Optimization of Waste Bank Management using Linear Programming: Case Study in Medan, North Sumatera

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Abstract: The numbers of waste are steadily increasing due to the increase in population and consumption. However, the management of waste is not effective and efficient which result in environmental, social and health problem. The waste bank, goverment program to lessen that waste issue, offers a solution that gives benefit not only for environment cleaness but also economically profitable. The enforcement of waste bank program is not reaching the society extensively leaving the program with less waste resource and become unprofitable. This study aims to determine optimization of waste bank of Sicanang to maximize profit with linear programming method. Waste Bank of Sicanang is the only minucipal main waste bank in Medan that involves community in waste management while reducing the amount of waste disposed to landfill. Waste management with waste bank needs to be improved, by optimizing the waste management capacity in this place, so that the profit earned becomes maximal. The result showed the maximum profit that can obtained by Sicanang waste bank per month reached Rp. 5.396.162 per month with garbage uptake efficiency reaches 0,52% waste capacity of Medan City per day. This study found the potential increase the percentage of recycling waste by 11,02% and the profit earned reached Rp. 113.319.408 per month by recycle the garbage up to 10 tons per day if Medan build 1 unit of waste bank center at each district.

1 INTRODUCTION

Most developing countries in Asia are facing waste problems (Dhokhikah and Trihadiningrum, 2012). The problem is caused by the amount of waste which increases along with the increase of population and comsumption. Furthermore, it is also caused by limitation on government funding for waste management, lack understanding of the impacts of bad waste management, and poor waste management in all sectors (Guerrero *et al.*, 2013). It is therefore necessary to do a sustainable long-term waste management effort (Kumar *et al.*, 2011). The sustanaibility of waste management can be enforced with the waste bank program (Indriati, 2016). The waste bank collects garbage from the people of surrounding community for recycling. The people will receive income accordance to the deposited garbage (Wulandari *et al.*, 2017). In addition, waste management through waste bank activities may reduce the amount of waste disposed to landfill (Dhokhikah *et al.,*2015)

Waste Bank of Sicanang is one of the main waste bank in Medan City. Eventhough, the waste management for recycling had run for few years, but the financial gain is still apprehensive. Revenue gained in 2017 is only sufficient to cover operating costs without generating profits.

The aim of this study is to determine the optimization of a waste bank to maximize profits. This can be solved by using an operational research approach, using a linear program. The results can be used by Waste Bank of Sicanang in resource planning in order to obtain maximum profit. The optimization result also can be a reference for other parties who want to establish a waste bank. Furthermore, optimization of waste banks can improve the efficiency of waste management of Medan City.

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2 METHODOLOGY

This study focused on Waste Bank of Sicanang, Medan, North Sumatera, Indonesia. Household, as the bank customers, segregate and deliver their an organic waste to "partner waste bank" and records it in a log book as saving money. The waste from partner waste bank is collected and sorted based on several categories and deliver to Sicanang waste bank. Furthermore Sicanang waste bank recorded in the log book. They re - separation of waste into paper, plastic, glass and metal waste into a more specific type, then to be packed and sold to waste buyers. In this case, Sicanang waste bank has established partnership with several waste buyers.

The data used in this study are labour working hours, the amount of waste, transportation, and energy used in operations. Optimization of waste bank using linear program model. Stages of analysis are as follows 1) Problem identification; 2) Formulation of linear program model; 3) Determine decision variables; 4) Determine the objective function; 5) Determine the constraints; 6) Solution of linear program model; 7) Sensitivity Analysis.

3 RESULT AND DISCUSSIONS

3.1 Problem Identification

The initial phase of this research is identifying the problem. Factors affecting the optimization of the Sicanang Waste Bank are labour working hours, transportation, waste supply, and energy. The waste supply obtained from the community is paper, plastic glass and metal that have been sorted according to its type. Prior to the formulation of linear program model, first calculated the operational cost of waste bank. The operational cost of the Sicanang Waste bank will be used to determine the profit earned by the Sicanang Waste Bank. The waste that has been managed and sorted here, then sold to the waste buyer or recycling industry. The difference between the purchase price of garbage to the waste bank partner with the garbage sale to the industry is the profit of Waste Bank of Sicanang.

The operational cost of the waste bank of Sicanang is Rp. 20.330.000 every month. The details are for the payment of salary of 10 employees, transportation cost, and operational cost and maintenance of the vehicle. Effective working hours are 6 days a week Monday - Saturday at 8:00 am - 5:00 pm. So, the daily operational cost is the operational cost divided by working days, then obtained Rp.847.083, - per day.

3.2 Formulation of Linear Problem

The formulation of the Linear Program Model consists of the formulation of decision variables, the formulation of objective functions, and the formulation of constraint functions. The constraints are working hours, transportation, paper supply, plastic supply, glass supply, metal supply, and energy.

