब्ध टैक्सी संसाधन का उपयोग मौजूदा एम्बुलेंस संचालन को मजबूत करने के लिए प्रस्तावित किया गया था ताकि उनके संचालन को अंतरराष्ट्रीय प्रदर्शन बेंचमार्क के अनुसार बेहतर बनाया जा सके।

पद्धति की दृष्टि से इस अध्ययन में मिश्रित विधियों का प्रयोग किया गया है। सबसे पहले दुर्घटना के बाद प्रतिक्रिया प्रणाली की साहित्य समीक्षा, उपलब्ध पहुंच संकेतकों का संश्लेषण, क्षेत्र अवलोकन और हितधारकों के साथ अनौपचारिक बातचीत ने इस थीसिस के लिए अनुसंधान अंतराल की पहचान करने और कार्यप्रणाली विकसित करने में मदद की। इसने पहले उद्देश्य में गुणात्मक शोध गाइडों का आधार भी बनाया, जिसका

विश्लेषण विषयगत विश्लेषण का उपयोग करके किया गया था। दूसरे उद्देश्य में, दुर्घटना के मोड बाद विकल्प और अस्पताल देखभाल उपयोग को एंडरसन की देखभाल ढांचे के संरचनात्मक निर्माण और हितधारक साक्षात्कार से गुणात्मक समझ का उपयोग करके तैयार किया गया था। ट्रॉमा सेंटर में प्राथमिक सर्वेक्षण के उपयोग से डेटा एकत्र किया गया था। तीसरे उद्देश्य में, चार साल के घातक दुर्घटना आंकड़े और अस्पताल की जानकारी का उपयोग करके स्थानिक पहुंच का आकलन किया गया था और यात्रा के समय की गणना गूगल मैप्स एपीआई का उपयोग करके की गई थी। चौथे उद्देश्य में दिल्ली स्थित एम्बुलेंस और पुलिस संचालन आंकड़े, टैक्सी प्रक्षेपवक्र डेटा, मोड विकल्प और अस्पताल पसंद निर्णय संभावना इत्यादि का उपयोग किया गया था। इन आदानों का उपयोग प्रस्तावित ढांचे में दुर्घटना के बाद के संचालन की व्यवस्थित समझ के आधार पर किया गया था जैसा कि दिल्ली में अध्याय एक और दो के माध्यम से वर्णित है। विकसित सिमुलेशन ढांचे ने बहु-मॉडल परिवहन और अस्पताल के निर्णयों की दुर्घटना के बाद की गतिशीलता को ध्यान में रखते हुए, कई प्रस्तावित परिदृश्यों की प्रतिक्रिया समय और कवरेज विशेषताओं का आकलन किया। इसने मरीजों को देखभाल तक पहुंचाने में टैक्सियों की महत्वपूर्ण भूमिका का संकेत दिया। इसे ध्यान में रखते हुए, पांचवें उद्देश्य ने टैक्सी के साथ एम्बुलेंस संचालन को पूरक करने का प्रस्ताव रखा। यह मौजूदा एम्बुलेंस और टैक्सी संचालन आंकड़े के साथ अनुकरण-अनुकूलन पद्धति का उपयोग करके किया गया था।

पहले उद्देश्य के परिणामों ने नीतियों, प्रक्रियाओं, प्रथाओं और देखभाल के बाद दुर्घटना के बाद के पहलुओं में अंतर्दृष्टि प्रदान की। एम्बुलेंस, दर्शक, टैक्सी और पुलिस देखभाल तक पहुंच को सक्षम करने में आवश्यक भूमिका निभाते हैं। वे कई कानूनों और नीतियों द्वारा व्यक्तिगत रूप से शासित और निर्देशित होते हैं। दूसरे उद्देश्य ने शिक्षा, वित्तीय स्थिति, सहायता कॉल करने वालों (बाध्यकारी और रिश्तेदार), और चोट की गंभीरता को ट्रॉमा केयर सुविधा के दुर्घटना के बाद के उपयोग के आवश्यक निर्धारक के रूप में पहचाना। निजी परिवहन, वित्तीय स्थिति, शिक्षा, चोट की गंभीरता और निजी अस्पताल में देखभाल की स्थिति अस्पताल-

