Application of Fuzzy Logic Concept to Profitability Quantification in Plastic Recycling

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ABSTRACT

This paper aims at applying a fuzzy logic control model to profitability in a case study of the plastic recycling industry in Nigeria. The studies of profitability components of the plastic recycling industry as used to develop a model framework and the application of fuzzy logic control model to the framework are given in this paper. A brief introduction to profitability concepts as well as useful suggestions and conclusions are all integral part of this paper which is based on the application of a fuzzy logic model of control to profitability concept in plastic recycling industry.

(Keywords: manufacturing, process analysis, mathematical modelling, profitability, return on investment, recycling, plastics, polymers, material reclamation)

INTRODUCTION

The profitability of recycling industries has been known to be highly dependent on the effective management of resources and management practices [1, 2, 3, 22, 28]. Taking the plastic recycling industry as a case study, the recycling of plastics or polymers has contributed in no small measure to the conservation of material and consequent low cost of production.

The ultimate resultant effect of the recycling process is high profit generated due to the low cost of production, hence, the link between profitability and recycling industry [8, 20, 21]. Since the ultimate aim of any capitalist industry is to make profit, the profitability concept is of great significance in the engineering industry [9, 11, 12, 16]. The profitability concept is thus verified using the plastic of recycling industry in Nigeria as a case study.

In the plastic recycling industry in Nigeria, recycling of materials like polyvinylchloride (PVC), polyethylene terephthalate (PET), high-density polyethylene (HDPE), etc., has proven beneficial to the nation's economy. The recycling process in the plastics industry is divided into two major parts: 1) the pre-recycling processes; (i) collection, (ii) size reduction (iii) separation or sorting and (iv) cleaning and drying; and 2) the extrusion process; which homogenises the plastic and produces a material that is easy-to-work on to produce new products.

The major equipment in the extrusion process is the extruder (e.g. single-screw extruder). This consists of a screw in a metal cylinder (or barrel). The barrel is surrounded by electrical heater bands and a fan (for melting and cooling). The screw is connected through a thrust bearing and gearing which drives a motor that rotates the screw in the barrel. A conical hopper is connected to the feed throat and a hole in the barrel near the drive end of the screw. The opposite end of the barrel is fully open and exposes the tip of the screw. A die is connected to the open end of the extruder. The extrusion process involves the feeding of solid plastic material into the extruding chamber after being heated to molten form, and finally extruded in a homogenous form through the die.

The point of interest in the application of a fuzzy logic model in the profitability concept is how the various processes involved in production affect the cost of production. Since the cost of production, as well as the selling price of products, influence the profit generated by an industry, both are used in generating a model using fuzzy logic, and in applying it to the profitability concept. The production cost is derived from the cost incurred to recycle the desired quantity of plastic materials as well as other costs of production including salaries, wages, rent, depreciation on machines and equipment, sundry expenses, and so on. The selling price is arrived at base on the cost of production and the profit generated from the relationship between the aforementioned phenomena (cost of production and selling price). Both are used as components of the fuzzy logic model in profitability concept of plastic recycling industry.

LITERATURE REVIEW

This section provides an overview of selected research on the concepts of "recycling", "design for recycling", and "life cycle costing". On life cycle research, a variety of investigations have been carried out in the area of logistics, economics of building, life cycle of manufacturing cells, and service organization [4, 5, 10, 17, 26]. Although these studies have established the relevance of life cycle analysis in any financial calculation functions such as discussed in this paper, very few articles have considered the concept of life cycle as applied to plastic recycling. A close study in this regard is credited to Larsen [15] who investigated on garbage life cycle model.

The strength of the work is that the plastic recycling mathematical functions considered here reduces to a considerable extent the amounts of raw and natural materials obtained from the earth. This justifies recycling in the plastics industry since preservation of natural resources is encouraged. The weakness of plastic recycling lies in the releases of chemical harmful to the environment. By considering Larsen's work [15], no efforts were made at implying the profitability of plastic recycling. This is a gap that the current work aims to close.

