



Optimization of Integrated Solid Waste Management Improvement Scenarios for Salt City in Jordan Using Computer-Based Decision Support Tool

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Abstract

The increasing amount of generated solid waste represents a great challenge to environmental engineers and scientists. Integrated solid waste management is highly required to control this important environment sector to reduce the possible negative impact on the environmental components (water, soil, and air). This study deals for the first time with solid waste management in Salt city. The evaluation of the current solid waste management program was carried out based on developed Decision Support Tool (DST) software. The DST was also used to generate options for modification of solid waste management program in the city. According to the Municipality reports, there is a deficit in the budget of the Environmental Health and Cleanliness Department of about 200,005 Jordanian Dinar (JD). Development of the Solid Waste Management program was proposed using DST software. The DST shows that by enhancing the separation at the source or disposal site, the Municipality can generate profits of 738,575 and 917,846 JD respectively. Sensitivity analysis was conducted on the DST result for the highest and lowest profits scenarios. The results show that separation of solid waste components plays a major role in the economic performance of solid waste management programs.

Subject Areas

Environmental Sciences

Keywords

Solid Waste Management, Decision Support Tool, Sensitivity Analysis, Municipality, Environmental Health Cleanliness Department

1. Introduction

The activities involved in Solid Waste Management (SWM) from the point of generation to the final disposal have been grouped into six functional elements: waste generation, waste handling and separation at the source, waste collection, waste processing and transformation, waste transfer and transport, and waste disposal [1]. By considering each functional element separately, it was possible to identify the fundamental aspects and relationships involved and to develop, where possible, quantifiable relationships for purposes of making engineering comparisons, analyses, and evaluations [2]. The separation of functional elements was important because it allowed the development of a framework within which to evaluate the impact of proposed changes and future technological advancement [3]. When all of the functional elements have been evaluated for use and all of the connections between elements have been matched for effectiveness and economy, an Integrated Solid Waste Management (ISWM) system can be developed [4].

Relatively, few studies have dealt with solid waste management systems in Jordan. Abo-Qudais (1987) recorded that the current system of solid waste management in Irbid city was ineffective, unsatisfactory, and very costly [5]. The average rate of solid waste generation was 0.78 kg/capita/day, whereas food wastes contributed to about 70% of the total produced MSW. Abo-Hassan (1988) has suggested modified heuristic a logarithm to satisfy the problem of collection vehicle routing. He reported that the node routing was the most suitable approach that can be used for waste collection, though the technique doesn't provide an optimum solution due to the large number of nodes in the study area [6].

Several studies in different periods identified the physical and engineering properties of different types of MSW in Amman city. Aranki (1987) reported that about 260 tons/day of commercial wastes were generated in Amman city at a rate of 0.3 kg/capita/day. Around 54% of this amount was food waste, 2.34% plastics, and 32.9% paper and cardboard [7]. Zeyadeh (1987) found that 0.4 kg/capita/day was the average generation rate of household refuse and the total produced household waste was 400 tons/day. The study recorded that 61.3% of total produced waste was organics, 15.6%, 8.3%, and 3.6% were respectively paper, cardboard and plastic. The combustible portion (food waste, paper, cardboard) constituted 85.2% of the total produced household waste. Regarding the quantities of combustible fraction, he suggested that converting these wastes into compost or animal feed are suitable alternatives for benefiting commercially [8].

Akour (1987) studied the generation and components of solid waste produced by the University of Jordan. The total produced waste was 527 tons/year with a generation rate of 0.12 kg/capita/day. Paper and cardboard accounted for 49.3%, food waste 29.8%, and plastic 13.42%. He concluded that by implementing a material recovery system, the University of Jordan can save 17,851 JD/year while by using an energy recovery system (incineration) for water heating about 6,322 JD/year can be saved [9]. Habaybeh (1994) showed that about 30.5 m³/day of

landfill space can be saved in Amman due to the collection of about 40 tons of paper and paper products each day. Moreover, he showed that if the total cost of collecting and disposing of one ton of MSW is 24.5 JD, the saving gained due to collecting papers for recycling was 204,100 JD for the year 1993 [10].

Several international and local studies were carried out concerning the MSW of Amman city. Hawksley (1979) performed a study to develop waste management and disposal system in Amman region. The average generation rate was found to be 0.43 kg/capita/day of household waste. In 1984 Municipality of Amman came to determine the generation rate and composition of MSW in two districts of Amman city (Basman and Al-Abdali). Vegetables and organic food wastes constituted 70.8% of the total produced wastes while 21.5%, 3.3%, and 4.4% respectively constituted papers and cardboard, metals, and glass [11].

The Royal Scientific Society (1995) showed that the total MSW amount dumped in the landfill was recorded as 1200 tons/day. The generation rate was calculated as 0.93 kg/capita/day for MSW and 0.465 kg/capita/day for household wastes of Amman city. Waste composition analysis showed that 53%, 17%, 8%, 10% and 12% were accounted for by organics, papers, metals, glass, and plastic respectively [12].

Several international and national studies were carried out concerning the evaluation of the policies of solid waste management in different countries and suggest different scenarios to solve the problem of solid waste [13]. USA-Environmental Protection Agency (EPA) (1989) prepared an agenda for action for solid waste dilemma, discussing the hierarchy of integrated management, goals and responsibilities, and planning of municipalities. The emphasis was on increasing available information, source reduction activities, recycling, and reducing risks of combustion and landfills [14].

