original article

The effect of the waste separation policy in municipal solid waste management using the system dynamic approach

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ABSTRACT

Aims: In the present study, Vensim was used to simulate waste management system of Tehran, the capital of Iran, with the system dynamic approach.
Materials and Methods: The environmental system dynamic modeling is one of the comprehensive simulation tools capable of simulating and analyzing complex systems. In this approach, the model is developed based on the existing realities and userâ€˜comments. User participation to develop the model could increase the reliability of the results.
Results: The simulation results revealed good conformity with the statistical data. Waste production prediction in the model with real data was more than 95%. Moreover, the effect of applying an encouraging policy for people to separate their waste was considered. The result indicated that applying a new policy, and the economic benefit through this policy would prevent getting a loan from the government after 20 years.
Conclusions: It could be concluded that public participation in waste separation was an effective policy to help in the financial independence of the municipality in terms of urban waste management. Moreover, conformity between the simulation results and real data revealed an appropriate capability of the simulated model to predict Tehran waste generation.

Key words: Simulation, system dynamic, Tehran, Vensim, waste management

INTRODUCTION

Urban solid waste contains large amounts of non-uniform material discharged from the urban communities, which may consist of agricultural, industrial, and constructional waste. Although the main components of urban solid waste, in many parts of the world, are somewhat similar, differences in economical situations, geographical location, climate, as also the cultural and social status, and the amount and density of produced waste are different from city to city and country to country.[1] The methods used to dispose solid waste are varied in different parts of the world. Some of these methods are dumping in open space, sanitary landfilling, incineration, and composting. Sanitary landfilling is prevalent in many developed industrial countries, while in underdeveloped or less developed countries it is not common. In such countries, regardless of the sanitary and healthy points, low-cost methods like dumping in open spaces, appears more acceptable than the other disposal methods. Despite the huge environmental problems of the dumping method, it is considered the main disposal method of urban solid waste in many Iranian cities.

In the last decade, waste recycling has been considered as one of the main components in the urban waste management strategies and planning, in the world. Recycling, not only improves the environment through proper utilization of the existing hazardous materials, but also encourages governments to use waste as Black Gold, due to its economic capability. Of late, the safe and economical exploitation of produced waste, like recycling, has been grown in Tehran. Although application

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of the new disposal and exploitation methods has grown, the effects of these approaches on the waste management system are unknown. Moreover, the efficiency of the applied policy, to change the economical and environmental situation, is not well recognized yet. It is difficult to explain any positive or negative effects of the applied policy in the waste management system, because of the presence of many dependent and complex parameters. The dependency of these parameters interferes with the mental model simulation. Therefore, application of a comprehensive approach to implement the appropriate policies and evaluate the results of the policies is necessary. Hence, using the system dynamics approach, which has the ability to analyze complex systems, has been taken into account. Understanding the feedback processes, including storage, flow structures, and time delays that determine the dynamics and nonlinearity behavior of the system, is one of the main and important modeling rule in this approach.[2] For the first time, Farester[3] applied the system dynamic analysis, to better understand the complex systems behavior. Since then, many applications of the system dynamic analysis have been presented in divers' field of engineering. For example, Sterman[2] in the business dynamic, Grant *et al*.,[4] in ecological systems, Farester[5,6] in the socioeconomical systems, Meadows and Meadows,[7] and Qu and Barney[8] in the agricultural systems applied the system dynamics analysis. In the field of environmental engineering, various applications of system dynamics simulation have been used. The environmental impact analysis of a coalfield (Vizayakumar and Mohapatra),[9,10] assessment of the euthrophication processes in lakes,[11] control of pesticides,[12] bioavailability of metals in constructed wetland sediments,[13] groundwater recharge,[14] regional environmental planning and management for a lake,[15] and Dynamic Modeling of Environmental Systems[16] are some of the applications of system dynamics in the environmental engineering field. Also, some researchers applied the system dynamic to simulate urban waste management. Mashayekhi[17] used the system dynamics approach to simulate New York waste management. Sudhir *et al*.,[18] studied and analyzed the inherent dynamic of the components of the waste management system, using the system dynamics approach. Dyson and Chang[19] applied the system dynamic approach to forecast municipal solid waste production in San Antonio, Texas. Sufian and Bala[1] developed a new model using the system dynamic approach, to simulate urban waste management in Dhaka city.