Good support for the plastic recycling model discussed here is found in Goosey and Kellner [7]. The work is concerned with new legislation to encourage the recycling of life electronics and moves to implement sustainable development in electronics manufacturing have focused attention on the large quantity of printed circuit boards (PCBs) being consigned to landfills. Also, in a recent investigation conducted on behalf of the UK's Department of Trade and Industry, the new methodologies for dealing with end of life circuit boards were identified as a priority issue. Within the UK it is estimated that ~50,000 tonnes per annum of PCB scrap is currently generated and investigations indicate that only ~15 percent is subjected to any form of recycling, with the remainder consigned to landfills. This paper reports the results of a scooping study carried out to identify the technologies and processes that can be used to recycle materials from end of life PCBs. Still, the work of Goosey and Kellney [7] has not adequately addressed the issue of plastic recycling. In particular, the profitability model proposed here was not mentioned. This justifies the need for the current work.

In a practical approach to life cycle management, Price and Coy [19] suggested that the scope of a manufacturer's environmental responsibility increasingly extends beyond the factory gate to include customer use and disposal of products. A practical case of 3M life cycle management (LCM) implementation is discussed. The process helps its more than 40 operating units meet or exceed such present and future requirements by achieving two objectives: 1) identification of environmental, health and safety (EHS) opportunities and competitive market advantages arising from superior performance in these areas; and 2) characterization and management of EHS risks as well as resources and energy use throughout a product's life cycle. The process consists of six steps leading to a life cycle matrix that organizes environmental, health and safety information at all phases, from raw material selection, development (laboratory), and manufacturing to customer use and disposal of the company's products. Although a similar LCM process is used for 3M Laboratories, the focus of this paper is on business-unit implementation.

The current authors' deduction from the work of Price and Coy [19] is that recycling is used to reduce environmental pollution. Through recycling, recycled products are modified, thus having a wide range of use than in the original product. Another strength of plastic recycling, in particular, is that it reduces the overall expenditure in production and it is highly profitable. However, the limitation found in Price and Coy [19] is that no attempt was made to introduce any financial ratio that relate to the profitability concept in plastic recycling. This gap has been identified and treated in the current work.

A plastic recycling investigation was carried out by Gobin and Manos [6]. The catalytic degradation of polyethylene over various microporous materials (i.e., zeolites, zeolite-based commercial cracking catalysts as well as clays and their pillared analogues) was studied in a semi-batch reactor. Over all catalysts the liquid products formed had a boiling point distribution in the range of motor engine fuels, which increases considerably the viability of the method as a commercial recycling process. From the zeolites, ZSM-5 resulted mostly in gaseous products and almost no coking due to its shape selectivity properties.

Commercial cracking catalysts fully degraded the polymer resulting in higher liquid yield and lower coke content than their parent ultra table Y zeolite. This confirmed the suitability of such catalysts for a polymer recycling process and its commercialization potential, as it confirmed the potential of plastic waste being co-fed into a refinery-cracking unit. Clays, saponite, and Zenith–N, a montmorillonite, and their pillared analogues were less active than zeolites, but could fully degrade the polymer. They sowed enhanced liquid formation, due to their mild acidity, and lower coke formation. Regenerated pillared clays offered practically the same performance as fresh samples, but their original clay's performance deteriorated after removal of the formed coke. Although performance of the regenerated saponite was satisfactory, with the regenerated zenith the structural damage was so extensive that plastic was only partly degraded.

A good strength of the paper is that it highlights the recycling process as important in helping research for suitable materials, as well as better and more efficient for industrial processes. This is implied for the study. However, the weakness of the recycling process in general is the high initial cost involved in setting up recycling plants. A great deal of research is needed to ascertain the best recycling modes for a particular material. Experimentally, it could be expensive. An opportunity that emerges from this reviewed paper is the need for some financial functions that measure profitability. The current work addresses this need.

Another study that relates to plastic recycling is from Lee et al. [14]. This study analyzed the recycling potential of plastic wastes generated by health care facilities for this study, the authors obtained waste streams and recycling data from five typical city hospitals and medical centers and three animal hospitals in Massachusetts. The authors analyzed the sources, disposal costs, and plastic content of medical wastes, and also determined the components, sources, types and amounts of medical plastic wastes. The authors then evaluated the recycling potential of plastic wastes produced by general city hospitals departments, such as cafeterias, operating rooms, laboratories, emergency rooms, ambulance service and facilities, and animal hospitals. Facilities, laboratories, operating rooms, and cafeterias were identified as major sources of plastic wastes generated by hospitals. It was determined that the recycling potential of plastics generated in hospital cafeterias was much greater than that in other departments, mainly due to a very slight chance of contamination or infection and simplification of purchasing plastic components.

