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A Goal Programming Approach for Plastic Recycling System in Thailand

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***Abstract*—**Plastic waste is a big issue in Thailand, but the amount of recycled plastic in Thailand is still low due to the high investment and operating cost. Hence, the rest of plastic waste are burnt to destroy or sent to the landfills. In order to be financial viable, an effective reverse logistics infrastructure is required to support the product recovery activities. However, there is a conflict between reducing the cost and raising environmental protection level. The purpose of this study is to build a goal programming (GP) so that it can be used to help analyze the proper planning of the Thailand's plastic recycling system that involves multiple objectives. This study considers three objectives; reducing total cost, increasing the amount of plastic recovery, and raising the desired plastic materials in recycling process. The results from two priority structures show that it is necessary to raise the total cost budget in order to achieve targets on amount of recycled plastic and desired plastic materials.

***Keywords*—**Goal Programming, Plastic Recycling, Thailand.

I. INTRODUCTION

THIS paper studies plastic recycling infrastructure planning problem in Thailand from multi-objective standpoints. According to the report of Pollution Control Department (PCD) of Thailand, the total amount of solid waste is about 40,000 ton a day in year 2005 or 14.5 million tons a year. This number has shown a steady increase since year 1993 as shown in Fig. 1. It's reported that the plastic waste accounts for about 14 percents of all generated solid waste amounts in year 2000. Yet, the recovery rate of plastic waste is only 23 percents in year 2000. Hence, the amounts of plastics that end up in the landfill are enormous. As a result, Thai governments have attempted to reduce the amount of plastic in the waste stream. The energy department of Thailand [1] plans to set up a facility in Samutprakarn to recycle plastic waste and convert them into oil using polymer energy technology. This facility could reduce plastic waste for the amount of 6 millions ton a day. However, the current situation of handling solid waste in Thailand still faces an uphill challenge. Data from PCD of Thailand also shows that only about 35% of the solid wastes collected from other parts of Thailand except Bangkok is properly managed. The remaining amount is piled up in open dumping area waiting to be dissolved. Therefore, the government plans to build more plastic recycling facilities to increase the plastic recycling percentage but has limited budget in investing in this project. Moreover, the quality aspect has to be considered because the type of plastics has an effect in the yield of oil in plastic recycling process. The challenge is how to balance these objectives. Therefore, the mixed integer goal programming (MIGP) is developed as a tool to make better decisions. Two priority structures are examined and the resulted are discussed.

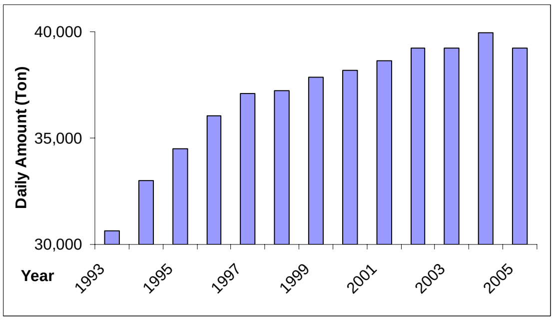

Fig. 1 Daily Amounts of Solid Waste in Thailand from year 1993-2005

II. LITERATURE REVIEW

A. Plastic Recycling Technology

Recently, there are a lot of publications involving plastic recycling [2], [3]. Some researchers put more effort on developing plastic recycling technology. One technology in particular, Polymer energy technology [3] offers a method to transform post-consumer plastics into oil. The main obstacles of this method are high investment cost and unsettled technology process. China has taken the lead on this technology and launched some pilot plants. According to [4], who studied current situation of recycling waste plastics into oil from both technology and economics standpoints in China, reported that there are more tasks to be done to constitute the standards for process and to manage the way the recycling plant should run in order to be profitable.

