Constraints Driven Reverse Logistics Model for Plastic Solid Waste (PSW)

B.G Mwanza[1], A. Telukdarie[2], C. Mbohwa[3]
[1,2,3]School of Engineering Management, University of Johannesburg, Johannesburg, South Africa
(bupe.mwanza@gmail.com)

Abstract - **The recovery and recycling of Plastic Solid Waste (PSW) is an important aspect of achieving sustainability. The study reviewed technical constraints (Modeling levers) that influence households' participation in waste recovery and recycling programs from both developed and developing economies. A questionnaire based on the identified levers is developed and distributed to test the validity and significance of the levers. The results are adopted in the development of a levers' based reverse logistics (RLs) model for PSW in the Zambian context. The model provides a new and useful engineering approach for the management of PSW in both developed and developing economies influenced by similar levers.**

Keywords – **Reverse logistics, Recycling, Plastics, Engineering Management**

I. INTRODUCTION

Plastic waste consumption and production as well as generation continue to increase since the first industrial scale production [1]. This increase has been accelerated as plastics are used in the production of many products. However, 20-25% of plastics are used as long term infrastructure products while almost 50% are produced for disposable applications i.e. packaging [2]. The use in a number of applications has been attributed to the substantial properties possessed by plastics such as durability, low weight and lower cost as compared to other types of materials [3]. Therefore, it is not surprising to find a great amount of PSW in Municipal Solid Waste (MSW).

In developing economies, the rapid increase in population, urbanization and economic development means the rate of PSW generation is also increasing at alarming rates [4]. As a result of this, authorities charged with the responsibility of managing waste are facing a number of challenges and this has placed excessive pressure on the authorities to provide efficient and effective services [5].

Several studies have looked at levers that influence the recycling or management of PSW in both developing and developed economies. Most of these studies have been conducted at the household or community level. At community level; a number of studies identified the constraints or levers that influence waste management and recycling [6 -7- 8]. These studies either reviewed or qualitatively analyzed the drivers or levers that influence solid waste management or recycling but none of the studies specially focused on PSW recovery and recycling. At household level [9-10- 11] identified levers influencing households to participate in waste recycling programs. The studies at household-level either empirically analyzed the specific levers that influence households to recycle or used a case-study approach. None of the studies at household level developed a reverse logistics model based on the identified levers for the recovery and recycling of PSW.

The objectives of this paper are firstly to review the levers or factors that influence the recovery and recycling of waste from developed and developing economies. Secondly, develop a questionnaire based on the identified levers and distribute it to selected households in Zambia. Thirdly, use the results from the analysis to design a levers' based reverse logistics model for PSW in the context of Zambia.

II. LITERATURE REVIEW

The industrial production of plastics continue to grow at a rate of 10% each year since the 1940s while since 1950 the global production has continued to increase from 1.3 million tons to 300 million tons in 2014 [12, 1].

In MSW management, plastic wastes mostly from thin-film plastic bags and packaging materials have become a major problem [3]. For this reason and others, it is cardinal to know the levers that influence the recovery of these wastes from the environment.

A. Plastic Recycling

Plastics have replaced many products previously made out of metal, glass, fiber and many other materials. According to [13] the drivers for such growth in the plastic industry are because plastics have low strength density and cost, fabrication and design capabilities and user friendly. However despite having these favorable properties, plastics have a negative effect on the environment if improperly managed.

For this research, recycling is viewed as a strategy that contributes to sustainable management of PSW. However, in order to sustainably recycle PSW, it is also important to understand the levers that influence the recycling of these plastics from both developed and developing economies.

B. Plastic Recycling in Developed Economies

Plastic waste recycling has received considerable attention in developed economies as compared to developing economies. Waste recycling researches in the developed economies has focused more on the

application of technology such as models and tools [14]. This may be attributed to the fact that developed economies own heavily industrialized recycling activities [7]. However, other studies have focused on socio-economic and psychological influences on human behaviors. Socio-economic research has focused on the correlation of recycling with levers such as income, age, education, gender and consumption patterns [15]. In other studies, plastic waste collection and recycling has been influenced by the collection methods.

C. Plastic Recycling in Developing Economies

MSW constitutes different types of waste categories and it is not surprising to find PSWs. Plastic waste constitutes 8-11% of the MSW composition in developing economies [16] and only 4% of waste generated in Africa is recovered [17]. Plastic packaging and containers represent the highest tonnage [16]. In developing economies, recycling activities are mostly conducted by the informal sector [18, 19]. However, [19] identified that lack of useful government interventions and legislations is the main problem with the collection and recovery system.

D. Technical Levers Influencing Plastic Recycling

A number of technological instruments exist for converting solid waste specifically destined for landfills such as energy production by incineration, material recovery through recycling and composting of organic wastes, all with the capability to be more sustainable methods of managing solid waste than via landfill [7]. This research extends into a review of levers affecting reverse logistics as detailed below.

