Integrated optimization model and methodology for plastics recycling: Indian empirical evidence

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K.M. Mahaboob Sheriff, Nachiappan Subramanian, Shams Rahman, Jayanth Jayaram

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Integrated optimization model and methodology for plastics recycling: Indian empirical evidence

K.M.Mahaboob Sheriff ^a, Nachiappan Subramanian ^b, Shams Rahman ^c, Jayanth Jayaram ^d

^a Professor , Department of Mechanical Engineering, Joginpally B.R Engineering College, Hyderabad, TS, India,

Email: meha_sheriff@rediffmail.com

^b Associate Professor of Operations Management, Nottingham University Business School China, 199 Taikang East Road, The University of Nottingham Ningbo, Ningbo 315100, China,

Email: nachiappan.subramanian@nottingham.edu.cn, sp_nachi@yahoo.com

^c Professor of Supply Chain Management and Head, Logistics and Supply Chain Division, RMIT University, Melbourne, Victoria 3001, Australia,

Email: shams.rahman@rmit.edu.au

^d Professor of Management Science and Moore Research Fellow
Moore School of Business, University of South Carolina Columbia SC 29208

E-Mail: jayaram@moore.sc.edu

Research Highlights

- We develop a decision model to integrate three decisions pertaining to location, allocation, and routing of different varieties of recycled plastics.
- We validate the model using data retrieved from a case study in India using a conventional decomposed modelling approach.
- Our integrated model reduces over ten percent of total recycling costs for both single and multiple products in the Indian context.
- Managers need to cluster the customers based on the facility location and offer attractive incentives to reduce cost and increase benefits.

Integrated optimization model and methodology for plastics recycling: Indian empirical evidence

Abstract

We develop a decision model to integrate three decisions pertaining to location, allocation, and routing of different varieties of recycled plastics. Our decision model allocates recycling collection points to the available centralized return center based on its capacity and ensures similar allocation to all facilities via optimal routing for trucks. The study addresses several pertinent questions such as how to deal with higher collection cost, how to develop a model that jointly considers operational cost reduction along with the achievement of higher environmental benefits, how to reduce sub optimization which is quite common when using standalone decision models, and what are the feasible ways to increase the utilization of collection facilities. We validate the model using data retrieved from a case study in India using a conventional decomposed modelling approach. Our findings demonstrate that the proposed integrated model reduces over ten percent of total recycling costs for both single and multiple products. The results also suggest managers to reduce variances in product quality levels in order to achieve substantial total costs reduction. In addition, to increase the plastic recycling returns and reduce the operational cost, managers need to cluster the customers based on the facility location and offer attractive incentives.

Keywords: *Capacitated problem, Location-allocation, Product recovery, Plastic industry, India, Recycling network*

1. Introduction

Plastics waste has attracted widespread attention worldwide and in India, particularly due to indiscriminate littering in open public places (Pinto, 2014). Past literature indicates that a substantial amount of plastics is neither being collected, nor recycled and thus find their way into drains, open lands, rivers, railway tracks and coasts (Singh, 2013). This could result in choked drains or get dredged in the soil, making the land infertile. An estimate suggests that the plastic waste generation in India is about 133,760 tonnes per day (TPD), of which only 9,250 TPD is collected and recycled (MOEF, 2012). In India approximately 1.5 million tons of plastic is expended in the bottling of 89 billion liters of water each year (Waste plastic recycling, 2014). Currently, there are more than 200 bottled water brands (manufacturers) operating in India of which approximately 80 per cent are local producers. India is one of the top 10 largest bottle water consuming nation in the world (Waste plastic recycling, 2014). Annual bottled water consumption in India has tripled from 1.5 billion liters in 1999 to 5

billion liters in 2004 (Waste plastic recycling, 2014). According to recent report the per capita consumption of bottled water in India was at 16.20 litres during 2010-11 and jumped by almost 21% to 19.60 litres in 2011-12 (DNA, 2016).

Based on the production and consumption trend of bottle water discussed earlier, the potential benefit from plastic recycling in India is huge. For example, the high labour-intensive reclamation process provides substantial employment, reduces cost of raw materials (Foolmaun and Ramjeawon, 2008) and import of raw materials (Masanet and Horvath, 2007), limits exploitation of natural resources (Kannan *et al.*, 2012), and restricts solid waste and cost of disposal (Accorsi *et al.*, 2013). Therefore, recycling practices fit well with the needs of developing nations who tend to have limited technical know-how and investment capacity (Groot *et al.*, 2013).

About 40 percent of the total plastics manufactured, are sorted, collected and recycled in India as opposed to only 10-15 percent in developed nations (Waste plastic recycling, 2014).. However, the activities and processes involved in the collection and recycling of plastic in India is highly unorganized. (Briassoulis *et al.*, 2012). The major obstacles are lack of responsible stakeholders for plastic waste management, inefficient handling of substantial increase of plastic waste, and unregulated manner of plastic recycling by many unauthorized units (Bing *et al.*, 2015).

