ON THE RELATIONSHIP BETWEEN FLOW RATE, COST AND PRODUCTIVITY IN A RECYCLING PLANT

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ABSTRACT

The growing need to manage businesses more competitively and more profitably is opening up new opportunities for research in industrial engineering. One of these research and practical opportunities is the development of cost and productivity theory for a recycling plant. Recycling technology has evolved as one of the most useful facilities that help us to maintain an environmentally friendly society. The world over, the need of recycling is heightened by the increasing awareness of product consumer, on the need to maximize the bundle of benefits from the products bought by them. This paper attempts a mathematical model for the solid waste-recycling problem. The focus is on development of a framework that incorporates flow rate, cost and productivity into a holistic theory.

KEYWORDS cost, productivity, solid waste, recycling, flowrate

1. INTRODUCTION

The subject of recycling has in recent times dominated discussion in the local and international literature on waste management [3-5, 9,11,15,16]. Gradually the literature is shifting away interest from qualitative descriptions to quantitative measures that adequately reflect the practical situations of the recycling problem [10,12,13,14]. Along with this interest, the various stakeholders in the environment are promoting the establishment of recycling plant that would aid in achieving the goal of an environmentally friendly community.

As a result, a huge amount of resources have been committed to the recycling area in order to achieve tangible and the desired results [17-20]. Part of the committed resources to solving the recycling problem is the provision of finance to support research on recycling. While a large amount of efforts have been invested in the mathematical modeling of the recycling problem, it is only in recent times that the benefits of such efforts are yielding results with the development of some robust mathematical tools [22-24,26,27].

In recent times, some researchers have developed a mathematical model that could estimate the flow rate of plastic recycled products. While this offers immense benefits to the waste management community, some important parameters such as cost and productivity have been largely neglected. Clearly scientific inquires are needed on models that would relate cost, productivity and flow rate in a simplified manner such that researchers and industrial practitioners would benefit from its application in real life. This problem is addressed in the present world.

2. RELATED LITERATURE

Research on recycling has an established history, spanning across solid waste glass recycling, medical products recycling and other categories waste. Apart, scholars have recently stated to integrate new emerging concepts and principles towards optimizing yields on recycling. For example, the research due to Chen [2], and Stessel [24], represent studies on concurrent engineering and conceptual design respectively. In a study by Romualdo et al. [23], the recycling of granite industry waste from the northeast region of Brazil was considered.

Although this work offers an important contribution to the environmental management and health literature, no mention is made about the integration of cost and productivity in their work. This is an important gap that the present research aims to address. In the Middle East, an interesting research on recycling practices on Tehran, Iran was conducted. The research serves as a framework for other scholars who are interested in applying the concepts described to other countries of the world. Unfortunately, little assistance is given on cost and productivity issues that is the main focus of this work.

Moreover, Gaiser and associates [9] examined glass recycling in the labour suite and concluded it is environmentally sound and economical. The background of their examination was that glass bottles were used for the storage of local anesthetics in US and were recyclable. They noted that recycling could result in hospital Solid waste reduction. The authors surveyed the members of the department of anesthesia to determine where those local anesthetic bottles were disposed of. From November 2002 to April 2003, glass bottles used on the labour and delivery suite were saved for recycling.

The number of bottles and the weight recycled were recorded. While this study is an important contribution to glass recycling, it is unfortunate that no mention of cost and productivity issue concerning recycling was made. This is therefore, a justification for the current study on the integration of cost and productivity into the existing framework. In the aspect of new management practices, a further investigation on recycling was carried out on development of integrated design for disassembly and recycling in concurrent engineering by Chen [2].

They noted that the extremely high and ever – increasing annual disposal rates of solid waste had caused a big problem for environment protection in the world. Unlike the first environment revolution in the 1970s, which was aimed at cleaning up hazards waste from contaminated sites and natural resources, the second revolution is addressing waste reduction at the source. The solution of those problems could not rely on legislation and might be supported by effective methods. The goal could be achieved through the design of products that promoted disassembly, reusing and recycling. In order to design environmentally friendly products in concurrent engineering, the paper applied axiomatic design to develop the integrated design guidelines with Axiom 1 (independence axiom) for generating acceptable designs and an evaluation score with Axiom 2 (information axiom) for determining better or the best design from the acceptable designs. From the work by Chen [2], it is obvious that there is possibility of utilizing some improvement tools to recycling.