Pirozzi *et al.* (2002) showed that to develop an integrated system for solid waste management, the Campania Regional Administration (Italy) had divided the region into two territorial areas. For each of these, a decisional model was applied so as to define the composition and the amount of solid waste flows to be collected and diverted to the treatment plants. Six different scenarios were considered, corresponding to the successive phases of Regional Program implementation. An optimization algorithm for the solution of the decisional model was used to spread the waste components among the envisaged plants with or without source-separated collection, while imposing four objectives for minimum material recovery. The obtained results are discussed and compared for the assumed cases in order to arrive at the best technical and economic solution for waste management, *i.e.*, compatible with choices made by the Regional Program, for the different phases of the municipal solid waste management plan [15].

Arena *et al.* (2003) showed that the life cycle assessment is an internationally standardized method that is able to account for upstream and downstream input and emissions related to the life cycle of the product or service. It is generally

considered the best environmental management tool that can be used to obtain an objective quantification of all the environmental impacts related to different solid waste management scenarios. It is used to assess the environmental performance of alternative solid waste management options that could be used in an area of the south of Italy suffering from a situation of weight solid waste emergency. The extreme delicacy of the decision-making process to which results have to contribute suggested, increasing the reliability of the assessment conclusions by using a high-quality of data and a deepened analysis of technical processes [16].

Sokka *et al.* (2007) showed that waste reduction was recognized as the main goal of waste management policy in the EU in the 1990s. Although knowledge of past waste generation is essential for effective waste reduction policy there are no comprehensive statistics on the past development of municipal solid waste (MSW) production. In this study, the production and composition of MSW in Finland between 1960 and 2002 are presented using historical data. The impact of population, affluence and technology on MSW production are analyzed using the IPAT equation and three scenarios are constructed until the year 2020. The results are compared with national future targets on MSW production [17].

Agunwamba *et al.* (2003) showed that actual transportation cost was estimated based on 1999 salaries and fuel prices. Optimum cost of collection via transfer stations to two disposal sites was compared with the existing situation of having no transfer station and only one disposal site. Post-optimality analysis was performed for several scenarios, investigating the sensitivities of the optimal cost to varying capacities of the transfer stations, investments and operating cost of the transfer stations, generation rates, and unit collection costs via transfer stations were each operated at a capacity of 300 tons per day. The introduction of transfer stations resulted in \$463.75 (38.9%) savings per day in the collection cost. Implementation of the programme will facilitate regular collection of solid wastes by reducing the operation cost [18]. This study aims to propose new scenarios of waste disposal management that would be economic and environmentally efficient. This has been accomplished using a computer-aided Decision Support Tool (DST) that is developed and designed to solve different integrated solid waste management problems.

2. Methodology

As previously discussed, the integrated solid waste management encompasses different functional elements. Each element may contain different forms of applications. For example, different waste components might be the target of SW separation program. In this work, the main functional elements that might significantly affect the ISWM decision are tabulated in **Table 1**. Functional elements that are taken into consideration in this study are: waste handling at source, waste collection, waste transportation, waste processing, and waste disposal.

Table 1. Different options of components of solid waste management scenarios.

Waste Handling, Separation and Processing at Source (A)	Bags (B)	Containers (C)	Collection (D)	Transportation (E)	Separation and Processing (F)	Disposal (G)
1) Commingled waste	1) 30 L 2) 70 L	1) 110 L	1) Once/2 week 2) Once/week	1) Capacity 4.5 m ³	1) Semi-automatic separation of commingled wastes: 2.1) Plastic 2.2) Metals 2.3) Glass 2.4) Organic 2.5) Paper 2.6) Rest	1) Landfill for rest of separation process 2) Sell to factories for glass, metals, papers, and plastic
2) Separation of recycled materials: 2.1) Organic (kitchen waste) 2.2) Plastic, metal, glass 2.3) Paper 2.4) Rest	3) 80 L 4) No bags	2) 220 L 3) 1100 L 4) No container	3) 3 times/week 4) 7 times/week 5) 14 times/week	2) Capacity 7.5 m ³ 3) Capacity 16 m ³	2) Semi-automatic separation of recycled materials wastes: 2.1) Plastic 2.2) Metals 2.3) Glass	3) Composting agricultural applied for organic matter

The combination of these elements to generate options and scenarios leads to a complicated matrix of ISWM. However, there are infinite possible number of options and scenarios for commingled MSW and separated waste in case of using of the three containers types at different percentages. There are 40 possible scenarios for both commingle and separated (20 commingled and 20 separated) for one assumed option of percentages of containers type.

2.1. Improvement of Decision Support Tool

Often, decisions are made about how to collect, recycle, transport, and dispose Municipal Solid Waste without an understanding of the economic and environmental implications. Therefore, there is a great need for a development of a tool—a Municipal Solid Waste Decision Support Tool (MSW-DST) to provide site-specific analysis of the environmentally efficient and economically effective MSW management [19]. The developed decision support tool (DST) was based on VB.Net language. It is a computer-based tool that provides a standard approach to evaluate integrated waste management strategies. The DST software provides a simple data entry for all ISWM input variables.

