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Facilitating Waste Paper Recycling and Remanufacturing via a Cost Modelling Approach

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Abstract. For a paper manufacturer to remain competitive, they must be able to manufacture at a low production cost. One such approach to reduce manufacturing cost could be the adoption of recycling and remanufacturing of waste paper. This article reviews the extent of how waste paper can be reused through recycling and remanufacturing. In addition, a cost modelling approach in recycling and remanufacturing has been developed to predict cost fluctuations under different manufacturing constraints, so that paper manufacturers can utilize this approach to predict potential costs when reusing waste paper as their source of raw material and therefore minimizes generation of waste.

1. Introduction

The paper industry is a major contributor to the global economy and yet, studies show that the paper industry offers little profit margins and requires large initial investments [1]. In the current economic climate, competition in meeting customers' demands is one of the driving factors affect profit margins [2]. When a company produces a product, various factors such as upfront costs of machinery, labour, raw material and transport will contribute to decision makings in price-setting. Hence price setting is the most common problem faced by all industries. Furthermore, the paper industry is also under constant pressure to reduce harmful emissions to the air and water. Therefore, the paper industry is not only concerned of cost prediction but also production efficiency and environmental impact due to the raw material and processes used in manufacturing.

Paper is manufactured using cellulose fibres as raw material which can be obtained from wastepaper, virgin wood or non-wood material. These fibres are then passed through mechanical or chemical processing to form pulp which is then machined to form paper. Paper is also termed as a recyclable product since it can be remanufactured at the end of its first life. Cost models can be used to reduce the end-of-life (EOL) cost. EOL cost is a process of estimating the cost of recycling/disposing a product. Thus, cost modelling is an important approach in production, as they play a crucial role in price tagging. If applied effectively, it can be used to reduce production cost, improving production processes and the quality of end products [3].

The aim of this paper is therefore to develop a cost modelling approach by taking considerations of all operational parameters. This approach could potentially

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increase the production rate of paper manufacturing using waste paper as their source of raw material and minimizes waste generation. The layout of this paper is as follows: Section 2 describes the relevant literature. Section 3 discusses the approach and its implementation. Section 4 describes a case study and data analysis and, finally, the conclusion and future work is presented.

2. Literature review

Various types of papers are manufactured depending on their physical properties, for example:

- Strength and resistance to breakdown when acted upon by various forces such as tearing apart, puncturing and pulling [4].
- Retention of physical strength and chemical properties when exposed to various agents that are encountered when the paper is stored [4].
- Ability to maintain standard print quality by preventing ink from fading away.

The variety of paper in the market ranges from soft paper for writing and printing to hard paper for storing and packaging. Paperboard is manufactured mostly from waste paper. It has high strength and offers resistance to breakdown thus is highly valued in the packaging sector. Paperboard cartons are the mainstream of resources in the packaging business [5]. In Europe alone, demands of paperboard for the packaging industry were around 46 million ton per year since 2007 [6].

Remanufacturing paperboard is both economically and environmentally sustainable as large quantities of paper can be manufactured using lesser amount of energy and raw material. The main source of raw material for remanufacturing paperboard is fibres which are usually obtained from waste paper. Manufacturing paperboard follows the same process as manufacturing of soft paper. The industrial practice in which recycled product is refurbished to its original form is termed as a remanufacturing [7, 8]. Firstly, waste products are disassembled to its individual components and materials through a sequence of manufacturing procedures. The functioning components and materials thus obtained are washed and repaired before reuse in the production line. Finally, by assembling the refurbished components and materials and replacing the non-functioning parts with similar new ones; a new product is made [8].

