A System Dynamics Study of Solid Waste Recovery Policies in Phnom Penh City.

Veasna Kum*
Department of Environmental Science, Royal University of Phnom Penh,
Room 112, RUPP Main Building, Russian Confederation Blvd., Phnom Penh,
Cambodia
Telephone: (855)-1-248-6068
Fax number: (855)-2-388-4523
Email addresses: veasna_kum@yahoo.com

Alice Sharp
Department of Environmental Technology
Sirindhorn International Institute of Technology, Thammasat University
P.O.Box 22, Thammasat Rangsit Post Office, Phathumthani 12121, Thailand
Email address: alice@siit.tu.ac.th

Napat Harnpornchai
Department of Civil Engineering
Sirindhorn International Institute of Technology, Thammasat University
P.O.Box 22, Thammasat Rangsit Post Office, Phathumthani 12121, Thailand
Email address: napat@siit.tu.ac.th

Abstract
There is an economic reason to extend the useful life of the landfill because once the old landfill is filled, the new one can be found only at greater distance, and this increases remarkably the transportation cost. Therefore, waste has to be recovered as much as possible. To do this, in developing countries context, small scale composting promotion is widely accepted and the contribution of informal recycling is also widely recognized. The question remains to what extent composting and informal recycling contribute to the waste diversion. To create a platform for discussion and learning, a model is established. The model in this paper is based on the system dynamics (SD) approach. The simulation results with the data collected in Phnom Penh city, Cambodia, show that waste recovery through small-scale composting and informal recycling cannot contribute significantly to the waste diversion without other supporting policies.

Keywords: Solid waste management, waste recovery, informal recycling, waste pickers, system dynamics, developing countries, Cambodia

1. Introduction

Stung Mean Chey dumpsite is the only official solid waste disposal site for the whole waste collected from the city of Phnom Penh. The present dumpsite at Stung Mean

* Corresponding author.

Chey needs soon to be closed when a new sanitary landfill operation starts in 2008 (JICA, 2003). Because the disposal cost for the new landfill will have to rise sharply to pay for the operating expense (Inter-Consult., 2002), the local waste authority of Phnom Penh has become interested in compost making to divert the waste at the future landfill. Though compost-making is intriguing, its strength and limitation of success when integrated into a solid waste system are still unclear. This can be shown by a large number of failed composting facilities in Asian cities (Furady, 1990). To facilitate learning the implications of the Municipality's policy towards composting on the waste to be disposed of, a computer model that can capture the interactions of components in the system of interest is built. The model in the paper is a system dynamics model. System dynamics is chosen as a methodology for the modeling work because it is appropriate for modeling a complex system such as solid waste management (SWM) system (Karavezyris et al., 2002; Mashayekhi, 1993). System dynamics models, whether they are used in business systems, ecological systems, or any other systems, are designed for general understanding, not point prediction (Ford, 1999).

2. Solid waste recovery in Phnom Penh city

2.1. Compost making sector

In the city of Phnom Penh, there is an introduction of compost-making using low technology into solid waste management system in order to reduce waste amount at the disposal site and the pilot project of urban waste composting has been implemented by the local waste authority, Phnom Penh Waste Management (PPWM). Compost-making using low technology, in spite of some potential constraints, is the most appropriate policy for waste diversion in the context of Phnom Penh city (Kum et al.,). A result of the research by Furady (1990) also confirmed that a "high technology" approach is not promising in developing countries and there is tendency toward a "low technology" approach for composting in these regions. She also noted that Asian city governments in the last twenty years often chose complicated mechanical plants for composting, but few cities have been able to operate these plants successfully while many others have had numerous mechanical problems and have been closed down; those still working rarely operate at capacity and generally produce compost that farmers do not want or cannot afford. This means that the local waste authority of Phnom Penh reaches a milestone in choosing the appropriate technology for compost-making.

Under the compost making system in the project area, collected waste is manually separated into three categories: recyclable for sale at the end of month, compostable for compost making and the left for disposal at the dumpsite. The compostable is stacked in bins with aeration tubes. The process takes three to four months. When the waste is fully decomposed, it is fed into another machine that sorts it by particle size. An important point is that the compost quality using the low technology is very high. This is because the waste to be composted is particularly selected from the mixed waste (JICA, 2003). Additionally, the compostable-to-compost coefficient is nine. This means that compostable nine tonnes is needed to produce one tonne of compost. The coefficient nine is estimated based on the data presented in the Table 1 and the assumed value of the density of compostable 450 kg/ m^3. It should be noted that waste-to-compost coefficient is dependent on the technique used in compost making. For example, a composting plant built in Hanoi, Vietnam in 1990 with a UNDP grant takes four tonnes of solid waste to make one tonne of compost (Sarin, 1998).

