Vol. 10 · October 2012
Print ISSN 2012-3981 • Online ISSN 2244-0445
doi: http://dx.doi.org/10.7719/jpair.v10i1.187

JPAIR Multidisciplinary Research is produced by PAIR,
an ISO 9001:2008 QMS certified by AJA Registrars, Inc.

Development of Solid Waste Recovery Model for a University Using System Dynamics

RYAN B. LAYTANI
ORCID No. 0000-0003-2191-3872
rlaytani@gmail.com

BENEDICT B. BANQUIL
rlaytani@gmail.com
bbbanquil@gmail.com
University of Cebu, Cebu City, Philippines

Abstract - A solid waste recovery model for a university is developed using system dynamics (SD). This model specifically focuses on cyclical cause-and-effect relationships about the solid waste system in University of Cebu. Dynamic behavior of three recovery policies, i.e. Policy 1: Recycling, Policy 2: Composting, and Policy 3: Recycling and Composting, is analyzed in the model using different field information and justified assumption. A software package called Vensim® is likewise utilized in designing the modeling structure, mapping the formulated equation, and performing the computer simulation. Vensim® is further used in generating graphics illustrating the system's behavior during the first ten years of policy implementation, i.e. 2012-2022. Time-series graphs suggest Policy 3 as most appropriate to be implemented in the university. Among the three policies, Policy 3 sets the least residual waste, greatest fund savings, and earliest break-even in the entire phase of simulation. Policy 3 is also the most environmentally effective, economically profitable, and socially acceptable among the three policies. Although Policy 3 entails an investment in setting a materials recovery facility (MRF), simulation results showed that it can be regained within 4.25 years of MRF productivity. This paper also recommends measures for model improvement and suggests initial strategies for policy implementation.

Keywords - Composting; materials recovery facility; RA 9003; recovery; recycling; solid waste management; system dynamics; University of Cebu; vermicomposting

INTRODUCTION

Ineffective solid waste collection and unsanitary disposal facility are perennial problems in most urban areas around the world today. Such problems have worsened in areas where rates of economic development and population growth exceed their carrying capacities and resource capabilities. Affluent lifestyles like continued consumption of products having higher proportions of non-biodegradable material further aggravate the waste problems. In the Philippines, the lack of guidelines in properly managing such wastes has led to the conceptualization of RA 9003 or the Ecological Solid Waste Management Act of 2000.

RA 9003 is a law that provides sound waste management programs, creates institutional mechanisms and incentives, declares prohibited acts and penalties, and appropriates waste management funds. It ensures proper segregation, collection, transport, storage, treatment, and disposal of solid waste using the best practices defined in ecological waste management. The law also promotes a paradigm of recovering wastes that are actually considered as resources situated only in wrong places. RA 9003 stipulates mandatory targets in diverting solid waste from its ultimate disposal to various dumpsites and landfills in the country.

Most solid wastes in Cebu City, dubbed as the second most significant metropolitan center in the Philippines, are disposed at the 17-hectare Inayawan dumpsite (SunStar Cebu, 2011). The dumpsite was designed as a sanitary landfill but ended up as an open dumpsite whose operations lack considerations regarding environmental, health, and safety standards. Its current operation is actually a violation of Section 37 of RA 9003 that prohibits the use of open dumpsites in the country. The Cebu City government cannot immediately close the said facility, which is already operating beyond the designed capacity, due to difficulty in establishing its suitable replacement.

Many local government units (LGUs) have failed to accomplish certain provisions in RA 9003, especially those involving targets and deadlines, because of insufficient capacity from local organization and weak determination from elected officials. As implementing agency, LGUs are mandated to operate an effective waste management system but failed due to inadequate administrative, financial, and technical capacities. This scenario worsens when no local officials are given sanctions for failing to comply with some RA 9003 provisions.

Certain sections in RA 9003 discuss the responsibilities of educational institutions in achieving an effective solid waste management. Section 21 mandates these institutions to segregate and store the solid waste according to compostable, non-recyclable, recyclable, and special. Section 45 provides incentives and financial assistances to the institutions if they implement innovative recovery activities. Section 56 further requires the institutions to strengthen the integration of resource conservation and recovery topics into their academic curriculum.

