

**AMBULANCE LOCATION OPTIMIZATION FOR ENHANCED
COVERAGE AND SURVIVABILITY IN DELHI**

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**AMBULANCE LOCATION OPTIMIZATION FOR ENHANCED
COVERAGE AND SURVIVABILITY IN DELHI**

by

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*"Dedicated to
my beloved grandparents,
whose love and support will forever reside in my heart.
Thank you for being my guiding stars.*

CERTIFICATE

This is to certify that the thesis entitled “**Ambulance Location Optimization for Enhanced Coverage and Survivability in Delhi**” is being submitted by **Mrs. Shayesta Wajid** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy**. This is a record of the research work and is entirely carried out by her under my supervision and guidance. The research report presented in this thesis has not been submitted for the award of any other degree or diploma.

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ABSTRACT

Well-responsive and efficient emergency medical services are in great demand across the world. The emergency services system guarantees safe transportation of a patient to the hospital and provides on-site stabilization to the patient. Researchers worldwide have been investigating multiple solution methods and approaches to improve the timeliness and operations of these services. What aggravates the situation is the lack of suitable ambulance fleet size, severe road congestion, and lack of proper positioning of ambulances to deal with fluctuations in demand and travel times. India has a very fragmented nature of emergency services, having different services for each state with no set operational standards for these services. The lack of evaluation studies poses a problem in analyzing the level of service of these services and their subsequent improvements.

This thesis works on two significant aspects of emergency services in Delhi. The first aspect is to analyze the current level of service of the system and the second is to build an efficient system by optimally locating the available fleet of ambulances. In this regard, first, the thesis estimates the variability in response times due to congestion. An important contribution of this study is formalizing a new model for estimating survival probability for life-threatening cases in Delhi. What distinguishes this study is that it addressed each of the life-threatening and non-life-threatening calls using separate performance measures. Secondly, the study tries to maximize the number of non-life-threatening calls attended by ambulances (coverage) by providing multiple backup ambulances for each call site. Thirdly, the study builds a new time-dependent survival model to incorporate the effect of varying demand and congestion on survivability. Lastly, trade-off solutions are obtained for the two performance measures (coverage and survivability) and the emergency service system.

The study quantified the effect of incorporating variability in response times and demand on these performance measures. Besides, the difference in performance measures with deterministic and stochastic versions of the problems was evaluated. The thesis was motivated to find a single set of ambulance locations for the day to cater to varying demands and avoid extra relocation costs. Therefore, previous approaches with relocations and the current methodology were also compared. Due to the larger problem size, the study also explored various metaheuristic techniques. It developed a new problem-tailored greedy heuristic

approach for a quick solution to the problems at hand. These approaches were evaluated and analyzed for several test instances to observe their closeness to the optimal solution.

The study acquired six months of call records and existing ambulance locations from Centralized Accidents and Trauma Services (CATS), the public emergency services in Delhi. The calls dataset was pre-processed, segregated into high and low priority, and finally clustered for incorporation as destination sites into the optimization model. New optimal ambulance locations gave a 20% improvement on the existing system and were more homogeneously distributed across the city. Moreover, the incorporation of uncertainty in travel times showed a dip in the coverage and survival parameters by 8% and 16%, respectively. This study also showed that previous research that relocates ambulances across multiple periods of the day lead to higher relocation cost. It was also noted that the two methods to address vehicle unavailability, i.e., estimation of busy probability and providing backup coverage, both give a similar performance on the coverage. The application of models to a large dataset of Delhi required the use of metaheuristic approaches that not only reduced the runtime significantly but also provided near-optimal solutions with a marginal gap. The study has provided the policymakers with a set of feasible ambulance locations and the best feasible solution to be implemented in Delhi.

Keywords: Emergency Medical Services, Double Standard Model, Integer Programming, Stochastic, Robust

सार

पूरी दुनिया में अच्छी प्रतिक्रियाशील और कुशल आपातकालीन चिकित्सा सेवाओं की भारी मांग है। आपातकालीन सेवा प्रणाली मरीज को अस्पताल तक सुरक्षित परिवहन की गारंटी देती है और मरीज को उनकी स्थान पर स्थिरीकरण प्रदान करती है। दुनिया भर के शोधकर्ता इन सेवाओं की समयबद्धता और संचालन में सुधार के लिए कई समाधान विधियों और दृष्टिकोणों की जांच कर रहे हैं। उपयुक्त एम्बुलेंस की कमी, सड़कों पर भीड़, और एम्बुलेंस की ज़रूरत में उतार-चढ़ाव से निपटने के लिए एम्बुलेंस की अनुचित स्थिति के कारण स्थिति बिगड़ती है। भारत में आपातकालीन सेवाओं की प्रकृति बहुत खंडित है, प्रत्येक राज्य के लिए अलग-अलग सेवाएँ हैं और इन सेवाओं के लिए कोई निर्धारित परिचालन मानक नहीं हैं। मूल्यांकन अध्ययन की कमी इन सेवाओं की सेवा के स्तर और उनके बाद के सुधारों का विश्लेषण करने में समस्या पैदा करती है।

