A SYSTEM DYNAMICS MODEL TO PREDICT MUNICIPAL WASTE GENERATION AND MANAGEMENT COSTS IN DEVELOPING AREAS

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ABSTRACT

This paper utilized system dynamics modeling as a new analytical approach to predict both the municipal waste generated and the associated disposal costs in developing areas. This approach facilitates the decomposition of general waste into its main components to enable municipalities to manage recyclables and find out the feasibility of performing recycling better rather than disposal by performing comparative disposal cost analysis. This study is different from previous work as it only considers population as a factor to predict the total waste generated and recycled, together with the associated expenditure and disposal cost savings.
The approach is verified by applying it to a case study in Nablus and demonstrates the evaluation of the quantity and composition of generated waste by considering population as the main influencing factor. The quantity and composition of municipal solid waste was evaluated to identify opportunities for waste recycling in the Nablus municipality. Municipal solid waste was collected and classified into eight main physical categories. The system dynamics model enable the quantity of each generated component such as plastic and metals to be anticipated together with the cost of recycling or disposal.

Keywords: System dynamic model; solid waste; waste characterization; economy; developing areas

INTRODUCTION

This paper presents a new analytical approach using system dynamics modeling to predict municipal solid waste (MSW) generation and disposal costs with a focus on developing areas and uses Nablus as a case study example. The approach evaluates the quantity and composition of generated waste by considering population and quantities of each generated waste component, such as metal and plastics together with the cost of recycling or disposing of the waste.

A variety of data must be collected and analyzed before a community adopts and implements any waste management approach or combination of approaches. Community's waste

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profile, types and quantities of waste generated and how much can be prevented realistically through source reduction and recycling are a prerequisite to develop a successful waste management program. This program will help determine the degree of detail needed in the waste characterization study. Modeling techniques are inexpensive and use generic waste generation rates and other information to provide only a general idea of waste volumes and types. Each management approach carries a price tag. Estimating costs before acting is essential to long-term success (USEPA, 1995).

The following municipal solid waste management (MSWM) practices have been observed in the Nabulus area. There is very limited segregation of MSW into different components. All types of MSW are collected, including hazardous household and infectious waste from hospitals, which are disposed of together. Various issues such as the safety of cleaning workers, public health For example, source reduction and landfill projects require only gross waste volume from estimates and recycling and waste-to-energy projects require accurate predictions of waste quantities and composition. and environmental protection, are often not considered by management. For example, MSW is disposed in many randomly distributed dumping sites, causing pollution to surface and ground water together with the spread of litter in streets and public places. Moreover, scavenging at disposal dumping sites often worsens the problems (Al-Khatib et al., 2007; Arafat et al., 2007; Al-Khatib et al., 2010).

A partnership was established among three organizations: Applied Research Institute-Jerusalem; PADICO, a major local company; and Nablus municipality. The new recycling plant signed a contract with the municipality giving the company exclusive rights to utilize solid waste in Nablus. The company will eliminate solid waste in an environmentally friendly manner; use organic solid waste to produce compost; recycle other components that include metals, glass, and plastics; create new jobs; and reduce the municipality's solid waste disposal costs. As of 2013, the new recycling plant is under construction, and it is expected to be operational by the end of the 2013 year.

Linear programming, input–output analysis, expert systems (a methodology that uses expert knowledge to solve problems of a complex system) and system dynamics have been applied to aid decision makers in the planning and management of solid waste management systems (Everett and Modak, 1996; Barsi, 2000; Ming et al., 2000; Heikki, 2000). More recently emphasis has been placed on the capability of system dynamics for the prediction of solid waste generation (Saysel, 2002; Themelis et al., 2002; Kum et al., 2005; Dyson and Chang, 2005; Sufian and Bala, 2007). However consideration was not given to separating the general waste into its main components, as the proposed model does. This paper does not compare and contrast these different tools but utilizes the efficiency of the system dynamics methodology to construct a stock and flow model. The proposed system dynamics model considers the population as a main waste generating factor and decomposes the generated waste into different components to provide a clearer picture about the generated quantities of each component. This could help decision makers to plan for the recycling and utilization of these components.

SYSTEM DYNAMICS APPROACH

This paper considers a system dynamics methodology as a computer-assisted decision making approach. Indeed computer-assisted decision making in the public policy field has become more common in recent years as policymakers have faced increasing demands for accountability (Rubenstein-Montano and Zandi, 2000).

System dynamics was founded as a new modeling approach in the 1960's by Jay Forrester. It takes feedback into consideration, which is a fundamental concept of systems analysis and is widely used as a modeling and simulation methodology for long-term decision-making analysis of industrial management problems. System dynamics also helps modelers and decision makers to conceptualize and rationally analyze the structure, interactions and mode of behavior of complex systems and sub-systems to explore, assess, and prognosticate their impacts in an integrated, holistic manner. System dynamics is also differentiated from simple spreadsheet programs as it facilitates a more sophisticated, quantitative simulation and is capable of more robust and reliable outcomes (Kollikkathar et al., 2010).