Table 1. Compost production output

Compost output	#1 compost (m^3)	#2 compost (m^3)	#1 compost (kg)	#2 compost (kg)
Compostable waste-1 box	0.29	0.67	130	170
Compostable waste-1 m^3	0.05	0.11	21.67	28.33

Source: Inter-Consult., 2002 (1 box is approximate at 6 m^3)

Though the quality of compost in the pilot project is quite high, the market of the compost is still very small and unstable. As a result, the local waste authority pays less and less attention to compost making from waste. The full capacity of the composting facility is designed for 4 tonne/day (JICA, 2003), but because of the very low compost demand, the present compost production rate is only about 1 tonne/month (Inter-Consult., 2002). The low compost demand may be due to the high compost sale price, 125 US$/tonne. It should be noted that the sale price does not include profit. This means that unit compost production cost is already high compared to that in Thailand. The value of sales of compost in Thailand in fiscal 1980 was reported to be Baht 7,744,968 (US$ 387,250) for a yearly quantity of 16,507 tonnes. According to these figures, the value per tonne of compost was Baht 469 (US$ 23.45). The manufacturing cost including depreciation of composting plant was Baht 934 (US$ 46.70) per tonne. The income from compost sales is only about 50% of the manufacturing cost (Lohani et al., 1984).

It should be noted that the unit compost production cost, US$ 125 per tonne was estimated based on the assumption that eight workers could sort about 500 kg of compostables from mixed waste. Based on this assumption, the labor sorting productivity is 5 tonne/month/person. The present condition is quite different. It is estimated that four workers can sort compostables from mixed waste up to 700 kg in four hours (Inter-Consult., 2002). This means that the labor sorting productivity is 10.5 tonne/month/person that is about two times higher. This certainly results in the lower unit compost production cost and then, compost sale price should be lower. However, the sale price has still not been updated. Moreover, though users of compost may afford to buy compost with a different price, compost sale price with market potential may be only 25US$/Tonne (Sarin, 1998). Compost price with market potential refers to the price farmers who are the second largest potential users of the product (see Table 2) can afford. The high unit compost production cost is seen to be a major problem to market the compost. Compost sale rate may increases if the compost sale price is lower. Compost sale price can be decreased if unit compost production cost is decreased. This factor will be considered and presented in the next section. Table 2 presents the estimated compost demand from various categories of potential compost users.

Table 2: Estimate of potential compost demand in Phnom Penh city

Category	Potential demand (tonne/year)
Agriculture	47600
Tree and garden (public)	51334
Plant nursery	100
Garden (private)	85

Source: Sarin, 1998

2.2. Informal recycling sector

Furady (1990) noted that Asian cities are characterized by extensive informal waste recovery and recycling. In spite of no reliable statistics of waste pickers, those who have observed them over a period of years report that there are increasing numbers of persons engaged in these activities. The argument is also true for the case of Phnom Penh city. In the city at present, recovery and recycling activities are conducted in an informal manner primarily by waste scavengers in streets in the city and on the dumpsite. “Informal” here is associated with unregistered, unregulated, or casual activities. There is no reliable figure of the total number of the waste pickers in the city. The total number of the waste pickers is estimated to be around 2000 people (Inter-Consult., 2002). A survey by Inter-Consult. in 2002 found that there are 300 waste pickers at the dumpsite (Inter-Consult., 2002). Another survey made by JICA study team a year later, in 2003 found that there are 460 waste pickers who are working at the dumpsite and on holiday, the number increases to over 500 persons (JICA, 2003). This shows that there is a considerable increase in the number of waste pickers at the disposal site.

Waste pickers at the disposal site, though they contribute informally to the waste recycling, create some problems for the local waste authority, PPWM in its disposal operation. The problem is that those waste pickers work around the collection vehicles and bulldozers while these machines are in operation in the landfill. This results in not only incomplete landfill operation but also eventual accidents. It is suggested that one possible solution is to eliminate waste pickers from the landfill (JICA, 2003). This paper, however, shows a different view.

It is obvious that the perspectives of organizations and individuals to solve the problem of informal recovery differ; some are mainly interested in economical and safe resource recovery, while others are more concerned with improvements in the well being and work of poor people (Furady, 1990). The view in this paper is that informal recovery by waste pickers should not be eliminated but the activity should be organized in a manner that waste pickers can work without disturbing the disposal operation at the disposal site. This is because firstly, the waste pickers benefit from the discarded material at the landfill as much as they can for their basic needs; retrieving recyclables for sale as an income, building their shelters from waste materials of all kinds (paper, palm leaves, broken bricks, wood scrap etc.). In a weak economic base and weak social welfare system such as Cambodia, this is seen to be a self-help survival strategy. Secondly, the average monthly income of the waste pickers found in a survey by JICA study team, US$40.5, (see Table 3) is as high as the basic salary paid for workers in some small local garment factories, 40US$. Thirdly, the waste pickers are mainly from the poor and socially disadvantaged group of the society. They may have no skill and this makes it very difficult to find a better job, but they need to live their lives. Preventing them from retrieving recyclables at the landfill seems preventing them from earning their *income* to live. This may generate a negative impact on their standard of living. As a result, they may tend to do something considered *bad* in the society as just for living. These are the reasons why the informal recovery at the disposal site should not be eliminated but organized in a manner that benefits both sides: waste pickers and the waste authority, PPWM. The view in the paper is that "if a thing cannot be made better, it should not be made worse."