The type of data required as input files are based on cost estimation of different components and sectors. The DST is capable to combine all this information and to conduct the corresponding calculations to determine the net profit of the scenario requested. The DST software was run based on actual data collected for different sources such as Municipality of Salt city, market, prices, and personal interviews. The result of the net profit help in the evaluation of the scenarios, the more positive net profit, and the more favorable is the scenario. The highest three favorable scenarios (highest net profits) of each type of handling processes

are chosen to be further analyzed.

2.2. Sensitivity Analysis

This part of the study is used to explore the effect of change of some input parameters on the scenarios and options at unchanged combination of solid waste functional element. The sensitivity analysis is conducted by varying the following input parameters: density of waste material, engine oil price, diesel price, salaries, container price, recycled material prices, and solid wastes fees. The sensitivity analysis allows investigating the effect of one parameter on the net profit of a scenario while the other parameters remain unchanged. **Table 2** shows the percentage change of the parameters that are used to carry out the sensitivity analysis.

3. Results and Discussion

3.1. Results of Decision Support Tool (DST)

This software is an easy DST which was developed to enable the decision maker to identify the solutions which would imply cost effective approach of an ISWM. DST-tool is based on cost benefit analysis. The software was run based on actual input data in the area. The validation of the model was checked by comparing the actual deficit of the solid waste management program reported by the municipality of Salt city with the theoretical deficit calculated by the DST program. The application of DST software on the actual parameters of the current solid waste management program showed an annual deficit of 201,071.37 JD. This agrees for more than 99% with the actual deficit calculated by the municipality of Salt city. This show, that the model can, for great extent, used to evaluate the current situation of municipal solid waste management programs.

The combination of the solid waste functional elements listed in **Table 1** generates 160 scenarios. These scenarios were run using the DST software. The two scenarios with the highest and the lowest benefits were taken to be discussed and analyzed. **Table 3** shows the result of the DST for scenarios with the two highest and lowest net profits.

Figure 1 shows the results of the DST for the highest two scenarios graphically

Table 2. Variation option for different parameter of scenarios.

Parameter	Variation option				
Density of compacted wastes	10%	20%	30%	40%	50%
Price of engine oil	20%	40%	60%	80%	100%
Price of diesel	20%	40%	60%	80%	100%
Salary for one employee	20%	40%	60%	80%	100%
Price of containers	20%	40%	60%	80%	100%
Price of recycled materials	20%	40%	60%	80%	100%
Solid waste fees	20%	40%	60%	80%	100%

Table 3. The net profit of the current SWM with the two highest and lowest scenarios.

Scenario	Input parameter	Net profit (JD)
Highest profits	H1 Separated (separated at source), using 100% of 110 L container, without bags, and with collection rate twice/day	1114660.94
	H2 Commingled (separated at landfill), using 100% of 110 L container, without bags, and with collection rate twice/day	1036653.97
Lowest profits	L1 Separated (separated at source), using 25% of 110 L, 25% of 220 L, and 50% of 1100 L container, without bags, and with collection rate once/2 weeks	-11010151.23
	L2 Commingled (separated at landfill), using 100% of 220L container, with bags 30 L, and with collection rate once/2 weeks	-6251809.01
Current SWM	Commingled (without separation at landfill), using 25% of 110 L, 25% of 220 L, and 50% of 1100 L container, with bags 80 L, and with collection rate 4 times/day	-200055.59

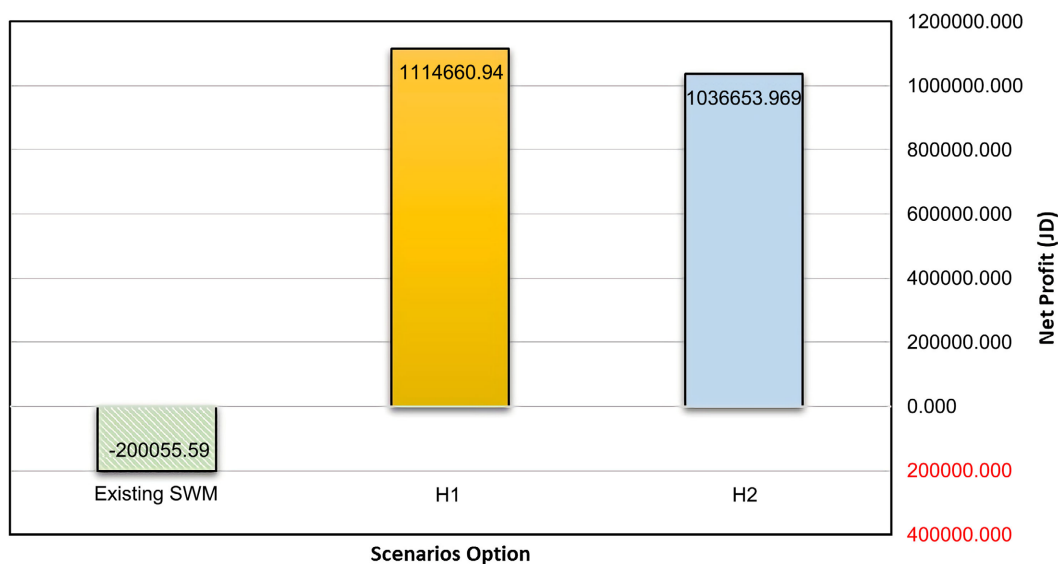


Figure 1. The two highest scenarios of the ISWM in Salt city.

presented along with the DST profit for the existing municipal solid waste management program at Salt city. It is clearly seen, that by choosing collection container of 110 L without solid waste bags and with separation at source at a twice daily collection rate, the profit is maximized with the amount of 1,114,660.94.