As a method, system dynamics is particularly suited to the simulation of complex systems, such as a waste management system. It has the capability of dealing with assumptions about system structures in a stringent fashion, and is, in particular, a way of monitoring the effects of changes in subsystems and their relationships. Furthermore, it is also capable of representing these changes and rendering them communicable.

The structure of system dynamics is exhibited by causal loop (influence) diagrams which capture the major feedback mechanisms, as shown simply in Figure 1. The diagram includes elements and arrows (which are called causal links) linking these elements together in the same manner and a sign (either + or -) on each link to indicate the relation between the two successive variables. If the relation is positive, it means that the two variables are moving in the same direction. An increase in one variable leads to an increase in the other. If

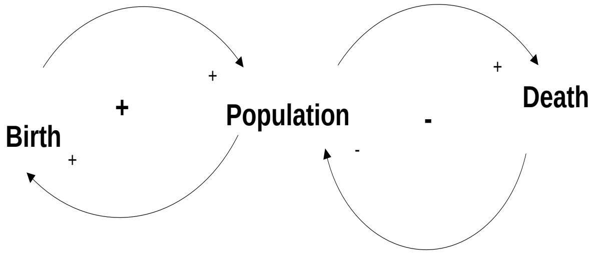

FIGURE 1
Population causal loop diagram

the relation is negative, it means that the two variables are moving in opposite directions as if one is increasing the other is decreasing and vice versa. These signs have the following meanings:

- The causal link between birth and population is positive (+), which means that the birth is added to population and an increase in births will lead to an increase in population.
- The causal link between death and population is negative (-), which means that the death is subtracted from population and an increase in death will lead to a decrease in population.

In addition to the sign of each causal link between any successive variable, the whole loop is given a sign. If the sum of negative signs in a loop is even, the whole loop is given a positive sign, which means the loop is reinforcing and the system is in unstable equilibrium. In contrast, if the sum of negative signs is odd, the whole loop is assigned with a negative sign, which means the loop is balancing and the system seeks to return to an equilibrium situation.

The next step in using system dynamics modeling is to convert the causal loop diagram into a process model, called a stock and flow diagram. Figure 2 shows a system dynamics model: the stock and flow model. It shows a convertor used to hold a value of a variable, for example death fraction. Another icon is used to represent the frequent flow of birth in a time unit (e.g. year). It is therefore a time related variable. Another icon represents a stock, otherwise known as a repository or accumulator. This accumulates quantities of a variable over a period of time, such as the number of people in a stock population in ten years' time. The model is built using the ithink simulation tool, which is a famous simulation modeling tool used in system dynamics. The mathematical mapping of a system dynamics stock-flow diagram occurs via a system of differential equations, which is solved numerically via simulation as shown in Appendix A. The model is used to simulate different scenarios to find out the optimal situation. All the parameters leading to this situation are recorded and a real model is built by switching the relevant parameters to the optimal values. Currently, high-level graphical simulation programs (such as ithink®, Stella®, Vensim®, and Powersim®) support the analysis and study of these systems.

System dynamics modeling has been used to address practically every sort of feedback system, including business systems, ecological systems, social-economic systems, agricultural systems, political decision making systems and environmental systems (Dyson and Chang, 2005). In terms of environmental concerns, the application has covered many issues. These vary from salt accumulation in lowlands under continuous irrigation practice (Saysel and Barlas, 2001);the value of water conservation (Stave, 2003); the consequences of dioxins to the supply chain of the chicken industry (Minegishi and Thiel, 2000); the eutrophication problem in shallow freshwater lakes (Guneralp and Barlas, 2003); the impact of environmental issues on long-term behavior of a single product supply chain with product recovery (Georgiadis and Vlachos, 2004); sustainability of ecological agricultural development at a county level (Shi and Gill 2005); estimation of methane emissions from rice welds (Anand et al., 2005), basin's environmental management system (Guo et al., 2001) and waste management (Dyson and Chang, 2005; UlliBeer, 2003; Karavezyris et al., 2002; Sudhir et al., 1997).

