

**System Dynamics Study and Assessment on  
Municipal Solid Waste Management for Macao**

by

Choi Fei

**Supervisor:** Prof. Wang Zhishi

A thesis submitted in partial fulfillment of the  
Requirements for the degree of

Master of Science in Civil Engineering,  
Hydraulics and Environmental Engineering



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System Dynamics Study and Assessment on Municipal Solid  
Waste Management for Macao

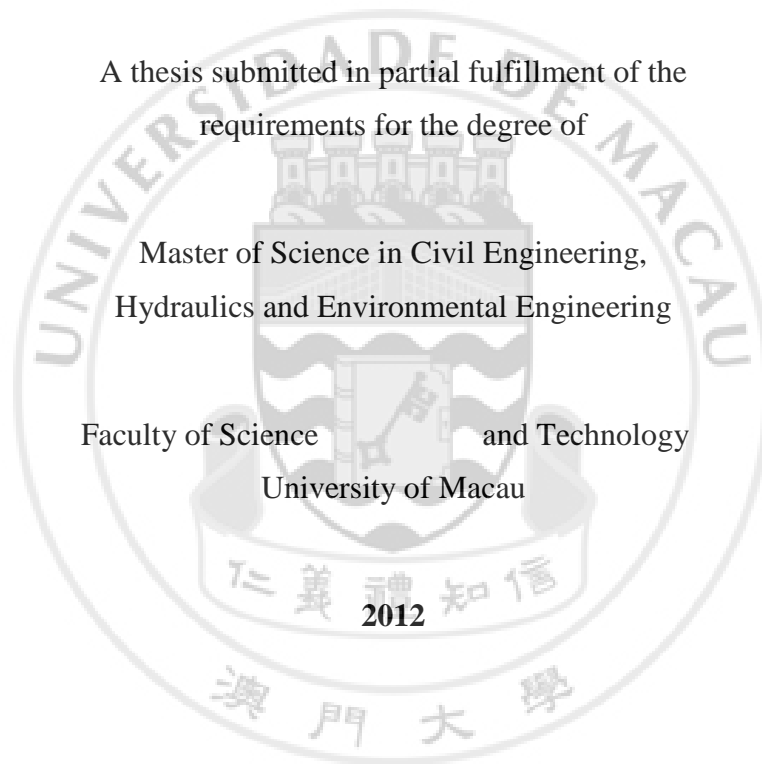
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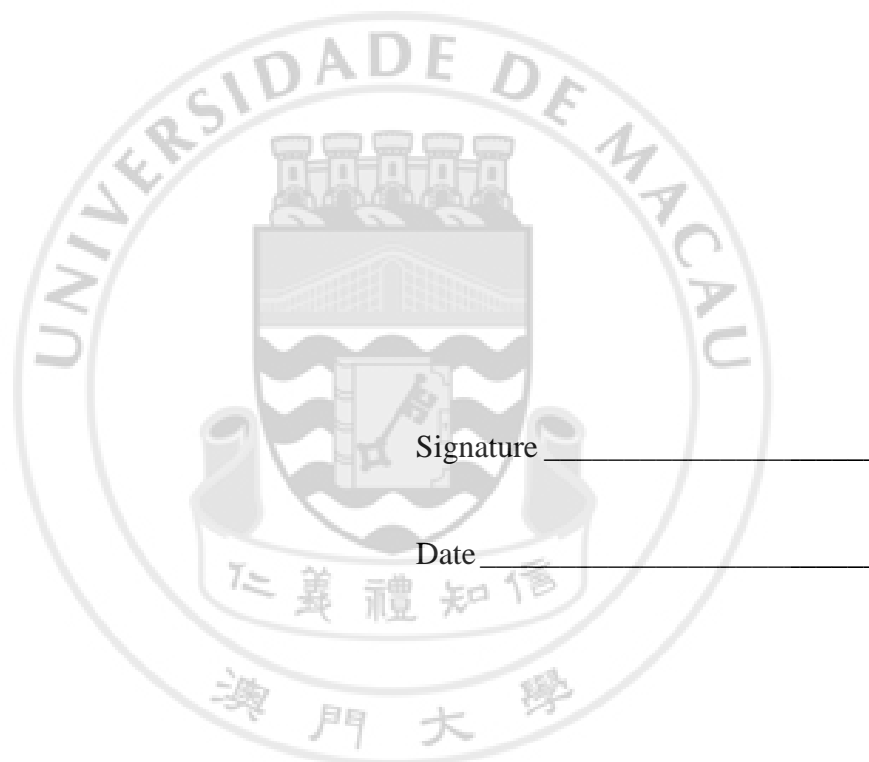
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**University of Macau**

**Abstract**

**System Dynamics Study and Assessment on Municipal Solid Waste  
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**by Choi Fei**

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**Department of Civil and Environmental Engineering**