3.2.1 Variables Function

The quantity of waste managed by Waste Bank of Sicanang is the decision variable of linear program model in this research, so in the preparation of model formed four decision variables that will be searched combination optimal product as follows:

- $x1$ = the total waste of paper (in kg)
- $x2$ = the total waste of plastic (in kg)
- $x3$ = the total waste of glass (in kg)
- $x4$ = the total waste of metal (in kg)

3.2.2 Objective Function

The coefficient of objective function is the profit per kg of each type of waste. The profit per kg of paper, plastic, glass and metal waste is Rp. 900; Rp. 1,800; Rp. 400; and Rp. 4,300 obtained by calculating the difference between the selling price and the purchase price. The objective function is to maximize the profit earned by Sicanang Waste Bank by calculating the profit value of each waste component minus the operational cost of the Waste Bank of Sicanang in Rp/day.

The formulation of the purpose function model is explained as follows:

$$\text{Max } z = [\, 900\, x1 + 1.800\, x2 + 400\, x3 + 4.300\, x4 \,] - \text{Rp. } 847.083 \quad (1)$$

3.2.3 Constraints

It is given that Sicanang Waste Bank has a total working hour a day is 32 hours per day. The ability of workers to sort 1 kg of paper waste is 0.02 hour. The ability of workers to sort 1 kg of plastic waste is 0.22 hour. The ability of workers to sort 1 kg of glass waste is 0.07 hour. The ability of workers to sort 1 kg of metal waste is 0.08 hour. The ability of labor to sort in units of kg is expressed in constrains as stated in Table 1.

Table 1: Constraints of working hours

Component of waste	Coefficient of working hours (hour/kg)
Paper	0,02
Plastic	0,22
Glass	0,07
Metal	0,08

Based on table 1 above, our equation becomes :

$$0{,}02\ x1 + 0{,}22\ x2 + 0{,}07\ x3 + 0{,}08\ x4 \leq 32 \quad (2)$$

The next constraints is a limitation for transporting waste purchasing activities from community. This activity includes paper, plastic, glass and metal waste simultaneously in the vehicle simultaneously. The total payload of 2 units of vehicle becomes the right-hand side value of the transportation constraint which is 3000 kg, so the transport constraint function is as follows:

$$x1 + x2 + x3 + x4 \leq 3000 \quad (3)$$

The third constraint is the total supply of waste is the limitation of the maximum amount of garbage that has been processed by Sicanang Waste Bank during 2017. The function of waste supply constraints for each type of waste is :

$$x1 \leq 294{,}63 \quad (4)$$
$$x2 \leq 59{,}5 \quad (5)$$
$$x3 \leq 115{,}73 \quad (6)$$
$$x4 \leq 72{,}38 \quad (7)$$

It is given that Sicanang Waste Bank has a total energy is 1300 kWh. The assumption of electrical energy used to operate the water pump, to extract water from the well is Rp. 200,000 from payment of electricity is Rp. 700.000 every month. Water is used only for plastic waste washing. For other types of waste does not require electrical energy, but only use human energy to sort things out. The energy coefficient is obtained from the cost of electricity paid divided by the price of electricity per kWh. Then, the coefficient of energy is 0.17 kWh. So our equation becomes:

$$0{,}17\ x2 \leq 1.300 \quad (8)$$

The values of x will be greater than or equal to 0. This goes without saying:

$$x1, x2, x3, x4 \geq 0 \quad (9)$$

3.3 Optimum Solution

Table 2: Answer report target cell

Name	Final Value
Profit	-Rp. 122.285

Table 3: Answer report adjustable cells

Name	Final Value
Paper (x1)	294,63
Plastic (x2)	59,50
Glass (x3)	103,24
Metal (x4)	72,38

Table 4: Answer report of constraints

Component of waste	Coefficient of working hours (hour/kg)
Working hour	Binding
Transportation	Not Binding
Paper Supply	Binding
Plastic Supply	Binding
Glass Supply	Not Binding
Metal Supply	Binding

The model obtained from the previous stage then solving a linear program using the program solver in Microsoft Excel software

Based on table 2, the maximum profit value obtained from the optimization result is -Rp.122.285, - per day, or equivalent to -Rp 2,934,845 per month. This condition is clearly not profitable for managers of Sicanang Waste Bank.

In table 3, product combination of optimization results for paper, plastic, glass and metal waste are 294,63 kg; 59.5 kg; 103.24 kg, and 72.38 kg. With a combination like this, Sicanang Waste Bank still can not earn decent profit.

Table 4 shows the constraints of working hours, paper supply constraints, plastic supply constraints, metal supply constraints have status 'binding' means slack value of 0 (zero), meaning that the resources provided have been used up to maximum. The reverse is true of transport constraints, glass supply constraints, and energy constraints, having values in the slack column. It means that there are still remaining resources on the constrains that have not been used, so the Sicanang Waste Bank does not need to make additional transportation, glass supply, and energy.