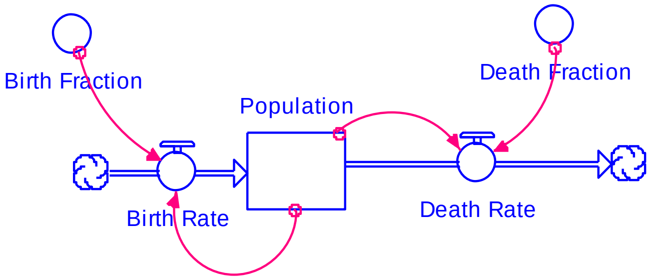

FIGURE 2
Population stock and flow diagram

MATERIALS AND METHODS

Waste characterization

The determination of waste composition is not straightforward and requires a small amount of training, as the nature of waste in general is heterogeneous. Therefore, common sense and random sampling techniques have evolved as generalized field procedures (Tchobanoglous et al., 1993).

Sampling was conducted according to Standard test method at Al-Serafi Transfer Station that is at the north east Nablus city, for determining the composition of unprocessed municipal solid waste (World Health Organization (WHO), 1988). The determined mean composition of MSW was based on the collection and manual sorting of 100 samples of waste during June – August 2010. Vehicle loads of waste were designated for sampling, and a sorting sample was collected from the discharged vehicle load and sorted manually into the following waste components (1) Organic waste (compostable, including food waste), (2) Plastics, (3) Paper and cardboard, (4) Glass, (5) Metals, (6) Textiles, (7) Other waste (leather, wood, ashes, etc.) and (8) Waste less than 10 mm size (passing through the mesh and termed as inert).

The weight fraction of each component in the sorting sample was calculated by the weights of the components. The mean waste composition was calculated using the results of the composition of each of the sorting samples. Vehicles for sampling were randomly selected during the sampling period to be representative of the waste stream.

To apply the WHO method, a tank of 0.5 $m^3$was filled with solid waste and shaken three times without applying any additional force. The tank contents were then disposed of on screening equipment (1.5 x 3m) with a (10 x 10mm) mesh surface size, specifically designed and fabricated for dealing with the heterogeneity of solid waste. The waste that did not pass through the mesh surface was then separated manually. The 'potential use' categorization was used to sort the waste instead of the traditional material-based categorization, as it was a preferable method for examining the feasibility of waste separation for composting and recycling (Al-Khatib et al., 2010).

Eight dustbins, each with a capacity of 80 litres, were used for the separation of solid waste into the above-mentioned components. A scale was used to weigh the dustbins at the different sampling locations. The percentage of the solid waste components and the total sample weight was computed. The average disposal cost was computed by dividing the total annual disposal cost by the total weight of waste generated in tons. The disposal cost was estimated on a monthly basis so that it was fluctuating, and based on that the cost range was determined.

System dynamics waste generation and disposal cost model

The consideration and planning of MSWM helps to address several interrelated issues, such as public health, the environment, solid waste generated and present the future costs incurred to society. The MSWM is a complex, dynamic and multi-faceted system, depending not only on available technology but also upon economic and social factors. Experimentation with an existing MSWM system containing economic, social, technological, environmental and political elements may be costly and time consuming or totally unrealistic. By simulating MSWM with a computer model, a series of computer experiments can be conducted to find out the best situation for the MSWM by considering all of the interrelated variables. Computer models enable the understanding of the dynamic behavior of such complex systems (Bala, 1999). Owing to the intrinsically complex nature of MSWM problems, it is advantageous to implement MSWM policy options only after careful modeling analyses which can lead to an optimal situation. The analysis involves the use of different modeling techniques, such as optimization, econometrics, input–output analysis, multi-objective analysis and system dynamics simulation.

Forrester's system dynamics methodology provides a foundation for constructing computer models to do what the human mind cannot do because of its complexity (Forrester 1968). The methodology can rationally analyze the structure, the interactions and mode of behavior of complex socio-economic, technological, and environmental systems. Hence, the system dynamics approach is the most appropriate technique to handle this type of complex problem, as it offers the opportunity to handle all the interrelated variables which can affect system behavior.

The proposed system dynamics model defines the key elements which have to be quantified as variables and their influences are formulated mathematically as shown in Appendix A. The model is definitively determined when the parameters and the initial values for the state variables (stocks) have been specified. Figure 3 shows a stock-flow