In the present study a new model was developed to study waste management in Tehran using the system dynamic approach with the Vensim software. Moreover, a new policy was developed and the efficiency of this policy was considered to encourage residents to separate their waste to achieve more income, more public participation, and also improve the current collecting and separating waste system. The present research is the first investigation using the system dynamic approach to simulate municipal waste management in Iranian cities. The main softwares that are prevalent in the system dynamic approach are Vensim, Stella, I think, and I see. However, the Vensim model that was used in the current investigation is more user-friendly than the other software mentioned. The current investigation has been conducted in April 2011, using the Tehran Municipality Data.

MATERIALS AND METHODS

Case study

It does not seem possible or reasonable to combust Tehran solid waste due to the high moisture content of the urban solid waste, and the necessity for high energy consumption to eliminate humidity (Quarterly Statistical Tehran solid waste, 2004 – 2009). Solid waste contains valuable materials, including paper, glass, some types of metals, and plastics. Analysis of the collected solid waste, in Tehran, is generally not accomplished. However, the result of waste composition analyses carried out by the municipality (2004) is presented in Table 1. Results show that around 32% of the Tehran solid waste is dry waste and the rest of it is wet. Thus, the high participation of dry waste revealed the necessity for separation of these valuable materials (dry waste).

As shown in Table 2 the amount of generated waste in Tehran is about 2.2 to 2.4 million tons annually. The population has a great effect on waste generation. Therefore, the uptrend of the waste production rate will continue because of population growth prediction, which causes increase in consumption. On account of the desirable financial income, waste recycling has been considered as an important issue in the waste management system. However, despite the need for recycling, no desirable policy has been taken with regard to Tehran waste management, to get a higher economic benefit. Some of the dry wastes, such as, paper, glass, and plastic, are the main raw materials for the recycling factory. Therefore, separation and collection of these materials improve recycling factory efficiency. There is no systematic separation plan to separate the dry waste from other waste in Tehran. The willingness of people to participate in a waste separation plan is very low. In 2005, some contractors were selected to separate and collect dry waste from different areas of Tehran (Quarterly Statistical Solid Waste, Tehran, 2004 – 2009). The amount of separated waste by these contractors from the households is presented in Table 3. All data in Table 3 is the percent of the amount of separated waste to total waste.

It can be concluded that only in the early implementation of this project (nine months of 45 months) the rate of dry waste collected has reached about 20% and in most cases the rate was less than 10%, which demonstrates the low efficiency of this policy [Table 3]. In other words, the physical analysis in 2004 [Table 1] revealed that about 32% of the household waste was dry waste. Hence, in the best situation only 20.1% of the 32% of total dry waste (about 6.4% of the total waste) was collected and separated, which indicated the low efficiency and undesirable result of this policy. In consequence, more research should be improved

Table 1: Tehran waste composition (2004) (Quarterly Statistical Solid Waste in Tehran, 2004 – 2005)

Wet waste	Plastic	Pet	Types of paper and cardboard	Ferrous metals	Non-ferrous metals	Glass	Rubber	Other material
67.82	2.75	0.71	8.13	1.55	0.2	2.4	0.71	15.74

Table 2: The amount of Tehran waste collected by municipality (Quarterly Statistical Solid Waste in Tehran, 2004–2005)

Year	Spring (Ton)	Summer (Ton)	Autumn (Ton)	Winter (Ton)	Total annual waste (Ton)
2004	572796	562484	560167	550314	2245761
2005	585269	570145	560264	551457	2267135
2006	568117	600701	576463	570062	2315343
2007	602628	605119	602866	550499	2361112
2008	584365	584913	565133	517823	2252224
2009	554860	--	--	--	--

and developed for the dry waste separation policy, to receive a higher amount of valuable dry waste.

Methodology

Owing to the inherent complex nature of the waste management systems, analysis of such large-scale complicated systems, which the human mind is unable to handle, requires effective tools. These tools should be involved taking into consideration the interaction between socioeconomic, environmental, and all components in the mental models. System dynamics was designed based on system thinking, which is a well-established methodology and provides a foundation to construct a capable computer model that allows model builders to conceptualize, document, simulate, and analyze complex models of dynamic systems.[19,20]