3.4 Sensitivity Analysis

Sensitivity analysis is conducted to determine the sensitivity of the model after the optimization result is obtained. In the sensitivity analysis, it can be seen the effect of the sensitivity hose consisting of the

Table 5: Sensitivity report of objective function

Name	Allowable Increase	Allowable Decrease
Paper (x1)	∞	785,71
Plastic (x2)	∞	542,86
Glass (x3)	172,727	400
Metal (x4)	∞	3842,9

minimum limit (allowable decrease) that is the limit of the constraint decrease that does not affect the model, and the maximum allowable increase is the limit of the increase of the constraint that does not change the model.

Table 5 shows the allowable decrease value or the allowable allowance limit of Rp.785,71 means the profit rate per kg of paper waste type should not be less than Rp. 785,71. Likewise with plastic and metal waste, the rate of profit per kg of this type of waste should not be less than Rp. 542.86 and Rp. 3842.9. For an allowable increase in paper, plastic and metal waste, the profit-increase limit is infinity. In the type of glass waste, the permitted price increase limit is Rp. 172 per kg of the starting price, and the limit of decline is Rp.400 from the initial profit .Tables must appear inside the designated margins or they may span the two columns.

In table 6. There is a final value column where the optimum solution of linear program model, such as 32 hours working hours with the transportation used is 529,75 kg, loading paper waste 294,63 kg, plastic waste 59,5 kg, glass waste 103,24 kg and metal waste as much as 72.38 kg per day, with energy used as much as 10.11 kWh. The function of the working hours constraint has a shadow price of Rp. 5,714,29 it means that every additional 1 hour working then it can get additional profit of Rp. 5,714,29. So also with the value of shadow price on the supply of paper, plastic, and metal, there will be an additional profit of Rp. 785,71; Rp, 542,85; and Rp.3.842,86 per additional 1 kg of garbage.

Allowable increase maximum limit of addition and allowable decrease minimum limit of right side reduction is specified in the sensitivity analysis to see the optimum profit limit as long as the constraint function is still within the permitted range. Allowable increase the maximum limit of the addition of transportation, supply of glass and energy is infinity. This condition indicates that Sicanang Waste Bank is not yet need to add transportation, supply of glass and energy. The range of limits for the sensitivity analysis of each constraint function is 24.77 ≤ working hours ≤ 32.87; 250,92 ≤ paper supply ≤ 655,98; 55,52≤supply plastic≤92,35; 61.45 ≤ metal supply ≤ 162,71. Then the sensitivity analysis of the right side constraint analysis will be made to show the limits of the profit range.

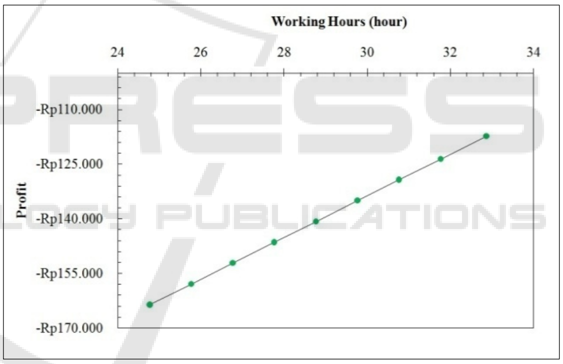

Figure 1: Sensitivity analysis of working hours

Table 6: Sensitivity report of constrains

Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
Working hour	32	5714,29	32	0,8741	7,227
Transportation	529,753	0	3000	∞	2470,2
Paper Supply	294,63	785,714	294,63	361,35	43,705
Plastic Supply	59,5	542,857	59,5	32,85	3,9732
Glass Supply	103,243	0	115,73	∞	12,487
Metal Supply	72,38	3842,86	72,38	90,3375	10,926
Energy	10,115	0	1300	∞	1289,9

