

# **Evacuation simulation and emergency exit choice behaviour analysis: a case study of the metro station**

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**Evacuation simulation and emergency exit choice behaviour analysis: a  
case study of the metro station**

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## Certificate

This is to certify that the thesis entitled “*Emergency evacuation simulation and emergency exit choice behaviour analysis: a case study of the metro station*” being submitted by **Mr. Tarapada Mandal**, to the Indian Institute of Technology Delhi, India, for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of original bonafide research work carried out by him. Mr. Tarapada Mandal has worked under our guidance and supervision. To the best of our 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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## **Abstract**

Emergency evacuation is of paramount importance at metro stations. Every day, a large number of commuters travel in the metro in most of the cities of the world. Providing fire safety to a large number of travellers is an important task for crowd managers and engineers. To study emergency evacuation, recreating such scenarios in real life can be dangerous and have ethical issues. Computer simulation is one of the useful descriptive methods to study emergency evacuation. It is also important to understand the behaviour of evacuees in emergency evacuation. Some of the commuters may have physical disabilities may be dependent on wheel chairs or other support for movement. Their timely evacuation is important for improving the overall safety of the commuters. Therefore, there is a need to understand the overall evacuation process, required safe evacuation time, available safe evacuation time, proportion of commuters on wheelchair and non-assisted evacuees. Emergency exit choice in emergency evacuation is an important task for the evacuees. It is necessary to understand the emergency exit choice behaviour of the evacuees during real evacuations. Efforts need to be made to study the emergency exit choice behaviour of the evacuees. Therefore, the main objectives of this study are to study the required and available safe evacuation times of the wheelchair assisted and non-assisted evacuees during evacuation from different types of metro stations. The other objectives are studying the exit choice behaviour of the evacuees using different tools and methods. In this thesis, extensive simulations are used to study the emergency evacuations. Fire at a metro station and evacuation both are studied.

The design of the experiment is used to include different factors of fire and evacuation simulation. Total evacuation time from different types of metro stations is calculated using simulation. Available safe evacuation time at different metro stations under different fire conditions is also calculated. Fractional effective dose for wheelchair assisted and non-assisted evacuees is also calculated. Choice experiments are conducted to understand the exit choice

behaviour of commuters in an emergency evacuation. Two different experiments are conducted. One using a sketch of 3D models of the station and printing on paper. Another experiment is done in partial immersive virtual reality. Scenarios are built according to the efficient choice design. Stated preference experiment is conducted separately for the sketch-up 3D models and unreal engine based virtual reality experience. Respondents were asked to choose one of three given exits and their choices were recorded. Discrete choice models are calibrated with the data. Standard and mixed logit models are calibrated with that data. Different environmental and personal factors and their effects are identified using the discrete choice models.

Machine learning models (GNB, SVM, DT, RF, GBM, XGBOOST) are calibrated with the data. Interpretable machine learning models are used to predict the choices of the respondents. The results of the simulation study indicate that assisted evacuees are the most vulnerable commuters as these assisted evacuees are mostly susceptible to asphyxiation due to prolonged smoke effect. The simulation results also indicate that smoke does not have any effects on non-assisted evacuees. The results of the emergency exit choice behaviour study indicates that the behaviour is dependent on situations. The queue time is found to be the most significant factor in emergency exit choice behaviour followed by distance and crowd level. The study results indicate that incorporation of a latent factor called safety knowledge improves the model fit of the logit and mixed logit models. The study results also indicate that the machine learning models can also predict the exit choice behaviour of the evacuees. The study results of the virtual reality experiment indicate that partial immersive virtual reality can predict the emergency exit choice behaviour of the evacuees. The emergency exit choice behaviour in this thesis has not been studied using fully immersive virtual reality. This is one of the limitations of this study. Further, the simulations performed in this study cannot be verified with real data or drills.

