

MODELING FOR SOURCE-BASED SOLID WASTE MANAGEMENT

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INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2025

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by

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Department of Mechanical Engineering

Submitted

in fulfillment of the requirement of the degree of Doctor of Philosophy

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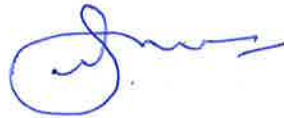


INDIAN INSTITUTE OF TECHNOLOGY DELHI

JULY 2025

CERTIFICATE

This is to certify that the thesis titled Modeling for Source-based Solid Waste Management, submitted by Made Adi Widyatmika (2020MEZ8600) to the Indian Institute of Technology Delhi for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work done by him under our supervision. The thesis has reached the standards, fulfilling the requirements of the regulations related to the award of a degree. The contents of this thesis, in full or in parts, have not been submitted to any other institute or university for the award of any degree or diploma.



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Place: New Delhi

Date: July 17th, 2025

Acknowledgments

All praise and gratitude to the Almighty *Brahman, Ida Sanghyang Widi Wasa*, for His abundant blessings and kindness, which have given me the strength to complete my research and Ph.D. thesis on time successfully.

I deeply thank my thesis advisor, Prof. Nomes Bolia, for his invaluable guidance, constructive feedback, and unwavering encouragement throughout my Ph.D. journey. His passion and expertise, particularly in simulation and modeling, have been an immense source of inspiration and knowledge. I aim to carry these skills and insights in my future learning and research endeavors.

I sincerely appreciate the feedback provided by Prof. S.G. Deshmukh, Prof. Varun Ramamohan, and Prof. Gourav Dwivedi, members of the Student Research Committee (SRC), on my research work. I am also incredibly grateful for the opportunity to serve as a teaching assistant under Prof. S. G. Deshmukh, which provided invaluable learning experiences.

My heartfelt thanks to the Ministry of Education, Government of India, for awarding me the Doctoral Fellowship in India for ASEAN (DIA) scholarship, which enabled me to pursue my doctoral studies at the Department of Mechanical Engineering, Indian Institute of Technology Delhi (IITD). I also appreciate all the respondents and waste management stakeholders in Indonesia and Delhi who actively participated in the data collection process during my survey.

I am deeply grateful to the Public Systems Lab (PSL) members for contributing to a memorable and enriching experience on campus. Special thanks to Dr. Mohit Tyagi, Prashant Kumar, and Gajendra Nagar for their constant support during my lab work and stay on campus.

I would like to express my profound gratitude to my parents, Bapak Nengah Medera and Ibu Made Karwini, for their unconditional love and unwavering support—both materially and spiritually, especially the invaluable help in caring for our children, Putu Arya Sindhu Dhaneswara, Made Arya Manubhawa Sidhartha, and Nyoman Arya Winayaka Adiputra. To my children, thank you for your understanding and patience during this journey; your love and encouragement have been a constant source of strength.

Last but not least, my deepest thanks to my beloved wife, Made Widayanti, for standing beside me with endless love and support. Her unwavering encouragement and strength have been a constant source of comfort and motivation throughout my Ph.D. journey in New Delhi.

Your love and support will forever be the foundation of my life. *Astu!*



Made Adi Widyatmika

Dedicated to

My parent, my wife, and my kids....

Abstract

This thesis explores innovative approaches to optimize source-based solid waste management in Indonesia, focusing on Jakarta and Bali. The study addresses critical gaps in understanding citizen and waste collector perceptions, the effectiveness of non-financial interventions, and the application of system dynamics modeling to enhance waste management efficiency and sustainability. Guided by four research objectives, the research analyzes citizens' perceptions of waste segregation and composting, evaluates waste collectors' views on collection, transportation, and disposal processes, assesses the effectiveness of behavioral interventions, and develops a culturally tailored system dynamics model for Bali.

Analyzing citizens' perceptions of waste segregation and composting using logistic regression analysis revealed that providing free dustbins and ensuring reliable, non-remixed waste collection significantly motivate households to segregate waste, with composting incentives resonating strongly among lower-income groups. These findings underscore the need for decentralized composting systems that address economic constraints in developing nations. For evaluating waste collectors' perception, PLS-SEM analysis highlighted that tangibility, reliability, assurance, and empathy influence job satisfaction and environmental responsibility among waste collectors. This evaluation emphasizes improving working conditions and incorporating cultural considerations to enhance systemic efficiency.