The highest option in commingled handling process is choosing a collection container 110 L without solid waste bags and with separation at the landfill not at a source at a twice daily collection rate. The difference in the profits of these two scenarios indicates that solid waste management program dealing with waste separation is more economical than that dealing with commingled waste.

By comparing these two options with the existing management, it is clearly seen that the existing solid waste management program needs to be modified to make a solid waste management an economical option. **Figure 2** shows the results of the lowest scenarios. It is obviously seen, that by choosing collection container 25 %110 L, 25% 220 L, and 50% 1100 L, with waste bags of 30 L and with separation at source and once in two-week collection rate, the profit is minimized with the amount of -11010151.23. The lowest option in commingle handling process is choosing a collection 220 L with waste bags of 30 L, with separation at the landfill at once in a two-week collection rate.

The DST software is used to find out possible modification of the current municipal solid waste management program in the city. The most influencing parameters that are believed to have effect on the economic performance of municipal solid waste management programs are the frequency of collection and implementing separation programs. DST was run using the current input data except for collection frequency and separation data. For collection frequency, it has been chosen to run the DST with two variations (once a week and three times a week). For separation programs, separations at source and at disposal site were introduced. The results of the DST are shown in **Figure 3**.

It is clearly seen that the frequency of collection plays a major role in the municipal solid waste management programs. The reduction of collection frequency to once a week T2, leads to increase in the deficit by -1843744.376 JD. Similarly, for the reduction of collection frequency three times a week T3, leads to decrease the net profit by -536,241 JD. The direct proportionality of the profit with the collection frequency can be explained by the increasing amount of solid waste containers that should be distributed over the city districts over the collection frequency is decreased and associated routings between containers locations and solid waste landfills. The numbers of containers required for the scenarios T2 and T3 comparing with the actual situation A1 are presented in **Table 4**.

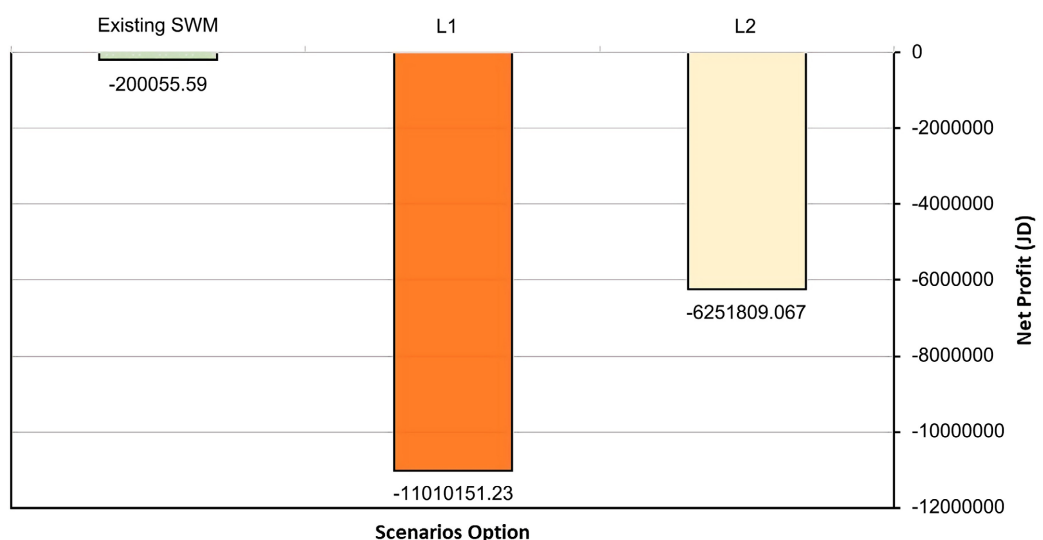


Figure 2. The two lowest scenarios of the ISWM in Salt city.