In spite of huge potential for applying optimization models in plastic recycling, the past literature suggests that a limited research has been conducted in the area of optimizing plastic waste recycling activities. Two early attempts of optimizing the plastic recycling are by Fletcher and Mackay (1996) and Haque *et al.*, (2000). Fletcher and Mackay (1996) developed optimization models to determine the lifetime of plastic usage and expected time for recycling in the context of Australia, where Haque *et al.*, (2000) illustrated the effect of balancing the quality of recycled plastics and the amount of non-recyclable plastics in the context of developing nations. Recently, Groot *et al.* (2014) developed a comprehensive waste collection cost model applied to post-consumer plastic packaging waste in Netherlands. However, none of these studies fully considered the inter-dynamics of location, allocation and routing decisions in the plastic recycling context.. Our study addresses this gap by developing a decision model to integrate three decisions pertaining to location, allocation, and routing of different varieties of recycled plastics. The model allocates recycling collection points to the available centralized return center based on its capacity and ensures

similar allocation to all facilities via optimal routing for trucks. The major contribution of our study is the development and validation of integrated decision model that simultaneously reduces recycling cost and increase the environmental benefits.

The rest of the paper is organized as follows: Section 2 summarizes the relevant literature on plastics recycling and identifies the research gap. Section 3 describes the recycling problem and develops the model. The methodology adopted for solving the proposed model is delineated in Section 4. The implementation of the model and methodology is illustrated using a case study in Section 5. The performance of the integrated model and ensuing potential contributions are offered in Section 6. Finally, Section 7 concludes the paper.

2. Literature review on modeling plastic recycling

The challenge of plastic waste recycling has been addressed in past research. Primarily, it has been viewed as an environmental problem that considers the harmful effect of plastic recycling on society rather than as a cost-benefit model that reduces recycling costs and has associated environmental benefits. Interestingly customers on an average return about 6% of product which includes plastic bottles and this could lead to a 6% to 10 % of savings by implementing efficient reverse logistics system (Mollenkopf and Closs, 2005, Jayaraman and Luo, 2007). Although, a recent study suggested a dynamic model and carried out cost-benefit analysis, however, the objective of the study is to evaluate policies in the context of end-of-life passenger cars in China (Chen et al., 2015). Hence, we develop a cost-benefit plastic recycling model. This section is organized into three paragraphs that corresponds to status quo of modelling in plastic recycling, state-of-the art of location allocation decisions in reverse logistics and effective ways adopted to increase the utilization of facilities and return rate.

Firstly, we would like to review few studies that discusses the inclusion of plastics in modelling. A model for recycling plastics by ‘phasing in’ recycling over a given period was offered by Fletcher and Mackay (1996). A simple mathematical model to discern and comprehend the material inflow and outflow of complex successive plastics recoveries and recycling, within the closed-loop recycling systems present in two countries, India and Bangladesh was developed by Haque *et al.*(2000). In terms of green operations, a few case studies have mentioned the use of plastics and bottle recycling (Ferreira et al., 2014; Sharma and Bansal, 2016; Tibben and Lembke, 2002). Other studies have explained the benefits of including plastics recycling during design or post use stage. A study presented by Masanet

and Horvath (2007) quantified the benefits of Design For Recyclability (DFR) for plastic PC enclosures using systems modeling and uncertainty analysis techniques. In the case of post use state, a study by Coelho *et al.* (2011) described the opportunities and challenges of the logistics model for post-consumer PET bottle recycling in Brazil, while provides insights of practices along the recycling chain. A recent study investigated the recycling process of post-consumer absorbent hygiene products and proposed few management solutions (Arena *et al.*, 2016). Similarly, a study by Bing *et al.* (2015) developed an optimization model for household plastic waste in the context of emission trading scheme to redesign global reverse supply. Groot *et al.* (2014), on the other hand developed a comprehensive cost model to reduce costs of post-consumer plastic packaging waste in municipalities. Such a model can be used for decision support when strategic changes are made to the collection scheme of municipalities.

From the above review of previous studies, it is clear that there are very few studies that addresses the plastic recycling problem with the consideration of logistical issues in emerging economies such as India. Specifically previous studies analyzed the benefits of including plastics recycling during design or post use and we find a comprehensive cost model for post use stage with respect to government or non-business perspective. Hence we attempted to develop a cost-benefit model that is suitable for businesses. Green operations studies reported the dominance of collection cost which is one of the highest among all reverse logistics (RL) costs and the existence of less standardized RL collection networks necessitates the design of an efficient mechanism for managing returned products in order to minimize cost and maximize the use of resources (Rogers and Tibben-Lembke, 2000). Therefore, we focus on reducing collection cost and design an efficient mechanism to increase the utilization of facilities and improve the return rate for plastic recycling collection network in the India context.

Secondly, we reviewed location, allocation, and transportation issues in reverse logistics networks to understand how integrated decisions challenges have been dealt so far. As the managers wrestle with these problems, management scientists have developed efficient problem solving techniques that use the concept of integrated logistics systems (Min, 1996). The crux of such techniques is the combined location-routing model. The main difference between the location-routing problem (LRP) and the classical location-allocation problem is that, once the facility is located, the former requires a visitation of customers/suppliers through tours, whereas the latter assumes the straight-line or radial trip from the facility to the

customer/supplier (Min *et al.*, 1998). In general terms, the combined location-routing model solves the joint problem of determining the optimal number, capacity and location of facilities (domiciles) serving more than one customer/supplier, and then finding the optimal set of vehicle schedules and routes. An integrated location-routing approach may help the firm develop more efficient logistics networks by avoiding sub-optimization (Nagy and Salhi, 2007, Cabellero *et al.*, 2007, Yu *et al.*, 2010; Sheriff *et al.*, 2014). We didn't find integrated models in the reverse logistics network that develops global optimal solution.