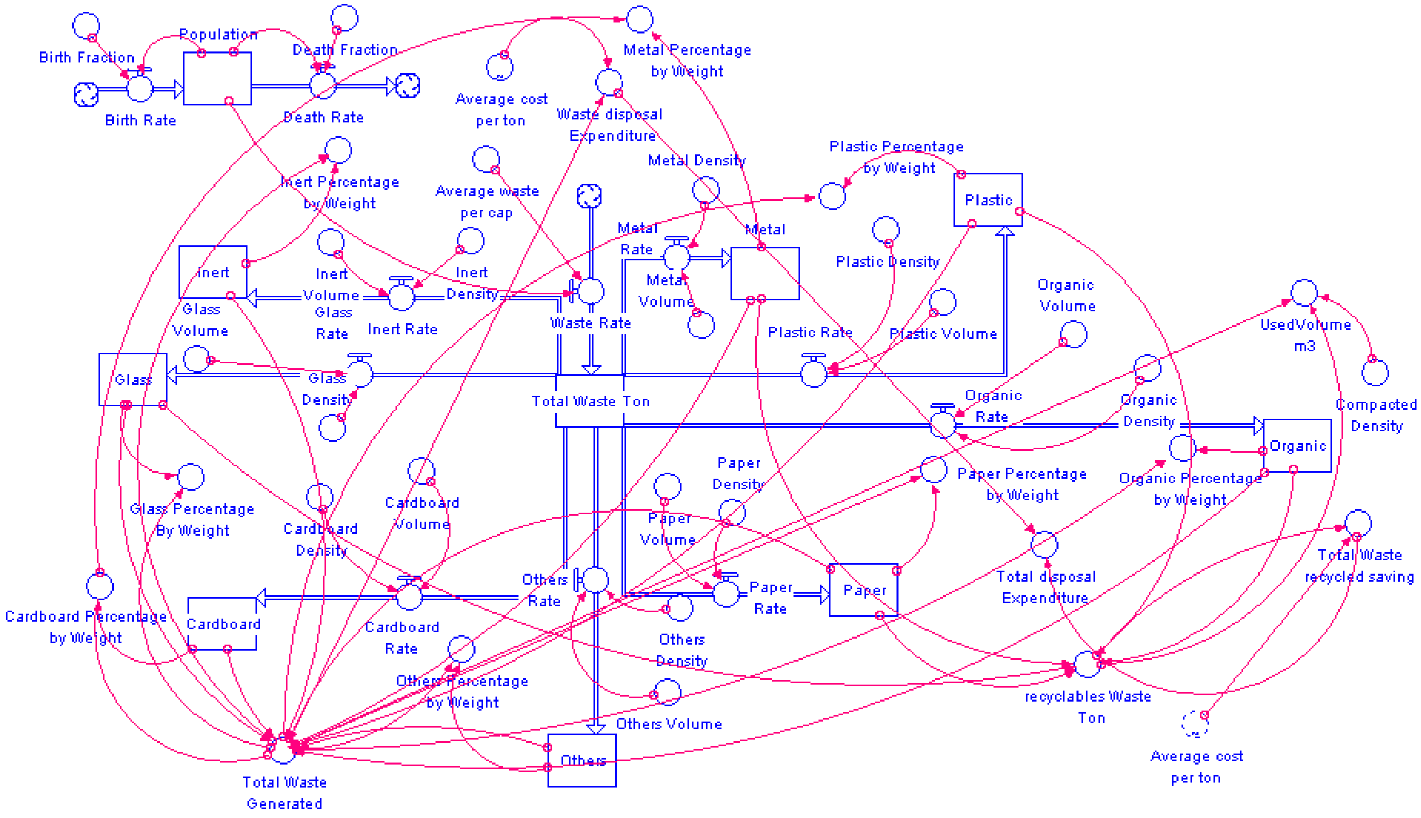

FIGURE 3

System dynamics waste management model

diagram for the waste disposal cost, which is designed using the ithink® 8.0 software package. It is a collection of different variables, such as stocks, flows and converters which generate and influence the behavior of the whole system. Any changes to variables will affect and result in changes to others. To run the model, the data available from the Nablus municipality is used as sample data to generalize a representation. The data was obtained from examining and testing different daily samples of waste and calculating the average disposal cost. Table 1 shows the data used as values in the model. It shows the population as a primary source of generating waste as household people, the waste generated per capita on an annual basis and the cost of disposal. The model also shows the main components of waste, which includes items such as paper and plastics. The model offers the ability to anticipate the quantity of each component generated in a period of time and the cost to recycle or dispose the waste. This model also provides an understanding of the future and could help with planning the best possible ways of disposing or recycling of such waste. In addition, it provides the volume estimation of accumulated wastes in the landfill (UsedVolume). UsedVolume equals the amount of waste sent to the landfill divided by the compacted density of solid waste in the landfill. According to the United Nations Environment Programme (2012) the compacted densities of solid waste in landfills go up to 700-1000 kg/m^3 after compaction on-site. 800 kg/m^{3}is recommended in this case study.

Table 1 uses samples generated throughout different subsequent years in the Nablus municipality (2002-2005). Data from years 2002-2005 were used to fit the model and calibrate its parameters, then the model was used to predict the outcome for other years (not used in the initial fitting) and the latter is compared to real data for the years 2006-2011 for model verification (Table 2).

Each year the population of the municipality generated a

TABLE 1

Solid waste quantities and their disposal cost for the years 2002-2005 Nablus municipality.