आधारित देखभाल प्राप्त करने के महत्वपूर्ण निर्धारक थे। परिवहन विकल्प मॉडल बाईस्टैंडर्स को पुलिस परिवहन के प्राथमिक मुखबिर के रूप में पाता है। एम्बुलेंस परिवहन पुलिस कर्मियों के साथ अस्पताल जाता है। विडंबना यह है कि आपातकालीन प्रतिक्रिया और स्वास्थ्य बीमा होने के बारे में जानकारी के बावजूद पीड़ित एम्बुलेंस आधारित परिवहन नहीं चुनते। तीसरे उद्देश्य में पाया गया कि दुर्घटना के बाद पीड़ित को ट्रॉमा केयर सुविधा या निकटतम अस्पताल में ले जाने का निर्णय अनिवार्य रूप से 90% मामलों में 15 मिनट का अंतर है। चूंकि ट्राइएजिंग कर्मियों को अक्सर देखभाल के प्रकार को तय करने की आवश्यकता होती है, इस उद्देश्य से बेहतर देखभाल चुनने के लिए मदद हो सकती है । चौथे उद्देश्य में परिदृश्य विश्लेषण ने समग्र पोस्ट-क्रैश एक्सेस तंत्र में अनौपचारिक परिवहन के महत्व को दिखाया। टैक्सी और पुलिस दुर्घटना पीड़ितों के लिए महत्वपूर्ण प्रतिक्रिया के रूप में उभरी। पांचवां उद्देश्य निजी तौर पर लगे टैक्सी उत्तरदाताओं द्वारा दुर्घटना के बाद पहुंच के समर्थक के रूप में निभाई गई महत्वपूर्ण भूमिका को दर्शाता है। सड़क यातायात दुर्घटनाओं के जवाब में मौजूदा एम्बुलेंस संचालन की क्षमता निर्माण के लिए इष्टतम एम्बुलेंस 1:4 देखा गया था।

थीसिस सड़क यातायात दुर्घटना के बाद देखभाल तक पहुँचने के कई पहलुओं का व्यापक अनुमान पेश करती है। दुर्घटना के बाद प्रतिक्रिया संचालन के व्यवस्थित ढांचे के आधार पर मूल्यांकन समय पर पहुंच प्रदान करने में निजी वाहनों की महत्वपूर्ण भूमिका पर प्रकाश डालता है। उनकी उपेक्षा करने से देखभाल की वास्तविक पहुंच में पक्षपात होगा। निम्न और मध्यम आय वाले देश जहां निजी स्वामित्व वाले वाहन एक बहुमूल्य संसाधन हो सकते हैं। निजी स्वामित्व वाली टैक्सियों के साथ सीमित संसाधनों को व्यवस्थित रूप से पूरक किया जा सकता है। अगर सही तरीके से प्रबंधित और एकीकृत किया जाए तो टैक्सी, एम्बुलेंस संचालन के लिए एक संपत्ति बन सकती है। इस थीसिस में दुर्गात्रा के उपरांत एक्सेसिबिलिटी अंतर्दृष्टि नीति निर्माताओं, एम्बुलेंस प्रदाताओं और ज्ञान के सामान्य निकाय के लिए मूल्यवान जानकारी होगी। यह सड़क दुर्घटना आपात

स्थिति के मामले में सिस्टम की कार्यात्मक जटिलताओं को समग्र रूप से कवर करता है। भारत में आपातकालीन प्रतिक्रिया प्रणाली की योजना, विकास और संचालन करते समय इन पहलुओं पर विचार किया जा सकता है।