B. Reverse Logistics Network Design and GP

The design of reverse logistics network design has gain interests among researchers. For example, Carter and Ellram [5] give a review of the literature on reverse logistics. Fleischmann et al. [6] present a characterization of logistic networks for product recovery. Ammons et al. [7] propose a generic mixed integer programming model to determine the

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infrastructure of the recovery system and present common features of the reverse production system. Caruso et al. [8] develop a multi-objective mathematical model of location allocation for planning the urban solid waste management system. Shih [9] develops a mixed integer programming model to study a reverse logistics system planning for electrical appliances and computers in northern Taiwan. Realff et al. [10] develop a mixed integer programming model to provide a decision-making tool for carpet recycling infrastructure design.

Apart from formulating the model to design the reverse logistics, some researchers apply Goal Programming (GP) to reverse logistics applications. GP is introduced by Charnes et al. [11] and often used to solve multi-objective programming. Chang and Wang [12], [13] applied GP to solve solid waste management problem in Taiwan. Pati et al. [14] analyzed three-objective paper recycling system in India using GP. Perlack and Willis [15] also look at waste disposal planning problem with multiple objectives.

III. FORMULATIONS OF MULTI-OBJECTIVE MIXED INTEGER GOAL PROGRAMMING

Aiming to find the tool to help make multi-objective recycling problem, the plastic reverse logistics network design is formulated as a mixed integer goal programming (MIGP). This model is based on the work by [16]. This formulation is able to capture inter-relationship among different goals for the network design problem at the strategic level. The models use the following assumptions: (1) all parameters are deterministic, (2) costs functions are linear functions, and (3) the location of all possible sites are predetermined. The continuous variables in the model represent the flows of materials and the integer variables in the model represent the existences of the potential infrastructures, [17]. There are five entities in the model i.e. initial source of plastic wastes, collection sites, processing sites, landfills, and customer's sites. The materials flow from initial source to collection sites. From collections, materials can be sent directly to landfill without recycling or to recycling processing sites. At the processing sites, the materials are recycled to oil and shipped to customers. In the formulation, the collection site is the subset of processing site. There are the processing sites that only perform recycling tasks and the ones that perform only collection tasks such as sorting and transporting. The total cost includes all fixed costs and operating costs incurred while operating the reverse logistics network. The objective function also includes two important costs which are the recycling processing cost at the processing sites if they are open and operating and landfill cost at the landfill sites. By nature of operation, the cost to open and operating landfill is lower than the cost to open and operating the recycling plant. The recycling materials in this model are the used plastic products such as broken plastic chairs, plastic water bottles, etc. Next, the three objectives of the MIGP model are presented.

1. Total cost (C): The total costs include both investment and operation costs. The goal is to minimize the total cost (TC) over given periods. In other words, the goal is to minimize the positive deviation from the available budget for opening/operating all associated sites (Δ_C^+).

2. Recycled Plastic target (R): Converting oil from plastic generates economical value and prevents plastic wastes from landfills. Hence, the objective is to raise the recycled plastic target as much as possible. This goal can be also stated as minimizing the negative deviation from the minimum desired recovery target amount (Δ_R^-).

3. Desired plastic waste target (D): According to [4] the total yield of fuel oil through recycling process depends on the composition of plastic waste. The ability to sort for desired plastic waste can increase the output of oil and decrease the total cost. The objective can be states as maximizing the desired plastic waste target at the collection site. In other words, the goal is to minimize the negative deviation from the minimum desired amount (Δ_D^-).

From these three objectives, the goal program is formulated using Eqs (1) – (29). The notations in the model are listed in Appendix A.