University of Cebu is a co-educational, non-sectarian, and private academic institution in Cebu City, Philippines that was established in 1964 (UC, 2010). Through the leadership of Atty. August W. Go, the university now has four campuses namely UC-Main, UC-Banilad, UC-LM (Lapu-Lapu–Mandaue), and UC-METC (Maritime Education and Training Center). UC is primarily committed in providing genuine education that instills the principles of humanity, nationalism, and academic excellence to the community.

Waste segregation is the only visible management strategy implemented in University of Cebu (UC). Many of its stakeholders are still not segregating their waste properly despite the presence of "biodegradable" and "non-biodegradable" bins inside the university. As a result, commingled wastes are often collected by community and city government waste trucks for disposal to Inayawan dumpsite. UC does not also have a materials recovery facility (MRF) that can serve as composting, recycling, and transfer stations for different solid waste generated among its stakeholders.

System dynamics (SD) is a system thinking method that provides comprehensive explanation on influential characteristics of a certain element with the other elements in a complex system (Forrester, 1961). An element can be best understood if its relationships with the other elements and interactions with the other systems are analyzed thoroughly rather than assessing each element separately. Studies concerning system dynamics generally aimed in understanding the causes of a dynamic problem, and in searching for policies that serve as solutions to minimize the adverse impacts of such problem.

Jay Forrester of Massachusetts Institute of Technology (USA) introduced system dynamics in mid-1950s as a modeling tool whose origin can be traced from engineering control and information feedback systems (Forrester, 1961). SD is primarily intended for long-term decision-making analyses regarding industrial management problems. Forrester revolutionized this concept to understand the root causes of undesirable outcomes in a system, and to control or eliminate them through implementation of new policies. SD currently evolves as a scientific method in addressing complex problems involving business, environmental, political, and socio-economic feedback systems.

Mathematical modeling like system dynamics constitutes the foundation of computer modeling (Nirmalakhandan, 2002). Advancement of high-speed hardware and programming language enables computers to store and calculate large volumes of data faster than any known manual procedures. Simulated results are further presented in different forms according to established objectives of the model. Despite such advancement, computer-based mathematical model remains a demanding task where only subject experts with advanced programming skills can grasp its principles.

A new set of software packages that helps subject experts with minimal programming skills became available in early 1990s (Nirmalakhandan, 2002). Such packages are known as software authoring tools that support experts/authors to create computer-based mathematical model through merely linking objects with predetermined equations and constants. The tools are rich with built-in features to ensure modeling interactivity like user-friendly interfaces for data entry, preprogrammed mathematical functions for calculation, and post-processing programs for graphical simulation.

Causal loop diagram (CLD) is a fundamental tool applied in system dynamics to capture major feedback mechanisms of the developed model. Such diagram serves as preliminary sketches about different causal hypotheses involving the solid waste system of a university. CLD also simplifies the model representation through visualizing first the variable relationship before transforming it into a stock and flow diagram with the aid of software authoring tools like Vensim®, Stella®, and Powersim®.

OBJECTIVE OF THE STUDY

This paper is generally aimed in developing a solid waste recovery model for a university using system dynamics. The paper is also envisioned to analyze the dynamic behavior of waste recovery policies, recommend measures for improving the developed model, and suggest initial strategies for implementing the selected policy.

MATERIALS AND METHODS

Concepts of system dynamics is applied to simulate the dynamic behavior of cyclical cause-and-effect relationships regarding the solid waste system of a university. The framework of the study is divided into four phases as presented in Fig. 1. Preliminary phase discusses different problems and objectives of this paper. It also reviews information concerning solid waste management and system dynamics. Model conceptualization phase characterizes the system, boundary, and surrounding about the solid waste generated in a university. This characterization is illustrated in the conceptualized causal loop diagram illustrated in Fig. 2. Model construction phase translates the causal loop diagram into a stock-and-flow diagram shown in Fig. 3 using a software authoring tool called Vensim®. This phase also modifies the model through continued calibration and simulation until achieving a set of acceptable and realistic time-series graphs. Finally, model analysis phase analyzes significance of these graphs and selects the most suitable waste recovery policy to be implemented in the university. This phase also recommends measures for model improvement and suggests initial strategies for policy implementation.