- *Waste Policy and Legislations*

At the global level a number of waste policies focus on promoting a circular economy and resource efficiency hence facilitating the closing of waste and resource loops [20]. A number of developed economies have formulated legislations or waste policies regarding the management of waste for sustainable development. An example of Australia, were a voluntary instrument in regards to packaging waste exists since 1999 focusing on facilitating recycling and reuse of packaging waste and promoting conservation [21].

- *Demographic Factors*

Households or stakeholders' participation in waste management programs has always been influenced by a number of levers and demographic factors such as race, age, gender and income level. Reference [22] revealed that recycling and waste management were significantly affected by age, income and waste management attitudes. Reference [23] affirms that age positively influences purchase and recycling behavior decisions. Educational and income levels have been indicated as having influence over citizens' perceptions and attitudes towards environmental policies [24].

- *Waste Collection Systems*

Waste collection systems are a very important pillar in waste management and for this reason a number of studies have been conducted. Reference [25] indicated that to ensure maximum participation rates and high diversion of recyclable materials, the correct collection scheme design has to be provided to households to capture traditionally "non committed recyclers."

- *Knowledge and Awareness on Recycling*

Reference [11] investigated households' attitudes towards recycling of SW in Malaysia. The results revealed that households' participation in recycling of waste relies on the level of understanding and awareness of recycling. Reference [6] affirmed that public awareness is an important lever for sustainable SW management. Therefore, consideration of public awareness and knowledge of waste management programs is important.

- *Economic Incentives*

Reference [9] conducted a study on recycling of domestic waste, collective action and economic incentives in Hong Kong. The study revealed that promotion of recycling rates in Hong Kong can work through economic incentives [9].

- *Informal Sector Incorporation in the Formalized System*

Waste recycling is a livelihood for the marginalized society in developing economies. However unlike the developed economies like the USA, recycling still remains an informal activity in developing economies [26]. A number of studies have indicated that integrating the informal recycling sector into a formalized recycling sector is a means to sustainable MSW recycling [26- 27].

E. Plastic Recycling in Zambia

In developing and emerging economies, recycling activities tend to be completely or to a greater part done by the informal sector. However, according to the study conducted by [28] in six different cities of developing economies; Lusaka, Zambia had the lowest recycling percentages in both sectors (formal and informal) with the formal sector twice as effective compared to the informal sector. Further, [29] indicates that only 9% of the waste generated in the city of Lusaka is recovered whilst the remaining 91% is unrecovered. With such low percentages, it can only be concluded that waste recovery and in particular PSW is still a big challenge in Zambia.

III. METHODOLOGY

A structured questionnaire to investigate the levers that influence households to participate in PSW recovery programs for recycling purposes is developed. The questionnaire is structured to focus on demographic factors of age, income level, education level, gender and household size. The other sections investigated the levers for implementation in the communities for households to

support PSW recovery and recycling. A number of statements focusing on; waste collections systems, knowledge and awareness of plastic recycling, incorporation of the informal waste sector in household recovery programs, provision of economic incentives and enforcement of regulations and legislations on PSW recovery and recycling are presented in the questionnaire.

For the demographic section, the reaction to the questions involved single scaling while for the other questions a likert-type scale is used. A total of 350 questionnaires were distributed using stratified sampling in the city of Ndola between the months of December, 2016 and March 2017. A total of 299 questionnaires were received and analyzed, a response rate of 85.4%. All the data is analyzed using SPSS version 11.5 for Windows.

IV. RESULTS AND DISCUSSION

Based on the demographic factors of the respondents that participated in the survey age, gender, household size, occupation, level of education and income is analyzed. Analysis of age indicated that majority of the respondents were younger than 26 years (57.9%). Analysis of the gender attribute illustrated 52.5% of the respondents were men while 47.5% were women. This indicated that more men participated in the survey compared to women. For education level distribution indicated that, the majority of the respondents had college education (36.1%). Income level analysis revealed that; the majority of the respondents earned between K1001 to K5000 and was represented by (33.4%). Household size analysis revealed that the majority of the respondents had five or six people living in the house (28.1%). In terms of the levers to support households' participation in PSW recovery and recycling programs, emphasis is paid to the levers with the highest response count. 70.6% of the respondents indicated that knowledge and awareness on PSW recycling can contribute to them supporting recovery programs (strongly agreed). Reference [6] and [11] have indicated that awareness and knowledge contributes to participation in recycling programs. 51.2% of the respondents revealed that introduction of economic incentives can lead to them supporting PSW recovery programs (strongly agreed). Reference [9] showed that economic incentives can promote recycling rates. 65.5% of respondents indicated that introduction of PSW recovery and recycling legislations at household level would influence participation (strongly agreed) whereas 60.9% of the respondents indicated provision of waste collection systems would influence households to recover PSW (agreed). Provision of legislations and regulations and proper collection systems influences recycling rates [21, 25]. 54.5% of respondents supported the introduction of informal waste collectors as a lever that can influence the recovery of PSW (agreed). Reference [26] and [27] affirm that informal waste recovery and recycling is still influential to sustainable recovery rates in developing economies

The results from the analysis of the levers that influence households to participate in recovery programs indicated that most of the households were in favor of the levers. Therefore, these levers were incorporated in the proposed reverse logistics (RLs) model.