From economics perspectives, studies have shown that remanufacturing can yield higher profit for new product development [7, 9]. From environmental perspectives, remanufacturing helps in reducing environmental impact as it avoids post consumption waste and needs lesser natural resources thereby extending a product's life. In general, remanufacturing will have an impact on sustainability, namely: economic, environmental and societal [10].Thus it can be concluded that remanufactured products are beneficial not only economically but also environmentally. There may be polluting emissions during the process of remanufacturing, repairing and refurbishment, such as heat and surface treatments [11]. However, by reusing waste material, this will reduce the level of harmful emissions compare with virgin materials extraction which could also improve a product's sustainability.

Cost modelling is an approach used for forecasting/estimating the futuristic cost of a manufactured good or service based on the facts and figures accessible at the given time [12], [13]. Cost estimation is also considered as an important tool for the management during the initial stages of planning for producing goods as it helps in setting a budget for allocating resources. It also assists the industry by predicting cost of alternative designs and the financial impact of the project being undertaken [14]. In business, cost estimation plays a crucial role for any company as even a small error in estimating the cost may lead to the loss of contract thus affecting the sales and profit of a company. Therefore, cost estimation is an important task in a product's lifecycle. However, EOL products cost estimation has been given little attention in the research community [15]. If a system was developed to predict the cost of its EOL value, it may lead to a more sustainable product for the environment and also greater profit margins.

3. A proposed approach of evaluating waste paper recycling and remanufacturing costs

Cost is incurred at various stages of production from collecting raw material to packing of the final output and disposal of waste generated in manufacturing the product. The initial cost can be categorized into (1) raw material cost; (2) energy cost; (3) cleaning and waste removal cost; and (4) labour charges. The method of cost evaluation begins with raw material as illustrated in Figure 1. The main forms of raw material used for manufacturing paperboard are as follows:

- Cellulose fibres are generally obtained from wood, waste paper and agricultural residue;
- Large quantity of water is used in the pulp making stage;
- Chemicals such as dyes, fluorescent whitening agents, alum and sizing agents are used during various manufacturing stages for improving the quality of the finished product and making the product more durable.

Energy plays an important role in the industry. Energy in the form of heat and electricity is used in manufacturing paperboard. The raw material passes through many processes before the finished product is obtained.

Recycling and remanufacturing paper and paperboard from wastepaper depends on numerous factors. It is important to consider and understand each of these factors and to recognize their influences on the production processes. The functional equations shown below form the fundamental standard of the factors that influencing the recycling and remanufacturing procedures [16]:

- *Wastepaper Demand*

The quantity of wastepaper required (QWPR) is reliant on real output price (OP), present value of wastepaper (PvWP) and the total quantity of paperboard produced (Z).
QWPR= f {OP, PvWP, Z}

- *Labour Requirement*

The number of employees required (LR) is determined by the real output price (OP), total quantity of paperboard produced (Z), labour rate (L) and amount of working required (W).
LR= f {OP, Z, L, W}

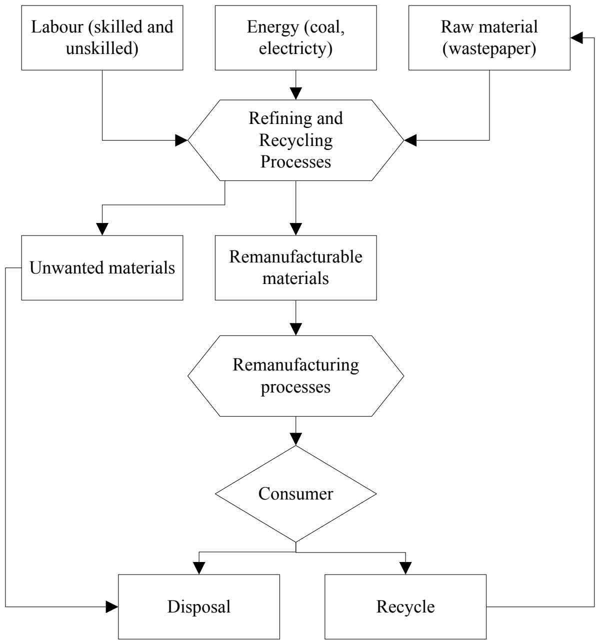

Figure 1. Approach of evaluating waste paper recycling and remanufacturing costs

- *Machine Operation*

The total amount spent on the working of the machineries (MO) is calculated by considering the total quantity of paperboard produced (Z), present value of energy (PvE), present value of the machine (PvM), quantity of wastepaper supplied (QWPR), efficiency of the machine (η) and the number of labour required (LR).
MO= f {Z, PvE, PvM, QWPR, η, LR)