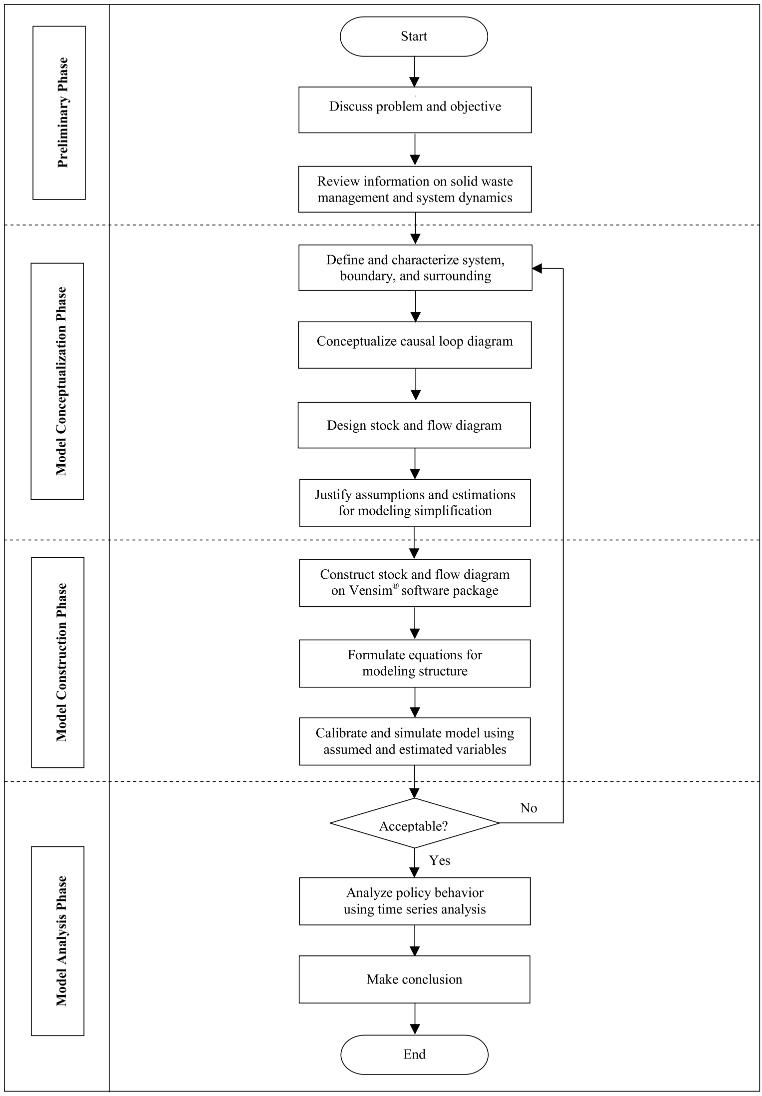

Fig. 1. Framework of the study.

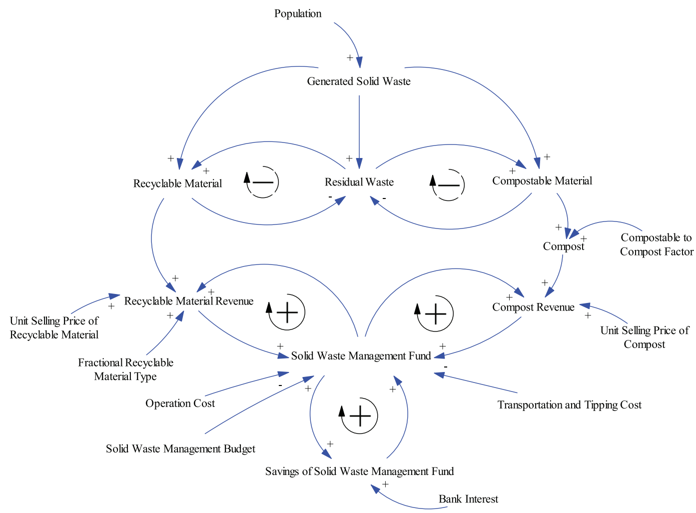

Fig. 2. Causal loop diagram of a system dynamics model for solid waste recovery in a university