Finally, we reviewed studies to understand few mechanisms or practices that could improve utilization and increase return rates. Despite their merits, few studies have holistically considered the inter-dynamics of location, allocation and routing decisions in the plastic recycling context. Also, having known the importance of balanced allocation to the plastic recycling network design, very few attempts have been made to tackle Balanced Allocation Problem (BAP) in plastic recycling networks. Balanced allocation of collection points with customers, centralized return centers and processing centers reduces inefficiencies, maximizes utilization rates and ensures coordination with all stages in the plastic recycling network design. BAP is primarily concerned with the optimal assignment of product flows between multiple distribution centers and a set of customers (Zhou *et al.*, 2002). Importance of utilization and allocation of China's natural resource has been stressed by Zhu *et al.* (2016). In addition, a study reported the attractiveness of coordination contracts with incentive payments for forward and reverse supply chain (Govindan *et al.*, 2013). Few attempts have been made to incorporate the incentive-payment effects which encourage consumers to return waste plastics and to ensure the quality of returns within the location modeling (Aras and Aksen, 2008a; Aras and Aksen, 2008b). However, these models were based on collection and recycling of a single-product (Welfens *et al.*, 2015). Consideration of multi-product varieties into the modeling process has been sparse. Hence, our integrated model included balanced allocation, incentive-payment and multiple products to fill the voids in the current literature.

3. Problem Description

The plastic recycling collection precedence network is as follows: customers, Initial Collection Point (ICP)s, Centralized Return Center (CRC)s and Processing Center (PC). To model the recycling collection network, we studied the existing process of the sequence for collecting used plastics. The plastic recycler or PC has their own procedure to collect used

plastic products from multiple ICP's and CRC's. Collection of used plastic products begins with agents who visit customers at their sites to collect waste plastic products and then sell them to ICP's. Each ICP is served by multiple agents who cover customers located in different parts of a city or district. As part of the collection process, they check for the quality of the product and classify them according to the quality of used products. After collecting the used plastic products, they sell the different categories of plastic products to the ICP's who are located close to them. Agents are paid (incentives) as per the quality of returned plastic products. The higher the quality, the higher is their payment (incentives). The incentives considered in this model starts from payment to ICPs.

The location and expected volume of used plastic products that are returned by a set of customers (I) and the total number of ICPs (t) and CRCs (s) as well as their capacities are known. Quality levels of the collected plastic products are denoted as k and the corresponding incentive paid to the collecting agents will be specified as IP_k for the used plastic products that are collected. Generally, the higher the quality levels of the collected product, the greater the incentive that is paid to the collecting agent. In other words, the collecting agent will get more incentive from the owner of ICP, if the delivered plastic products at the particular ICP are of good quality. The product returns are specified in units of the weight of the representative commodity. The vehicles used for transport and the CRCs have limited capacity. If q_i is the total units returned from a customer, each customer with $q_i > 0$ must be allocated in a balanced manner to a CRC via ICPs located near the customer until all quantities have been almost equally allotted to available CRCs. Then, capacitated vehicles will make a round optimal trip from each CRCs to the set of ICPs that are assigned to each CRC. Then, the shipment of used plastic products from CRC to PC will be done through a separate vehicle. The mathematical model that integrates balanced allocation among CRCs and capacitated routing for single variety of used plastic products collection is referred as Capacitated Routing and Allocation with Balancing - Integrally solved Single Product (CRAB-ISP) model. The conceptual CRAB-ISP plastic recycling collection network is depicted in Figures 1a and 1b. The objective of this model is to find the optimal location of ICPs and CRCs, along with the balanced allocation of ICPs to CRCs and to determine the routing pattern with the shortest distance from CRCs to the ICPs. The purpose of balancing is to improve the utilization of CRCs and distribute the workload among the available CRCs.

INSERT FIGURE1 HERE

3.1. Assumptions

We make the following assumptions for the proposed model:

- There is no direct shipment from the customers to CRCs.
- Each ICP has sufficient capacity to hold returned products (with different quality levels) from customers.
- Incentive payment to collection agents is considered based on who initiates the collection process.
- The collection agent's transportation cost to ICP is included in his incentive payment
- Travel distance is a surrogate measure for transportation cost (generally transportation cost is proportional to the vehicle's travel distance).
- The volume of returned products allocated to each CRC is approximately equal (e.g., a difference between the highest and lowest allocated volume does not exceed more than 10% of the average allocated volume).
- The capacity of each vehicle which picks up returned products from all assigned ICPs is equal or greater than the capacity of each CRC.