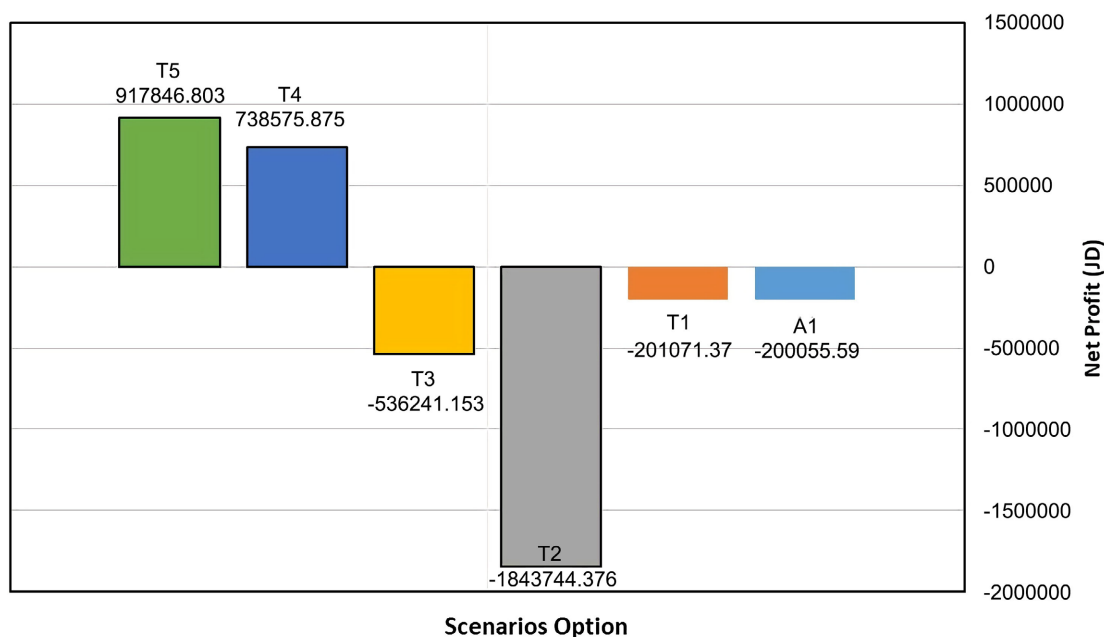


Figure 3. The effect of collection frequency and separation program on the net profit.

Table 4. Numbers of containers for modified scenarios.

Scenarios options	Number of containers		
	110 L containers	220 L containers	1100 L containers
A1 or T1 : (actual or theoretical) application of the existing SWM without separation with a collection rate twice/day	200	125	95
T2 : theoretical application of SWM without separation and with collection rate once/day	2644	1322	529
T3 : theoretical SWM without separation and with collection rate 3 times/week	880	440	176
T4 : theoretical application of SWM with separation at source with a collection rate twice/day	145	73	29
T5 : theoretical application of SWM with separation at landfill with a collection rate twice/day	189	95	38

The implementation of separation programs has been found to have a great influence on the net profit. The DST software showed that the implementation of separation program at the disposal site (T5) can increase the annual profit up to 917846.8 JD.

This increase in the profit comparing with the actual profit deficit is attributed to the selling prices of the recycled materials. The reuse of recycled materials is not only of benefit to the municipality financing department, but also has great impact on environment by concerning the natural resources. Similarly, for the separation at source (T4), the amount of saving and benefits achieved is about 738,575.875 JD. This is a bit less than the profit achieved by T5 scenario and can

be explained by the expenditures required for the bags and extra containers needed for the T4 scenario.

3.2. Results of Sensitivity Analysis

Sensitivity analysis has been conducted by running the DST-software for the two ISW options with the highest profits and the two ISW options with lowest profits (H1), (H2), (L1), and (L2). This is carried out in order to investigate the vulnerability of the DST and its supported algorithm to the possible changes in some independent variables.

Table 2 lists the mode of change of the variable that is used to conduct the sensitivity analysis. The effect of increasing the density of recycled materials on the net profit for the two options with the highest and lowest profits illustrated in Figure 4. It is obviously shown from Figure 4, that the density of recycled materials has relatively little effect on the net profit for all options. The 50% increase in density of separated materials resulted in increasing in the net profit for all option except L2 option and the percentage change in net profit is 0.09%, 0.08%, 0.28% and -0.41% for H1, H2, L1, and L2 respectively.

Figure 5 shows the effect of increasing the engine oil price on the net profit for the two highest and lowest profit option (H1, H2, L1, and L2). It is clearly seen in Figure 5 that the engine oil price has relatively little effect on the net profit for all option the 100% increase in oil price resulted in a decrease in the net profit of -0.0027% , -0.0024% , -0.0077% and -0.00096% for H1, H2, L1, and L2 respectively.

The results of the sensitivity analysis regarding the increase in diesel prices are illustrated in Figure 6. It was clearly seen from Figure 6 that the effect of diesel price increase resulted in little decrease in the net profit. This can be attributed