- *Capital Investment Required*

The total amount of initial investment required (CIR) to start the remanufacturing and recycling process is calculated by considering the real output price (OP), total quantity of paperboard produced (Z) present value of the capital (PvC), number of labour required (LR), quantity of wastepaper required (QWPR), cost of machine operation (MO), present value of wastepaper (PvWP) and the present value of energy (PvE).
CIR= f {OP, PvC, Z, LR, QWPR, MO, PvWP, PvE}

- *Total Production*

The total quantity of paperboard produced (Z) depends on the labour requirement (LR), capital investment required (CIR), quantity of wastepaper required (QWPR) and the machine operation (MO).

Z= f {LR, CIR, QWPR, MO}

- *Total Output*

The total output (TO) of the company is determined by the present value of wastepaper (PvWP), total quantity of paperboard produced (Z), section of the wastepaper not recyclable (CWPNR), present value of energy (PvE), present minimum wage rate (PmW) and by (WF).

$$WF = \frac{(\text{Amount of wastepaper supplied})}{(\text{Amount of wastepaper required})}$$

TO= f {PvWP, Z, CWPNR, PvE, PmW, WF)

3.1 Life Cycle Cost (LCC)

The life cycle cost analysis specifies a structural model for indicating the projected overall incremental expenditure of designing, manufacturing, consuming and disposing a particular product. The life cycle cost can be calculated as follow [17]:

LCC= (Ci + OM present value + P present value + RR present value - Dis - D)

Ci = The initial "capital investment" required to carry on with the proposed project plan. Expenditure incurred by any company at the beginning of the project refers to its capital cost. This includes machinery cost, land rent, design, fixation and construction cost. Capital costs are fixed cost and are independent of the quantity of output.

- OM = Operating and maintenance cost is the cost incurred by the company while running the manufacturing and packaging process. Wage of the operators, insurance, inspection cost, expenditure for purchasing materials used for maintenance such as lubricants and coolants are types of operating and maintenance costs.
- P = Power cost involves the summation of money spent on various sources of energy required for the project. Electricity, coal and natural gas are the most common forms of energy used. Their usage varies with the level of output; hence it's a type of variable cost.
- RR = Repair and Replacement cost is the cost incurred by the company to repair the machine which breakdown during their usage and replacing parts at the end of the life span.
- Dis = Disposal cost is the cost incurred to dispose the waste and the products produced with defects.
- D = Depreciation cost a company suffers. The cost of machineries depreciates every year from the time it is in use.

3.2 Recycling Cost

Recycling cost is the cost incurred to recover the remanufacturable material from the waste. It involves the cost of refining the waste collected and removing the unwanted materials. Therefore, the cost incurred to recycle can be calculated using the equation given below [19]:

RC = ((QW * PVm – OC) – ((T * LC * f) + EC)

RC (£) = Recycling Cost.
OC (£) = Opportunity cost.
LC (£/hr) = Labour cost.
EC = Energy cost
f = Refining and deinking factor.
QW (Kg) = Quantity of wastepaper used in kilograms.
PV (£/kg) = Present value of per kilogram of wastepaper.
T (hrs) = Time required for refining and deinking the wastepaper.