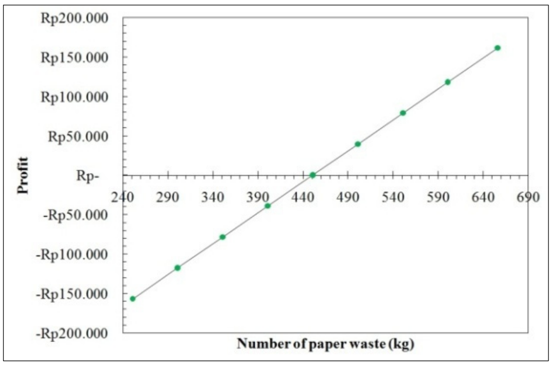

Figure 2: Sensitivity analysis number of paper

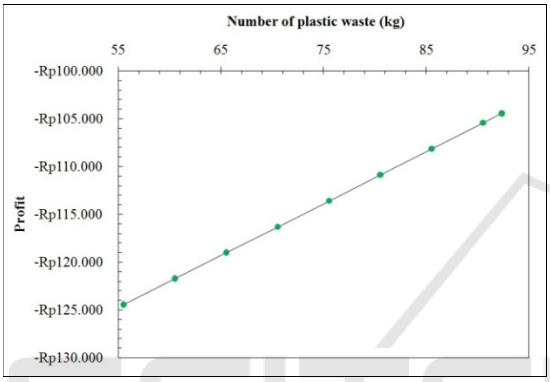

Figure 3: Sensitivity analysis number of plastic

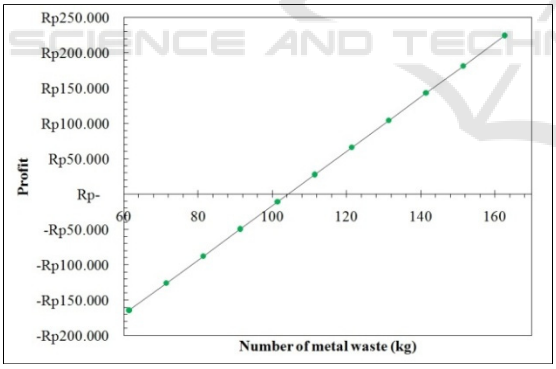

Figure 4: Sensitivity analysis number of metal

Figure 1 shows the most advantageous change of profits is to combine working hours up to 32.87 hours per day so that the benefits are -Rp. 117.314. Figure 2 shows the maximum profit is to process paper waste up to 655.98 kg per day is Rp.161.633 or equivalent to Rp. 3.879.192. Figure 3 shows the maximum gain that can be achieved with the change of plastic supply up to 92.35 kg per day is -Rp.104.452. Figure 4 shows the best gains by changing the amount of processed metal waste up to 162.71 kg per day for a profit of Rp. 224.840 or equivalent to Rp. 5.396.162 per month. The combination of optimum waste that can be processed of waste bank with maximum profit, the amount of paper, plastic, glass and metal are 294,63 kg/day, 59,5 kg/day, 0,0085 kg/day, and 162,71 kg/day.

Medan city have generates waste 0,295 kg/person/day. Percentages waste of paper 4,14%, plastic 5,43%, glass 3,7%, and metal 1,73% (include aluminium 1,04%) (Khair *et al.*, 2018). Population of Medan Municipality reach 2.229.408 lifes (BPS Medan, 2017). Based on that data, the number of waste in Medan City can calculated upon by multiply generates waste with percentages of waste and multiply with the population at each component of waste.

Table 7 shows the amount of domestic waste in Medan City, only 0.52% of the waste can be managed by the Sicanang Waste Bank. The amount of waste that can be processed the most is the metal waste that is 1.45% of waste of Medan City, because the profit of metal selling is the highest. In order for the amount of waste to be processed evenly for all types of garbage, it takes the value of profits that are not much different. Therefore, it is expected that the goversnment's participation will give subsidy to the selling price of waste.

Table 8 shows the assumption percentage of recycling waste in order to improve the efficiency of waste management of Medan City through recycling of garbage, one of the ways is to improve the performance of waste banks and involve community participation.

Table 7: Percentage of recyclingwaste

Component of waste	Percentage (%)
Paper	1,08
Plastic	0,17
Glass	0,00004
Metal	1,45
Total	0,52

Table 8: Assumption percentage of recycling waste

Component of waste	Percentage (%)
Paper	22,72
Plastic	3,50
Glass	0,00074
Metal	30,38
Total	11,02

If it is assumed that there is 1 unit of waste bank in every sub-district in Medan City, there will be 21 unit of municipal waste bank, with the absorption of garbage can reach 10 853,82 kg/day or 11,02% waste of Medan City can be recycled. By maximizing the participation of the community to sort the waste at home, and depositing the waste into the existing waste bank in each sub district, it is estimated that the profit from this activity reaches Rp 113.319.408 per month.

4 CONCLUSIONS

Based on the optimization result using linear program model, it can be concluded that the linear program model can maximize the profit of Sicanang Waste Bank with the combination of paper, plastic, glass and metal waste up to 294,63 kg/day, 59,5 kg/day, 0, 0085 kg/day, and 162,71 kg/day with profit Rp. 224.840/day or equivalent to Rp. 5.396.162 per month with garbage uptake efficiency reaches 0.52% of waste of Medan City. This study found the potential increase the percentage of recycling waste by 11,02% and the profit earned reached Rp. 113.319.408 per month by recycle the garbage up to 10 tons per day if Medan build 1 unit of waste bank center at each district. We hope you find the information in this template useful in the preparation of your submission.

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