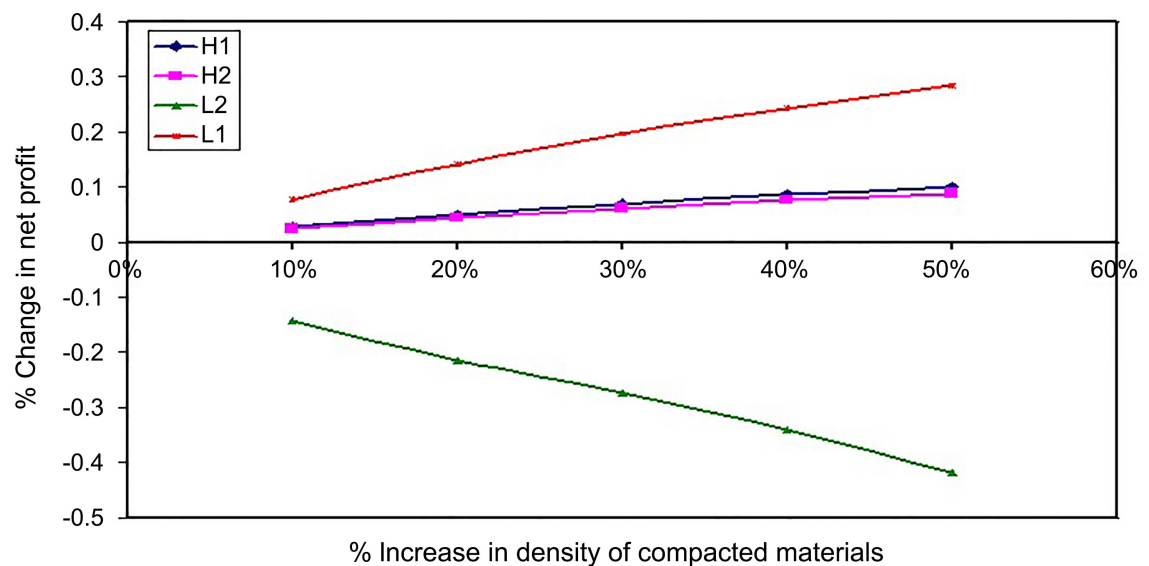


Figure 4. The effect of percent increase in density of compacted materials on the percent change of net profits of H1, H2, L1 and L2 options.

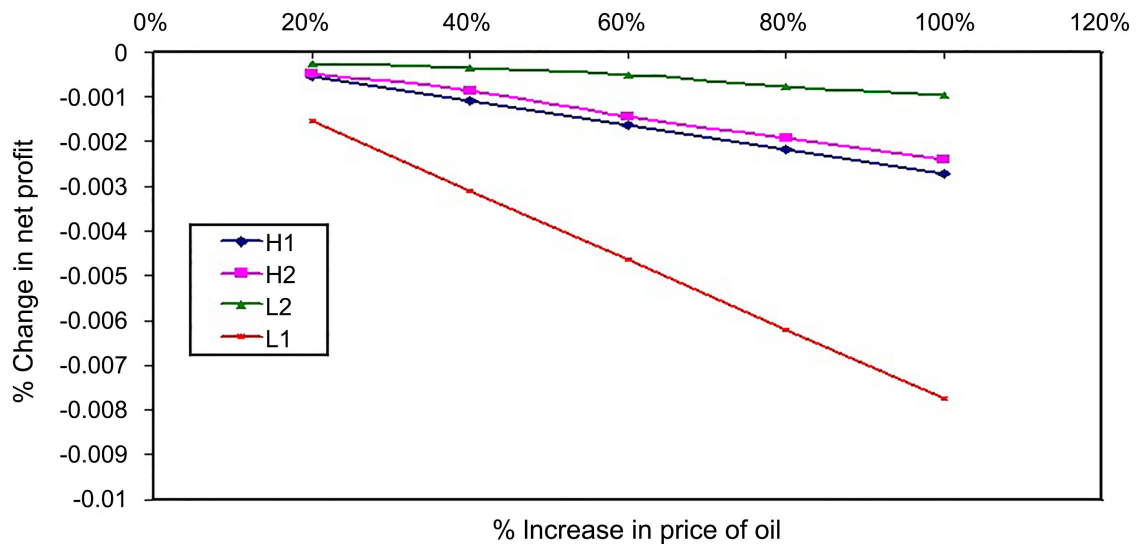


Figure 5. The effect of percent increase in engine oil price on the percent change of net profits of H1, H2, L1, and L2 options.

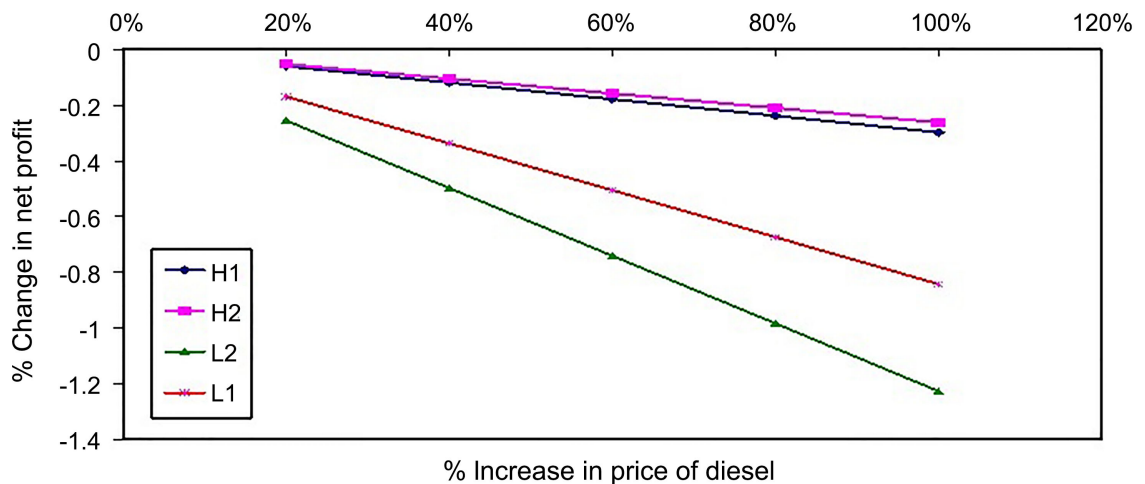


Figure 6. The effect of percent increase in diesel price on the percent change of net profits of H1, H2, L1, and L2 options.

to the short travel distance between the collection area and the landfill. The longer distance means the higher effect of diesel price increase.