Year	Quantity (tons/year)	Population	Mean generation rate (kg/cap/day)	Mean generation rate (kg/cap/year)	Annual Disposal Cost (NIS)*	Cost Range (NIS/ ton)	Average cost (NIS / ton)
2002	42,153	154,649	0.75	270	1,321,200	20-45	31.3
2003	59,284	159,753	1.02	367.2	1,901,100	20-49	32.1
2004	40,716	164,864	0.68	244.8	2,492,000	60-62.5	61.2
2005	51,160	169,975	0.82	295.2	3,137,000	30-62.5	61.3

**New Israeli Shekels, 1 NIS equals 3.8 $US*

TABLE 2

Solid waste quantities and their disposal cost for the years 2002-2011 Nablus municipality.

Year	Quantity (tons/year)	Population	Mean generation rate (kg/cap/day)	Mean generation rate (kg/cap/year)	Annual Disposal Cost (NIS)*	Cost Range (NIS/ ton)	Average cost (NIS / ton)
2002	42,200	154,649	0.75	270	1,321,200	20-45	31.3
2003	59,300	159,753	1.02	367.2	1,901,100	20-49	32.1
2004	40,700	164,864	0.68	244.8	2,492,000	60-62.5	61.2
2005	51,200	169,975	0.82	295.2	3,137,000	30-62.5	61.3
2006	52,700	170,211	0.85	309.6	10,604,100	45-67.3	62.3
2007	53,300	179,659	0.81	296.6	9,953,100	41-58.6	55.4
2008	51,500	185,834	0.76	277	10,927,000	38-64.3	58.8
2009	55,900	189,893	0.81	294.4	12,039,200	45-68.7	63.4
2010	56,100	195,457	0.79	287.2	12,763,300	54-67.4	65.3
2011	56,000	198,267	0.77	282.5	12,728,700	51-65.3	64.2

**New Israeli Shekels, 1 NIS equals 3.8 $US* certain amount of waste. Table 1 also shows the cost for disposing of the waste generated on an annual basis in local currency (New Israeli Shekels which is equivalent to 3.8 $ US dollars).

RESULTS AND DISCUSSION

The data for 2002 provided the initial values (shown in Table 1) in the stocks that were used to predict results yearly until 2011 (shown in Table 2). Most of the core elements contained in this model are now discussed below.

Population: the population in 2002 was 154,649. For each 1000 the birth and death rates were 32.7 and 4.3 respectively. The difference between births and deaths generates the net population, which is used to calculate waste generation. Table 3 shows the population predicted until 2011 and how much waste will be generated. The predicted population from the model (Figure 3) was compared to the population and total waste generated from Table 2 for verification purposes. These two numbers are quite close as Table 2 shows the population in 2006 was 170,211, while predicted population from the model (Figure 3) was 178,381. This suggests the model is 95% accurate. Additionally, the simulated population and waste generation until 2011 are shown in Table 3. The population increases from a base year data to 213,981 at the end of the simulation. If the constant rate of birth and death in year 2002 is considered, the population would be 213,981 by the end of 2011.

Waste generation: The total quantity of waste generated is calculated by multiplying the waste generation rate (kg/day/capita) and total population. Finally, the model shows the total amount of waste generated by the total population as shown in Table 4. The amounts of waste generated are accumulated amounts, which means each amount is composed of that generated in a particular year added to the amount of waste generated in the previous year. For example, in 2002 the amount of waste generated was 37,920 ton and that in 2003 was75,840 ton. This being the accumulated amount of waste generated in 2002 and 2003.The difference of 37,920 ton is therefore the generated amount of waste in 2003.

Table 3 shows the population on a yearly basis and the representative estimated values of all the waste fractions considered that are likely to be generated in the assessment year. The tonnage continues to increase with increasing population and changing socio-economic conditions, as expected. For example, in a study conducted in Ghana, the results showed wide variation in levels of association between the socioeconomic variables and environmental conditions, with strong evidence of a real difference in environmental quality across socioeconomic classes with respect to total waste generation ($p < 0.001$) and waste collection rate (Fobil et al., 2010). In this study, for example in 2002 the population was 154,648, generating 18,890 kg of organic waste while generating 720 kg of glass waste. Hence the glass waste in 2011 will be 720 kg while organic waste will be 188,860 kg. The model studies the different types of waste (i.e. cardboard, glass, inert (less than 10 mm in diameter), metal, organic, paper, plastic, others). The model also shows the quantity of each type generated as shown in Table 3. The model considers the possibility of adopting some kind of recycling, concluded from the nature of the region as agricultural where there is scope for different types