Recognizing its importance and hoping that future government policy will not affect the informal waste recovery at the disposal site, the informal recycling sector is included in the model. It should be note that, for simplification, all waste pickers both in streets city and at disposal site are considered informal recycling forces.

Table 3: Daily earning of waste pickers at the disposal site

Total daily earning	Adult	Chile
Riel	6,400	4,100

Source: JICA, 2003

Riel: Cambodian currency. The rate of exchange in 2003 is approximate at 4000 Riels per 1$U.S

3. A model for learning

A model is a substitute for a real system. Models are used when it is easier to work with a substitute than with the actual system (Ford, 1999). The model in this paper is designed to serve as a tool to make easier learning about the implications of different policies on waste to be disposed of.

3.1. Verbal description of the model

Waste to be disposed of in a landfill in Phnom Penh city context can be controlled by in-flow rate (collection rate) and outflow rate (compost production and informal recycling rate). The model does not include factors that may affect the collection rate, assuming that waste at source of generation can be all collected and transported from the city. Moreover, incineration is not considered because it may not be an economic and feasible option for the city.

The compost production rate depends on the demand of the product. The compost demand depends on the price clients can afford and the quality of compost. The quality of compost is not included in the model assuming that the quality is high enough to be acceptable to the public. This assumption is based on the feasibility of JICA study team (JICA, 2003). Then, the compost demand depends on only unit compost sale price (UCSP).

For a product such as compost, it is not expected to make money from sales. It is enough that the compost is sold (Lohani et al, 1984). Therefore, UCSP should be set to be equal to unit compost production cost (UCPC) so that compost can be sold as much as possible. As mentioned in previous section, UCSP (now UCPC) is very high. In this section, factors that affect UCPC is reviewed.

Unit compost production cost is equal to the sum of fuel cost, electricity cost, maintenance cost, unit labor cost, and unit depreciation cost. While fuel cost, labor cost and maintenance cost are constant, unit labor cost and unit depreciation cost are changeable depending on other factors. Unit depreciation cost depends on compost production rate, i.e., the more compost produced, the lower the unit depreciation cost.

Unit labor cost in compost production using low technology can be influenced by the labor sorting productivity itself. This is because workers need to be paid on a monthly basis. So, the more compostable recovered by them during a period considered (the more compost they can make), the lower the unit labor cost. This means that an increase in labor sorting productivity will contribute to the decrease in unit labor cost.

As mentioned earlier, compostable to be used for compost making is manually sorted from mixed waste. If compostable is damaged beyond recovery, labor sorting productivity will be zero. This case may be too strong to be possible but it can only be inferred that source separation does have an impact on the labor sorting productivity. The waste separation at source can greatly be contributed by public. However, the public may not be interested in doing so if there is no incentive or other driving forces. It is assumed that recyclable price can have influence on the willingness of the public to separate waste at source, i.e., the public will separate recyclables for sale if unit recyclable price is high enough for them. Unit recyclable price is up if supply of the recyclable is far below the demand but tends to be down when there is a surplus of the material. These cause-and effect relationships form two feedback loops that interconnect through a measure of recyclable surplus index.

The recyclable surplus index is simply the recyclable stock at dealers' divided by the recyclable stock capacity. Recyclable stock capacity is the total capacity at junk dealers' for temporarily stocking the recyclables bought from waste pickers. A value of the recyclable surplus index exceeding one means that there is abundant recyclable materials at junk dealers' and the recyclable price start going down. As mentioned in the previous section, the market of recyclables in Phnom Penh city depends almost completely on the demand in Vietnam and junk dealers have to stock the bought recyclables in a limited land. Though it is generally believed that the junk dealers make good profits from their business operations, they may not tend to buy big land for only stocking the recyclable because land price in the city is not cheap enough to allow them to do so. With the assumption that junk dealers have limited land, recyclable stock capacity is assumed to be constant.

Recyclable stock at junk dealers' can be controlled by an in-flow rate (informal recycling rate) and an out-flow rate (recyclable shipment). Informal recycling rate depends upon the size of the informal recycling force and the recycling labor productivity. Informal recycling force is the number of people engaged in the waste picking practice.

People must depend on a source of income to obtain money for food, clothing and shelter. The source of income for the waste picker is resources that are discarded as wastes. They have to spend time retrieving the recyclables from waste and sell them to junk dealers as an exchange for basic needs. Because this kind of job does not require any high skill, the job attracts poor and socially disadvantaged individuals and groups on streets, in slums and the disposal site. However, the attractiveness is dependent on the earning they can make from the job. The job attractiveness in the model is simply the monthly earning divided by desired earning by waste pickers. The desired monthly earning per waste picker is assumed to be 50 US$/month. It should be clearly noted that the value is applied to only waste pickers in the city taking their living condition into consideration and it should not be interpreted that the desired earning for the general public is the same.