3.2. Model Parameters

The following are the model parameters used to specify the index, range of customers, ICPs, CRCs, processing centers (PCs), product types, quality levels of returns, geometric locations, various costs, distances, and probabilities associated with them:

- i - Index for customers
- j - Index for ICPs
- c - Index for CRCs
- k - Index for quality levels of the collected plastic products
- p - Index for PCs
- v - Index for product varieties
- I - Set of customers $\{1, \dots, r\}$
- J - Set of ICPs $\{1, \dots, t\}$
- C - Set of CRCs $\{1, \dots, s\}$
- K - Set of quality levels of returned plastic products $\{1, \dots, nq\}$
- P - Set of PCs $\{1, \dots, f\}$
- V - Set of product varieties $\{1, \dots, h\}$
- x_i, y_i - Geometric location (quadrant) of customer i
- x_p, y_p - Geometric location of PC p
- q_i - Units of returned product from customer i

- FTC_j - Fixed cost for establishing ICP j
- Q_j - Capacity of ICP j
- D_{cj} - Distance from CRC c to ICP j
- D_{cp} - Distance from CRC c to PC p
- Q_c - Capacity of CRC c
- FCR_c - Fixed cost for establishing CRC c
- Q_p - Capacity of PC p
- $D_{jj'}$ - Distance between ICP's j and j'
- u_j - An intermediate variable, non-negative and real number of ICP j
- $u_{j'}$ - An intermediate variable, non-negative and real number of ICP j'
- IP_k - An incentive paid to the collecting agents for quality level k of collected product;
- PC_k - Processing cost for quality level k of collected product.

3.3. Decision Variables

The symbols used for representing the volume utilized by ICPs, CRCs, and their geometric locations along with binary variables used in the proposed model are given below:

- $\bar{x}_j, \bar{y}_j$ - Geometric location of ICP j ;
- x_c, y_c - Geometric location of CRC c ;
- n_j - Number of customers assigned to ICP j ;
- n_c - Number of ICPs assigned to CRC c ;
- V_{cp} - Total units transferred through CRC c to PC p ;
- V_{cj} - Number of units allocated to CRC c by ICP j ;
- V_j - Number of units allocated to ICP j ;
- $Y_{ij} = 1$, if customer i is assigned to ICP j , 0, otherwise;
- $X_{cj} = 1$, if ICP j is allocated to CRC c , 0, otherwise;
- $Z_{jj'}$ - 1, if vehicle travels from ICP location j to ICP location j' , 0, otherwise;
- $N_c = 1$, if CRC c is open, 0, otherwise;
- $N_j = 1$, if ICP j is open, 0, otherwise;
- $U_{ik} = 1$, if product returned from customer i is of quality level k , 0, otherwise;

3.4. Model Formulation

The proposed problem (objective criterion) is a combination of three sub problems: capacitated clustering problem (CCP), location balanced allocation problem (LBAP) and travelling salesman problem (TSP), which are solved in an integrated manner to demonstrate the holistic results from the problem solving process. The following sub-sections describe the formulation of these three sub-problems.

3.4.1 Phase I: Capacitated Cluster problem

A calculation of the centroid of each customer cluster or the position of the ICPs is the crux of the Capacitated Clustering Problem (CCP). In CCP, the aim is to find capacitated clusters (each cluster with a given capacity) that are centred by a median of its individuals (objects or customers) that minimizes the objective function. Herein, the objective function is total cost (TC) which is expressed as the sum of the total dissimilarity between each individual and its median (Mulvey and Beck, 1984, Ahmadi and Osman, 2005). The calculated centroid of each customer cluster becomes the designated location of the ICP. The cost components of this problem are specified below.

- (i) Variable cost: Is a surrogate measure of total travel distance between customers and their assigned ICPs.
- (ii) Fixed Cost (FTC): Is the cost of establishing ICP that includes land purchase/lease, building construction, and property tax.
- (iii) Total Incentive: Is the sum of all incentives paid to the collecting agents by ICP owners based on the quality levels of products collected.

The CCP sub-problem is formulated as follows:

$$\text{MinTCI} = \sum_{i \in I} \sum_{j \in J} [(x_i - \bar{x}_j)^2 + (y_i - \bar{y}_j)^2]^{1/2} Y_{ij} + \sum_{j=1}^t \text{FTC}_j N_j + \sum_{i \in I} \sum_{k \in K} q_i IP_k U_{ik} \quad (1)$$

Subject to

$$\sum_{j \in J} Y_{ij} = 1, \forall i \in I \quad (2)$$

$$\sum_{i \in I} Y_{ij} = n_j, \forall j \in J \quad (3)$$

$$\sum_{i \in I} q_i Y_{ij} \leq Q_j N_j, \forall j \in J \quad (4)$$

$$\sum_{i \in I} q_i Y_{ij} \leq V_j N_j, \forall j \in J \quad (5)$$

$$\sum_{k \in K} U_{ik} = 1, \forall i \in I \quad (6)$$

Constraint (2) requires that each customer is allocated to exactly one ICP. Constraint (3) binds the total number of customers allocated to each ICP. Constraint (4) limits the capacity of each ICP. Constraint (5) determines the total number of units allocated to each ICP. Constraint (6) specifies that products returned from each customer will be of different quality levels.