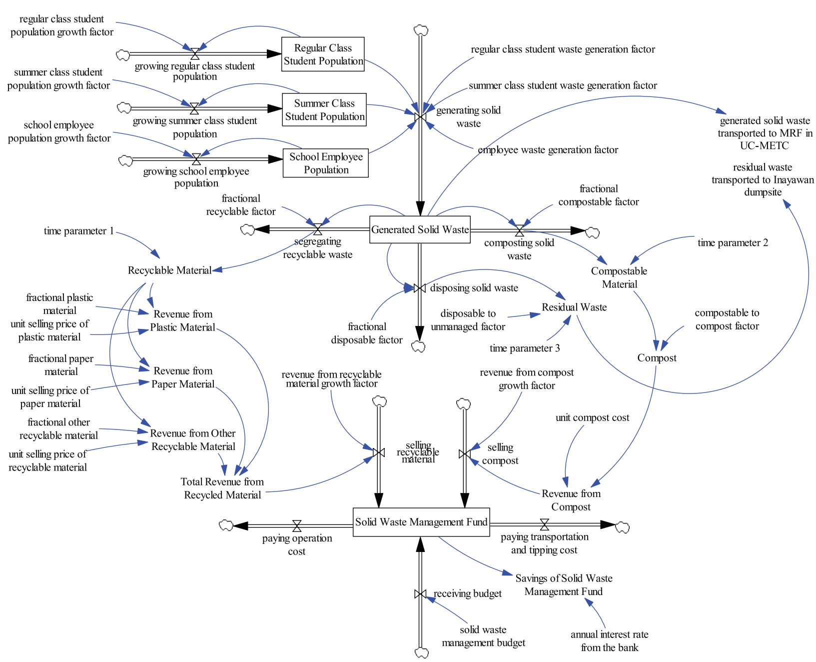

Fig. 3. Structure of system dynamics model for solid waste recovery in a university

Alternative methods are applied to quantify modeling variables whose data are not readily available in University of Cebu. One of these methods is establishing realistic assumptions that can substantially yields reliable and sensible results. The authors utilized such procedure considering it will take longer time to build a highly sophisticated model only to find the required data are not available, or the problem is already addressed using simpler methods barely before the model is completed. In this connection, the authors conducted an extensive inquiry over the internet to obtain literatures that give reasonable values for variables in the model.

Specifications about the developed SD model are presented in Table 1. The table includes names of different modeling variables whose initial values and constants are determined using field information and justified assumption. These numerical values are encoded in Vensim® software package, and are used in modeling calibration and simulation. The table also includes units of these variables to ensure dimensional consistency in the formulated equation.

Table 1. Specifications of system dynamics model for solid waste recovery.

Variable	Name	Initial Value/ Constant	Unit
Stock	Regular Class Student Population	17,774	capita
Stock	Summer Class Student Population	4,572	capita
Stock	School Employee Population	538	capita
Stock	Generated Solid Waste	0	ton
Stock	Solid Waste Management Fund	-200,000	PhP
Time Step	dt[a]	0.125	year
Flow	growing regular class student population	n.a.[b]	capita/ Year
Flow	growing summer class student population	n.a.	capita/ Year
Flow	growing school employee population	n.a.	capita/ Year
Flow	generating solid waste	n.a.	ton/Year
Flow	segregating recyclable waste	n.a.	ton/Year
Flow	composting solid waste	n.a.	ton/Year