It is assumed that the monthly earnings of the waste pickers is dependent only on the recyclable price set by junk dealers though the monthly earnings of the waste pickers are in fact also dependent on their labor productivity. The labor productivity is influenced by the changing in technique of the solid waste collection and disposal, for example, introduction of collection system using hydraulic compactor trucks that do extensive damage to recyclables and policing of the disposal site that prevents waste pickers from going through the garbage to take out items.

In the modeling work, the technique of the solid waste collection and disposal is not taken into account firstly because adding this factor in the model, the model becomes too cumbersome to be useful for learning and secondly, it is expected that the local waste authority of Phnom Penh can find techniques for waste collection and disposal that are appropriate for the local surroundings and take appropriate measures in favor of the poor waste pickers. Then, it is assumed in the model that the recycling labor productivity of the waste pickers is constant.

3.2. Model formulation

In order to enable a model to be simulated to determine the dynamics behavior implied by the model's assumptions, the model needs to be formulated in a way that can translate the model structure into mathematical equations. In system dynamics, this can be greatly facilitated by using stocks and flows diagram.

3.2.1. Stock and flow diagram of the model

Stock and flow diagram of the model is shown in Figure 1.

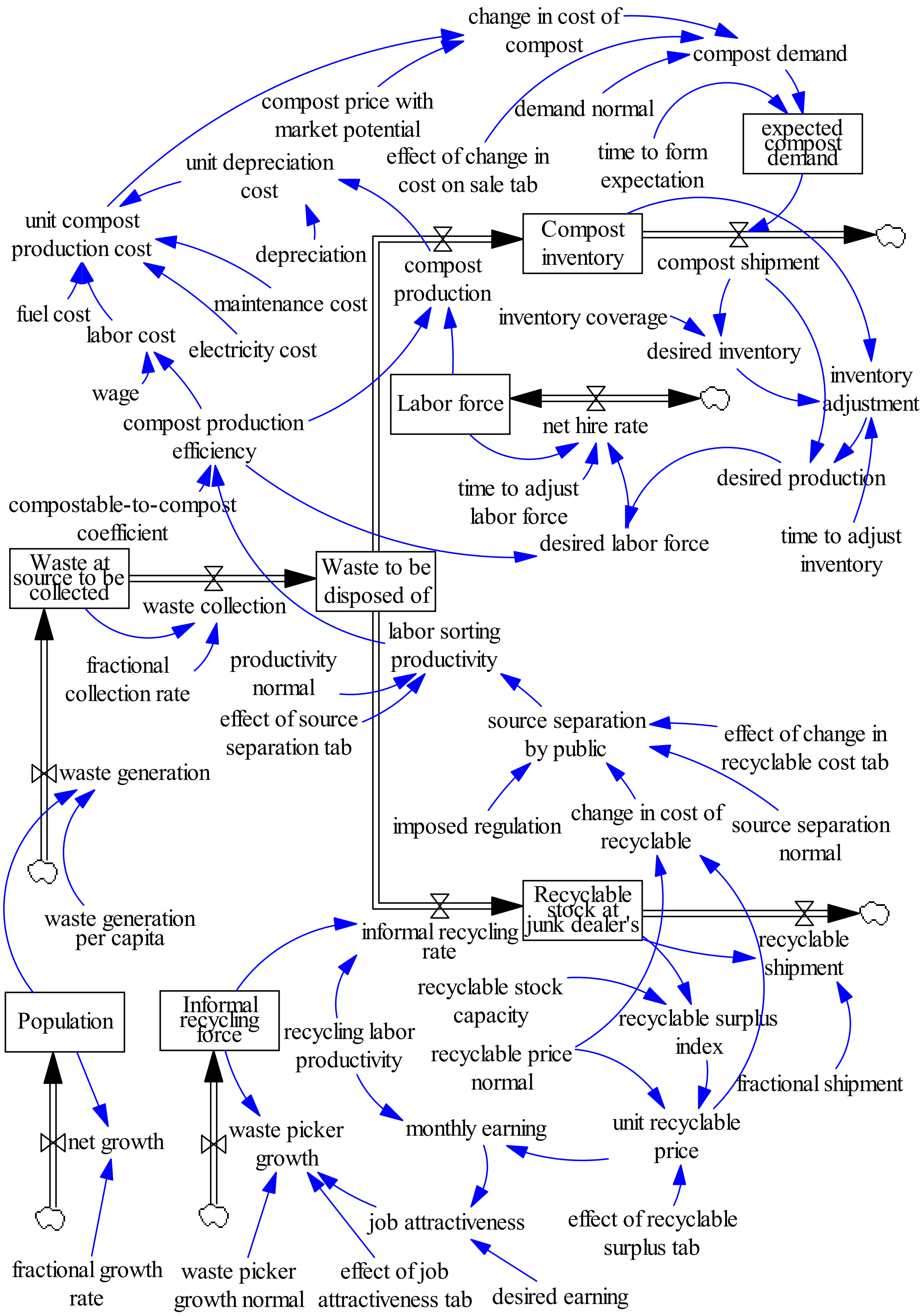

Figure 1: Stock and flow diagram of the model

3.2.2. Some specific values in the model

The model use data collected in Phnom Penh city for the simulation run and testing. Some specific values of parameters and initial values of stocks are presented in Table 4.