Finally, the authors discuss methods to increase the recycling of medical plastic wastes. This study suggests that a classification at waste generation sources, depending upon infection chance and/or plastic component, could be a method for the improved recycling of plastic wastes in hospitals. The implication of the research by Lee at al. [14] is that recycling creates economic opportunities. Recycling could become a major sector in many economic in the years to come because of its importance to people and the environment. Recycling is also a major source of employment and research opportunities. Again no consideration is given to profitability measures of the plastic recycling system such as addressed in this work.

A related study on plastic recycling is due to Smith et al. [25]. The study is basically a survey of a scheme in the United Kingdom to collect plastic bottles for recycling. The authors stated that the Environment Act imposes a legal requirement for plastic packaging to be recycled. Recycling of post consumer polyethylene terephthalate (PET), polyvinylchloride (PVC), and high-density polyethylene (HDPE) bottles was expected to make a significant contribution to the Environment Act's national target of 15% recycling of plastic of plastic packaging waste by 2001. This paper summarizes the finding of a national survey of local authority post-consumer plastic bottle recycling schemes conducted at the end of 1997, establishing an overview of UK activity. Areas investigated included – the type, distribution and efficacy of schemes. Survey results are considered in the light of experience in the UK and abroad.

While plastic bottle recycling has grown rapidly since 1990, projections based on current recycling rates and local authority plans suggest that further assistance was required for the 2001 target to be met. Quite clearly, survey projects do not shed light into modelling, but the gap in the plastic recycling industry relating to the development of profitability financial functions was identified by the authors. This is an important omission that the current work attempts to address.

The environmental effect of reusing and recycling a plastic-based packaging system was studied by Ross and Evans [24]. The study presents the findings of a lice cycle assessment (LCA) that examined whether a re-use and recycle strategy for a plastic-based packaging that substantially reduces the quantity of waste to landfill would also reduce the overall environmental burden.

The resources and environmental effects assessed over the life of each of the packaging included fossil fuel consumption, greenhouse gas emissions, and photochemical oxidant precursors. The results demonstrate that recycle and reuse strategies for plastic-based products can yield significant environmental benefits. The study also includes some interesting findings regarding the relative contributions of transportation and construction energy, and the potential benefits of adjusting the impact assessment results to take into account the spatial variation in the significance of some environmental effects. The strength of this work lies in the analysis of recycling costs with the use of the life cycle cost concept; a highly valued approach in recycling problem solving. Unfortunately no efforts were made to discuss the relationship that life cycle has with profitability. This is an aspect with great potential for development. The issue of profitability is therefore justified in the current work.

In a study on recycling, Treloar et al. [27] analyzed the factors influencing waste minimization and the use of recycled materials for the construction of residential buildings. They commented that residential building construction activities (new builds), negatively impact the environment in the form depleting natural resources, increasing waste production, and causing pollution. Previous research had identified the benefits of preventing or reducing material waste, mainly in terms of the limited available space for waste disposal, and escalating costs associated with landfills, waste management, and disposal and their impact on a building company's profitability. There had, however, been little development internationally on innovative waste management strategies aimed at reducing the resource requirement of the construction process.

The authors contended that embodied energy is a useful indicator of resource value. Using data provided by a regional high-volume residential builder in the State of Victoria, Australia, the paper identified the various types of waste that were generated from the construction of a typical standard house. It was found that in the particular case, wasted amounts of materials were less than those found previously by others for cases in capital cities (5-10 percent), suggesting that waste minimization strategies were successfully being implemented. Cost and embodied energy savings from using materials with recycled content were potentially more beneficial in terms of embodied energy and resource depletion than waste minimization strategies.