The effectiveness of behavioral interventions assessment using an RCT framework demonstrated that non-financial interventions like nudges, rooted in behavioral theories such as the Theory of Planned Behavior and the Human of Motivation Theory, can effectively drive household waste segregation. Context-specific interventions that consider

occupation and demographic diversity were particularly impactful. The system dynamics model developed for Bali integrated informal sector participation, temple-specific waste generation, and cultural elements. This model simulated feedback loops and policy scenarios, providing a replicable framework for assessing long-term intervention impacts and optimizing waste management strategies.

The model evaluates dynamic policy measures, highlighting the most desired urban incentive: the guarantee of unmixing waste after collection and transportation. It also emphasizes the crucial role of formal waste collectors, showing that waste management service quality affects their environmental responsibility, mediated by job satisfaction. In the non-financial incentives trial, the study reveals that the residents' demographic characteristics significantly influence the effectiveness of non-financial nudges. Additionally, the study highlights the importance of cultural and religious practices in shaping waste management behaviors, ensuring a scalable and context-sensitive framework.

The findings emphasize the importance of trust, systemic reliability, cultural integration, and behavioral insights in fostering effective and sustainable waste management practices. This research contributes insights to global efforts to develop inclusive, cost-effective, and scalable waste management systems tailored to local contexts by combining quantitative methods with cultural and behavioral considerations.

Keywords: Source-based waste management, solid waste management, household waste, citizen's perception, segregation, composting, waste collector, waste management system, system dynamics, non-financial incentives, culture and religious practice.

सारांश

यह शोध इंडोनेशिया में स्रोत-आधारित ठोस कचरा प्रबंधन को अनुकूलित करने के लिए अभिनव दृष्टिकोणों की जांच करता है, जो मुख्य रूप से जकार्ता और बाली पर केंद्रित है। यह अध्ययन नागरिकों और कचरा संग्राहकों की धारणाओं, गैर-वित्तीय हस्तक्षेपों की प्रभावशीलता, और प्रणालीगत गतिकी मॉडलिंग के उपयोग को समझने में महत्वपूर्ण अंतराल को संबोधित करता है ताकि कचरा प्रबंधन की दक्षता और स्थिरता को बढ़ाया जा सके। चार शोध उद्देश्यों द्वारा निर्देशित, यह शोध कचरा पृथक्करण और खाद बनाने के संबंध में नागरिकों की धारणाओं का विश्लेषण करता है, संग्रह, परिवहन और निपटान प्रक्रियाओं पर कचरा संग्राहकों के विचारों का मूल्यांकन करता है, व्यवहारिक हस्तक्षेपों की प्रभावशीलता का आकलन करता है, और बाली के लिए सांस्कृतिक रूप से अनुकूल प्रणालीगत गतिकी मॉडल विकसित करता है।

कचरा पृथक्करण और खाद बनाने पर नागरिकों की धारणाओं का तार्किक प्रतिगमन विश्लेषण का उपयोग करते हुए पता चला कि मुफ्त कचरा डिब्बे उपलब्ध कराना और विश्वसनीय, गैर-मिश्रित कचरा संग्रहण सुनिश्चित करना घरेलू स्तर पर कचरा पृथक्करण को प्रोत्साहित करता है। खाद बनाने के लिए प्रोत्साहन विशेष रूप से निम्न-आय वर्ग के लोगों में प्रभावशाली साबित हुआ। ये निष्कर्ष विकासशील देशों में आर्थिक बाधाओं को संबोधित करने वाले विकेन्द्रीकृत खाद बनाने की प्रणालियों की आवश्यकता को रेखांकित करते हैं। कचरा संग्राहकों की धारणाओं का मूल्यांकन करने के लिए आंशिक न्यूनतम वर्ग विधि विश्लेषण ने दिखाया कि ठोस कचरा प्रबंधन में "स्पष्टता", "विश्वसनीयता", "आश्वासन", और "सहानुभूति" जैसे कारक उनके नौकरी से संतोष और पर्यावरणीय उत्तरदायित्व को प्रभावित करते हैं। यह मूल्यांकन कार्य परिस्थितियों में सुधार और सांस्कृतिक विचारों को शामिल करने पर जोर देता है ताकि प्रणालीगत दक्षता को बढ़ाया जा सके।