Lexicographical Minimize

$$\Delta_C^+ ,\ \Delta_R^- ,\ \Delta_D^- \tag{1}$$

Constraints **Subject to:**

(a)
$$TC_{\text{actual}} + \Delta_C^- - \Delta_C^+ = TC_{\text{target}} \tag{2}$$

(a)
$$\sum_{i,\, j\neq i, k\in Plastics, m, t} x_{jkimt}^{(tr)} + \Delta_R^- - \Delta_R^+ = b \sum_{i, k\in Plastics, t} S_{ikt} \tag{3}$$

(a)
$$\sum_{j\in i_p(collect), i\in i_p(process), k\in Desired} x_{jkimt}^{(tr)} + \Delta_D^- - \Delta_D^+ = DW_{\text{Target}} \tag{4}$$

(a)
$$TC_{\text{actual}} = \sum_{i,t} F_{it}^{(oper)} y_{it}^{(oper)} + \sum_{i,t} F_{it}^{(open)} y_{it}^{(open)} + \sum_{i,t} F_{it}^{(close)} y_{it}^{(close)} + \sum_{i,\, j\neq i, m, t} F_{ijmt}^{(tr)} y_{ijmt}^{(tr)} + \sum_{i,\, j\neq i, k, m, t} V_{ijmt}^{(tr)} x_{ikjmt}^{(tr)} + \sum_{i, P, t} F_{iPt}^{(pr)} y_{iPt}^{(pr)} + \sum_{i, p, t} V_{ipt}^{(pr)} x_{ipt}^{(pr)} \tag{5}$$

(b)

$$\sum_{j\neq i,m} x^{(tr)}_{jkimt} - \sum_{j\neq i,m} x^{(tr)}_{ikjmt} - \sum_{c,m} x^{(tr)}_{ikcmt} + \sum_{p,P} \rho'_{kp} x^{(pr)}_{ipP} - \sum_{p,P} \rho_{kp} x^{(pr)}_{ipPt} = 0 \qquad \forall i \in i_p, k, t \tag{6}$$

(b)

$$x^{(pr)}_{ipt} = \sum_{P:p\in P} x^{(pr)}_{ipPt} \qquad \forall i, p, t \tag{7}$$

(c)

$$\sum_{k} \frac{x^{(tr)}_{ikjmt}}{C^{(tr)}_{ikjm}} \leq y^{(tr)}_{ijmt} \qquad \forall i, j \neq i, m, t \tag{8}$$

(c)

$$\sum_{p\in P} \frac{x^{(pr)}_{ipPt}}{C^{(pr)}_{pP}} \leq y^{(pr)}_{iPt} \qquad \forall i, P, t \tag{9}$$

(d)

$$\sum_{jkmt} x^{(tr)}_{jkimt} \leq CAP_{it} \qquad \forall i, t \tag{10}$$

(e)

$$\sum_{ikjm} x^{(tr)}_{ikjmt} = S_{ikt} \qquad \forall i \in i_s, k, t \tag{11}$$

(e)

$$\sum_{i,m} x^{(Tr)}_{ijcmt} \leq D_{ckt} \qquad \forall k, c, t \tag{12}$$

(f)

$$ICAP_{i0} = CAP_i \qquad \forall i \in i^l_p \tag{13}$$

(f)

$$ICAP_{it} = ICAP_{t-1} - \sum_{jkm} x^{(tr)}_{jkim,t-1} \qquad \forall i \in i^l_p, t : t > 1 \tag{14}$$

(f)

$$y^{(close)}_{i,t+1} - 1 \leq M\overline{y}^{(close)}_{i,t+1} \qquad \forall i \in i^l_p, t \tag{15}$$

(f)

$$LCAP_i - ICAP_{it} < M(1 - \overline{y}^{(close)}_{i,t+1}) \qquad \forall i \in i^l_p, t \tag{16}$$

(g)

$$y^{(close)}_{i,t-1} \leq y^{(close)}_{it} \qquad \forall i, t : t > 1 \tag{17}$$

(g)

$$y^{(oper)}_{it} - y^{(oper)}_{i,t-1} \leq y^{(open)}_{it} \qquad \forall i, t : t > 1 \tag{18}$$

(g)

$$y^{(oper)}_{i,t-1} - y^{(oper)}_{it} \leq y^{(close)}_{it} \qquad \forall i, t : t > 1 \tag{19}$$