Table 4. Specific values used in the model

Variable	Name	Unit	Initial values/ Constant
Stock	Compost inventory	Tonne	0
Stock	Informal recycling force	Person	2000
Stock	Labor force	Person	7
Stock	Population	Person	1199410
Stock	Recyclable stock at junk dealers'	Tonne	2123
Stock	Waste to be disposed of	Tonne	0
Time step	dt	Month	0.25
Auxiliary	compostable-to-compost coefficient	Dmnl	0.112
Auxiliary	compost price with market potential	$/Tonne	25
Auxiliary	demand normal	Tonne/Month	1
Auxiliary	depreciation	$/Month	51.33
Auxiliary	electricity cost	$/Tonne	0.044
Auxiliary	fuel cost	$/Tonne	0.51
Auxiliary	maintenance cost	$/Tonne	0.74
Auxiliary	recycling labor productivity	Tonne/Person/Month	0.492
Auxiliary	recyclable price normal	$/Tonne	65.45
Auxiliary	recyclable stock capacity	Tonne	11500
Auxiliary	time to form expectation	Month	3
Auxiliary	inventory coverage	Month	1
Auxiliary	time to adjust labor force	Month	0.5
Auxiliary	time to adjust inventory	Month	3
Auxiliary	waste picker growth normal	Fraction/Month	0.014
Auxiliary	wage	$/Month	40.5

4. Simulation results and discussion

4.1. Model simulation

Vensim is a visual software to help conceptualize, build, and test system dynamics models (Ventana systems, 2003). The model to be used for the policy experiment in this paper is developed using the software package.

Hypothetically, the desired behavior of the model, when policy experiments are conducted, is considered as one that results in the decrease in the stock 'Waste to be disposed of'. However, social benefits such as higher offering job opportunities from policy experiment are also considered.

- Simulation run with current policy

In this simulation, labor sorting productivity initially estimated by the foreign consultant, 5 tonne/month/person, is used. Moreover, the market of recovered recyclables is dependent on the demand of the material in Vietnam. There is no policy to promote local processing industries and recyclable shipment rate is herein assumed constant at 1221 tonne/month (present rate). These are the current policies of the local waste authority concerning waste recovery in the present solid waste system in Phnom Penh city.

Simulation results shown in Figure 2 display the behavior of the model under the current policies. The figure shows that the model is capable of well replicating the recorded data: unit compost production cost 125 US$/tonne and compost shipment 1 tonne/month. The figure also shows that the waste to be disposed of exponentially increases and continues to increase at the end of simulation time frame, whereas the informal recycling force, growing at first, starts to decline at around month 66. The decline in the informal recycling force is due to the recyclable surplus that causes the unit recyclable price to decline. The decline in price of recyclables prompts the waste pickers to find other job.