व्यवहारिक हस्तक्षेपों की प्रभावशीलता के आकलन के लिए एक यादृच्छिक नियंत्रण परीक्षण ढांचे का उपयोग किया गया। इसने दर्शाया कि नियोजित व्यवहार सिद्धांत और मानव प्रेरणा सिद्धांत जैसे व्यवहारिक सिद्धांतों पर आधारित गैर-वित्तीय हस्तक्षेप, घरेलू स्तर पर कचरा पृथक्करण को प्रभावी ढंग से प्रोत्साहित कर सकते हैं। विशेष रूप से, पेशा और जनसांख्यिकीय विविधता को ध्यान में रखने वाले संदर्भ-विशिष्ट हस्तक्षेप अधिक प्रभावशाली साबित हुए।

बाली के लिए विकसित प्रणालीगत गतिकी मॉडल ने अनौपचारिक क्षेत्र की भागीदारी, मंदिर-विशिष्ट कचरा उत्पादन, और सांस्कृतिक तत्वों को शामिल किया। इस मॉडल ने प्रतिक्रिया चक्रों और नीति परिदृश्यों का अनुकरण किया, जो दीर्घकालिक हस्तक्षेप प्रभावों का आकलन करने और कचरा प्रबंधन रणनीतियों को अनुकूलित करने के लिए एक पुनरुत्पादनीय ढांचा प्रदान करता है। यह मॉडल गतिशील नीति उपायों का मूल्यांकन करता है, यह दर्शाता है कि संग्रह और परिवहन के बाद कचरे को गैर-मिश्रित बनाए रखने की गारंटी सबसे अधिक वांछित शहरी प्रोत्साहन है। यह औपचारिक कचरा संग्राहकों की महत्वपूर्ण भूमिका पर भी जोर देता है, यह दिखाते हुए कि कचरा प्रबंधन सेवा की गुणवत्ता उनके पर्यावरणीय उत्तरदायित्व को प्रभावित करती है, जिसे नौकरी से संतोष द्वारा मध्यस्थ किया जाता है।

गैर-वित्तीय प्रोत्साहनों के परीक्षण में, अध्ययन से यह पता चलता है कि निवासियों की जनसांख्यिकीय विशेषताएं गैर-वित्तीय प्रोत्साहनों की प्रभावशीलता को महत्वपूर्ण रूप से प्रभावित करती हैं। इसके अतिरिक्त, यह अध्ययन कचरा प्रबंधन व्यवहारों को आकार देने में सांस्कृतिक और धार्मिक प्रथाओं के महत्व को उजागर करता है, जिससे एक स्केलेबल और संदर्भ-संवेदनशील ढांचा सुनिश्चित होता है।

निष्कर्षों से पता चलता है कि प्रभावी और स्थायी कचरा प्रबंधन प्रथाओं को बढ़ावा देने में विश्वास, प्रणालीगत विश्वसनीयता, सांस्कृतिक एकीकरण, और व्यवहारिक अंतर्दृष्टि का महत्व है। यह शोध स्थानीय संदर्भों के अनुरूप समावेशी, किफायती, और स्केलेबल कचरा प्रबंधन प्रणालियों को विकसित करने के वैश्विक प्रयासों में अंतर्दृष्टि प्रदान करता है, जो सांस्कृतिक और व्यवहारिक विचारों के साथ मात्रात्मक तरीकों को जोड़ता है।

मुख्य शब्द: स्रोत-आधारित कचरा प्रबंधन, ठोस कचरा प्रबंधन, घरेलू कचरा, नागरिकों की धारणा, पृथक्करण, खाद बनाना, कचरा संग्राहक, कचरा प्रबंधन प्रणाली, प्रणालीगत गतिकी, गैर-वित्तीय प्रोत्साहन, संस्कृति और धार्मिक प्रथा।

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