## सार

मेट्रो स्टेशनों पर आपातकालीन निकासी सबसे महत्वपूर्ण है। दुनिया के ज्यादातर शहरों में रोजाना बड़ी संख्या में यात्री मेट्रो में सफर करते हैं। भीड़ प्रबंधकों और इंजीनियरों के लिए बड़ी संख्या में यात्रियों को अग्नि सुरक्षा प्रदान करना एक महत्वपूर्ण कार्य है। आपातकालीन निकासी का अध्ययन करने के लिए, वास्तविक जीवन में ऐसे परिदृश्यों को फिर से बनाना खतरनाक हो सकता है और इसमें नैतिक मुद्दे हो सकते हैं। आपातकालीन निकासी का अध्ययन करने के लिए कंप्यूटर सिमुलेशन उपयोगी वर्णनात्मक विधियों में से एक है। आपातकालीन निकासी में निकासी के व्यवहार को समझना भी महत्वपूर्ण है। कुछ यात्रियों को शारीरिक अक्षमता हो सकती है जो व्हील चेयर या आवाजाही के लिए अन्य समर्थन पर निर्भर हो सकते हैं। यात्रियों की समग्र सुरक्षा में सुधार के लिए उनकी समय पर निकासी महत्वपूर्ण है। इसलिए, समग्र निकासी प्रक्रिया, आवश्यक सुरक्षित निकासी समय, उपलब्ध सुरक्षित निकासी समय, व्हीलचेयर पर यात्रियों के अनुपात और गैर-सहायता प्राप्त निकासी को समझने की आवश्यकता है। वास्तविक निकासी के दौरान निकासी के आपातकालीन निकास विकल्प व्यवहार को समझना आवश्यक है। निकाले गए लोगों के आपातकालीन निकास विकल्प व्यवहार का अध्ययन करने के लिए प्रयास किए जाने की आवश्यकता है। इसलिए, इस अध्ययन का मुख्य उद्देश्य विभिन्न प्रकार के मेट्रो स्टेशनों से निकासी के दौरान व्हीलचेयर सहायता प्राप्त और गैर-सहायता प्राप्त निकासी के लिए आवश्यक और उपलब्ध सुरक्षित निकासी समय का अध्ययन करना है। अन्य उद्देश्य विभिन्न उपकरणों और विधियों का उपयोग करके निकासी के विकल्प के व्यवहार का अध्ययन कर रहे हैं। इस थीसिस में आपातकालीन निकासी का अध्ययन करने के लिए व्यापक सिमुलेशन का उपयोग किया गया है। मेट्रो स्टेशन में आग और निकासी दोनों का अध्ययन किया गया है।

प्रयोग के डिजाइन का उपयोग आग और निकासी सिमुलेशन के विभिन्न कारकों को शामिल करने के लिए किया गया है। सिमुलेशन का उपयोग करके विभिन्न प्रकार के मेट्रो स्टेशनों से कुल निकासी समय की गणना की गई है। विभिन्न मेट्रो स्टेशनों पर अलग-अलग अग्नि स्थितियों के तहत उपलब्ध सुरक्षित निकासी समय की भी गणना की गई है। व्हीलचेयर सहायता प्राप्त और गैर-सहायता प्राप्त निकासी के लिए आंशिक प्रभावी खुराक की भी गणना की गई है। आपातकालीन निकासी में यात्रियों के बाहर निकलने की पसंद के व्यवहार को समझने के लिए विकल्प प्रयोग किया गया है। दो अलग-अलग प्रयोग किया गया है। एक स्टेशन के 3डी मॉडल के स्केच का उपयोग करके और कागज पर छपाई का। एक और प्रयोग आंशिक इमर्सिव वर्चुअल रियलिटी में किया गया है। परिदृश्य कुशल पसंद डिजाइन के अनुसार बनाए गए हैं। स्केच-अप 3D मॉडल और अवास्तविक इंजन आधारित आभासी वास्तविकता अनुभव के लिए अलग से घोषित वरीयता प्रयोग आयोजित किया गया है। उत्तरदाताओं को दिए गए तीन निकासों में