In a system dynamic, first the model is created using four main components, to show the cause and effect relationship between the all the components involved in the model. The four components are: Storage, flow, arrow, and converters. The storage is used to describe each parameter, and the component has a cumulative behavior. The flow shows the processes that make storage full or empty by entering the storage into or discharge from it.[4] Arrows are used to show relationships between variables in the model, and their direction indicates how the parameters are dependent. The system dynamics method is based on the hypothesis of feedback processes. A feedback system is affected by its past activities and results of the past activities will be used in future processes. Different software are used to simulate the model in a system dynamics environment. In the present study, Vensim was used to simulate the Tehran waste management system and assess the new separation policy's effect. The Vensim software was provided by the Ventana Company. Vensim PLE version 5.5, which was used in the current investigation, was the academic version that was released in 2005. The main components of this model were population, recycling systems, public concern, sanitary landfilling, and a suitable policy to encourage people to increase their participation in waste separation. The relationship between the model's components was based on the incorporation of mathematical, empirical, and economical issues.

RESULTS

The simulated model in Vensim is presented in Figure 1. In this model, waste generation is affected by population growth. The population model has been developed taking into consideration the negative immigration program, which controls population growth in Tehran. Tehran's population is estimated to be about 7.6 million people. According to the existing programs and assuming efficient policies applied in the negative immigration program, Tehran's population will be around 8.6 million in 2020 (Quarterly Statistical Tehran Solid Waste, 2004 – 2009). Moreover, according to the Quarterly Statistical Tehran Solid Waste (2004 – 2009) waste production has been estimated to be equivalent to 850 g per day for each person who lives in Tehran. Also, according to the annual economic development program, the average per capita income will be increased. Increasing per capita income affects waste production; it causes an increase in waste production.[20] The effect of increasing average per capita has been considered with regard to waste generation for each person. Regarding this issue, the simulated model also considers the income per capita's effect on waste production, by using coefficients varying from 1 to 1.3. In consequence, waste generation per capita will be not fixed and will change due to variation in the per capita income during the simulation time (2000 – 2020). The main and considerable cost of waste management plans are assigned to waste collections and transfer. Therefore, the simulated model must consider these costs. For this purpose the cost fraction parameter is defined as the ratio of total municipality budget available to the cost of collecting and transferring the waste. If this ratio is smaller than one, the total municipal budget will be spent on waste collection and transfer. Therefore, the municipality has to get loans from the government to manage other municipal activities. An insufficient budget may force the municipality to dump the collected waste, without any concern for the environmental problems that will follow this action. This will increase environmental pollution, such as, water and soil pollution. Furthermore, it provides a suitable environment for insects and animals, such as mice, which may cause a spread of diseases and failing human health.

Increasing the amount of dumping waste increases public pressure and attention and the municipality will be forced to follow sanitary landfilling. Public pressure can persuade the

Table 3: Separated solid waste collected by contractors (Quarterly Statistical Solid Waste in Tehran, 2005 – 2009), all data are in percent

Year	April	May	June	July	August	September	October	November	December	January	February	March
2005	--	--	--	--	--	--	2.4	2.6	4.2	4.2	5.4	5.6
2006	20.1	17	19	18.59	18	19.2	17.2	17.3	20	4.8	5.1	6.5
2007	4.7	5.2	4.8	4.9	4.9	5.9	4.85	5.94	6.74	5.97	5.82	6.58
2008	2.94	3.2	2.7	3	3.31	3.01	4.2	4.7	4.6	5.23	6.5	6.59
2009	6.5	7.78	8.56	--	--	--	--	--	--	--	--	--