3.4.2. Phase II: Location Balanced Allocation Problem

In phase II, we solve the problem of determining the location of CRCs and allocating ICP to each CRC at a minimum cost, but in a balanced manner. This problem is referred to as the Location Balanced Allocation Problem (LBAP). The objective of this LBAP is to minimize the following costs:

- (i) Variable cost: This represents the cost of transshipping collected products from all ICPs to their assigned CRCs and the cost of transshipping collected products from each CRC to the PC for final processing. It also includes the cost of loading and unloading the collected products.
- (ii) Fixed cost: Is a cost of establishing the CRCs including land purchase/lease, building structure, and property tax.
- (iii) Total processing cost: Is the sum of all costs required for the final processing of the collected products with varying quality levels at PC by using machinery/equipment as well as labor.

The LBAP model is expressed as:

$$\text{Min } TC2 = \sum_{c=1}^s \sum_{j=1}^t \sum_{p=1}^1 (D_{cj} + D_{cp}) X_{cj} + \sum_{c=1}^s FCR_c N_c + \sum_{i \in I} \sum_{k \in K} q_i PC_k U_{ik} \quad (7)$$

$$\sum_{c=1}^s X_{cj} = 1, \forall j \in J \quad (8)$$

$$\sum_{j=1}^t X_{cj} = n_c, \forall c \in C \quad (9)$$

$$\sum_{j=1}^t V_j X_{cj} = V_{cj}, \forall c \in C \quad (10)$$

$$\sum_{j=1}^t V_j X_{cj} \leq Q_c N_c, \forall c \in C \quad (11)$$

$$DOI = \{ [\text{Range of } (\sum_{j=1}^t V_{1j}, \dots, \sum_{j=1}^t V_{sj})] / [\text{Mean of } (\sum_{j=1}^t V_{1j}, \dots, \sum_{j=1}^t V_{sj})] \} \leq 10\% \quad (12)$$

Where DOI is the Degree of Imbalance.

$$\sum_{k \in K} U_{ik} = 1, \forall i \in I \quad (13)$$

Constraint (8) ensures that each ICP is allocated to only one CRC. Constraint (9) determines total number of ICPs allocated to a CRC. Constraint (10) determines the total volume of units allocated to each CRC. Constraint (11) ensures that the total volume of units allocated to each CRC never exceeds its capacity. Constraint (12) specifies that DOI (i.e., the deviation of the allocated volume of collected plastic products among the CRCs) should not exceed 10%. Constraint (13) refers to the quality of the returned used plastic product.

3.4.3. Phase III: Travelling Salesman Problem

The actual vehicle routes from each CRC to their assigned ICPs were determined by solving the classical Travelling Salesman Problem (TSP). The objective of this sub-problem is the minimization of cost/ distances for performing optimal tours from all CRCs to their assigned ICPs. This sub-problem is formulated as:

$$\text{Min } TC3 = \sum_{j=1}^t \sum_{j'=1}^t D_{jj'} Z_{jj'} \quad (14)$$

Subject to

$$\sum_{j=0}^t Z_{jj'} = 1, j' = 1, 2, \dots, t; j \neq j' \quad (15)$$

$$\sum_{j'=0}^t Z_{j'j} = 1, j = 1, 2, \dots, t; j' \neq j \quad (16)$$

$$u_j \leq n_c - 1 - (n_c - 2) * Z_{jj'}; j, j' = 2, 3, \dots, t; i' \neq i \text{ (Sub tour constraint)} \quad (17)$$

Where j' is the index for specifying another ICP j ;

Constraint (15) ensures that each vehicle visits each ICP only once. Constraint (16) ensures that the vehicle leaves each ICP location once. Constraint (17) ensures avoidance of any sub-tour.

3.5 Objective Criterion

The objective of the integrated model (CRAB-ISP model) is the minimization of the total cost which is the sum of all costs listed in expression (1), (7), and (14):

$$TC = TC1 + TC2 + TC3 \quad (18)$$

$$\begin{aligned} \text{Minimize } TC = & \sum_{i \in I} \sum_{j \in J} [(x_i - \bar{x}_j)^2 + (y_i - \bar{y}_j)^2]^{1/2} Y_{ij} + \sum_{j=1}^t FTC_j N_j + \sum_{i \in I} \sum_{k \in K} q_i IP_k U_{ik} \\ & + \sum_{c=1}^s \sum_{j=1}^t \sum_{p=1}^1 (D_{cj} + D_{cp}) X_{cj} + \sum_{c=1}^s FCR_c N_c + \sum_{i \in I} \sum_{k \in K} q_i PC_k U_{ik} + \sum_{j=0}^t \sum_{j'=1}^t D_{jj'} Z_{jj'} \end{aligned} \quad (19)$$

4. Solution Method

The proposed problem was solved using LINGO Version 8.0. A flow diagram of the solution methodology is shown in Figure 2.