In yet another study, the recycling of construction and demolition wastes in the UK was investigated by Lawson and colleagues [13]. In England and Wales, the construction industry produced 53.5Mt of construction and demolition waste (C&D waste) annually, of which 51 percent went to landfills, 40 percent was used for land reclamation, and only 9 percent was crushed for future use or directly recovered. C&D waste may be contaminated, either through spillage from industrial processes or contact with contaminated land. There were no guidelines on how to classify C&D waste as contaminated or on risk management for contaminated C&D waste. Research at the UK Building Research Establishment and the University of Manchester had shown that new taxes were making disposal of C&D waste to landfills uneconomic, that low grade "land-modelling" recycling is increasing, and that disposal on-site is preferred. Sampling spatially of structures before demolition and temporally of processed C&D waste emerging from crushers was enabling sources of contamination and excedance of guideline values to be compared with natural background levels. Improved sampling procedures and recommendations for risk assessment for the re-use of C&D waste were being prepared.

An additional investigation on recycling was carried out on the development of integrated designs for disassembly and recycling in concurrent engineering by Chen [1]. 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 hazardous 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 only 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.

Furthermore, Pohlen and associates [18] investigated 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.

Romualdo et al. [23] carried out a study on recycling of granite industry waste from the Northeast region of Brazil. They discovered that solid wastes are today 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 their work is to analyze the possibility of using sawing granite wastes as alternative ceramic raw materials for the production of bricks and roof tiles. Samples were collected from wastes of several granites companies form the Northeast region of Brazil. They were 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 have particle size distribution and mineralogical composition similar to conventional non-plastic ceramic raw materials. They discovered that the wastes could be used in substitution of conventional raw materials in ceramic formulations in proportions up to 50 percent. This can be important to save traditional raw materials from the region.

MODEL FRAMEWORK

This framework is based on the major components in the profitability concept using a case in the plastic recycling industry. These components, which are: 1) Selling Price (SP); 2) Cost Price (CP); 3) Quantity Recycled (QR); and 4) Profit (X)

The schematic diagram that follows shows the relationship of these components as used in the profitability concept.

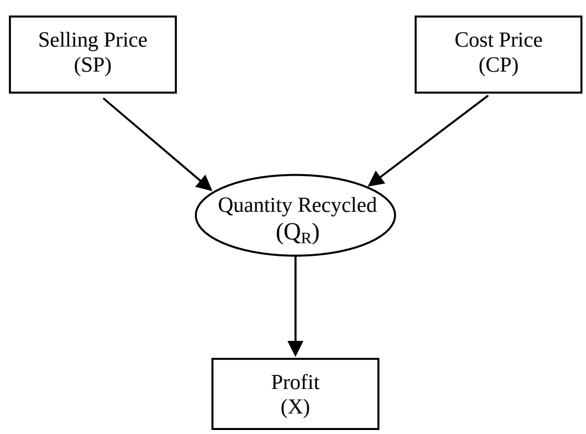


Figure 1: Schematic Diagram Showing the Major Components in Profitability Concept.

CASE STUDY

Definition of terms

1. *Selling Price (SP)*: This is the selling price per item of the quantity recycled.

2. *Cost Price (CP)*: This is the cost price per item of the quantity recycled. This includes all expenses incurred directly during the recycling processes.

3. *Quantity Recycled (Q_R)*: The quantity recycled is determined by the control model based on the configuration of the components of the recycling equipment as follows:

D = Screw diameter
H = Channel depth in the metering zone
B = Flow width
W = Channel width parallel to the screw axis
θ = Helix angle of the screw
N = Screw speed in revolutions per second (rps)
V = Linear velocity

Thus,

$$(Q_R) = \frac{\text{Volume flow rate}\left(\text{Q in m}^3/\text{s}\right)\text{x Period}\left(\text{T in sec}\right)}{\text{Volume}\left(\text{V in m}^3/\text{item}\right)}$$

$$= \left[\frac{\pi DhWNCos^2\theta}{2} - \frac{h^3WPCos\theta}{12L\mu a}\right]\frac{T}{V}\text{item}$$

where,

T = period between the beginning of recycling and the expected completion in time.

V = volume that makes each item of the recycled product.