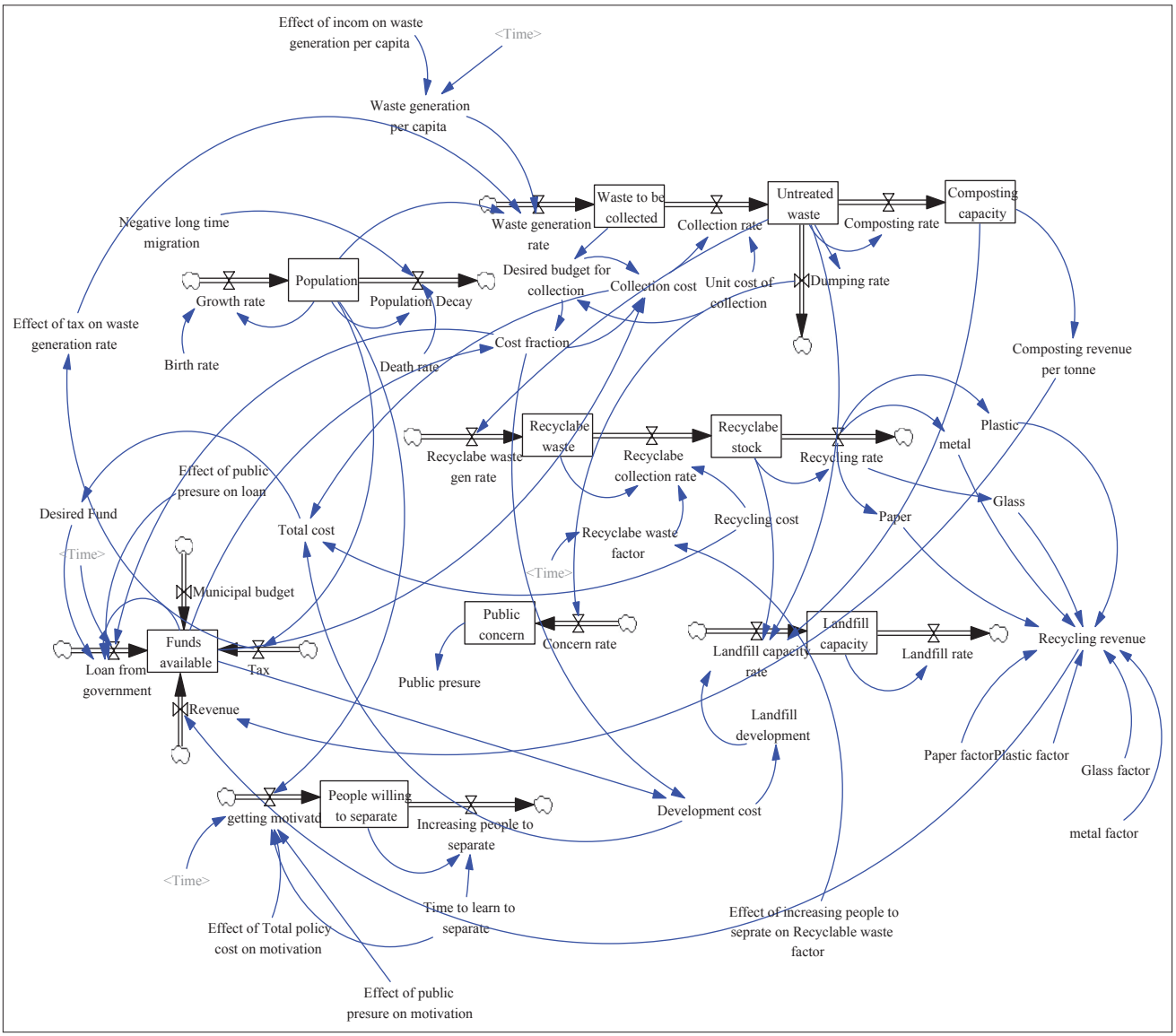

Figure 1: Tehran waste management simulated model in Vensim

municipality to obtain more loans from the government to apply a more desirable management policy. As per the above description, none of the existing plans are productive and are only expensive. Application of the approaches with regard to waste recycling has a desirable economic cycle in urban waste management and a positive effect on the local economics and employment. In the simulated model, materials produced by recycling factories are paper, metals, glass, and plastic. What more materials provide to recycling plants, recycled production rate, and revenue will be increased. The separation policy with regard to people participation may provide a higher amount of paper, metals, glass, and plastic. Therefore, people's assistance and cooperation in waste separation can significantly help in waste recycling. Hence, a new policy provided in the model has been developed, and is based on increasing public awareness about the benefits of waste recycling. Besides, the municipality can encourage people to separate their waste through an incentive plan such as special discount in chain store or tax reduction. Assuming that such a policy is applied in a desirable manner, the

citizen's enthusiasm to separate their waste will be increased, which will cause an increase in recycling plant efficiency.

As mentioned earlier, the rate of waste production has a close relationship with population and per capita income. Figure 2 shows a variation in waste production in Tehran during the simulation period. As shown in Figure 2, the amount of waste produced in 2000 has been estimated to be about 2.2 million tons. One of the main methods to verify and calibrate the simulated model is the compliance rate of the simulated result with the real data. There is acceptable coincidence between the waste production in the simulated data in Figure 2 and the real data [Table 2]. The simulated model reveals that the amount of waste produced during the period 2002 to 2006 is around 2.2 to 2.4 million tons, which is very close to the real data [Table 2].