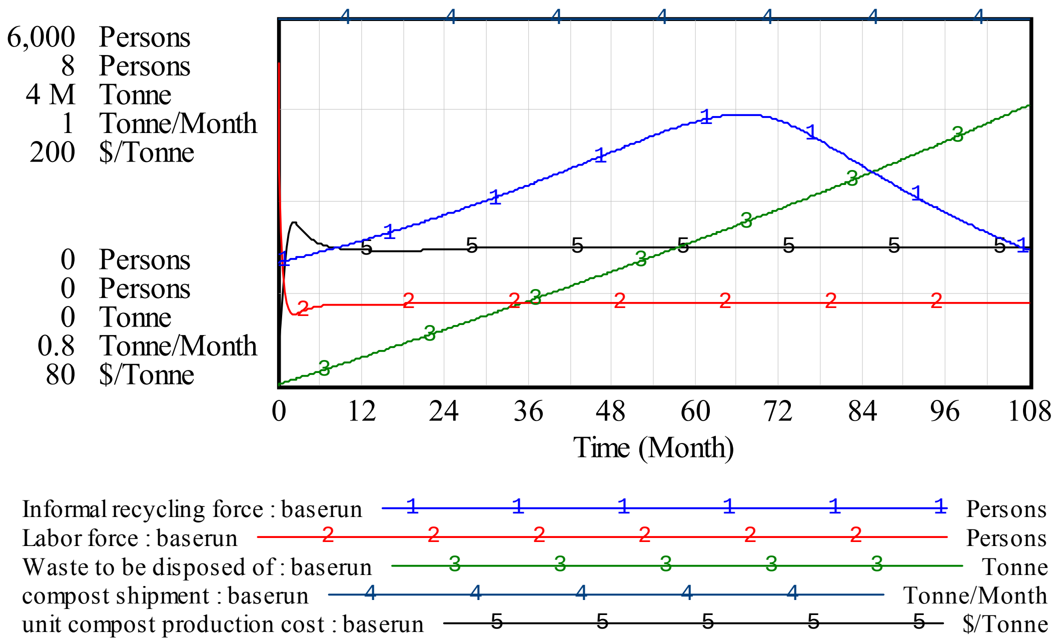

Figure 2: Simulation run with current policy

- Simulation run with alternative policy N1

Simulation under the current policies shows that the waste to be disposed of is exponentially increasing and compost demand is really low. In this simulation, the recyclable shipment is reformulated in a way that all recovered recyclables can find their market and this is just to avoid the recyclable surplus problem. The previous labor sorting productivity, 5 tonne/month/person, is replaced with a newly estimated one, 10.5 tonne/month/person, that is about two times higher. The new estimated value of labor sorting productivity was made according to the improvement in shredding and composting set-up (Inter-Consult., 2002). This means that the labor sorting productivity is still not used in full capacity. Figure 3 shows the simulation run of the model. The simulation shows waste to be disposed of is still increasing but it slightly decreases from 3.052 to 2.984 million tonnes at the end of simulation time frame but the difference is too small to see in the graph with such a small scale. However, an interesting result that can be observed is that unit compost production cost is considerably decreased and the compost shipment increases from 1 to 15 tonne/month.

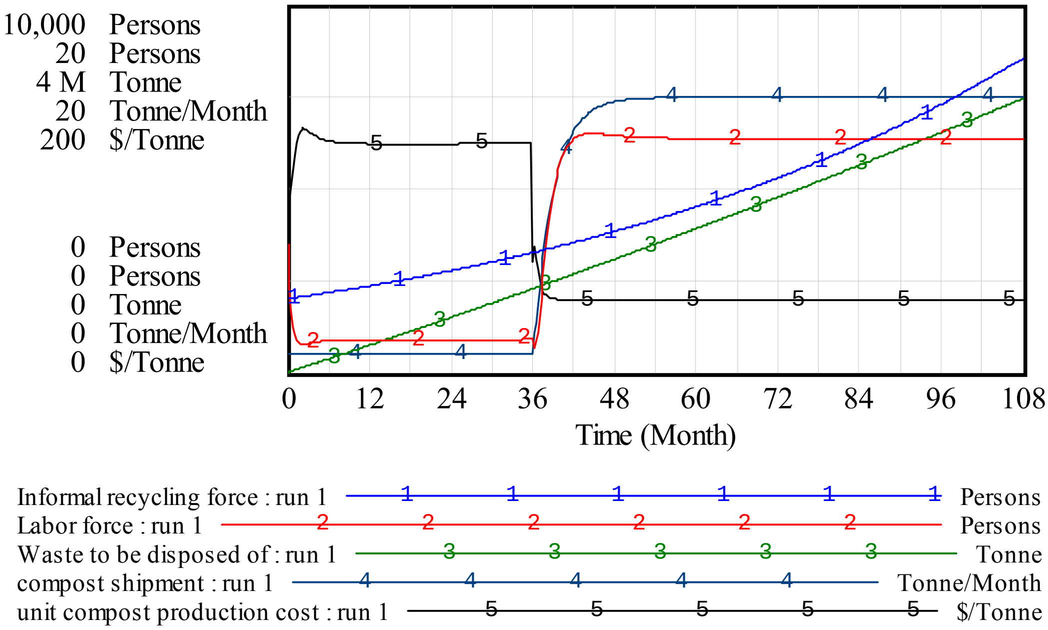

Figure 3: Simulation run with alternative policy N1

- Simulation run with alternative policy N2

The conditions of the simulation reviewed in this section are the same as those in alternative 1, except for labor sorting productivity. A simulation run with policies in alternative 1 shows that there is a considerable decrease in unit compost production cost. This means labor sorting productivity is an important factor to decrease the unit compost production cost. As mentioned earlier, capacity of labor can still be increased. It is expected that source separation by the public can facilitate sorting compostables from mixed waste, and this increases labor sorting productivity.

In the previous simulation run, source separation is dependent on the public, and the action from the public is dependent on whether or not the recyclable price interests them. Because the unit recyclable price may not be expected to increase but labor sorting productivity needs increasing to decrease the unit compost production cost, source separation by the public is needed. This may be achieved by imposing regulations concerning the separation of waste at source. In this simulation run, regulation is included in the model as an exogenous factor, and it has influence on the source separation by the public. Regulation increases steadily from month 36 with the slope 0.005. Figure 4 shows the simulation result of such a policy. The compost shipment increases dramatically at the end of simulation time frame. This shows that unit compost production cost approaches the compost price at which farmers can afford.