TABLE 3

Prediction of population and all the waste components

Years	Population	Cardboard (kg)	Glass (kg)	Inert (Kg)	Metal (Kg)	Organic (Kg)	Paper (Kg)	Plastic (Kg)	Others (Kg)
2002	154,648	2,130	720	2,160	1,820	18,890	750	5,060	6,400
2003	160,267	4,260	1,440	4,320	3,630	37,770	1,500	10,110	12,800
2004	166,091	6,390	2,160	6,480	5,440	56,660	2,250	15,160	19,200
2005	172,126	8,530	2,880	8,640	7,260	75,540	3,000	20,220	25,600
2006	178,381	10,660	3,600	10,800	9,070	94,430	3,750	25,270	32,000
2007	184,862	12,790	4,320	12,960	10,890	113,310	4,500	30,330	38,400
2008	191,580	14,920	5,040	15,120	12,700	132,200	5,240	35,380	44,810
2009	198,541	17,050	5,760	17,280	14,520	151,090	5,990	40,440	51,210
2010	205,756	19,180	6,480	19,440	16,330	169,970	6,740	45,490	57,610
2011	213,981	21,310	7,201.0	21,600	18,145.0	188,860	7,490	50,550	64,010

TABLE 4
Prediction of population, total waste generated and used volume (the no recycling scenario)

Years	Population	Total Waste Generated (ton)	Waste Disposal Expenditure (ton)	Used Volume (m^3)
2002	154,648	37,920	2,320,800	74.4
2003	160,267	75,840	4,648,800	94.8
2004	166,091	113,750	6,973,000	147.19
2005	172,126	151,670	9,297,200	189.58
2006	178,381	189,580	11,621,400	236.98
2007	184,862	227,500	13,945,600	284.37
2008	191,580	265,410	16,269,800	331.77
2009	198,541	303,330	18,594,000	379.16
2010	205,756	341,240	20,918,200	426.55
2011	213,981	379,160	23,242,400	473.95

of recycling. When using the model for the purpose of considering recycling, it is shown that large savings can be achieved.

Solid waste contains significant amounts of valuable materials such as steel, aluminum, copper and other metals which, if they are recovered and recycled or reused, could reduce the volume of waste to be collected and occupied in the landfill, and at the same time yield significant salvage and resale incomes. In addition, better reclamation techniques could help to save valuable natural resources and turn waste, which could be dangerous, into useful products. Some important solid wastes that have been successfully reclaimed are paper, plastics, glass and metals.

This study is undertaken to evaluate the quantity and composition of MSW to identify opportunities for waste recycling in Nablus municipality. MSW solid waste was collected and classified into 8 main physical categories. The system dynamics model was utilized for the estimation of the yearly average MSW solid waste generation rate. The model (Figure 3) was compared to the population and total waste generated from Table 1 for verification purposes.

The system dynamics model generated three simulated scenarios showing the amount of waste generated, the amount recycled and the disposal expenditure.

Partially recycling scenario

Concerning the quality of service provided, Nablus municipality has begun to work on plans to tackle the waste problem. These plans include improving waste collection to make streets cleaner and setting up a system to manage waste disposal in a way that is cost efficient as well as environmentally safe. In the area of waste recycling, the waste management department at Nablus municipality is undertaking some sorting of garbage. Thus, on a small scale the garbage at ‘Al-Serafi Transfer Station’ is classified into plastic, iron, and paper. Paper material is sold for Israeli industries and Nablus factories are buying the plastic and the iron. UsedVolume (m^3) = (total waste – recycled waste)/800. The results of this scenario are summarized in Table 5.

No recycling scenario

This scenario represents closing the Al-Serafi Transfer Station and stopping the segregation process as it is operated mainly manually. In this case all wastes will be disposed of in the landfill, and the used volume will be maximized as UsedVolume (m^3) = total waste (kg)/800.The results of this scenario are presented in Table 4. The total waste generation (ton/year) increases with time, as population increases. Consequently, the total waste disposal expenditure will increase. Therefore, by the end of 2011 the total waste disposal expenditure would be 23,242,450 NIS.

Recycling all recyclables scenario

Table 6 provides estimates on the change in disposal costs associated with recycling all recyclables waste at the end of each year, rather than the use of landfill. The table shows that total disposal expenditure will be reduced and the total waste recycled saving will be 17,513,410 NIS (New Israeli Shekel) as shown in Table 6. This expenditure is reduced if recycling procedures have taken place. The recycled saving of 17,513,410 NIS is based on an assumption that the Nablus municipality adopt recycling procedures. If recycling procedures do not occur, the resultant large expenditure should prompt the authority to investigate measures to reduce costs and even gain an income by possible recycling methods.