Flow	disposing solid waste	n.a.	ton/Year
Flow	selling recyclable material	n.a.	PhP/Year
Flow	selling compost	n.a.	PhP/Year
Flow	paying operation cost	25000	PhP/Year
Flow	paying transportation and tipping cost	100000	PhP/Year
Flow	receiving budget	n.a.	PhP/Year
Auxiliary	regular class student population growth factor	0.05	dmnl/Year
Auxiliary	summer class student population growth factor	0.05	dmnl/Year
Auxiliary	school employee population growth factor	0.05	dmnl/Year
Auxiliary	regular class student waste generation factor	0.0095	ton/capita/Year
Auxiliary	summer class student waste generation factor	0.0018	ton/capita/Year
Auxiliary	school employee waste generation factor	0.0115	ton/capita/Year
Auxiliary	fractional recyclable factor	0.70 (RP 1)[c] 0.00 (RP 2) 0.70 (RP 3)	dmnl/Year
Auxiliary	fractional compostable factor	0.00 (RP 1) 0.16 (RP 2) 0.16 (RP 3)	dmnl/Year
Auxiliary	fractional disposable factor	0.30 (RP 1) 0.84 (RP 2) 0.14 (RP 3)	dmnl/Year
Auxiliary	recyclable to recycled material factor	1	dmnl
Auxiliary	time parameter 1	1	Year
Auxiliary	fractional plastic material	0.475	dmnl
Auxiliary	fractional paper material	0.475	dmnl
Auxiliary	fractional other recyclable material	0.05	dmnl
Auxiliary	unit selling price of plastic material	10000	PhP/ton
Auxiliary	unit selling price of paper material	2500	PhP/ton
Auxiliary	unit selling price of recyclable material	35000	PhP/ton
Auxiliary	Revenue from Plastic Material	n.a.	PhP
Auxiliary	Revenue from Paper Material	n.a.	PhP
Auxiliary	Revenue from Other Recyclable Material	n.a.	PhP

Auxiliary	Total Revenue from Recycled Material	n.a.	PhP
Auxiliary	revenue from recyclable material growth factor	0.02	dmnl/ Year
Auxiliary	revenue from compost growth factor	0.02	dmnl/ Year
Auxiliary	Revenue from Compost	n.a.	PhP
Auxiliary	unit compost cost	6000	PhP/ton
Auxiliary	solid waste management budget	150000	PhP/Year
Auxiliary	annual interest rate from the bank	0.07	dmnl
Auxiliary	Savings of Solid Waste Management Fund	n.a.	PhP
Auxiliary	Compostable Material	n.a.	ton
Auxiliary	compostable to compost factor	1.67[d]	dmnl
Auxiliary	Compost	n.a.	ton
Auxiliary	time parameter 2	1	Year
Auxiliary	Residual Waste	n.a.	ton
Auxiliary	disposable to unmanaged factor	1	dmnl
Auxiliary	time parameter 3	1	Year
Auxiliary	residual waste transported to Inayawan dumpsite	n.a.	ton
Auxiliary	"generated solid waste transported to MRF in UC-METC"	n.a.	ton

[a] A smaller *dt* gives more accurate results.
[b] n.a. means not applicable.
[c] RP means recovery policy.
[d] DTI (2009) assumed that 150 kg of compostable material and 2 kg of worms will be changed to 90 kg of compost. For model simplification, the author further assumed that 1.50 tons of compostable material will be converted to 0.90 ton of vermicompost. This will eventually result to a "compostable to compost factor" of 1.67.

Model formulation in system dynamics is a process of translating modeling structures into equations. It basically deals with transforming informal qualitative concepts to formal quantitative representations of a particular system. In this connection, the equations enumerated in Table 2 correspond to real processes about the solid waste system in University of Cebu. These equations are likewise checked for dimensional consistency and extreme case validity.

Table 2. Formulated equations in the system dynamics model for solid waste recovery.