V. PROPOSED LEVERS' DRIVEN PSW REVERSE LOGISTICS MODEL

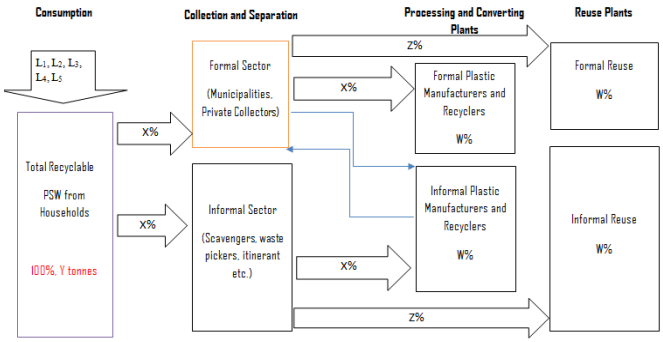

Fig. 1. Proposed levers' driven plastic solid waste reverse logistics model

Fig. 1 above depicts the proposed model for the recovery and recycling of PSW in Zambia. The model consists of the following stages; consumption, collection and separation, processing and converting plants and reuse plants. The consumption stage consists of the households while the collection and separation stages consist of the formal and informal waste collectors. The levers incorporated in the model at the consumption stage (households) are chosen based on theory or evidence from previous studies. The five levers are denoted as follows;

L_1: Waste policies and legislations: These are levers set by the government or local authorities in terms of waste management such as mandatory waste recycling or waste separation legislations.

L_2: Knowledge and awareness: This lever examines the level of knowledge and awareness households have in terms of PSW recovery and recycling.

L_3: Waste collection systems. This lever consists of waste collection systems namely; curbside, drop-off point and buy-back centers.

L_4: Economic Incentives. This lever consists of monetary or non-monetary incentives.

L_5: Informal waste sector incorporation. This lever assessed the incorporation of the informal waste collectors into household PSW recovery for recycling purposes.

After testing the validity and significance of each lever, they were incorporated at the consumption stage of the model since households are considered as the main generators of PSW in the model. The influence of these levers on the households determines the amount of PSW recovered by the formal and informal waste collectors. The PSWs recovered by the informal and formal waste collectors equates to the amount of PSWs recovered for

recycling and reuse purposes by processing and converting plants.

Incorporation of the levers in the model is intended to satisfy the assumption that PSW recovered by the formal and informal waste collectors equals to the amount of PSW recycled and reused by the converting and manufacturing companies. Hence the assumption is 100% of PSW is generated and recovered from households. However, the recovery of 100% recyclable and reusable PSW is dependent on the influence of each lever per household. Therefore;

$$\sum \{LX_1 + LX_2\} + U_r = W_t \quad (1)$$

Where L is

$$f(L) = \{L_1L_2L_3L_4L_5L_6\} \quad (2)$$

X_1 is the amount of PSW recovered by formal waste collectors

X_2 is the amount of waste recovered by the informal collectors

Wt is the amount recycled and reused by formal and informal manufacturers and recyclers.

U_r= Unrecovered

The model is constituted based on the results of the questionnaire. The dependency of the variables (linear/none) is constituted into equations and adopted for the model.

Considering all converting and processing conditions stable in the manufacturing and recycling companies, Wt is the actual PSW recycled and reused in-house by both formal and informal manufacturers and recyclers. Any changes in how L_1, L_2, L_3, L_4 and L_5 influences household participation in PSW recovery programs results in a proportional change affecting W%.

VI. CONCLUSION

It is imperative to incorporate the technical levers in the model designed for the Zambian context as such levers, if properly implemented leads to optimal recovery of PSW for recycling and reuse purposes.

The proposed levers driven plastic waste recovery and recycling model provides useful factors that should be considered during the development and implementation of waste management programs. The model provides the three stakeholders; households, formal and informal waste collectors and the processing and converting plants with information that can optimize the recovery of PSWs. Further, it is cardinal to note that management of solid waste or plastic waste involves more than one stakeholder but and requires the integration of all the relevant stakeholders for it to be sustainably recovered and managed.

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