Variation in the amount of loan received from the government is presented in Figure 3. As Figure 3 implies, the loan rate received has a downtrend and at the end of 2020 will have significantly decreased. As mentioned earlier, obtaining economic benefit is one of the main objectives of the waste recycling plan. Simulation results reveal that more than 90% reduction in getting loans from the government indicates a positive effect of the encouraging policy on the municipality economic cycle.

Figure 4 shows people's tendency to separate their waste, influenced by an encouraging policy.

It can be inferred that if such policies perform in an appropriate manner, public participation in waste separation programs will be increased. Encouraging and informing people through the public media will have a positive effect on the willingness of the people to continue their waste separation. Moreover, to prevent the monotony of encouraging a policy over a long time period, more innovative plans may be thought of to keep or attract people to separate their waste.

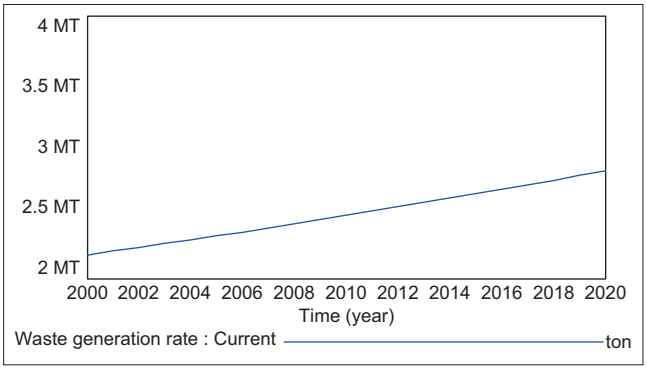

Figure 2: Prediction of urban solid waste generation in Tehran

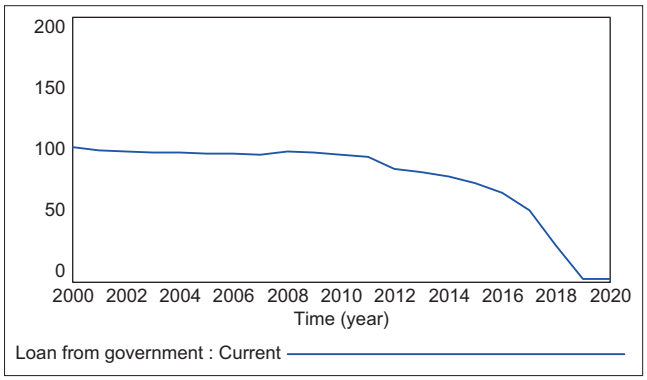

Figure 3: Variation of getting a loan as a result of the waste separation policy

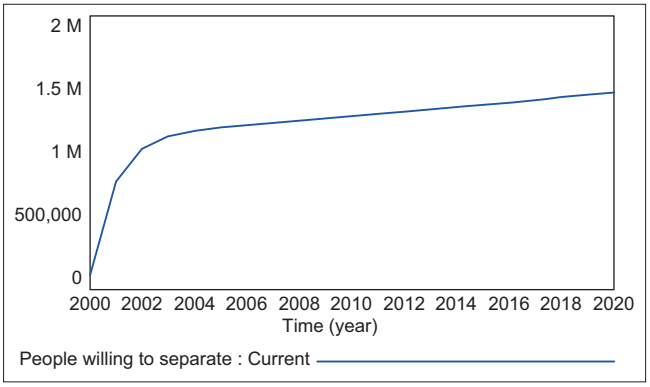

Figure 4: People willing to separate their waste

DISCUSSION

Simulation of various systems using the system dynamics approach has an acceptable ability to analyze applied policies in complex systems like waste management. Also, the effect of an applied policy on system behavior can be determined using the system dynamic approach. Due to the inherent complexity of the urban waste management system, mental simulation does not seem to be possible. Simulation of the Tehran waste management system in a environmental system dynamic modeling reveals appropriate usage of this approach to analyze and simulate the urban waste management system. The simulation results indicate a positive effect of waste recycling on the economic cycle of municipality. Application of a suitable separation policy, with regard to people participation, has improved the economic benefit of recycling plants. Results reveal that more than 90% reduction in the loan will be achieved after 20 years. Therefore, it can be concluded that public participation in waste separation is an effective policy to help in the financial independence of the municipality, in terms of urban waste management. Moreover, conformity between the simulation results and real data has revealed an appropriate capability of the simulated model to predict Tehran waste generation.

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