TABLE 5

Prediction of population and total accumulated waste generated and the partially waste recycled scenario

Years	Population	Total Waste Generated (ton)	Partial Recycled Waste (ton)	Waste Disposal Expenditure (NIS)	Partial Waste Recycled Savings (NIS)	Used Volume (m^3)
2002	154,648	37,920	8,970	2,320,800	548,700	11.69
2003	160,267	75,840	17,930	4,648,800	1,099,100	23.37
2004	166,091	113,750	26,890	6,973,000	1,648,600	35.05
2005	172,126	151,670	35,860	9,297,200	2,198,100	46.73
2006	178,381	189,580	44,800	11,621,400	2,747,600	58.41
2007	184,862	227,500	53,790	13,945,600	3,297,100	70.10
2008	191,580	265,400	62,750	16,269,800	3,846,600	81.78
2009	198,541	303,330	71,710	18,594,000	4,396100	93.46
2010	205,756	341,240	80,680	20,918,200	4,945,600	105.14
2011	213,981	379,160	89,640	23,242,400	5,495,100	116.82

TABLE 6

Prediction of population, total waste and disposal expenditure and recycling saving ($US) (recycling all recyclables scenario).

Years	Population	Total Waste Generated (ton)	Recyclables Waste (ton)	Waste Disposal Expenditure (NIS)	Total Waste Recycled Savings (NIS)	Used Volume (m^3)
2002	154,648	37,920	28,570	2,320,830	1,748,700	11.69
2003	160,267	75,840	57,140	4,648,830	3,502,880	23.37
2004	166,091	113,750	85,710	6,973,030	5,254,190	35.05
2005	172,126	151,670	114,280	9,297,240	7,005,510	46.73
2006	178,381	189,580	142,850	11,621,440	8,756,830	58.41
2007	184,862	227,500	171,420	13,945,640	10,508,140	70.10
2008	191,580	265,400	199,990	16,269,840	12,259.460	81.78
2009	198,541	303,330	228,560	18,594,040	14,010,780	93.46
2010	205,756	341,240	257,130	20,918,240	15,762,090	105.14
2011	213,981	379,160	285,700	23,242,450	17,513,410	116.82

Sensitivity analysis

Model sensitivity analysis would need to take into consideration key influencing factors, such as population, generated waste components and costs together with boundary and policy changes. The growth and decline of a population would be directly influenced by changes in birth and death rate fractions where both of them assumed to be constant throughout the period between 2002-2011. The model can be enhanced by considering different factors which affect the birth and death rates which make the model more comprehensive. This will be a proposal for future consideration to perform further development to the model. However it does not take other factors such as immigration and emigration into consideration. Such figures could be considered to be not significant enough to largely alter population figures, although this may become more of an influential factor in cases of war and famine. Used volume depends on both the waste generated and waste recycled (fully, or partial) while the compacted density is constant. Which means, if the generated waste increases due to an increase in population, the volume used will increase. Equilibrium will be achieved between the waste generated and the waste recycled. An increase in waste generated stimulates the municipality to increase recycling and reduce disposal costs and landfills. Indeed the model is not fully comprehensive but built in a way that would enable the addition of such factors as further converters without altering the structure of the model. Fluctuations in disposal costs can be directly reflected in the results of the model.

CONCLUSION

Prediction analysis

The paper has demonstrated an initial inquiry into the possibility of using systems dynamics to solve complex waste-management problems and reduce future uncertainty of the impact of waste generation on the economy, environment and socio-economic environment in developing areas. It is different from previous studies in that it only considers population as a factor to predict the total waste generated and recycled, together with the associated expenditure and disposal cost savings. It demonstrates that system dynamic modeling provides a more comprehensive and sophisticated simulation method for integrated assessment of complex waste-management processes. The results from the simulation process show that the generation of MSW undergoes a general increase during the period of forecast, due to the increase in the dimensions of influencing socio-economic and population variables. Similarly, MSW disposal costs were shown to follow an increasing trend during the period of forecast. The simulated recycling scenario demonstrates that huge savings can be gained by reducing the cost generated from disposing of waste. Recycling is highly recommended to save money, utilize waste in beneficial ways and assist in reducing environmental pollution.

Supporting decision making in developing areas

The system's model presents a more practical and realistic picture of the next decade in solid waste-disposal for cities like Nablus, as compared with traditional approaches. The model can be used as a decision support tool to anticipate the future situation and the volume of different types of waste generated in the area of Nablus. Indeed the model is especially useful for local and national decision makers as it is able to determine the future potential economic impact of recycling or resource recovery activities. The model can also provide an alert for waste generation decision makers, enabling confrontation of the situation either by proposing proactive and preventative procedures or by inventing creative solutions relating to recycling different types of waste.