4. Profit (X): The profit made is the difference in Selling Price (SP) and Cost Price (CP) multiplied by the quantity recycled (QR). This is given by:

$$\text{Profit, X} = \left[(SP - CP)\frac{\pi DhWNCos^2\theta}{2} - \frac{h^3WPCos\theta}{12L\mu a}\right]\frac{T}{V}$$

Error terms

$(S_P)\ (Q_R) - (C_P)\ (Q_R)$ = O, "Zero Error" (Z)
(No profit no loss)
$(S_P)\ (Q_R) - (C_P)\ (Q_R)$ = -, "Negative Error" (N)
(Loss)
$(S_P)\ (Q_R) - (C_P)\ (Q_R)$ = +, "Positive Error" (P)
(Profit)

Error – dot terms

d{$(S_P)(Q_R)$-$(C_P)(Q_R)$}/dt = 0, "Zero error-dot" ($\dot{Z}$)
(No profit no loss over time)
d{$(S_P)(Q_R)$-$(C_P)(Q_R)$}/dt = -, "Negative error-dot" ($\dot{N}$)
(Loss over time)
d{$(S_P)(Q_R)$-$(C_P)(Q_R)$}/dt = +, "Positive error-dot"($\dot{P}$)
(Profit over time)

To make the fuzzy model in this profitability concept more effective, the characteristic fuzziness of the model is utilized, which is highly advantageous in effective control of any system. Thus, more "error" and "error-dot" terms are generated as follows:

More error terms

$(S_P)(Q_R)$-$(C_P)(Q_R)$ = >>> (-), "High negative error" (HN) (Great Loss)
$(S_P)(Q_R)$-$(C_P)(Q_R)$ = >>> (+), "High positive error" (HP) (High Profit)
$(S_P)(Q_R)$-$(C_P)(Q_R)$ = >>>>>> (-), "Very high negative error" (VHN) (Very great Loss)
$(S_P)(Q_R)$-$(C_P)(Q_R)$ = >>>>>> (+), "Very high positive error" (VHP) (Very high profit)
$(S_P)(Q_R)$-$(C_P)(Q_R)$ = <<< (-), "Low positive error" (LN) (Small Loss)
$(S_P)(Q_R)$-$(C_P)(Q_R)$ = <<< (+), "Low positive error" (LP) (Low Profit)

More error-dot terms

d{$(S_P)(Q_R)$-$(C_P)(Q_R)$}/dt = >>> (-), "High negative error-dot" $\left(\dot{HN}\right)$ (Great loss over time)

d{$(S_P)(Q_R)$-$(C_P)(Q_R)$}/dt = >>> (+), "High positive error-dot" $\left(\dot{HP}\right)$ (High profit over time)

$d\{(S_P)(Q_R)-(C_P)(Q_R)\}/dt$ = >>>>>> (-), "Very high negative error-dot" $(\dot{VHN})$ (Very great loss over time)
$d\{(S_P)(Q_R)-(C_P)(Q_R)\}/dt$ = >>>>>> (+), "Very high positive error-dot" $(\dot{VHP})$ (Very high profit over time)
$d\{(S_P)(Q_R)-(C_P)(Q_R)\}/dt$ = <<< (-), "Low negative error-dot" $(\dot{LN})$ (Small loss over time)
$d\{(S_P)(Q_R)-(C_P)(Q_R)\}/dt$ = <<< (+), "Low positive error-dot" $(\dot{LP})$ (Low profit over time)

Note: >>> implies large quantity, <<< implies low quantity, >>>>>> implies very large quantity and <<<<<< implies very low quantity.

Rule – Matrix

1 ϕX	2 L	3 X
4 HL	5 HX	6 VHL
7 VHX	8 LL	9 LX

Rule structure

- IF $(S_P)(Q_R)-(C_P)(Q_R) = Z$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = \dot{Z}$

THEN Output = ϕX

- IF $(S_P)(Q_R)-(C_P)(Q_R) = N$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = \dot{N}$

THEN Output = L

- IF $(S_P)(Q_R)-(C_P)(Q_R) = P$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = \dot{P}$

THEN Output = X

- IF $(S_P)(Q_R)-(C_P)(Q_R) = HN$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = (\dot{HN})$

THEN Output = HL

- IF $(S_P)(Q_R)-(C_P)(Q_R) = HP$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = (\dot{HP})$