Name	Equation
Regular Class Student Population	=INTEG(growing regular class student population, 17744)
Summer Class Student Population	=INTEG(growing summer class student population, 4572)
School Employee Population	=INTEG(growing employee population, 538)
	=INTEG(generating solid waste-segregating recyclable waste-composting solid waste-disposing solid waste, 0)
Solid Waste Management Fund	=INTEG(receiving budget+selling compost+selling recyclable material-paying transportation and tipping cost-paying operation cost,-200000)
growing regular class student population	= Regular Class Student Population*regular class student population growth factor
growing summer class student population	=Summer Class Student Population*summer class student population growth factor
growing school employee population	=School Employee Population*employee population growth factor
generating solid waste	=(Regular Class Student Population*regular class student waste generation factor)+(Summer Class Student Population*summer class student waste generation factor)+(Employee Population*employee waste generation factor)
segregating recyclable waste	=fractional recyclable factor*Generated Solid Waste
composting solid waste	=fractional compostable factor*Generated Solid Waste
disposing solid waste	=fractional disposable factor*Generated Solid Waste
selling recyclable material	= revenue from recyclable material growth factor*Total Revenue from Recycled Material
selling compost	=Revenue from Compost*revenue from compost growth factor
receiving budget	=solid waste management budget
Revenue from Plastic Material	=fractional plastic material*Recycled Material*unit selling price of plastic material
Revenue from Paper Material	=fractional paper material*Recycled Material*unit selling price of paper material

Revenue from Other Recyclable Material	=fractional other recyclable material*Recycled Material*unit selling price of recyclable material
Total Revenue from Recycled Material	=Revenue from Plastic Material+Revenue from Paper Material+Revenue from Other Recyclable Material
Revenue from Compost	=Compost*unit compost cost
Savings of Solid Waste Management Fund	=Solid Waste Management Fund+Solid Waste Management Fund*annual interest rate from the bank
Compostable Waste	=composting solid waste*time parameter 2
Compost	=Compostable Waste/compostable to compost factor
Residual Waste	=disposing solid waste*disposable to unmanaged factor*time parameter 3
residual waste transported to Inayawan dumpsite	=Residual Waste
"generated solid waste transported to MRF in UC-METC"	=Generated Solid Waste

RESULTS AND DISCUSSION

Simulated amount of residual waste is one of the two determining factors utilized in this paper for selecting the most appropriate waste recovery policy. Based from Fig. 4, Policy 3 (Recycling and Composting) exhibits the slowest increase and generates the least residual waste among the three policies. It further presents no signs of initial exponential growth from the entire period of simulation. These findings suggest Policy 3 as most appropriate to be implemented in the university.

Graphical pattern of Policy 1 (Recycling) indicates relatively no signs of initial exponential growth within the ten-year period, while Policy 2 (Composting) exhibits such sign at the start of fifth year of simulation. This scenario is attributed to low percentage of compostable materials comprising only 16% of generated solid waste in a university waste stream. Additionally, the recovered 70% of generated solid waste that is assumed as recyclable material can reduce more residual waste over time compared to composting.

Policy 3 (Recycling and Composting) generates the least residual waste with approximately 40 tons during the last simulation year compared to 85 tons in Policy 1 (Recycling), and 240 tons in Policy 2 (Composting). This is primarily attributed to combined reduction effect of both recycling and composting measures where 86% of generated solid waste, i.e. 16% compostable and 70% recyclable materials, can be potentially recovered from disposal to Inayawan dumpsite.

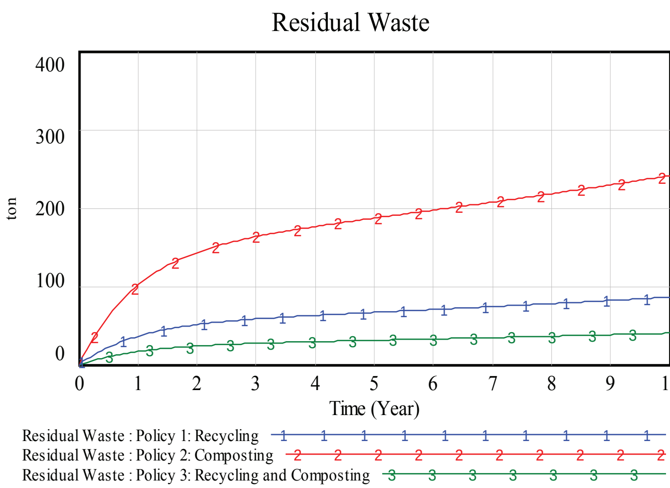

Fig. 4. Simulated amount of residual waste under three policies.

