

**ESTIMATING THE NUMBER OF FATAL ACCIDENTS  
AND INVESTIGATING THE DETERMINANTS OF  
SAFETY PERFORMANCE IN INDIAN CONSTRUCTION**

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**DOCTOR OF PHILOSOPHY**



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SAFETY PERFORMANCE IN INDIAN CONSTRUCTION**

by

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*Submitted*

*In fulfillment of the requirements of the degree of*

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**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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**DECEMBER 2015**

*Dedicated*  
*to*  
*My Parents*

## **CERTIFICATE**

This is to certify that the thesis entitled, “**Estimating the Number of Fatal Accidents and Investigating the Determinants of Safety Performance in Indian Construction**” being submitted by **Patel Dilipkumar Arvindkumar** to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy** is a bonafide record of research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirement for the degree of **Doctor of Philosophy**.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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## ABSTRACT

Construction workers and employees are extremely vulnerable to injuries and fatalities due to the hazardous conditions of their work, unsafe acts, and deficient safety management. These lead to poor safety performance. The study was conceptualized and implemented in four phases to meet the following objectives: (1) the estimation of the number of fatal accidents in the Indian construction sector; (2) the development of a model to predict the safe work behavior of employees and co-employees working in a construction project; (3) the formulation of a model to predict the safety climate of a construction project; (4) the creation of a framework to evaluate the project hazard level; and (5) the assessment of some hypotheses on determinants of safety performance and their interrelationships. The research methodology which was used included the artificial neural network (ANN), fuzzy set theory, fuzzy measure, fuzzy integral, multi attribute decision making (MADM) methods, and the structural equation modelling (SEM).

An important finding of the study is that on an average, 38 fatal accidents occur daily in the Indian construction industry. Safety climate constructs including the supervisory environment, work pressure, employees' involvement, personal appreciation of risk, supportive environment, commitment, appraisals of physical work environment, work hazard, and communication are sensitive to safe work behavior while management commitment, supervisory environment, appraisal of physical work environment and work hazard are sensitive to safety climate of the projects. The study contributes to theory and practice in the form of models and methodologies to: (1) predict the safe work behavior of employees and safety climate in construction projects; (2) to discover the outliers in projects based on the safety climate and the safe work behavior of employees working in them; and (3) to evaluate a project's hazard level.

The study lays emphasis on the systematic and functional accident data recording

system at the state and national level. It also advocates the use of sensitive constructs for speedy improvement in safe work behavior and safety climate of projects. The study offers valuable resources for the improvement of safety performance.

**Keywords:** Construction safety, hazard, accident, safety performance, behavior, artificial neural network, fuzzy set theory, structural equation modeling, Delphi method, India.

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## LIST OF ABBREVIATIONS

AAD	Average Absolute Deviation
AD	Anderson-Darling
AGFI	Adjusted Goodness of Fit Index
AHP	Analytical Hierarchy Process
AIIMS	All India Institute of Medical Sciences
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
ANP	Analytic Network Process
APD	Absolute Percentage Deviation
AVE	Average Variance Extracted
BLS	Bureau of Labor Statistics
BMS	Bandhkam Majur Sanghthan
BN	Bayesian Network
BOCW	Building and Other Construction Workers
BP	Back Propagation
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CIX	Construct Index
CIDC	Construction Industry Development Council
CMA	Cement Manufactures' Association
CRS	Constant Return to Scale
CV	Coefficient of Variation
CWG	Common Wealth Games
DGFASLI	Directorate General Factory Advice Service and Labor Institutes
DMRC	Delhi Metro Rail Corporation
DOF	Degree of Freedom
FAFR	Fatal Accident Frequency Rate
FAHP	Fuzzy Analytical Hierarchy Process

FIR	First Information Report
FMADM	Fuzzy Multi Attribute Decision Making
FMCDM	Fuzzy Multi Criteria Decision Making
FMEA	Failure Mode and Effect Analysis
GDP	Gross Domestic Product
GFI	Goodness-of-Fit Index
GLM	General Linear Modeling
GNP	Gross National Product
HM	Hazard Management
HSE	Health and Safety Executive
IFI	Incremental Fit Index
ILO	International Labor Organization
IR	Incident Rate
IRDA	Insurance Regulatory and Development Authority of India
IS	Indian Standards
KMO	Kaiser-Meyer-Olkin
LISERAL	Linear Structural Relations
LM	Levenberg Marquardt
MADM	Multi Attribute Decision Making
MAPE	Mean Absolute Percentage Error
MCDM	Multi Criteria Decision Making
MI	Modification Index
MLE	Maximum Likelihood Estimation
MLR	Medical Legal Registers
MODM	Multiple Objective Decision Making
MR	Multiple Regression
MSE	Mean Square Error
NCR	National Capital Region
NCT	National Capital Territory

NFI	Normed Fit Index
NGO	Non-Government Organization
NHAI	National Highway Authority of India
NNFI	Non-Normed Fit Index
NSCI	National Safety Council of India
NSDC	National Skill Development Corporation
OHS	Occupational Health and Safety
OSHMS	Occupational Safety and Health Management System
PGFI	Parsimony Goodness of Fit Index
PHI	Project Hazard Index
PNFI	Parsimony Normed Fit Index
PPE	Personnel Protective Equipment
RAM	Risk Assessment Model
RFI	Relative Fit Index
RMSE	Root Mean Square Error
RMSEA	Root Mean Square Error of Approximation
RNI	Relative Non-centrally Index
RTI	Right to Information
SAW	Simple Additive Weighting
SB	Safety Budget
SC	Safety Climate
SEM	Structural Equation Modeling
SP	Safety Performance
SPSS	Statistical Package for Social Sciences
SR	Safety Rules and Regulations
SRMR	Standardized Root Mean Residual
STS	Socio Technical System
SVR	Safety Violation Rate
TBM	Tunnel Boring Machine

TFN	Triangular Fuzzy Number
TLI	Tucker Lewis Index
USD	United States of America Dollar
UT	Union Territories
WB	Safe Work Behavior
WCI	Workman Compensation Insurance
WSM	Weighted Sum Method