Therefore, future investigations should consider the application of soft computing tools into existing studies. Tools that include genetic algorithm, artificial neural network and others may be useful when integrated into studies such as discussed above. Nevertheless, there is no account of cost and productivity consideration from the work of Chen [2]. This is an obvious gap that the work aims to close.

Furthermore, Pohlen and associate [22] investigated into reverse logistics in plastic recycling. The authors noted that recycling had experienced rapid growth as a technique to reduce the solid waste stream volume. Despite the public appeal and acceptance of recycling, the reverse logistics channels used in recycling had received minimal attention. However, the reverse channels' membership and capabilities had a significant impact on the efficiency of processing recyclable material for remanufacture into recycled products.

Differing product characteristics, extensive handling, and low-density shipments posed considerable obstacles to establishing an efficient reverse channel for recyclable commodities. A framework, based on interviews and current literature, described the reverse logistics channel structure, membership and functions, and provided a foundation for identifying the issues affecting efficiency and marketability and possible future directions for improving efficiency within the reverse channel structure. From this study the important aspects of the recycling industries is shown as a necessity for future investigations.

Apart from logistics, scholars could research into maintenance systems, production system analysis, the design of quality assurance system, and the application of ISO quality systems to the recycling industries. Result from such studies could form the bedrock of future investigations that may keep researchers busy for some years to come. However, we would point out that the study by Pohlen and associates [22], is limited due to its inability to consider cost and productivity issues in recycling.

Yet in another study, Menezes and colleagues [19], examined the recycling of granite industry waste from the northeast region of Brazil.

They noted that solid wastes were then one of the worst problems in the world, mainly because of the increase in volume and the high capacity of environmental contamination. The aim of the work was to analyze the possibility of use saving granite waste as alternative ceramic raw materials for the production of bricks and rood tiles. Samples were collected from wastes of several granites companies from the northeast regions of Brazil. They are submitted to particle size and mineralogical characterization. Some ceramic compositions were prepared with granite waste and submitted to technological tests.

The results indicated that the wastes had particle size distribution and mineralogical composition similar to conventional non-plastic ceramic raw materials. Those wastes could be used in substitution of conventional raw materials into ceramic formulations, in proportions up to 50 percent. Those could be important to save traditional raw materials from the region and decreasing the aggression to the environment. This particular study stimulates interests in researching into recycling in the mining industries. Extension of this study could be made in particular cases in the Coal

Marble, Tin, Iron Ore and Limestone Industry. This would create an interesting pool of research for researchers in this area.

Feiock and Kalan [6] examines variation in the success of solid waste recycling programs in Florida based on the administrative design of recycling program, state – level incentives and constraints, economic resources, and citizen environmental support. The estimated a model to explain variation in the success of recycling as indicted by recycling rates. The empirical analysis applies pooled cross-sectional time series techniques. The results demonstrate that economic resources have grater significance to program success than either administrative design or environmental support. They also discussed the implications of their finding both the study and practice of local solid waste management.

In conclusion, they highlighted the need for future research to examine interactions among economic resources, citizen attitudes, and administrative factors to identify the contexts in which particular programmatic design factors are likely to be most effective. The paper by Feiock and colleague [6] is quantitatively based, thus redirecting interest in quantitative research that exposed readers to some of its salient parts. Unfortunately, it has not addressed the productivity and the cost issue, which is the main focus of the current work.

Fullerton and Kinnaman [7] built a simple theoretical general equilibrium model of household choice between consumption and leisure and among these disposal options, gabbage, recycling and illicit burning and dumping. A single consumption good w as produced using a single pry factor, recycled input, and virgin materials such as timber or minerals. They later considered this aggregate goods and services. The model also includes three extremities. Firs, municipal gabbage collection and disposal may impose aesthetic and health cost on those who lie near the landfills or incinerator.

Second, improper burning or dumping may impose even higher cost on others. Third, the extraction of virgin materials involve clear-cutting or strip-mining that may adversely affect not only land owner who sells Timber or mineral rights but others who enjoy wilderness and wildlife. The theoretical framework developed by these authors is useful but has not taken into account the issues of productivity and cost. This is therefore the justification of the current work.

In another work, Fullerton and Kinnaman [8], investigated into curbnous policy, a price per bag of cabbage has has a negative on recycling. Correction for endogenous local policy increases the user fee on cabbage and the effect of curbside recycling collection on recycling.