Another determining factor in selecting the most appropriate waste recovery policy is simulated savings of solid waste management (SWM) fund. According to Fig. 5, Policy 3 (Recycling and Composting) attains the earliest break-even from the proposed PhP 200,000.00 investment of setting a materials recovery facility (MRF). This scenario is predicted to happen around 4.25 years after implementing the policy. Policy 3 (Recycling and Composting) also generates the highest savings at nearly PhP 370,000.00 during its tenth year of implementation. These results served as another evidences implying this policy as most appropriate to be implemented in the university.

Fig. 5 further shows Policy 2 (Composting) as last to reach the break-even at approximately 6.5 years after its implementation. This scenario happens because Policy 2 has the lowest recovery percentage and lowest selling price, i.e 16% of generated solid waste and PhP 6,000 per ton respectively. Policy 1 (Recycling) landed second in reaching the break-even, which occurs around 4.75 years, with 70% of generated solid waste sold as recyclable material at PhP 7,687.50 weighted price per ton.

Policy 1 (Recycling) and Policy 3 (Recycling and Composting) both reaches the break-even during their fourth year of implementation. With additional savings from selling compost, Policy 3 (Recycling and Composting) is only ahead by approximately 0.5 year. Exponential growth patterns of both policies suggest that their savings gap increases over time. This result implies Policy 3 (Recycling and Composting) will become even more profitable compared to Policy 1 (Recycling) with respect to time.

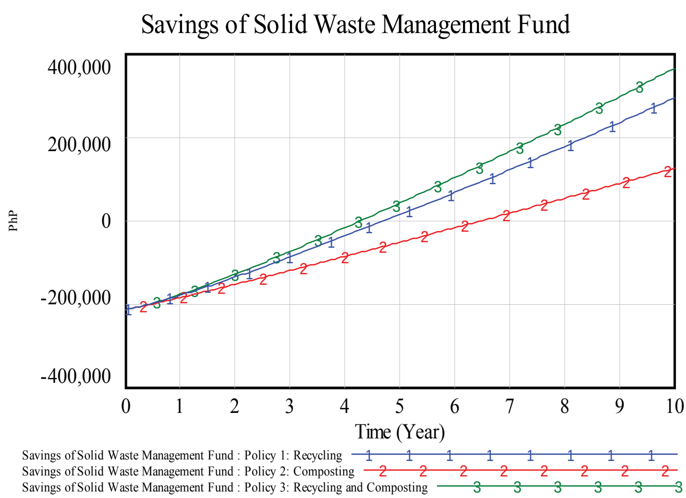

Fig. 5. Simulated savings of solid waste management fund under three policies.

Implementation of Policy 3 can give several benefits to the environment, universities, LGUs, industries, and communities. It can indirectly protect our environment through saving finite natural resources, conserving nonrenewable fossil fuel, lowering greenhouse gas emission, and lessening adverse pollution impact. Policy 3 can also aid universities in complying different regulations on solid waste management specifically RA 9003. Aside from this compliance, Policy 3 can assist universities and buy-back centers in generating revenue from selling recovered materials. Agricultural sectors can further generate revenue from decreased production cost due to application of high-quality vermicompost as cheaper alternative to inorganic fertilizers. Policy 3 can further help LGUs, industries, and communities in stretching landfill lifespan, reducing waste management cost, reducing energy consumption, decreasing production cost, creating job opportunities, enhancing life quality, and improving public health and sanitation.

CONCLUSIONS

The developed SD model can facilitate a simulated environment about recovering solid waste in a university. Using Vensim® software, it can generate rough estimates of waste quantity and potential revenue that are sufficient enough to plan an institutional waste recovery policy and allow investment to proceed for policy implementation. In the model, all input variables are quantitative giving definite parameters to various elements in a solid waste system. Exclusion of qualitative variables is done to provide users more time in analyzing the dynamic behavior of a system rather than evaluating the methodological validity to quantify such variables. With this scenario, critical discussions are now directly focused on various benefits and costs of implementing such policy in the university.