The results of the effect of salaries increase on the net profit of ISWM are shown in **Figure 7**. It is obviously seen, that an increase of 100% of the salaries would decrease a net profit of the option H1, H2, L1 and L2 by -18.5%, -4.89%, -1.87% and -0.82%. Due to the importance of the personnel and workers in the proper implementation of the ISWM and as a result of this part of sensitivity analysis, which shows a low effect of salaries changes on net profits, the number of workers can be increased without affecting the net profit or exceeding the allocated budget.

Figure 8 shows the effect of increasing the container price on the net profit for the two options with the highest and lowest profits H1, H2, L1, and L2. It is

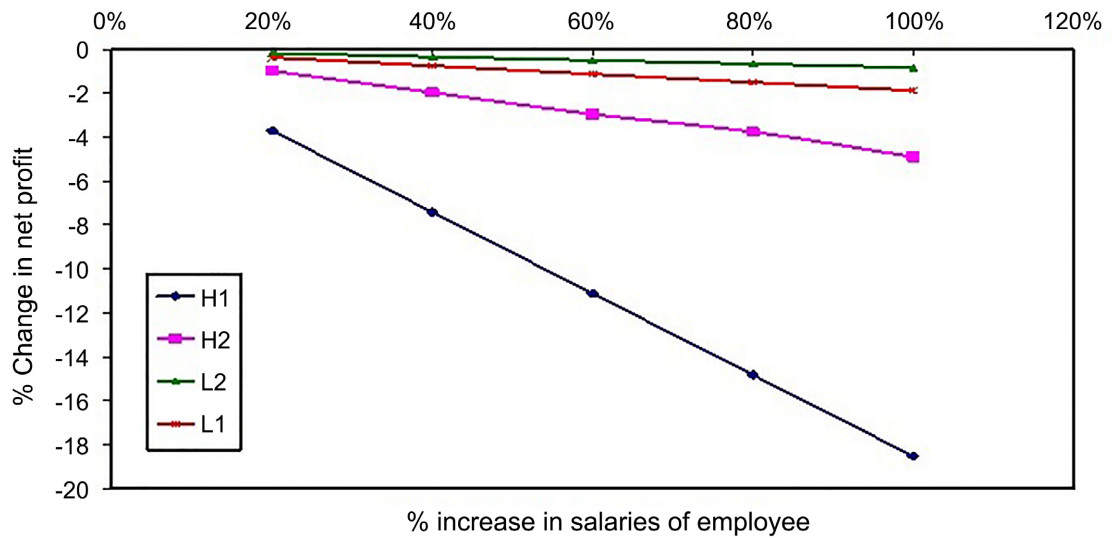


Figure 7. The effect of percent increase in salaries on the percent change of net profits of H1, H2, L1, and L2 options.

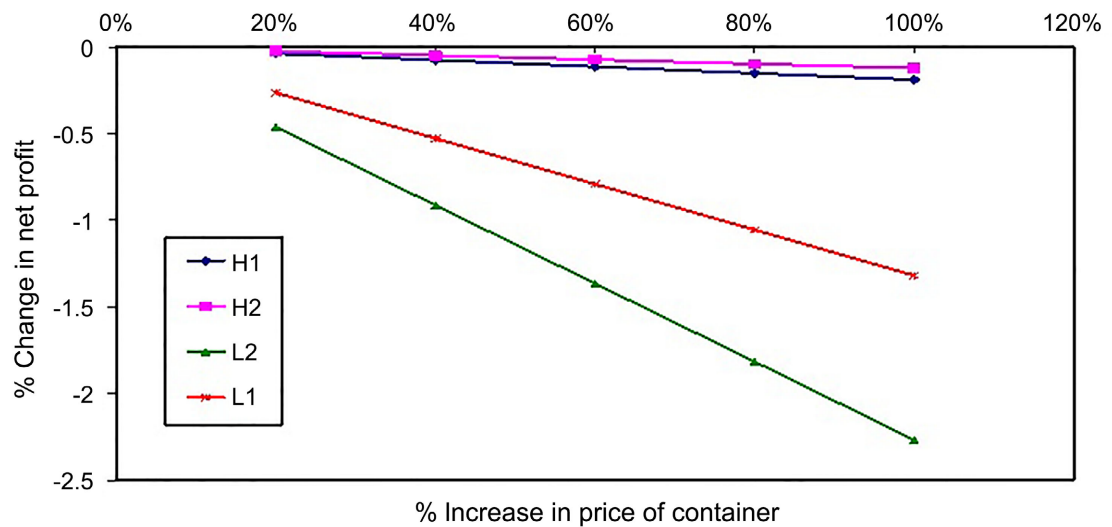


Figure 8. The effect of percent increase in containers price on the percent change of net profits of H1, H2, L1, and L2 options.

clearly seen from **Figure 8** that the container price has relatively little effect on the net profit for all option. The 100% increase in container resulted in a decrease in the net profit of -0.18% , -0.12% , -1.31% and -2.26% for H1, H2, L1 and L2 respectively.

The effect of recycled material selling price on the net profit is show in **Figure 9**, where the percentage increases in selling prices of recycled materials are plotted versus the percentage change in the net profit. **Figure 9** shows clearly, that the selling price of the recycled materials plays a major role in the ISWM.