They also estimated a fee of one dollar per bag to increase recycling by only 30 pounds per person per year. Although the work seems useful for the environmental recycling community, little or no reference has been made to the incorporation of cost and productivity in their work. This is a gap that is filled at the present work.

Kimbrough and associates [16] explored the current laws and regulations that discourage recycling, the technologies available for silver recovery and options to promote increased silver recycling in the photographic/radiographic area.

These were done by considering the fact that much of silver consumption in the United State is used in photographic and radiographic applications. They stated that small operations such as local doctors' and dentists' offices, veterinary clinics, and one-hour film developers consume the bulk of this silver during the photographic/radiographic developing process. These are qualitative in nature and add to the discussion of the subject. Thus improving our understanding on the legal aspect of recycling. The scope of the legal aspect needs to be expanded to incorporate some sociological and psychological relationships on their effects on the recycling program. Apart, it could be stressed that the important subjects of incorporating cost and productivity into the recycling model has been omitted. This is investigated in the present study.

Bruvoll [1] analyzed the effect of income, waste management fees and population density on the overall amount of waste generated, and of income, fees and recycling services on the choice of waste management methods. The results showed that economic incentives are effect in influencing the selection between different waste management methods. It was stated that landfill fees reduce the waste amounts being landfilled and increase recycling and incineration. However, the effect of the landfill fees on total waste generation is negative, but not significant. An increase weight in recycling in the states with the highest landfill fees might undermine the effect of fees on waste generation.

Thus, the total effects if substituting recycling for landfilling instead of source reduction. It went further to using the environmental Kuzuets curve theory that suggests that waste generation first increases, and then decreases with rising income. In the study, the overall of municipal solid are not influenced by income. Recycled plastic resins resist attacks by living organisms and marine borers, do not rust or decompose, present strength characteristics and have impact resistance higher than wood and are environmentally sound in soil and groundwater media. In addition, durability of plastic resins due to sunlight exposure is typically addressed by the industry with the use of additives in the resin mix. Although an investigation into waste management is proposed through the integration of the recycling program, it is absent in the concepts of cost and productivity which is pursued in this work.

Goulias [11] presents the results from a technical feasibility assessment of reinforced recycled plastic resins for highway utility poles. In order to produce a composite construction material that will meet the expected performance requirements and design specifications, technological and economic feasibility assessment, product development and engineering performance evaluation was needed. The paper described the economic technical feasibility evaluation undertaken in the study. First, the adaptability of these reinforced composite materials to current specifications was examined. Then, typical in-service loading conditions were identified for evaluating preliminary pole designs with these resins. Next, standard pole design criteria were used for developing alternative reinforced recycled composite pole designs that are comparable to wood poles. Finally, the economic advantages of reinforced composite-based poles were identified.

The methodology and results of the study could be used for evaluating the potential of using recycled polymeric based resins in similar infrastructure applications. The ideas gained from the work by Goulias [10] are the need to expand the scope of products that recycling could cover. In the developed countries, standard-regulatory policies are evidenced in environmental practices. However, the control of environments in developing countries has a number of shortcomings. For instance, in West Africa where a large number of packaged water products are produced in sachets and plastic packages, the issue of recycling of these wastes is least addressed. The case of Nigeria is a good example. Thus, researchers are encouraged to investigate into how to improve the recycling activities in the region and expand the scope of operations in terms of waste products ranges.

Tofigh [25] stated in one of his papers that recovery should be practiced by taking the cost analysis and environmental factors into consideration. He also said that an effective and efficient recovery starts through waste recovery separation techniques at the port of origin. Given the huge amount of garbage wastes in the city of Tehran that amounts to 68 – 73% of total waste in Iran, utilization of compost process and techniques, is deemed necessary. Participation and assistance of citizens could help to separate and to collect the dried, toxic and hygienic foodstuff wastes, therefore making the stages for processing foodstuff into compost less costly and more hygienic. The work by this author addressed the issue of incorporating cost into recycling framework but has not touched the concept of productivity which is an important element of the current paper. While the principle discussed by Tofigh [25] seems useful for future investigations, research workers are encouraged to incorporate productivity measures for a holistic viewpoint of the study.