यह थीसिस दिल्ली में आपातकालीन सेवाओं के दो महत्वपूर्ण पहलुओं पर काम करती है। पहला पहलू आपातकालीन सेवा प्रणाली की सेवा के वर्तमान स्तर का विश्लेषण करना है और दूसरा एम्बुलेंस के उपलब्ध का इष्टतम स्थान बनाकर एक कुशल प्रणाली का निर्माण करना है। इस संबंध में, सबसे पहले, थीसिस भीड़भाड़ के कारण प्रतिक्रिया समय में परिवर्तनशीलता का अनुमान लगाती है। इस अध्ययन का एक महत्वपूर्ण योगदान दिल्ली में जीवन-घातक मामलों के लिए जीवित रहने की संभावना का आकलन करने के लिए एक नए मॉडल को औपचारिक रूप देना है। इस अध्ययन में जो बात अलग है वह यह है कि इसने अलग-अलग प्रदर्शन उपायों का उपयोग करके जीवन-घातक और गैर-जीवन-घातक प्रत्येक मांग को संबोधित किया। दूसरे, अध्ययन प्रत्येक कॉल साइट के लिए कई पूर्तिकर एम्बुलेंस प्रदान करके एम्बुलेंस (आवृत्त क्षेत्र) द्वारा सेवा किए गए गैर-जीवन-घातक कॉल की संख्या को अधिकतम करने का प्रयास करता है। तीसरा, अध्ययन उत्तरजीविता पर अलग-अलग मांग और भीड़भाड़ के प्रभाव को शामिल करने के लिए एक नया समय-निर्भर उत्तरजीविता मॉडल बनाता है। अंत में, दो प्रदर्शन उपायों (आवृत्त क्षेत्र और उत्तरजीविता) और आपातकालीन सेवा प्रणाली के लिए व्यापार-बंद समाधान प्राप्त किए जाते हैं।

अध्ययन ने इन प्रदर्शन उपायों पर प्रतिक्रिया समय और मांग में परिवर्तनशीलता को शामिल करने के प्रभाव को निर्धारित किया। इसके अलावा, समस्याओं के नियतात्मक और स्टोकेस्टिक संस्करणों के साथ प्रदर्शन उपायों में अंतर का मूल्यांकन किया गया था। थीसिस को अलग-अलग मांगों को पूरा करने और अतिरिक्त स्थानांतरण लागत से बचने के लिए दिन के लिए एम्बुलेंस स्थानों का एक सेट खोजने के लिए प्रेरित किया गया था। इसलिए, स्थानांतरण के साथ पिछले दृष्टिकोण और वर्तमान पद्धति की भी तुलना

की गई। समस्या के बड़े आकार के कारण, अध्ययन ने विभिन्न मेटाह्यूरीस्टिक तकनीकों का भी पता लगाया। इसने मौजूदा समस्याओं के त्वरित समाधान के लिए एक नया समस्या-अनुरूप ग्रीडी अनुमान विकसित किया। इष्टतम समाधान के प्रति उनकी निकटता का निरीक्षण करने के लिए कई परीक्षण उदाहरणों के लिए इन दृष्टिकोणों का मूल्यांकन और विश्लेषण किया गया।

अध्ययन में दिल्ली में सार्वजनिक आपातकालीन सेवाओं, सेंट्रलाइज्ड एक्सीडेंट्स एंड ट्रॉमा सर्विसेज (कैट्स) से छह महीने के कॉल रिकॉर्ड और मौजूदा एम्बुलेंस स्थानों का अधिग्रहण किया गया। कॉल डेटासेट को पूर्व-संसाधित किया गया, उच्च और निम्न प्राथमिकता में अलग किया गया, और अंततः अनुकूलन मॉडल में गंतव्य साइटों के रूप में शामिल करने के लिए क्लस्टर किया गया। नए इष्टतम एम्बुलेंस स्थानों ने मौजूदा प्रणाली में 20% सुधार दिया और पूरे शहर में अधिक समान रूप से वितरित किया गया। इसके अलावा, यात्रा के समय में अनिश्चितता के समावेश से कवरेज और उत्तरजीविता मापदंडों में क्रमशः 8% और 16% की गिरावट देखी गई। इस अध्ययन से यह भी पता चला है कि पिछले शोध से पता चलता है कि दिन के कई समय में एम्बुलेंस को स्थानांतरित करने से स्थानांतरण लागत अधिक हो जाती है। यह भी नोट किया गया कि वाहन की अनुपलब्धता को संबोधित करने के दो तरीके, यानी, व्यस्त संभावना का अनुमान और बैकअप कवरेज प्रदान करना, दोनों कवरेज पर समान प्रदर्शन देते हैं। दिल्ली के बड़े डेटासेट में मॉडलों के अनुप्रयोग के लिए मेटाह्यूरीस्टिक दृष्टिकोण के उपयोग की आवश्यकता थी, जिसने न केवल रनटाइम को काफी कम कर दिया, बल्कि सीमांत अंतर के साथ लगभग-इष्टतम समाधान भी प्रदान किया। अध्ययन ने नीति निर्माताओं को व्यवहार्य एम्बुलेंस स्थानों का एक सेट और दिल्ली में लागू करने के लिए सर्वोत्तम संभव समाधान प्रदान किया है।