More than one to one ratio between percentage increase in selling price of recycled material and percentage increase in the net profit is noticed. This shows that for proper economical and profitable ISW projects, separation should be

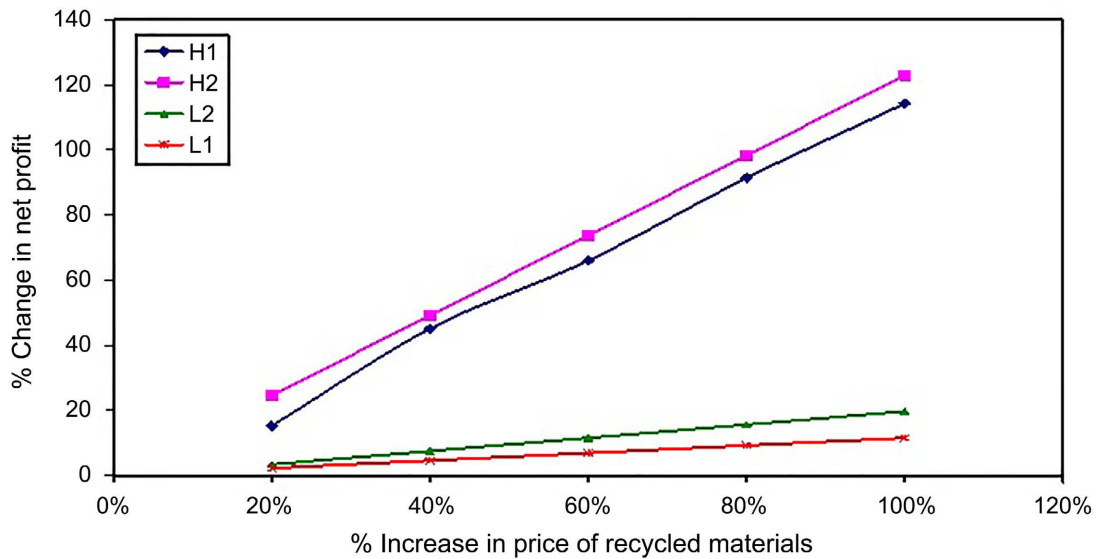


Figure 9. The effect of percent increase in price of recycled materials on the percent change of net profits of H1, H2, L1 and L2 options.

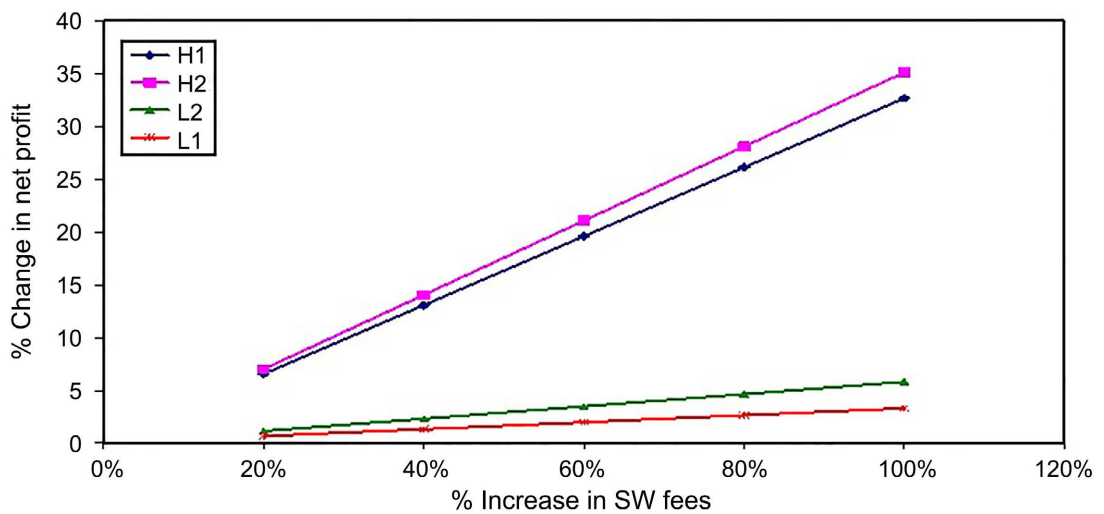


Figure 10. The effect of percent increase in SW fees on the percent change of net profits of H1, H2, L1, and L2 options.

highly recognized and therefore enhancing and marketing the recycled products should be supported.

Figure 10 shows the effect of the increase in the revenues in form of collected SW fees on the net profits for the four options H1, H2, L1 and L2. **Figure 10** shows that in case of positive net profit options H1 and H2, more than 30% increase in the net profits is expected when the solid waste collection fees are doubled. For options L1 and L2, less than 10% increase in the net profits was found as solid waste collection fees are increased by 100%.

4. Conclusion

This study shows that DST software enables the decision-maker to identify the

solution which would imply a cost-effective approach toward an ISWM. Separation of solid waste at source or disposal site might enhance the MSWM programs and generate profits. It has been shown that the highest net profit scenario is the one with a collection container of 110 L without waste bag and separation at source at a twice-daily collection rate. The most positive and effective factor in the net profit of the highest and lowest scenarios is the increase in the price of recycled materials, followed by increasing revenues from collected SW fees. In addition, the most negative effect on net profits of the highest and lowest scenarios resulted from increasing the salaries of employees.

Conflicts of Interest

The author declares no conflicts of interest.

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