(g)

$$y^{(oper)}_{it} \leq y^{(open)}_{it} \qquad \forall i, t = 1 \tag{20}$$

(h)

$$G^{(tr)}_{ijmt} \leq y^{(tr)}_{ijmt} \leq H^{(tr)}_{ijmt} A^{(tr)}_{ijmt} y^{(oper)}_{it} \qquad \forall i, j \neq i, m, t \tag{21}$$

(h)

$$G^{(tr)}_{ijmt} \leq H^{(tr)}_{ijmt} A^{(tr)}_{ijmt} y^{(oper)}_{jt} \qquad \forall i, j \neq i, m, t \tag{22}$$

(h)

$$G^{(pr)}_{iPt} \leq y^{(pr)}_{ipt} \leq H^{(pr)}_{iPt} A^{(pr)}_{iPt} y^{(oper)}_{it} \qquad \forall i, P, t \tag{23}$$

(h)

$$x^{(tr)}_{ikjmt}, x^{(pr)}_{ipt}, x^{(pr)}_{ipPt}, \Delta^-_C, \Delta^+_C \Delta^-_R, \Delta^+_R, \Delta^-_D, \Delta^+_D \geq 0 \qquad \forall i, k, j \neq i, t, p, P, m \tag{24}$$

(h)

$$y^{(oper)}_{it}, y^{(open)}_{it}, y^{(close)}_{it} \in \{0,1\} \qquad \forall i, t \tag{25}$$

(h)

$$y^{(tr)}_{ijmt} \in \{0,1,2,\ldots,H^{(tr)}_{ijmt}\} \qquad \forall i, j \neq i, m, t \tag{26}$$

(h)

$$y^{(pr)}_{iPt} \in \{0,1,2,\ldots,H^{(pr)}_{iPt}\} \qquad \forall i, P, t \tag{27}$$

(i)

$$\Delta^-_C \Delta^+_C = 0; \Delta^-_R \Delta^+_R = 0; \Delta^-_D \Delta^+_D = 0 \tag{29}$$

The MIGP can also be summarized as follows:

Lexicographically Minimize: Δ^+_C , Δ^-_R , Δ^-_D

Subject to: (a) Slack variable constraint for multi-objectives
(b) Flow balance between sites and between time periods for each material constraints
(c) Transportation and processing capacity constraints
(d) Upper bound for each site constraints
(e) Demand and supply constraints
(f) Closing of Full-capacity Landfill constraints
(g) Site opening and closing constraints
(h) Logical, non-negativity, and binary constraints
(i) Complementary constraints

Constraint (a) represents the slack variables for the three objectives. Constraint (b) makes sure that flow-in and flow-out of materials at each site are balanced. Constraint (c) enforces the capacity of machines and transportation vehicles at each location site. Constraint (d) enforces the operating capacity of each site. Constraint (e) makes sure that the amount of materials generated from the source must be all processed. Constraint (f) guarantees that the full-capacity landfill site must be closed and cannot be operated at later time periods. Constraint (g) ensures the logical relationship of binary variables representing site opening and closing actions. Constraint (h) enforces logical relationships between variables and non-negativity of variables. Last, constraint (i) ensures that either negative or positive deviation variable of all objectives must be zero.

IV. IMPLEMENTATION OF MODEL AND SOLUTION PROCEDURE

The three priorities are defined as follows: (1) Total cost or C (2) Recycled plastic target or R and (3) Desired plastic waste target or D. Next, the problem is solved with the follow priority structures; CRD and CDR. The steps in finding solutions is to partition the objective function according to the priority setting and the sequential solution of the resultant mixed integer linear programming model. At the lower level problem, the constraint is added by using the solution obtained at the upper level.