INSERT FIGURE.2 HERE

The inputs to the CRAB-ISP problem are given as follows:

- (i) Coordinates of customer locations (x_i, y_i) , their number of return units (q_i) ;
- (ii) Total number of returned product quality levels (nq);
- (iii) Total number of ICPs (t) and their capacity (Q_j) , Fixed cost of establishing a ICP (FTC_j) ;
- (iv) Total number of CRCs (s) and their capacity (Q_c) , Fixed cost of establishing a CRC (FCR_c) ;
- (v) Location of PC (x_p, y_p) ;

Solving this model by using the above inputs, we obtain the following outputs.

The outputs of CRAB-ISP are given as follows:

- (i) Position of ICPs along with their coordinates $(\bar{x}_j, \bar{y}_j)$, total number of customers assigned to each ICP (n_j) and the incentive paid to the collecting agents for quality level k (IP_k) ;

(ii) Position of the CRCs along with their coordinates (x_c, y_c) , total number of ICPs allocated to each CRC (n_c) , total number of return units carried through a CRC (V_{cj}) , processing cost for quality level k of collected product, vehicle routes from each CRC to their assigned ICPs.

5. Case Study

In India, central and state pollution control boards are the authorities to monitor and regulate plastic recyclers. The major types of plastics recycled are PE, PP, PVC, PET, PS, ABS and PMMA. Quantum of plastics recycled is 3.6 million tons in 2012. Indian plastics recycling industry is a highly unorganised sector. As per the recent survey report from 60 Indian cities there are 3500 organised plastics recycling units and 4000 plastics unorganised units (CIPET, 2014). We selected a case company from rural part of Southern India where there are not many organised recycling units as well as the people are not aware of how to safely dispose the used plastic products. The selected city for our study is a major tourist's attraction with dominant usage of PET water bottles. Also, the use of water bottles is quite common as there are several problems in the tap water distribution of the city council. We selected different variety of PET and plastic bottles as representative samples for our study. PET bottles recycling yields by products such as flakes, pellets, fibres, extruded sheets, and injection moulded parts (CIPET, 2014). The company selected for our study is a major organised recycler in the city. The company recycles almost all big brands food and pharmaceutical PET bottles and extracts raw materials for producing various products as mentioned above. For confidentiality reasons, this company will be referred to as 'Alpha' for the remainder of this paper. Alpha was established in the year 2007 with an employee size of 20 and recycles approximately 100 tons of used empty plastic bottles annually. These bottles are classified into three different types: (1) PET bottles as product variety 1; (2) plastic soft drink bottles belonging to product variety 2; (3) small plastic bottles used for filling face powder, tooth powder and other food items under product variety 3.

Plastic bottles are sorted into different colour fractions, and baled for onward sale. Baled bottles are sorted and they are washed. Non-plastic fractions such as caps and labels are removed during this process. After washing, baled bottles are crushed, chopped into flakes, pressed into bales, and offered for sale. The clean flake is dried. Further treatment can take place, for example, melt filtering and pelletizing or various treatments to produce food

contact approved recycled PET (RPET) which can be purchased by food industry and pharmaceutical industry for packaging and storage purposes.

The company's supply chain in relation to our problem description is given as follows: Customers, Rag pickers (Collecting agents), Scrap dealers (ICP), Collection centers (CRC) and Recycling company (PC). The aim of the company is to develop an efficient optimal plastic collection network while minimizing the total collection costs. The data for the case study has been collected through interviews with those persons who are involved in the plastic recycling collection network. Separate set of questions was provided to the manager of processing center, one CRC owner, two ICP owners and two collecting agents to obtain the case data and also they are interviewed to get other details. The distance data are collected from the city map. The basic input parameters are given in Tables 1-3. The location of processing center is identified as $(x_p = 100, y_p = 60)$. The output results are summarized in Tables 4-6.

INSERT TABLES 1 TO 6 HERE

6. Results and Discussion

This section analyzes the impact of the considerations other than cost that have to be included while modelling the CRAB-ISP network. The performance of the CRAB-ISP model has been tested by conducting a series of experiments on Intel® Core(TM)2 Duo processor (3.00 GB RAM, T6400 @ 2.00 GHz frequency and 32-bit Windows-Vista Home Basic OS) using different problem settings and the results are summarized in Table 7. From the test, it is found that the computational time varies from 20 minutes to one hour depending upon the problem size and complexity. This section summarizes the results based on influence of integration, contribution of each phase to cost reduction and product varieties.

We tested the impact across multiple contexts. To further examine the model sensitivity, we relaxed some of the model constraints (e.g., balancing or clustering constraints) and changed the model parameters (e.g., varying the degree of product quality levels) to various problem scenarios. We summarize the major outcome of our findings in the next section.

6.1 Impact of Integration

CRAB-ISP model has been decomposed into three phases (CRAB-DSP), and each phase is solved in a sequential manner as shown in Figure 3.

INSERT FIGURE.3 HERE

The results obtained by solving CRAB model with (CRAB-ISP) and without integration (CRAB-DSP) are shown in Figure 4. It is evident from Figure 4 that the total cost is increased in most of the problem instances if it is not solved in an integrated manner i.e. an integrated methodology results in reduced costs. It is found that the performance of the integrated methodology (CRAB-ISP) is better than the performance of the decomposed methodology (CRAB-DSP). The reason behind this improvement is mainly due to the reduction in loss of information when solving it in an integrated manner. We find integrated methodology more suitable to real used plastics recycling network than decomposed methodology.