THEN Output = HX

- IF $(S_P)(Q_R)-(C_P)(Q_R) = VHN$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = (\dot{VHN})$

THEN Output = VHL

- IF $(S_P)(Q_R)-(C_P)(Q_R) = VHP$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = (\dot{VHP})$

THEN Output = VHX

- IF $(S_P)(Q_R)-(C_P)(Q_R) = LN$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = (\dot{LN})$

THEN Output = LL

- IF $(S_P)(Q_R)-(C_P)(Q_R) = LP$

AND $d[(S_P)(Q_R)-(C_P)(Q_R)]/dt = (\dot{LP})$

THEN Output = LX

System operating rules

INPUT #1:
("Error", Positive (P), Zero (Z), Negative (N), High Negative (HN), High Positive (HP), Very

High Negative (VHN), Very High Positive (VHP), Low Negative (LN) and Low Positive (LP))

INPUT #2:

("Error – dot", Positive ($\dot{P}$), Zero ($\dot{Z}$), Negative ($\dot{N}$), High Negative $\left(H\dot{N}\right)$, Very High Negative $\left(VH\dot{N}\right)$, Very High Positive $\left(VH\dot{P}\right)$, Low Negative $\left(L\dot{N}\right)$, High Positive $\left(H\dot{P}\right)$ and Low Positive $\left(L\dot{P}\right)$).

CONCLUSION:

("Output", No profit no Loss (ϕX), Loss (L), Profit (X), High Loss (HL), High Profit (HX), Very High Loss (VHL), Very High Profit (VHX), Low Loss (LL) and Low Profit (LX))

INPUT #1: System Status
Error: $(S_P)(Q_R) – (C_P)(Q_R)$
P = Profit, Z = No profit no loss, N = Loss

INPUT #2: System Status
Error – dot: d(Error)/dt
P = Profit over time, $\dot{Z}$ = No profit no loss over time, $\dot{N}$ = Loss over time.

OUTPUT Conclusion and System Response
Output H = High, L = Low, VH = Very High

APPLICATION OF PROJECT MANAGEMENT PRINCIPLES

The approach to achieving the objective of this research is the use of a fuzzy logic control model. The fuzzy logic model is used to evaluate the relationship with the parameters necessary in the profitability concept, which are: selling price, the quantity of solid waste recycled, and cost of recycling the solid waste.

The fuzzy logic command used in this regard is "IF, AND, THEN". IF is the relationship between selling and cost price of recycled product; AND is the relationship over time; and THEN is the output.

In the course of applying this command to the profitability in solid waste recycling, the various components of fuzzy logic model are used, and they are as follows:

i. LINGUISTIC VARIABLE:
$(SP)_{QR} – (CP)_{QR}$

ii. ERROR TERMS:
$\{(SP)_{QR} – (CP)_{QR}\}$ = Positive = Optimistic = O_p
$\{(SP)_{QR} – (CP)_{QR}\}$ = Negative = Pessimistic = P_e
$\{(SP)_{QR} – (CP)_{QR}\}$ = Zero = Most Likely = M_L

iii. ERROR-DOT TERMS:
$d\{(SP)_{QR} – (CP)_{QR}\}/dt = \dot{P}$ = Optimistic = O_p
$d\{(SP)_{QR} – (CP)_{QR}\}/dt = \dot{N} = P_e$
$d\{(SP)_{QR} – (CP)_{QR}\}/dt = \dot{Z} = M_L$

From these components of fuzzy logic model, a rule matrix, rule structure and system operating rules are generated for effective control of the profitability and solid waste recycling system.

Rule Matrix

(Error)

(Error-dot)	P	N	Z
	1 O_p	2 P_e	3 M_L

Rule Structure

i. IF $\{(SP)_{QR} – (CP)_{QR}\}$ = P, AND $d\{(SP)_{QR} – (CP)_{QR}\}/dt = \dot{P}$, THEN output = O_p

ii. IF $\{(SP)_{QR} – (CP)_{QR}\}$ = N, AND $d\{(SP)_{QR} – (CP)_{QR}\}/dt = \dot{N}$, THEN output = P_e

iii. IF $\{(SP)_{QR} – (CP)_{QR}\}$ = Z, AND $d\{(SP)_{QR} – (CP)_{QR}\}/dt = \dot{Z}$, THEN output = M_L