The data in the problem can be described as follows. There are total of 76 sources which are located at all provinces in Thailand. It's assumed that there are 15 potential collection sites or three collection sites in Northern, Southern, Eastern, Northeastern, and Central regions. Also, there are five potential landfill sites and each one is located in each region with one site already operating in central region. In addition, there are five potential processing sites and each one is located in each region with one site already operating in central region. It's assumed the same capacity for all processing sites. Each processing site can perform 2 processing tasks; sorting and grinding. The problem is solved for 3-year period. The population in each province is used to estimate the plastic waste and the total supply for each year is assumed to be 1,900,000. This number comes from the estimated amount of plastic in Thailand in year 2005. With this information, the supply of plastic waste in each province can be obtained based on population. The transportation cost is estimated from the truck transportation mode and the distance between two sites. The model is developed in GAMS version 2.0.27.7 using CPLEX solver and performed on a Pentium (R) 4 CPU, 2.40 GHz computer with 1 GB of RAM. Some of the costs are as follows: 1) Fixed opening cost for landfill: 12,050,639 Baht 2) Fixed opening cost for processing site: 65,000,000 baht 3) Fixed transportation cost: 1.7 baht/kilometer 4) Variable operating cost for landfill: 100 baht/ton. It is estimated that the total reverse logistic cost available is 10,000 million baht over 3 years. The minimum recycled plastic target is 30% of all available plastic waste or 570,000 tons a year. The minimum amount of desired materials is 400,000 tons a year.

V. RESULTS AND CONCLUSIONS

The MIGP model is used to analyze the inter-relationship of three goals of plastic recycling system and result in the following observations.

The objective priority structure "CDR" and "CRD" is investigated because there is a potential impact of total cost target on the ability to meet the other two objectives. First, CDR is considered, where the desired plastic waste target has higher priority than plastic recovery target. In this case, desired plastic waste is achieved first and this goal can be achieved with all considered total cost targets. However, it requires a huge amount of financial resource to invest in the recycling facility in order to raise the recovery target. It's shown in Fig. 2 that both goals "D" and "R" can be achieved together with minimum of 50% increase in total cost target.

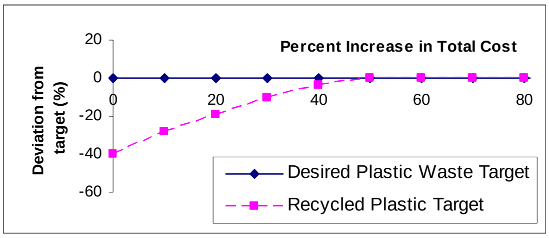

Fig. 2 Result from varying cost budget for priority structure "CDR"

Next, priority structure CRD is investimated, where the plastic recovery target has higher priority than desired plastic waste target. It's shown in Fig. 2 that goals "R" and "D" can be achieve with minimum of 50% in crease in total cost target. It can be seen that none of both goals can be achieved without increasing the total cost target. Since "R" is given higher priority, the financial resource is assigned to recover plastic as much as possible first and leave little financial resource to achieve "D" objective. In summary, it's necessary to raise the total cost target to achieve the remaining objectives regardless of priority order of "D" and "R".

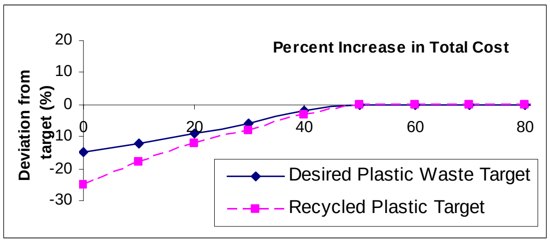

Fig. 3 Result from varying cost budget for priority structure "CRD"

In this paper, a MIGP model is presented to analyze the relationships among three important goals for plastic recycling network design in Thailand. These goals have significant impact in financial, environmental, quality aspects. From the results, it can be seen that there is a need to increase total cost target to achieve high quality recyclables and recovery percentage. The future study includes looking at all possible priority structures to analyze inter-relationships among proposed three goals. The proposed tool can aid the management of solid waste collection and processing systems in Thailand by aiming to raise the percentage of plastic recycle economically. As a result, Thailand will see less plastic wastes in the environment and raise the quality of life for Thai people.