Possible future research

Future enhancement to the model could involve consideration of additional sources of waste apart from the population, such as factories, industries and hospitals and medical centers. Further development of the model is warranted for the solution of complex problems requiring more refined results for waste generation, such as landfill siting capacity, waste prevention and associated budget allocations. This study concentrated primarily on the general economic impacts, and certain limitations remain in the lack of other associated economic, environmental and social impact modeling. There exists a tremendous scope to extend and further its utility by introducing new sub-component ranges and by integrating various natural and anthropogenic system components, thereby facilitating the system actors across boundaries to come together for developing integrated solutions. It should also be noted that other factors that influence waste generation such as the monthly income of the family, education levels, consumption habits, family size and locality type could be taken into consideration.

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Appendix A: System Dynamics Model Equations

Cardboard (t) = Cardboard (t - dt) + (Cardboard Rate) * dt
INIT Cardboard = 1

INFLOWS:
Cardboard Rate = (Cardboard Density*Cardboard Volume)
Glass (t) = Glass (t - dt) + (Glass Rate) * dt
INIT Glass = 1

INFLOWS:
Glass Rate = (Glass Density*Glass Volume)
Inert (t) = Inert (t - dt) + (Inert Rate) * dt
INIT Inert = 1

INFLOWS:
Inert Rate = (Inert Density*Inert Volume)
Metal (t) = Metal (t - dt) + (Metal Rate) * dt
INIT Metal = 1

INFLOWS:
Metal Rate = (Metal Density*Metal Volume)
Organic (t) = Organic (t - dt) + (Organic Rate) * dt
INIT Organic = 1

INFLOWS:
Organic Rate = Organic Density*Organic Volume
Others (t) = Others (t - dt) + (Others Rate) * dt
INIT Others = 1

INFLOWS:
Others Rate = (Others Density*Others Volume)
Paper (t) = Paper (t - dt) + (Paper Rate) * dt
INIT Paper = 1

INFLOWS:
Paper Rate = (Paper Density*Paper Volume)
Plastic (t) = Plastic (t - dt) + (Plastic Rate) * dt
INIT Plastic = 0

INFLOWS:
Plastic Rate = (Plastic Density*Plastic Volume)
Population (t) = Population (t - dt) + (Birth Rate – Death Rate) * dt
INIT Population = 154648

INFLOWS:
Birth Rate = Population*Birth Fraction
OUTFLOWS:
Death Rate = Population*Death Fraction
Total Waste Ton (t) = Total Waste Ton (t - dt) + (Waste Rate - Organic Rate - Plastic Rate - Metal Rate - Glass Rate - Cardboard Rate - Others Rate - Paper Rate - Inert Rate) * dt
INIT Total Waste Ton = 1

INFLOWS:
Waste Rate = (Population*Average waste per cap)
OUTFLOWS:
Organic Rate = Organic Density*Organic Volume
Plastic Rate = (Plastic Density*Plastic Volume)
Metal Rate = (Metal Density*Metal Volume)

Glass Rate = (Glass Density*Glass Volume)
Cardboard Rate = (Cardboard Density*Cardboard Volume)
Others Rate = (Others Density*Others Volume)
Paper Rate = (Paper Density*Paper Volume)
Inert Rate = (Inert Density*Inert Volume)
Average waste per cap = .275
Birth Fraction = .04
Cardboard Density = .08
Cardboard Percentage by Weight = Cardboard/Total Waste Generated
Cardboard Volume = 74*360
Compacted Density = 800
Death Fraction = .0043
Glass Density = 1
Glass Percentage by Weight = Glass/Total Waste Generated
Glass Volume = 2*360
Inert Density = .50
Inert Percentage by Weight = Inert/Total Waste Generated
Inert Volume = 12*360
Metal Density = .36
Metal Percentage by Weight = (Metal/Cardboard Percentage by Weight)
Metal Volume = 14*360
Organic Density = .43
Organic Percentage by Weight = Organic/Total Waste Generated
Organic Volume = 122*360
Others Density = .27
Others Percentage by Weight = Others/Total Waste Generated
Others Volume = 52*360
Paper Density = .08
Paper Percentage by Weight = Paper/Total Waste Generated
Paper Volume = 26*360
Plastic Density = .07
Plastic Percentage by Weight = Plastic/Total Waste Generated
Plastic Volume = 254*360
Recycle recyclables Waste Ton = Glass+Metal+Organic+Plastic
Total disposal Expenditure = Total Waste recycled saving + Waste disposal Expenditure
Total Waste Generated = Cardboard+Glass+Inert+Metal+Organic+Others+Paper+Plastic
Total Waste recycled saving = Recycle recyclables Waste Ton*Average cost per ton
UsedVolume m^3 = (Total Waste Generated-Recycle recyclables Waste Ton)/Compacted Density
Waste disposal Expenditure = Total Waste Generated*Average cost per ton
Average cost per ton = GRAPH (time)
(2002, 31.3), (2003, 32.1), (2004, 61.2), (2005, 61.3)