Where, f can be calculated by:

$$\frac{\text{(Effective Residual Ink Concentration (ERIC) value of the wastepaper completely refined and deinked)}}{\text{(ERIC value of the wastepaper before ink removal and unwanted particles – ERIC value of the waste after deinking)}}$$

3.3 Remanufacturing Cost

Remanufacturing paper and paperboard from wastepaper includes the cost of refining, deinking as well as the cost associated with remoulding of the pulp, the probability of failure and the cost of improving the quality of the end product. Remanufacturing cost while pulp forming and moulding can be calculated on the basis of the equation given below [18]:

RmC = ((TimeD – TimeA) x n x LR) + (PF x CF) + EC + UC)

Remanufacturing cost per ton of paper used can be calculated on the basis of the equation given below:

RmC = ((TOT x PQ x LR x n) + (Er x EC) + UC + (I x IC) + (PF x CF))

RmC (£) = Remanufacturing cost
n = number of labourers
LR (£/hr) = Labour rate
IC (£) = Cost of input
I (kg) = total Input
Er (unit) = Energy required
CF (£) = Cost due to failure
TOT (hrs) = total operation time
EC (£) = Energy cost
TimeD (hrs) = time required for refining and deinking
TimeA (hrs) = Time required for molding the pulp
PF = probability of failure in the refining, deinking and molding process
UC (£) = Uncertainty cost
PQ (kg/hr) = production quantity per hour

3.4 Machine repair Cost

The plant operates 24 hours, 7 days a week. Continuous working of the machineries for remanufacturing paperboard leads to machine parts wear out. The production is halted if a certain machine breaks down and requires immediate repairing for resuming the production. Repairing any component requires expenditure. The repairing cost can be calculated using the equation given below [19]:

RepC = CF + (fa x LR x Trt)

Where,

$$fa = \frac{\text{(Number of assemblies to dissemble)}}{\text{(Total number of assemblies)}}$$

RepC (£) = Repairing cost
fa = Repairing factor
Trt (hrs) = Total repairing time
CF (£) = Cost due to failure
LR (£/hr) = Labour rate

3.5 Service Cost

Service cost involves the cost incurred to pay the man force employed to carry out the maintenance of the machineries used in the production process. The service cost can be calculated from the equation given below [17]:

LSC = ((Lt + Ltp) x LR + (Pc + Pcp))

LSC (£) = Labour service cost	Lt (hrs) = labour time
Ltp (hrs) = Labour time penalty	LR (£/hr) = Labour rate
Pc (£)= Material cost	Pcp (£) = Material cost penalty

4. Case study

The cost equations as explained in Section 3 are used to determine the cost of recycling and remanufacturing the paperboard under different manufacturing constraints as shown in Table 1. The data were obtained from S.P. Paper and Paperboard Mill Ltd in India and the company is certified by ISO 14001 for environmental management and by ISO 9008 for quality management. Output data generated from the cost models can only give an indication of the associated costs by applying different manufacturing constraints.

The pedestal bearing was being considered as a part of the case study to estimate its repair cost as it often breaks down which causes disruption to the production process. The amount of waste paper used for the estimation was one ton. As a result, the final costs under different scenarios are shown in Table 2. It can be seen that due to break down of the press roller, the production cost has been increased and the production rate was reduced as the manufacturing process was interrupted until the machine has been repaired. In addition to this the company bore extra cost in order to repair the bearing.

	No manufacturing constraints	With machine breakdown	Low labour attendance	Shortage in raw material supply	More work force than required
Cf	0	30	0	0	0
fa	0	43	0	0	0
Trt	0	4	0	0	0
QW	60000	60000	60000	50000	60000
PV	0.08	0.08	0.08	0.08	0.08
T	18	18	18	18	18
n	21	21	21	21	21
LC	7	7	7	7	7
f	0.87	0.87	0.87	0.87	0.87
EC	6.75	6.75	6.75	6.75	6.75
TimeA	0.33	0.33	0.33	0.33	0.33
TimeD	0.5	0.5	0.5	0.5	0.5
Cf	530	530	530	530	530
PF	1.20E-03	1.20E-03	1.20E-03	1.20E-03	1.20E-03
TOT	24	24	24	24	24
PQ	2.1	2.1	2.1	2.1	2.1
CC	0.08	0.08	0.08	0.08	0.08
CE	0.1	0.1	0.1	0.1	0.1
NT	60	60	60	60	60
I	60000	60000	60000	60000	60000
TO	50	50	40	43	50
IC	0.8	0.8	0.8	0.8	0.8
n	26	27	24	26	30
cC	10	10	10	10	10
Lt	8	8	8	8	8
Ltp	0.5	0.5	0.5	0.5	0.5
Pc	20	20	20	20	20
Pcp	2.5	2.5	2.5	2.5	2.5