INSERT FIGURE 4 HERE

6.2 Impact of each phase

The total cost of each phase of CRAB-DSP model is compared with each other as shown in Table 7. It is evident from Table 7 that the total cost of phase-I is higher than other phases i.e., clustering of customers and incentive pricing to customers of phase-I play an important role on the performance of CRAB-DSP model.

INSERT TABLE 7 HERE

Hence it is clear that clustering ultimately reduces the total cost. The rationale is that clustering helps to identify the true population centers of customers and thus helps to create the effective customer zones weighed by the number of customer populations. In other words, the clustering procedure is useful for finding the locations of the ICPs convenient (in proximity) to their customers. The convenient location of the ICPs can lower the transportation cost between the customer location and the ICP site.

6.3 Impact of product varieties

The objective function for multiple product varieties (CRAB-IMP) is similar to the CRAB-ISP except some small variations in the index of incentive and processing cost. All other constraints and solution methodology are same as CRAB-ISP.

The objective function of CRAB-IMP is given as follows:

$$\begin{aligned} \text{Minimize } TC = & \sum_{i \in I} \sum_{j \in J} [(x_i - \bar{x}_j)_2 + (y_i - \bar{y}_j)_2]^{1/2} Y_{ij} + \sum_{j=1}^t FTC_j N_j + \sum_{i \in I} \sum_{k \in K} \sum_{v \in V} q_{iv} IP_{kv} U_{ikv} + \\ & \sum_{c=1}^s \sum_{j=1}^t \sum_{p=1}^1 (D_{cj} + D_{cp}) X_{cj} + \sum_{c=1}^s FCR_c N_c + \sum_{i \in I} \sum_{k \in K} \sum_{v \in V} q_{iv} PC_{kv} U_{ikv} + \sum_{j=0}^t \sum_{j'=1}^t D_{jj'} Z_{jj'} \quad (20) \end{aligned}$$

We have taken single and three product varieties referred in Figure 5 as CRAB-ISP and CRAB-IMP. PET bottles are coming under product variety 1, plastic soft drinks bottles belong to product variety 2 and product variety 3 consist of small plastic boxes used for filling face powder, tooth powder other food items. We observe that greater the number of product varieties, lesser the total cost in most of the problems. That is to say, if a firm wants to reduce the total cost, it needs to reduce the extent of variances in product quality levels. The possible explanation may be that the processing of varying degrees of product quality levels requires extra time to sort returned products and multiple setups to process them for reuse and recycling. Thus, if a firm wants to reduce the processing cost, the number of quality levels of returned products should be reduced. Also, if a firm wants to reduce the price paid to the collecting agents, there should be more product quality levels put in place.

INSERT FIGURE.5 HERE

7. Conclusion

Since the collection of waste plastic is less systematic, more complicated and costly, our focus in this paper is to develop an effective model for plastic recycling collection network to overcome several contextual challenges. The objective of the proposed model was to minimize the total collection (location and distribution) cost. The performance of the issues in the CRAB-ISP model is analysed by comparing it with its variants such as CRAB-DSP and CRAB-IMP models using data retrieved from a case study conducted on a plastic recycling company. Initially a model based on spatial consolidation was developed for solving CRAB-

DSP with the use of a decomposed methodology in which location, allocation and routing decisions were considered in a sequential manner. Since the actual information of the problem may be lost during transition phase of the decomposed methodology, the same CRAB-DSP model was modified by developing a model (CRAB-ISP) based on combined location, allocation and routing decisions with the use of an integrated methodology. Since the availability of single product is very rare in real plastic recycling environment, this model based on the combined location, allocation and routing decisions was extended to a multi-product plastic recycling problem (CRAB-IMP) environment, and was solved with the use of the integrated methodology. The proposed models for solving the CRAB-ISP and the CRAB-IMP were validated in a real-world setting in India. Through a series of model experiments and sensitivity analysis, the proposed models were proven to be useful for gaining insights into the reverse logistics operations involving recyclable plastic bottles.

Our study points to a number of avenues for future research. First, this work can be extended by taking into account inventory related costs. Second, stochastic demand and dynamic pricing can be considered. Third, the aspects such as multi-period and multi-objective may also be included into the current model. Finally, the co-ordination of two markets such as supply side (returns) and returns disposition may be taken into account in future studies.