Municipal Solid Waste (MSW) generation and management have currently graduated to a global problem, vexing the social, environmental, economic and political challenges. Providing a reliable assessment method for curbing the waste generation is considered helpful for assisting sustainable planning, scientific decision-making and implementation of waste management and policy processes, especially in rapidly growing regions like Macau. Being a small, densely populated and rapidly growing city (land area of 29.5 km<sup>2</sup>; population of 542,200 and GDP of Mop 143,091,490 in 2009) [1], Macao has one of the highest per capita waste generation in the world accounting for an average of 1.64 kg per capita per day in 2009 [2]. Integrated MSW prediction is crucial for the MSW assessment and management of Macao that analyzed its relationship with the environmental, economic and social variables, figure out the key variables and achieved the optimized strategies. This study presents a system dynamics (SD) approach to predict the trend of environmental, economic and social performances that underlie the key variables of Municipal Solid Waste (MSW) management practice in Macao. Literature review, regression and sensitivity analysis were conducted to identify the key variables, which then converted to stock-flow diagrams. MSW generation, Population (*P*), Salary Median (*SM*), Government Spending (*GS*), Gross Domestic Product (*GDP*), Hotel Rooms (*HR*), Gaming Revenue (*GR*), Tourists (*T*), Import Material and Half-product (*IMH*) of Macao from 2000 to 2022 are studied using Vensim modeling, theories of system dynamics and statistic analysis. The MSW Management model is

composed of three modules which are Domestic Solid Waste (DSW) Modules, Industrial and Commercial Solid Waste (ICSW) Modules and Coastal Solid Waste (CSW) Module. The simulation results showed that the generation of MSW and the per capita generation of waste undergo a general increase during the period of forecast, due to the steady increase in the dimensions of the influencing socio-economic and economic variables in Macao. According to the simulation results: 1) The total MSW will reach 907,166.9 tons by 2022. It corresponds to 906,509.2 tons per year of MSW need to be treated by the Macao Incineration Plant (the recycled material will be recycled). If the treatment capacity is same as 2012, it has exceeded the existing maximum yearly treatment capacity of 576,650 tons of Macao Incineration Plant. 2) The daily mean MSW produced per capita of Macao sharply increase from 1.64 kg per capita per day in 2009 to 3.5 kg per capita per day in 2022. 3) The DSW will reach 162,724.03 tons by 2022. 4) The ICSW (CSR) will reach 654,081.1 tons by 2022. 5) The ICSW (Non-CSR) will reach 89,704.0 tons by 2022. 6) The CSW will decrease to a negligible level. 7) The recycled material will reach 657.7 tons by 2022. The resulting model was validated using data collected from the Statistics and Census Service and the Environmental Protection Bureau, the government of Macao Special Administrative Region (SAR). This study contributes to the body of waste management knowledge by having produced an integrated dynamic model that not only provides an improved understanding of how MSW management activities are dynamically influenced by the key variables, but is also capable of providing strategies for waste management in stead of enlarging the incineration plant.

This research provides the results of three primary research objectives: First, it is to estimate the possible future scenario of MSW generation at environmental, economic and social variables rate using a prediction model for Macao and determining the limitations according the existing treatment capacity. Second, it is to describe the dynamic relationships between the contributing variables and MSW generation, explore possibility of integrating systems dynamics methodology for a comprehensive assessment of waste management system and their impacts so as to provide assessments though a systems perspective and contribute to sustainable planning. The third objective was to assess the possibilities of developing alternate solutions for the issue of urban solid waste management of Macao. By the evaluation procedure of

current methods of management, it would be possible to make comprehensive understand and better decision in administering and planning of MSW to attenuate adverse future environmental, economic and social impacts.



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## LIST OF ABBREVIATIONS

For the purposes of this dissertation the following abbreviations have been used

**BMW:** Biodegradable Municipal Waste

**CSR:** Companhia de Sistemas de Resíduos, Limitada (Macau Waste Systems Company Limited)

**CSW:** Coastal Solid Waste

**DSPA:** Environmental Protection Bureau

**DSW:** Domestic Solid Waste

**ELVs:** End of Life Vehicles

**FAO:** Food and Agricultural Organization

**GDP:** Gross Domestic Products

**GHG:** Green House Gases

**IACM:** Civic and Municipal Affairs Bureau

**ICSW:** Industrial and Commercial Solid Waste

**IMSWM:** Integrated Municipal Solid Waste Management

**ISWM DST:** Integrated Solid Waste Management Decision Support Tool

**IUCN:** International Union for Conservation of Nature

**Macao SAR:** Macao Special Administrative Region

**MIRP:** Macao Incineration Plant

**MSW:** Municipal Solid Waste

**OECD:** Organization for Economic Cooperation and Development

**PAYT:** Pay-As-You-Throw

**PET:** Polyethyleneterephthalate

**RCAC:** Resource Conservation and Recovery Act (RCRA)

**RFMB:** Recycling Fund Management Board

**SD:** System dynamics

**UNEP:** United Nations Environmental Program

**UNESCO:** United Nations Educational Scientific and Cultural Organization

**USEPA:** United States Environmental Protection Agency

**VCF:** Volume-based Collection Fee

**WCS:** World Conservation Strategy

**WMM:** Waste Management Models

**WRAP:** Waste and Resources Action Program

**WWF:** World Wildlife Fund

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## DEDICATION

I would like to dedicate my thesis to my family especially my father.