Table 1. Data obtained from S.P. Paper and Paperboard Mill Ltd

The labourers considered as ‘grade B’ labourers as they worked inside the plant. The total number of ‘grade B’ labourers working in the plant was 26. While evaluating this cost of remanufacturing and recycling, it was assumed that 3 employees were absent. It is seen the cost increased and the company bore a loss as the production rate reduced from 2.1 tons per hour to 1.7 tons per hour. This was mainly because of the absence of the employee designated to a certain machine which reduced the efficiency of the plant.

Further testing scenario was that the quantity of raw material input decreased from 60 tons to 50 tons. As seen from Figure 2, the cost increased as the capital cost remains constant and the output decreased due to lack of availability of raw material that the plant was able to process in a given day. Very often the management misinterprets that more employees increases the yield rate. As a result, one of the testing constraints was to consider 4 additional labours (3 extra machine operators and an extra technician as standby). Cost is thus being evaluated with 4 excess labourers. It’s seen that the cost increases significantly as the labour spends extra unnecessarily time for the same level of output.

Considering the practical application of the cost models, it is seen that in the real world the factors of production varies day to day thus requiring continuous changes in the input parameters. The developed approach has proven to be highly advantageous as it reduces the effort of data input and saves time. Every company aims to reduce waste generation. Steps are being taken and technologies are being developed to reintroduce waste back into the manufacturing cycle thereby reusing parts or materials. The cost of production can be reduced only if the company improves the efficiency of the plant. In other words if it is able to increase the yield and keeping the total cost of production unchanged. The following points can be considered to improve the efficiency of the plant; (i) machine and operation improvement; (ii) labour management.

	No manufacturing constraints	**With machine breakdown**	**Low labour attendance**	**Shortage in raw material supply**	**More work force than required**
Recycling 1 ton of waste paper	41.86	41.86	52.33	30	41.86
Remanufacturing 1 ton of waste paper to form the pulp	8.6	9.45	10.766	10	8.6
Remanufacturing 1 ton of paperboard to form the pulp	482.12	490.02	513.02	560	513.37
Recycling and remanufacturing per ton	532.6	541.33	576.11	600.7	563.84
Repairing	0	42.04	0	0	0
Labour service	82	82	82	82	82
total spent on recycling wastepaper for a day	2093	2093	2093	1293	2093
total spent on remanufacturing wastepaper for a day	430.63	472.67	430.63	430.63	430.63

Table 2. Recycling and Remanufacturing Cost Evaluation under different constraints