System Operating Rules

INPUT # 1:
("Error," Positive (P), Negative (N), Zero (Z))

INPUT # 2:
(Error-dot," Positive ($\dot{P}$), Negative ($\dot{N}$), Zero ($\dot{Z}$))

CONCLUSION:
("Output", Optimistic (O_p), Pessimistic (P_e), Most Likely (M_L))

INPUT #1:
System Status
Error $= \{SP)_{QR} - (CP)_{QR}\}$
P = Optimistic, N = Pessimistic, Z = Most Likely

Error-dot $= d\{SP)_{QR} - (CP)_{QR}\}/dt$
$\dot{P}$ = Getting Optimistic, $\dot{N}$ = Getting Pessimistic, $\dot{Z}$ = Getting Most Likely

OUTPUT
Conclusion & System Response
Output O_p = Optimistic, P_e = Pessimistic, M_L = Most Likely

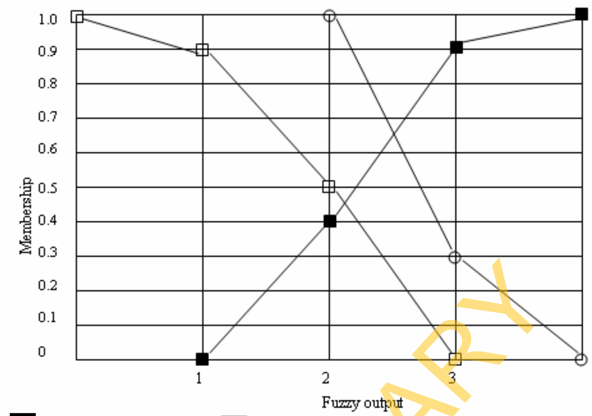
OTHER EXTENSIONS

Representing the components of the fuzzy logic control model of the profitability concept in solid waste recycling with membership functions, we obtain Table 1:

Table 1: Components of Fuzzy Logic Model

Level No.	Interpretation	Fuzzy Output	Linguistic Variables
1	Pessimistic	Negative	$\{(SP)_{QR} - (CP)_{QR}\}$
2	Most Likely	Zero	$\{(SP)_{QR} - (CP)_{QR}\}$
3	Optimistic	Positive	$\{(SP)_{QR} - (CP)_{QR}\}$

where the degree of relationship between fuzzy output and membership function ranges from 0 – 1.0. Illustrating the above table graphically, we have the following (Figure 2):



■ denotes positive □ denotes negative ○ denotes zero

Figure 2: Graph of Fuzzy Logic Control Model

The interpretation of the graph shows that:

i. When the selling price of quantity of solid waste recycled is more than cost price of quantity recycled the model prompts positive (optimistic output) 3 (■ = 0.9).

ii. When the cost price of quantity of recycled is more than selling price of quantity recycled the model prompts negative (pessimistic output) 3 (□ = 0.9).

iii. When the selling and cost prices of the quantity of solid waste recycled are equal the model prompts zero (Most Likely output) 2(○ = 1.0).

Representing the fuzzy logic control model relationship by the use of direct graph we have:

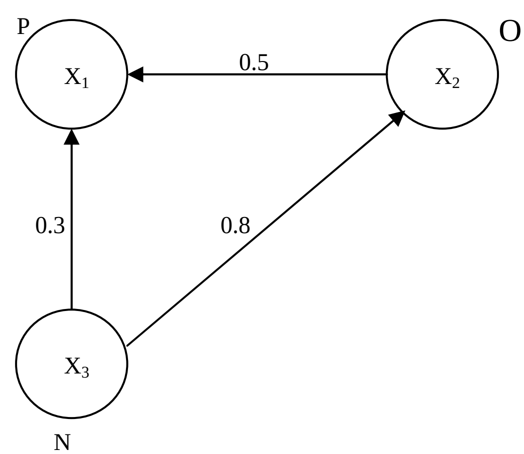


Figure 2: Showing the Strength of Relationships within the Fuzzy Logic Outputs; Positive, Zero and Negative.