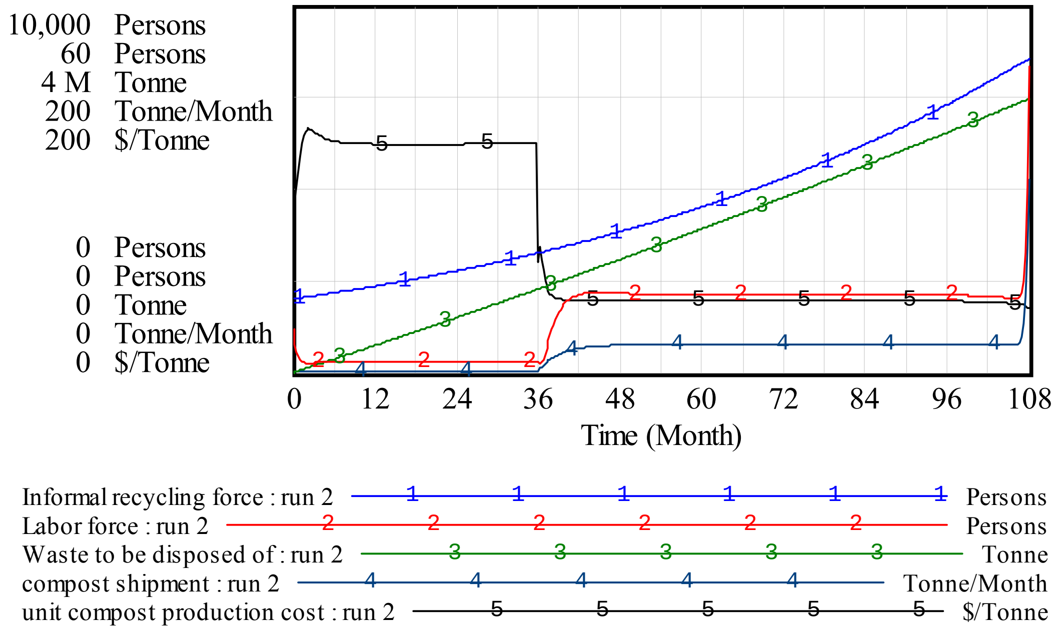

Figure 4: Simulation run with alternative policy N2

4.2. Discussion

A simulation result shows that source separation has a great influence on labor sorting productivity that leads to a considerable decrease in unit compost production cost. However, high source separation may not be expected/possible in Phnom Penh city where an appropriate storage system has yet to exist. So, unit compost production cost may not be lower than 35 US$/tonne. That is still higher than the compost price at which farmers can afford, 25 US$/tonne. This proves to be a major problem to find market for compost.

However, with the high quality of compost produced as confirm by the JICA study team and with the low amount of low cost fertilizers available in the market (JICA, 2003), the problem may be alleviated. This means that waste recovery strategy through compost-making in the city may have a chance of success, and the amount of waste to be disposed of can also be reduced. However, it seems that the local waste authority PPWM has failed to consider seriously enough the potential of waste recovery through composting. Low compost demand during the pilot project period makes PPWM even pay less attention to the promising strategy. PPWM has failed to take the cause of the low compost demand into account. The present compost sale price set by PPWM is so high that farmers cannot afford it. The compost sale price was first estimated by a hired foreign consultant at the beginning of the pilot project and the price is documented. The consultant considers the labor sorting productivity too low. The labor sorting productivity found later is higher, and the unit compost production cost can be considerably decreased. Unfortunately, PPWM does not update the compost sale price and follows only the document written by the consultant. This shows that PPWM lacks ability to adjust to changing situations in managing solid waste system. This proves to be a serious weakness because foreign consultants can provide guidance, training and technology, but only the nationals in each country can convert this help into a fully practical, operating system (Rushbrook and Fenecy, 1988).

PPWM should consider and promote compost making using low technology because firstly, compost-making using low-technology is the only feasible way in the city context to reduce the waste at the disposal site. Secondly, though the disposal cost at the future landfill (sanitary landfill) has yet to be calculated, it is estimated that the future disposal cost should be around 8 $/tonne (Inter-Consult., 2002) which is much higher than the cost of compost-making. This is based on the fact that, as mentioned earlier, nine tonnes of compostable produce only one tonne of compost. Then, if nine tonnes of waste go to the sanitary landfill, PPWM has to spend around US$ 72 for the waste disposal. However, if nine tones of waste are processed to produce one tonne of compost, PPWM spends only US$ 35. Moreover, if compost can be sold at price farmers can afford, 25US$/tonne, PPWM makes a loss of only US$ 10. These are clear reasons why in Phnom Penh city, compost making has to be seriously considered and promoted though this may not be possible without government subsidies.