APPENDIX: NOTATIONS USED IN MODEL FORMULATION

TABLE I
INDICES IN MIGP MODEL

Indices	Description	indices	Description
s	Provinces	i, j	Nodes of sites
i_p^l	Processing sites (landfill)	i_p	Processing sites
c	Customer sites	m	Transportation mode
k, q	Material types	P/p	Main/sub-process types

TABLE II
PARAMETERS IN MIGP MODEL

Parameters	Definition and description
$F_{it}^{(oper)}$	Fixed operating costs at site i at time period t
$F_{it}^{(open)}$, $F_{it}^{(close)}$	Fixed opening and closing cost at site i at time period t
$F_{ijmt}^{(tr)}$, $F_{icmt}^{(tr)}$	Fixed cost per vehicle to transport materials from site i to j/customer c by transportation mode m at time period t.
$F_{iPt}^{(pr)}$	Fixed cost for one unit of the main-process P at site i at time period t
$V_{ipt}^{(pr)}$	Processing cost per standard unit for sub-process p at site i at time period t
$V_{ijmt}^{(tr)}$,$V_{icmt}^{(tr)}$	Transportation cost per standard unit of material, to transfer material from site i to j/customer c at time period t
ρ_{kp} , ρ'_{kp}	The proportion of material type k consumed by process p The proportion of material type k produced by process p
$C_{ikj}^{(tr)}$,	The maximum amount of material k that a vehicle can transfer per time period from site i to j at time period t
$C_{pP}^{(pr)}$	The maximum amount of material that a machine of main process P, sub- process p can operate per time period
$H_{ijmt}^{(tr)}$	the maximum number of vehicles in transportation mode m to transfer material from site i to j at time period t
$H_{iPt}^{(pr)}$	The maximum number of machines of main-process P at site at time period t at time period t
$G_{ijmt}^{(tr)}$	=1 if vehicles in transportation mode m to transfer material from site i to j must be utilized at time t; 0 otherwise
$G_{iPt}^{(pr)}$	=1 if machines of main process P at site i must be utilized at time t; 0 otherwise
$A_{ijmt}^{(tr)}$	=1 if vehicles in transportation mode m to ship material from site i to j is allowed to be utilized; 0 otherwise
$A_{iP}^{(pr)}$	=1 if machines of main process P at site i is allowed to be utilized; 0 otherwise
S_{skt} , D_{kct}	= the amount of supply of material k at province s at time period t = the amount of demand of material k from customer c at time period t
CAP_i	= the maximum amount of all materials that processing site i can operate at the beginning
$LCAP_i$	= the minimum capacity amount of all materials that landfill i can hold before closing down
M	= positive large number
b	= the minimum plastic recovery percentage
DW_{target}	= Desired Waste Material Amount
TC_{target}	= Available budget for recycling
TC_{Actual}	= Actual total recycling cost

TABLE III
DECISION VARIABLES IN MIGP MODEL

Decision Variables	Definition and description	
$y_{it}^{(oper)}$	=1 if site i is opened and operating	0 otherwise
$y_{it}^{(open)}$, $y_{it}^{(close)}, \overline{y}_{it}^{(close)}$	=1 if site i is just opened at the beginning of time period t =1 if site i is just closed at the end of time period t-1, dummy variable	0 otherwise
$y_{ijmt}^{(tr)}$	the number of vehicles needed to transfer materials from site i to j by transportation mode m at time period t	
$y_{iPt}^{(pr)}$	the number of machines of main process P needed at site i at time period t	
$x_{ikj}^{(tr)}$	the amount of material k transferred from site i to site j at time period t	
$x_{ipt}^{(pr)}$, $x_{ipPt}^{(pr)}$	the amount of material processed by sub-process p at site I at time period t, the amount of material processed by main-process P, sub-process p at site i at time period t	
$ICAP_{it}$	= the amount of all materials that processing site i can operate at time period t	

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