कीवर्ड: आपातकालीन चिकित्सा सेवाएँ, दोहरा मानक मॉडल, पूर्णांक प्रोग्रामिंग, स्टोकेस्टिक, मजबूत

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List of Abbreviations

AACM	Ambulance Allocation Capacity Model
AAPI	American Association of Physicians of Indian Origin
ACO	Ant Colony Optimization
AIC	Akaike Information Criterion
ALS	Advance Life Support
AMEXCLP	Adjusted Maximum Expected Coverage Location Problem
AVL	automatic vehicle location
BLS	Basic Life Support
CATS	Centralized Accidents and Trauma Services
cc-DSM	Chance Constrained Double Standard Model with Deterministic Coverage
cc-DSSM	Chance Constrained Double Standard Model with Stochastic Coverage
cc-EDSM	Chance Constrained Expected Double Standard Model
CPR	Cardiopulmonary resuscitation
DACL	Dynamic Available Coverage Location
DALYs	Disability-adjusted life years
d-DSM	Dynamic Double Standard Model
DRCL	Dynamic Redeployment Coverage Model
DSM	Double Standard Model
DSRSM	Double Standard Robust Survival Model
DSSM	Double Standard Stochastic Model
EM	expectation-maximization
EMALP	Maximal Availability Location Problem with hypercube model
EMEXCLP	Maximum Expected Coverage Location Problem with hypercube model
EMRI	Emergency Management and Research Institute
EMT	Emergency Medical Technician
FLEET	Facility-Location, Equipment-Emplacement Technique
GA	Genetic Algorithm
GD	Generational Distance
GEMSA	Gujarat Emergency Medical Services Authority
GMM	Gaussian Mixture Model

GVNS	General Variable Neighbourhood Search
HOSC	Hierarchical Objective Set Covering
HV	Hypervolume
LSCP	Location Set Covering Problem
MALP	Maximal Availability Location Problem
MCDM	Multi-Criteria Decision Making
MCLP	Maximal Covering Location Problem
MCLP+PR	Maximal Covering Location Problem with probabilistic response time
m-DSM	Multi-period Double Standard Model
MECRP	Maximum Expected Coverage Relocation Problem
MEPLP-HR	Maximum Expected Performance Location Problem for Heterogeneous Regions
MESLMHP	Maximal Expected Survival Location Model for Heterogeneous Patients
MEXCLP	Maximum Expected Coverage Location Problem
MILP	Mixed Integer Linear Problem
MIP	Mixed Integer Problem
MOCLP	Multi-Objective Competitive Location Problem
MOEA/D	Multi-Objective Evolutionary Algorithm with Decomposition
MOPSO	Multi-Objective Particle Swarm Optimization
MoRTH	Ministry of Road Transport & Highways
MOSDSM	Multi-Objective Stochastic Double Standard Model
MPBDCM	Multiperiod Backup Double Covering Model
MSLP	Maximal Survival Location Problem
NHS	National Health Services
NPS	Number of Pareto Solutions
NSGAI	Non-dominated Sorting Genetic Algorithm II
NSGAIII	Non-dominated Sorting Genetic Algorithm III
O-D	origin-destination
OHCA	Out-of-Hospital Cardiac Arrest
PAES	Pareto Archived Evolution Strategy
PLSCP	Probabilistic Location Set Covering Problem
PROFLEET	Probabilistic Facility-Location, Equipment-Emplacement Technique
PTA	Patient Transport Ambulances

PTD	Pre-trip delay
Q-MALP	Queuing Maximal Availability Location Problem
QPLSCP	Queuing Probabilistic Location Set Covering Problem
r-DSM	Robust Double Standard Model
RECRP	Robust Expected Covering Relocation Problem
REL-P	LSCP and MCLP with service time reliability
ROC	Receiver Operator Characteristic
ROSC	Return of Spontaneous Circulation
RT	Response Time
S	Spacing metric
SD	Standard Deviation
SPEA	Strength Pareto Evolutionary Algorithm
TEAM	Tandem Equipment Allocation model
TH	Time to hospital
TIMEXCLP	Maximal Expected Covering Location Problem with Time Variation
TOPSIS	Technique for Order of Preferences by Similarity to Ideal Solution
TT	Travel time of ambulance from base location to demand site
VND	Variable Neighbourhood Descent
VNS	Variable Neighbourhood Search
VNS+LB	Variable Neighbourhood Search with Local Branching