Analyzing the dynamic behavior of waste recovery policies is relatively easy since all their respective time-series graphs show no signs of oscillation. In the model, only goal-seeking and initial exponential growth patterns are observed from graphs of two solid waste elements selected for simulation. Time-series graphs showing policy behavior from 2012 to 2022 suggest Policy 3 (Recycling and Composting) as most appropriate to be implemented in the university. This policy sets the least residual waste, greatest fund savings, and earliest break-even in the entire phase of simulation. Policy 3 is likewise the most environmentally effective, economically profitable, and socially acceptable among the three policies analyzed in this paper.

Improvement measures are recommended to make a more comprehensive modeling structure and reliable simulation result. Inclusion of additional SWM elements in the modeling structure can improve its comprehensiveness, e.g. revenue from selling handicrafts made of recyclable material, and selling earthworms *(Eudrilus euginiae)* as cock feeds or fish baits. Utilization of more actual data can also improve the reliability of results especially in simulating the SWM fund savings. This option may require financial support from university's top management in conducting a solid waste characterization that determines the composition of recyclable, compostable, and residual waste.

Formal validation is another improvement measure recommended to be done in the developed SD model. This procedure establishes the ability of a model to replicate the dynamic behavior of a real solid waste system through comparing predicted values from the model and observed values from the university. Associated statistics such as coefficient of determination (R^2) are typically utilized to measure the variability, otherwise known as "goodness of fit", of these two sets of information. In this manner, the developed SD model will be verified to check the consistency of simulation output and actual field information.

Initial strategies about Policy 3 implementation are also recommended in this paper. Top management of UC is thus suggested to provide foundation in implementing the selected policy especially on financing the materials recovery facility. Although this entails an investment in the part of UC, simulation result shows it can be recovered within 4.25 years of MRF productivity. The management is also recommended to adopt its 8th institutional goal, i.e. developing programs that promote environmental awareness among its stakeholders and inspires them in achieving sustainable development in their respective communities. With this goal, the management is further recommended in upholding its 6th core value, i.e. environmental stewardship that protects the right of an individual to live a balanced and healthful ecology.

ACKNOWLEDGMENTS

The author is thankful to Atty. Augusto W. Go and Chancellor Candice G. Gotianuy for extending their financial support in accomplishing this paper. The author is also grateful to Prof. Abescar G. Base Jr., Mrs. Ma. Teresa T. Jochin, Mr. Robert S. Osabel, Dr. Ma. Salud M. de los Santos, Dr. Mauro Allan P. Amparado, Dr. Rosielyn D. Tan, Engr. Allan R. Navarro, Engr. Ma. Nila R. Sabal, Engr. Mark N. Abadiano, Mrs. Ma. Elena O. Agravante, and Engr. Ellen May Z. Reynes for sharing their constructive criticism and technical expertise in improving this paper.

LITERATURE CITED

DTI (Department of Trade and Industry, Philippines)
2009 Starting a business: Vermicomposting. A Brochure Made by the Bureau of Micro, Small, and Medium Enterprise Development (BMSMED). Makati City, Philippines.<http://www.dti.gov.ph/uploads/DownloadableFiles/SAB_Vermi- composting _09.pdf> (accessed 10.30.11).

Forrester, J.W.
1961 Industrial Dynamics. The MIT Press, Massachusetts, United States of America.

Nirmalakhandan, N.
2002 Modeling Tools for Environmental Engineers and Scientists. CRC Press, Florida, United States of America

SunStar Cebu
2011 Editorial: Plan to close Inayawan dumpsite <http://www.sunstar.com.ph/cebu/opinion/ 2011/03/18/ editorial-plan-close-inayawan-dumpsite-145597> (accessed 04.29.11).

UC (University of Cebu)
2010 Faculty Manual. University of Cebu, Cebu City, Philippines.