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Table 1: Locations and Return Units of Customers

<i>No</i>	<i>Coordinates</i> (<i>x,y</i>)	<i>Weight of returned</i> <i>plastic products(q_i)</i> <i>in kg</i>	<i>No</i>	<i>Coordinates</i> (<i>x,y</i>)	<i>Weight of returned</i> <i>plastic products(q_i)</i> <i>in kg</i>
1	(20,20)	25	26	(60,30)	4
2	(20,30)	5	27	(60,40)	12
3	(20,40)	7	28	(60,50)	2
4	(20,50)	4	29	(60,60)	4
5	(20,60)	8	30	(60,70)	5
6	(20,70)	12	31	(70,20)	7
7	(30,20)	11	32	(70,30)	4
8	(30,30)	9	33	(70,40)	3
9	(30,40)	13	34	(70,50)	16
10	(30,50)	14	35	(70,60)	10
11	(30,60)	17	36	(70,70)	2
12	(30,70)	19	37	(80,20)	20
13	(40,20)	16	38	(80,30)	5
14	(40,30)	4	39	(80,40)	6
15	(40,40)	5	40	(80,50)	4
16	(40,50)	9	41	(80,60)	14
17	(40,60)	8	42	(80,70)	8
18	(40,70)	7	43	(90,20)	10
19	(50,20)	4	44	(90,30)	19
20	(50,30)	14	45	(90,40)	24
21	(50,40)	2	46	(90,50)	10
22	(50,50)	3	47	(90,60)	12
23	(50,60)	5	48	(90,70)	22
24	(50,70)	12	49	(100,20)	11
25	(60,20)	6	50	(100,30)	14

Table 2: Parameters of ICP and CRC

<i>Parameter</i>	<i>ICP</i>		<i>CRC</i>	
	<i>Index</i>	<i>Value</i>	<i>Index</i>	<i>Value</i>
Capacity	Q_j	200	Q_c	800
No	t	8	s	2
Fixed cost(INR*)	FTC_j	5,000	FCR_c	10,000

*1USD (United States of America Dollar) = 67 INR (Indian Rupee) @ July 2016

Table 3: Parameters of returned plastic products

<i>Parameter</i>	<i>Index</i>	<i>Value</i>
No of product quality levels	np	3
Incentive (INR)	IP_a	30
(IP_k)	IP_b	25
	IP_c	20
Processing Cost	PC_a	5
(INR) (PC_k)	PC_b	8
	PC_c	10

Table 4: Inspection results of returned plastic products

<i>No.</i>	<i>Quality Level</i>	<i>Incentive (IP_k) (INR*)</i>	<i>Processing Cost (PC_k) (INR*)</i>
1	C	20	10
2	B	25	8
3	A	30	5
4	A	30	5
5	C	20	10
6	B	25	8
7	C	20	10
8	C	20	10
9	C	20	10
10	A	30	5
11	B	25	8
12	A	30	5
13	A	30	5
14	A	30	5
15	A	30	5
16	A	30	5
17	B	25	8
18	A	30	5
19	C	20	10
20	A	30	5
21	C	20	10
22	C	20	10
23	C	20	10
24	A	30	5

25	B	25	8
26	A	30	5
27	B	25	8
28	B	25	8
29	B	25	8
30	A	30	5
31	C	20	10
32	A	30	5
33	C	20	10
34	B	25	8
35	C	20	10
36	B	25	8
37	B	25	8
38	C	20	10
39	A	30	5
40	C	20	10
41	A	30	5
42	C	20	10
43	B	25	8
44	C	20	10
45	C	20	10
46	C	20	10
47	C	20	10
48	C	20	10
49	A	30	5
50	A	30	5

*1USD (United States of America Dollar) = 67 INR (Indian Rupee) @ July 2016

Table 5: Position of ICP's

<i>ICP</i> <i>No.</i>	$\bar{x}_j$	$\bar{y}_j$	<i>Customer allocation</i>	n_j (Units)	V_{cj} (Kg)
1	88.98	40.36	31,32,45,49	4	140
2	89.99	37.92	13,19,20,21,25,26	6	150
3	48.90	37.14	4,5,6,10,11,12,17,18	8	200
4	30.07	60.75	1,2,3,7,8,9,14,15	8	200
5	57.92	61.15	16,22,23,24,27,28,29,30	8	200
6	64.47	39.34	33,34,35,39,40,46	6	175
7	81.84	39.67	36,41,42,47,48	5	175
8	35.73	37.30	37,38,43,44,50	5	200

Table 6: Balanced Allocation of all ICP's with CRC's and their aggregated vehicle routes

<i>CRC</i> <i>No.</i>	<i>Position</i>		<i>ICP served</i>	V_{cp} (Kg)	<i>ICP Vehicle route sequence</i>
	x_c	y_c			
1	46.71	47.87	2,3,4,5	750	CRC1- ICP2 –ICP5-ICP4- ICP3-CRC1
2	81.84	43.68	1,6,7,8	690	CRC2-ICP6-ICP7-ICP8-ICP1-CRC2
Final best solution				TC = INR 106050.12	

Table 7: Impact of each phase

<i>r</i>	<i>t</i>	<i>nq</i>	<i>Phase-I (INR)</i>	<i>Phase-II(INR)</i>	<i>Phase-III(INR)</i>
50	8	3	74885.05	30988.17	176.899
55	6	3	69075.36	32163.43	128.4020
60	6	3	76619.81	34406.88	101.9786
65	6	3	81884.04	36590.28	169.2860
70	6	3	90455.54	39501.46	157.6147

Figure 1a: Allocation of ICP to CRC, CRC location and vehicle routing

Figure 1b: Allocation of customers to ICP and ICP location

Figure 2: Structure of CRAB-ISP methodology

Figure.3: Structure of CRAB-DSP methodology

Figure.4.Impact of Integration

Figure.5: Impact of Product variety