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Glossary of Terminology

Term	Definition
Abbreviated Injury Scale (AIS); **Injury Severity Score (ISS);** **Revised trauma score (RTS)**	The abbreviated Injury Scale (AIS) describes the anatomical injury severity using consensus-based scores determined by experts. The Revised Trauma Score (RTS) is based on physiological parameters independent of injury diagnoses. The Injury Severity Score (ISS) consists of the square of the highest AIS scores in the three most severely injured body regions (Nakahara and Yokota., 2011).
Advanced prehospital care	The third-tier care interventions include the establishment of complex regional call management centres and highly integrated communications networks, as well as the provision of advanced invasive techniques. On a system level, advanced prehospital interventions include call management centres, the development of integrated wireless communication networks, and the purchase and maintenance of a fleet of sophisticated ground ambulances or air ambulances. Broadly termed "advanced life support," clinical services like these generally require the skills of a professional prehospital care provider – either a physician or a non-physician paramedic with hundreds, or even thousands, of hours of training (World Health Organization, 2005).
Ambulatory	Ambulatory or outpatient care refers to health services provided to patients who are not confined to an institutional bed as inpatients during the time the services are rendered. Ambulatory care includes medical services of a general (primary) and specialized (secondary) nature (World Health Organization, 2016).
Basic prehospital care	The second tier of care can be provided at the community level by those who have been trained in the principles of basic prehospital trauma care (also known as basic life support). These providers should have extensive formal training in prehospital care, scene management, rescue, stabilization, and the transport of injured people (Oestern, Garg, and Kotwal., 2013).
Emergency Medical Services	Emergency Medical Service (EMS) is a branch of emergency services dedicated to providing out-of-hospital acute medical care and/or transport to definitive care to patients with illnesses and injuries that the patient, or the medical practitioner, believes constitutes a medical emergency (Rishipathak, Yeravdekar, and Rajhans., 2018).

First responder care	These first responders can be taught to recognize an emergency, call for help and provide treatment until formally trained healthcare personnel arrive to give additional care (Rishipathak, Yeravdekar, and Rajhans., 2018).
Health care system	A health system consists of all organizations, people, and actions whose primary intent is to promote, restore or maintain health. This includes efforts to influence determinants of health as well as more direct activities that improve health (World Health Organization, 2007).
Medico-Legal Certificate	Any case of injury or ailment where the attending doctor, after history taking and clinical examination, considers that investigations by law enforcement agencies (and superior military authorities) are warranted to ascertain circumstances and fix responsibility regarding the said injury or ailment according to the "law" (World Health Organization, 2007).
Primary level /District / Rural/ Community/ General hospital	Primary-level hospital: few specialties—mainly internal medicine, obstetrics and gynaecology, paediatrics, and general surgery, or just general practice; limited laboratory services available for general but not specialized pathological analysis (Debas et al., 2015).
Secondary/Regional/Provincial /General hospital	Secondary-level hospital: highly differentiated by function with 5 to 10 clinical specialties; size ranges from 200 to 800 beds; often referred to as a provincial hospital (Debas et al., 2015).
Tertiary-level /National/Central/Academic or teaching or university hospital	Tertiary-level hospital: highly specialized staff and technical equipment— for example, cardiology, intensive care unit, and specialized imaging units; clinical services highly differentiated by function; could have teaching activities; size ranges from 300 to 1,500 beds (Debas et al., 2015).
Trauma Centre (or Trauma Centre or Trauma care)	A trauma center (or trauma centre) is a hospital equipped and staffed to provide care for patients suffering from major traumatic injuries such as falls, motor vehicle collisions, or gunshot wounds. A trauma center may also refer to an emergency department (also known as a "casualty department" or "accident & emergency") without the presence of specialized services to care for victims of major trauma (Sasser et al., 2009).

List of Abbreviations/Acronyms

AIC	Akaike Information Criterion
AIS	Abbreviated Injury Score
API	Application Programming Interface
Auto	Three- wheeler taxi/ three wheeled vehicle/ Auto-rickshaw
BIC	Bayesian Information Criterion
BPL	Below Poverty Line
CATS	Centralized Accident and Trauma Services
EMS	Emergency Medical Services (Ambulance)
ERS	Emergency Response Services (Ambulance, Police)
FIR	First Information Reports
GMM	Gaussian Mixture Model
GS	Good Samaritan
ICU	Intensive Care Units
IoT	Internet of Things
ISS	Injury Severity Score
LAMA	Leave Against Medical Advice
LMIC	Low- and Middle-Income Countries
MP	Medical Personnel
MACT	Motor Accident Claims Tribunal
MHRD	Ministry of Human Resource Development
MLC	Medico-Legal Certificate
MP	Medical Personnel
MRD	Medical Record Department
NERS	Nationwide Emergency Response System
NH	Nearest Hospital
NIH	National Institutes of Health
O-D	Origin - Destination
OS	Other Stakeholder
PCR	Police Control Room
PP	Police Personnel
PSAP	Public Safety Answering Point
RTO	Regional Transport Office or Road Transport Office
SC	Supreme Court
TC	Trauma Centre
TD	Taxi Driver
VRU	Vulnerable Road Users
WHO	World Health Organization