Piga and Shehu [21] conducted a study in order to assess a new wet benefication treatment for the recovery of the sulfuric acid soluble titanium dioxide contained in the waste from an Italian TiO_2 pigment facility. The waste was produced during treatment of a Ti-enriched slag and contains as main components TiO_2 (54% of which 42% acid-soluble and 12% insoluble), SiO_2 (27%) and Al_2O_3 (6%). Eighty percent of the material was finer than 35μm. Their first step was to ascertain the possibilities offered by size classification, wet gravity separation, froth floatation and wet high-intensity magnetic separation to improve the grade and recovery of the acid soluble TiO_2 and reduce SiO_2 content. The next step was to optimize the operating conditions of the various separations and assemble them into a completed flow sheet. Benefication ensures the recovery of about 46% of the acid soluble titanium that was disposed of in a landfill.

In addition, the treatment of the sludge permits to double the life of the landfill. The ideas presented in this work suggested the need to explore further the recovery of liquids, therefore recycling activities should also have an orientation towards treatments of liquids. With this, a wide range of products will be captured.

3. THE MODEL

The model developed is based on three important variables:

(1) productivity, (2) cost and (3) recycled product flow rate.

The first variable, productivity is a function of the output value divided by the value of the input. The cost function is expressed in terms of the volume of input multiplied by a constant. The flow rate is a function of six variables labeled as W, θ, h, p, μ, and L.

Mathematically,

if P represents the productivity value of the recycling system and Q and I represent the output and input volumes of the recycled materials respectively,

then P = Q/I is the ideal expression for the productivity of the recycle plant.

Also, if we represent the cost of the recycled product with the letter C, and x is the unit cost of input, then C = Ix is the expression for the cost considered for the system.

Again, we know from the literature that the expression for the flow rate is

$$f = \frac{W \cos\theta\, h^3 p}{12\mu L}.$$

Now let us consider a mass of recycled fluid flowing through the pipe.

But $I = Q + \mu I$ where μ is viscosity constant.

By adding equations (2) and (3), we have $Q + C = I(P + x)$.

By making I the subject of the expression, the relationship becomes $I = \frac{Q+C}{P+x}$

$P = Q/I$	$C = Ix$	$f = \frac{W \cos\theta\, h^3 p}{12\mu L}$
prod.	cost	flow rate

Let us consider a mass of fluid flowing through the pipe

I is the input volume
Q is the output volume

But $I = Q + \mu I$

Where, μ is the viscosity constant

and $C = Ix$

$P = Q/I$

$C = Ix$

$Q = IP$

Equation (2) and (3): $(Q + C) = I(P + x)$

$$I = \left(\frac{Q+C}{P+x}\right)$$

From (*)

$$-\mu = \frac{Q}{I} + 1$$

$$\mu = 1 - P$$

From (5)

$$f = \frac{W\,Cos\theta\,h^3 p}{12(1-P)L}$$

$$12(1 - P)Lf = W\cos\theta h^3 p$$

$$1 - P = \frac{W\,Cos\theta\,h^3 p}{12Lf}$$

$$P = 1 - \frac{W\,Cos\theta\,h^3 p}{12Lf}$$

$$\frac{Q}{I} = 1 - \frac{W\,Cos\theta\,h^3 p}{12Lf}$$

$$\frac{Q}{I} = \frac{12Lf - W\,Cos\theta\,h^3 p}{12Lf}$$

$$I = \frac{12LfQ}{12Lf - W\,Cos\theta h^3 p} \qquad (6)$$

Equating (6) and (4),

$$\left(\frac{12LfQ}{12Lf - W\,Cos\theta h^3 p}\right) = \left(\frac{Q+C}{P+x}\right) \qquad (7)$$

$$P = \frac{Q+c}{Q} - \frac{\omega\,Cos\theta h^3 e(Q+c)}{12LFQ} - x \qquad (8)$$

$$C = \left(\frac{12LFP + 12LFQ}{12LF - \omega\,Cos\theta h^3 e}\right) - Q \qquad (9)$$