4.3. Beyond the system dynamics

Solid waste management (SWM) system is recognized to be a complex system (Karavezyris et al., 2002; Mashayekhi, 1993; Rhyner et al., 1995; Tchobanoglous et al., 1993) and System Dynamics is also recognized to be a powerful tool to help us understand a complex system (Mashayekhi, 1993; Sushil, 1993; Sterman, 2002; Wolstenholme, 1994). Moreover, system dynamics is considered as a method that is appropriate for modeling dynamic consequences in solid waste systems (Karavezyris et al., 2002; Mashayekhi, 1993). However, using only system dynamics approach to study solid waste system is not sufficient. The study of a complete SWM system may require several methods both qualitative and quantitative. Because the system often involves political, social, environmental, economic factors, qualitative analysis is often needed. Moreover, the choice of technology to be used in the SWM system is also a very important factor that needs to be seriously considered. It is recognized that ineffective or failed SWM systems in developing countries are often due to the failure to consider seriously enough whether the technology introduced into the systems is appropriate for their local surroundings (Furady, 1990). Therefore, appropriate methods are needed for technology assessment before a technology can be introduced into the waste management system. SD may not be an effective tool for technology assessment. Quantitative methods such as cost-benefit analysis may be found much more appropriate. However, SD is an effective tool for understanding the implications of different policies on the performance of solid waste system that is adopted.

5. Conclusion and recommendation

The model in this paper can facilitate in experimentation in a simulated environment a debate on the impact of waste recovery on the amount of waste to be disposed of under varying policy assumptions. The model should be helpful to the local solid waste management planners to set up an appropriate financial planning for solid waste disposal at the landfill. Moreover, it can be inferred that planning in urban solid waste management in developing countries requires socio-technological and economic understanding, and direct application of quantitative techniques may not be able to capture the essential features of the solid waste system.

The below recommendations are based on the study findings and discussions as presented in previous sections:

- PPWM is strongly recommended to reconsider the presently operational management system of compost making in the city. Compost sale price, a controlling parameter in the compost system, should be seriously reviewed. The research in this paper found that compost sale price can be lower that is a potential to promote composting.
- The research also found that the compost making in the city may not be possible without the subsidies from the Municipality. The Municipality should pay more attention to the composting sector and should recognize the important role of the sector in the overall waste management system.
- A present serious weakness of the Municipality that should be avoided is the failure to solve solid waste issues from a system perspective. For example, it tries to promote the development of a sanitary landfill, but takes very little notice on the composting sector that can reduce waste at the landfill. Considering solid waste issues in such a way, the Municipality cannot find appropriate solutions to the local waste issues.
- The municipality should not eliminate the informal waste picking at the existing disposal site or in the prospective new landfill, but should organize the waste pickers to work in a manner that they do not cause any disturbance to the disposal operation at the disposal site. The elimination of informal waste picking at the disposal site may cause the standard of living of waste pickers to further decline.

Acknowledgment

Authors wish to thank Robert Deutsch of the JICA study team for providing some unpublished reports related to the SWM study in Phnom Penh city.

References

[1]. Ford, A., 1999. Modeling the environment: An introduction to system dynamics models of environmental systems. Island Press, Washington, DC.

[2]. Furady, C., 1990. Social aspects of solid waste recovery in Asian cities. Environmental Sanitation Review, No. 30.

[3]. Karavezyris, V.; Timpe, K-P. and Marzi, R., 2002. Application of system dynamics and fuzzy logic to forecasting of municipal solid waste. Mathematics and computers in Simulation, 60: 149-58;

[4]. Kum, V.; Sharp, A. and Harnpornchai, N. Towards sustaining municipal solid waste management in urban poor communities in Phnom Penh city, Proceedings of the 19th international conference on solid waste technology and management, 21-24 March 2004, Philadelphia, PA. pp 657-667.
[5]. Lohani, B.N; Todino, G.; Jindal, R. and Ludwig, H.V., 1984. Recycling of solid wastes. Environmental Sanitation Review, No. 13/14.
[6]. Mashayekhi, A.N., 1993. Transition in the New York State solid waste system: a dynamic analysis. System Dynamics Review, 9(1): 23-47.
[7]. Rushbrook, P.E. and Finnecy, E.E., 1988. Planning for future waste management operations in developing countries. Waste Management and Research, 6: 1-21.
[8]. Rhyner, C.R.; Schwartz, L.J.; Wenger, R.B. and Kohrell, M.G., 1995. Waste management and resource recovery. CRC press, Boca Raton.
[9]. Sarin, C., 1998. Urban solid waste disposal: A case study of the city of Phnom Penh, Cambodia. Master thesis, Asian Institute of Technology, Thailand.
[10]. Ventana Systems, 2003. Vensim® Standard, User's guide, Version 5. Ventana Systems Inc.
[11]. Sushil, K.S., 1993. System dynamics: a practical approach for managerial problems. Wiley Eastern Limited, New Delhi.
[12]. Sterman, J.D. 2002. Business dynamics: system thinking and modeling for a complex world. Irwin/McGraw-Hill, New York.
[13]. Tchobanoglous, G.; Theisen, H. and Vigil, S. 1993. Integrated solid waste management. McGraw-Hill, New York.
[14]. Vesilind, P.A.; Worrell, W.A. and Reinhart, D.R. 2002. Solid waste engineering. Brooks/Cole, CA.
[15]. Wolstenholme, E.F. 1994. System inquiry: A system dynamics approach. John Wiley&Sons, New York.