Note:

X_1 = Positive
X_2 = Zero
X_3 = Negative
0.8 = Strong relationship
0.5 = Weak relationship
0.3 = Weaker relationship

This implies that when the selling price of the quantity of solid waste recycled is higher than the cost price, it is difficult to run at loss where the cost price is higher (Negative) as indicated by:

$$\begin{array}{ccc} X_1 & \xrightarrow{0.3} & X_3 \\ P & & N \end{array}$$

= Weaker relationship

When the selling price of the quantity of solid waste recycled is equal to the cost price, it is very easy for the selling price to go lower than the cost price of the quantity of solid waste recycled, thus,

$$\begin{array}{ccc} X_2 & \xrightarrow{0.8} & X_3 \\ O & & N \end{array}$$

= Stronger relationship

Whereas it is not that easy for the selling price which is equal to the cost price to go higher than the cost price, as indicated by:

$$\begin{array}{ccc} X_1 & \xrightarrow{0.5} & X_2 \\ P & & O \end{array}$$

= Weak relationship

For a more simplified graphical illustration, the following table of membership functions and cost levels is given:

Table 2: Relationships between Cost Level and Membership Function

Membership	Cost level	Cost %
0 – 2	Low cost	0 – 40
2.5 – 4.5	High cost	41 – 60
5 – 8.5	Very high cost	61 – 80
9 – 1.0	Maximum cost	81 – 100

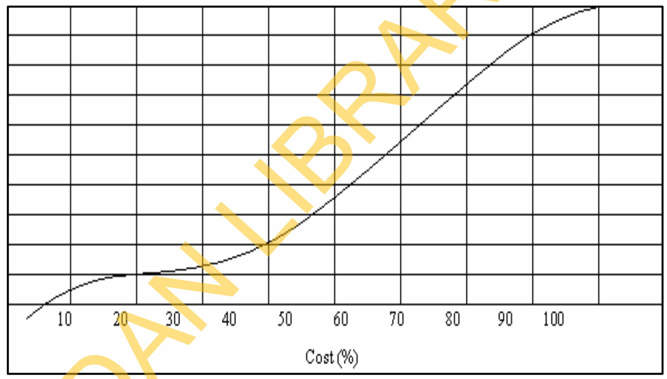


Figure 3: Graphical Illustration of Relationship between Cost Level and Membership Function

To define the fuzzy logic model more clearly a term is used to represent the procedure followed. This term is known as "defuzzification".

DEFUZZIFICATION

Defuzzification is the term used for the procedure followed in an attempt to convert the fuzzy set having overall conclusions to a single conclusion or value. There are various methods used in defuzzification, the common one being the center of gravity of the overall fuzzy set conclusions. If a fuzzy set is represented by Z, defined over the interval (a, b), the center-of-gravity defuzzification c is given by:

$$c = \frac{\int_a^b xz(x)dx}{\int_a^b z(x)dx}$$

Based on this idea of defuzzification, an extension of fuzzy logic model is thought of in looking into how more specific output can be achieved.

This leads to further research into neuro-fuzzy model which intends to combine both fuzzy logic and neural networks.

RECOMMENDATIONS

Effective control of profitability should be given high consideration in future research work, so as to help in maximizing profit, the basic reason for which any industries are set up.

It is recommended that software be developed in subsequent research work based on the fuzzy logic model with consideration to a standard that will always ensure profit maximization despite varying costs of production upon which the selling price, and ultimately profit, in an industry depend. The fuzzy logic model is of great significance in this regard, since the desired outcome of an operation can be controlled and ensured due to the fuzziness of fuzzy logic which accommodates wide variation in input parameter(s) like production cost.

The fuzzy logic model reveals clearly that loss is incurred in various magnitudes, only when the cost of production is high, compared to the selling price. In the case of the plastic recycling industry, the cost of production depends on recycling process and other processes involved in production, hence in engineering terms, it is recommended that the configuration of the recycling equipment (extruder) which determines the quantity of materials recycled should be designed so as to reduce the cost of recycling to the barest minimum.

CONCLUSION

Since the survival of any industrial process is dependent on the profitability concept, and it is clear that the fuzzy logic model is highly effectively in controlling profitability to desired standard, more research work is encouraged in the area of application of fuzzy logic to profitability concept in industries.

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