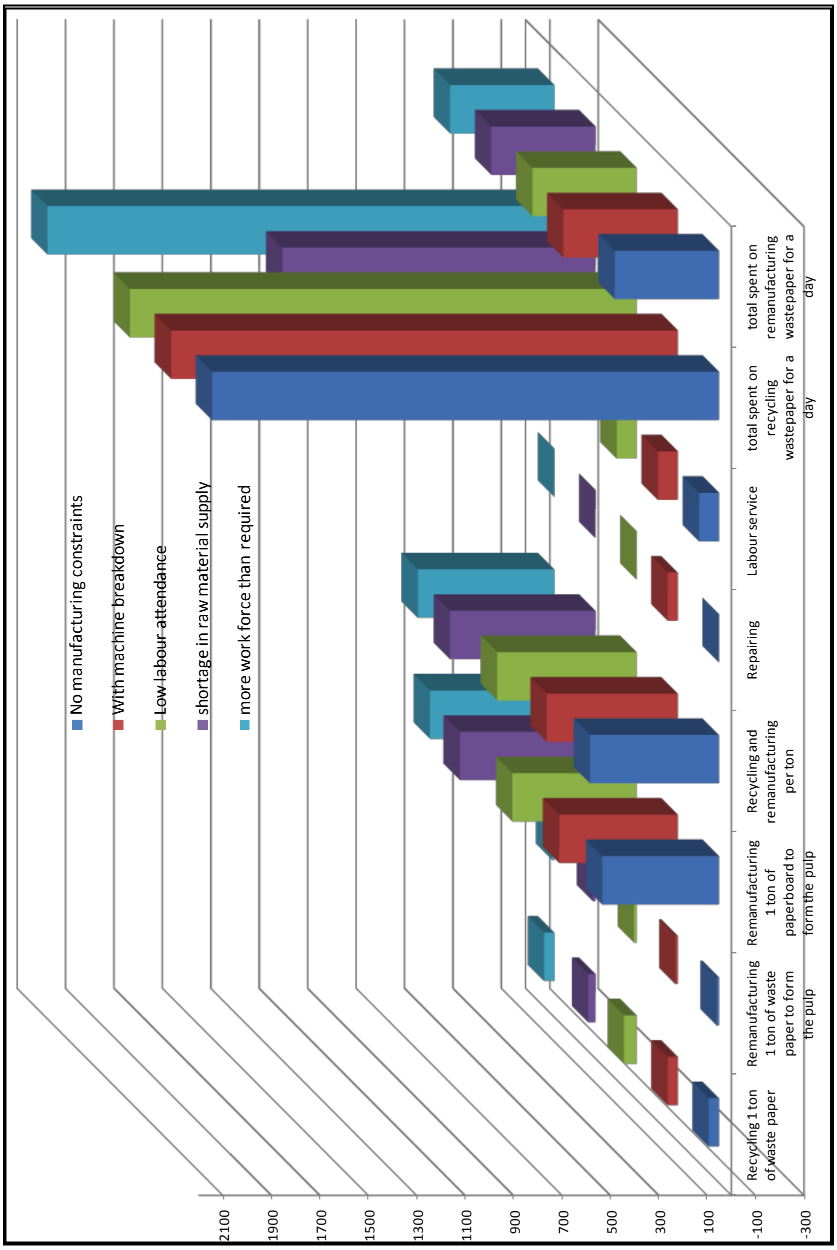

Figure 2. recycling and remanufacturing cost evaluation under different constraints with different scenarios

5. Conclusion and future work

The success of this research has contributed important viewpoints and approaches to the paper industry for reducing waste in terms of cost. The research also identified the most common forms of production constraints to estimate the costs in association with waste paper recycling and remanufacturing. This research was focused on the costing aspect of remanufacturing of wastepaper. All forms of raw material and various types of energy required were highlighted along with the quantity of each required for a ton of waste paper's output. This research investigation provided the cost functions to help a particular company to understand each of the production factors as well as their influence on its final cost. The current evaluation was for a period of one day, if it was for a period of one month or one year the final costs would be more significant. In conclusion it can be said that this project has been successfully in designing a new model for estimating the cost of recycling and remanufacturing wastepaper. The cost models designed are flexible and can be applied to all industries associated with waste paper and cardboard recycling and remanufacturing. It provides a valid and detailed cost calculating solution and can be used under different manufacturing situations.

To reuse of recyclable and remanufacturable waste paper will always be considered by paper manufactures because of environmentally and economically beneficial. Future work could be the development of methods to estimate the production rate and the amount of reusable paper waste that can be produced given a certain amount of raw materials and other influential production factors.

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