For production

$$\frac{\partial p}{\partial Q} + \frac{\partial p}{\partial f} + \frac{\partial p}{\partial C} = 0$$

and differentiating p (production down from eqn. (8) above)

$$\Rightarrow p = 1 + \frac{c}{Q} - \frac{\omega Cash^3 e}{12LF} + \frac{\omega Costh^3 ec}{12LFQ} - x$$

$$\frac{\partial p}{\partial Q} = O + \left[\frac{Q(o) - c}{Q^2}\right] - O + \left[\frac{12FQC(o) - \omega Cost\, \theta h^3 eL\,(12LF}{(12LF(2)^2}\right]$$

$$\frac{\partial p}{\partial f} = O + O - \left[\frac{O\ - \omega Cost\ \theta h^3 e\,(12L)}{(12LF}\right] + \left[\frac{O - \omega Cost\ \theta h^3 eL\,(12LQ))}{(12LFQ)^2}\right]$$

$$\frac{\partial p}{\partial c} = O + \left[\frac{Q - O}{Q^2}\right] - O + \left[\frac{12LFQ - \omega Cost\ \theta h^3 e}{(12LF(2)^2}\right] - O$$

Determination of max production

$$\frac{\partial p}{\partial Q} = O \quad \frac{\omega Cost\ \theta\ h^3 e12L}{(12CLF)} - \frac{\omega Cost\theta h^3 ec12LQ}{(12CLFQ^2)}$$

$$\frac{1}{12LF} = \frac{Q}{(12LFQ)^2} \Rightarrow \left|F = \frac{1}{12LQ}\right|$$

depends on flow chart (F)

$$\frac{\partial p}{\partial C} = \frac{1}{Q} + \left[\frac{12LFQ - \omega Cos\ \theta h^3 e}{(12LFQ)^2}\right]$$

Does not depend on cost (C)

For Cost

$$\frac{\partial c}{\partial Q} + \frac{\partial C}{\partial F} + \frac{\partial C}{\partial P} = O$$

Differentiating C (Cost down from equation (9)

$$\frac{\partial c}{\partial Q} = O - 1$$

Does not depend on Q

$$\frac{\partial c}{\partial Q} = O = (12LF\ - \omega Cos\ \theta h^3 e)(12LF + 12Lx) - (12FP - 12Lx)\ 12L$$

Make F the subject formula

$$\Rightarrow \qquad PF + (12L)^2 Fx - 12LP\ e\omega h^3\ Cos\theta - 12Lxe\omega h^3\ Cos\ \theta - (12L)^2 Fx$$

$$\Rightarrow \quad 2(12L)^2Fx - 12Le\omega h^3 \, Cos\theta - 12Le\omega h^3 \, Cos\theta \, (P + X)$$

$$\Rightarrow \quad 2(12L)^2Fx - 12Le\omega h^3 \, Cos\theta \;\; (P + X)$$

$$\frac{\partial c}{\partial p} = \left[\frac{12LF - \omega Cost\,\theta h^3 e12LF}{(12LF - \omega Cos\,\theta h^3)^2}\right] \text{ does not depend on production (P)}$$

In summary,

For production: Max output of production occurs when

$$F = \frac{1}{12LQ}$$

For Cost:- Max output of Cost occurs when

$$F = \frac{e\omega h^3 Cos\,\theta\,(p + x)}{24L}$$

4. CONCLUSION

In this work we present a mathematical model that would relate cost, productivity and flow rate in a simplified manner such that it could be easily applicable in diverse situations. Thus, we challenge the performance measurement community to probe our submission. With this, a series of studies are expected. While this work appears to be relatively new in the area much opportunities for its extension could be proposed. Firstly, the cost element in the model attracts an inflation factor when considered in different periods. Such a factor depends on the particular environments upon which the model is to be tested. For example, in countries where the rate of inflation is low the inflation factor that would be integrated into the cost model may not be too sensitive to changes. However, for developing countries where the rate of change of the inflation factor is high, a more sensitive integral part of the inflation factor should be used. By incorporating productivity into the existing framework certain variance of the present structure of the model are possible.

For example, the idea of using base period for comparative basis would add value to the existing mathematical model. The idea of incorporating the concept of profitability, which has been demonstrated severally in many productivity studies where the American productivity model has been used, will be of significance to the enhancement of the model proposed in this work. From the existing model, it could be observed that the major inputs into manufacturing (such as labour, materials, energy, equipment and money) have been omitted. The incorporation of such inputs would permit us to measure the dynamic productivity. Again, since cost is an important element of the model and is susceptible to uncertainties, the application of fuzzy logic concept would enhance the model. The IF-THEN logic statement could then create variants of problems to be solved using fuzzy logic or neurofuzzy concepts.

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