से एक को चुनने के लिए कहा गया और उनकी पसंद दर्ज की गई। असतत पसंद मॉडल डेटा के साथ कैलिब्रेट किया गया है। मानक और मिश्रित लॉगिट मॉडल उस डेटा के साथ कैलिब्रेट किया गया है। असतत पसंद मॉडल का उपयोग करके विभिन्न पर्यावरणीय और व्यक्तिगत कारकों और उनके प्रभावों की पहचान की गई है।

मशीन लर्निंग मॉडल (GNB, SVM, DT, RF, GBM, XGBOOST) को डेटा के साथ कैलिब्रेट किया गया है। उत्तरदाताओं की पसंद का अनुमान लगाने के लिए व्याख्यात्मक मशीन लर्निंग मॉडल का उपयोग किया गया है। सिमुलेशन अध्ययन के नतीजे बताते हैं कि सहायता प्राप्त निकासी सबसे कमजोर यात्री हैं क्योंकि ये सहायता प्राप्त निकासी लंबे समय तक धुएं के प्रभाव के कारण श्वासावरोध के लिए अतिसंवेदनशील होते हैं। सिमुलेशन परिणाम यह भी संकेत देते हैं कि गैर-सहायता प्राप्त निकासी पर धुएं का कोई प्रभाव नहीं पड़ता है। आपातकालीन निकास विकल्प व्यवहार अध्ययन के परिणाम इंगित करते हैं कि व्यवहार स्थितियों पर निर्भर करता है। कतार का समय आपातकालीन निकास पसंद व्यवहार में सबसे महत्वपूर्ण कारक पाया जाता है जिसके बाद दूरी और भीड़ का स्तर होता है। अध्ययन के परिणामों से संकेत मिलता है कि सुरक्षा ज्ञान नामक एक गुप्त कारक को शामिल करने से लॉगिट और मिश्रित लॉगिट मॉडल के मॉडल फिट में सुधार होता है। अध्ययन के परिणाम यह भी संकेत देते हैं कि मशीन लर्निंग मॉडल भी निकासी की पसंद के व्यवहार का अनुमान लगा सकते हैं। आभासी वास्तविकता प्रयोग के अध्ययन परिणामों से संकेत मिलता है कि आंशिक इमर्सिव आभासी वास्तविकता निकासी के आपातकालीन निकास पसंद व्यवहार की भविष्यवाणी कर सकती है। इस थीसिस में आपातकालीन निकास विकल्प व्यवहार का पूरी तरह से इमर्सिव वर्चुअल रियलिटी का उपयोग करके अध्ययन नहीं किया गया है। यह इस अध्ययन की सीमाओं में से एक है। इसके अलावा, इस अध्ययन में किए गए सिमुलेशन को वास्तविक डेटा या अभ्यास के साथ सत्यापित नहीं किया जा सकता है।

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## List of notations and abbreviations

|       |  |
|-------|--|
| ANOVA | Analysis of variance                           |
| ASET  | Available safe evacuation time                 |
| BDI   | Belief-desire-intension                        |
| CFD   | Computational fluid dynamics                   |
| DOE   | Design of experiments                          |
| DOF   | Degrees of freedom                             |
| FDS   | Fire dynamics simulator                        |
| FEC   | Fractional effective concentration             |
| FED   | Fractional effective dose                      |
| GBM   | Gradient boosting machine                      |
| GNB   | Gaussian naïve bayes                           |
| ICE   | Individual conditional expectation             |
| ICLV  | Integrated choice and latent variable          |
| MNL   | Multinomial logit                              |
| NIST  | National Institute of Standards and Technology |
| PADM  | Protective action decision model               |
| PDP   | Partial difference plot                        |
| PET   | Pre-evacuation time                            |
| RF    | Random Forest                                  |
| RSET  | Required safe evacuation time                  |
| RUM   | Random utility model                           |
| SFPE  | Standards for Fire Protection Engineers        |
| SSG   | Simulation and serious games                   |
| SVM   | Support vector machine                         |
| TVS   | Tunnel ventilation system                      |
| VR    | Virtual reality                                |
| XGBM  | Extreme gradient boosting machine              |