Facilitating Waste Paper Recycling and Repurposing via Cost Modelling of Machine Failure, Labour Availability and Waste Quantity

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Abstract. For a paper manufacturer to remain competitive and sustainable, they must be able to manufacture at a low production cost with minimum resource consumption. One such approach to reduce manufacturing costs and take environmental issues into consideration could be the adoption of recycling and repurposing of waste paper. However, recent recycling research to address both environmental and economic challenges is predominately focused on the mechanical or electrical and electronics sectors. As the paper industry and consumers produce a large amount of waste paper, this lack of research highlights an important knowledge gap in the field of study. This article reviews the extent to which waste paper can be reused through recycling and repurposing. As a result, a cost modelling approach has been developed to predict cost fluctuations under different manufacturing constraints. The overall contributions of this research are: (i) identification of testing scenarios and parameters in waste paper; (ii) methods of recycling and repurposing cost modelling. A case study has been used to validate the method and based on the proposed approach, senior management of paper manufacturers could potentially achieve the best result to prevent unexpected costs and therefore maximise waste paper reuse.

Word Counts: 5921

Keywords: Waste paper, paper industry, cost modelling, recycling cost, repurposing cost

1. Introduction

In the last two decades, environmental concerns have extended into almost all aspects of the manufacturing industry and all phases of a product's life cycle (Wang and Chan. 2013). Due to the growing concern about environmental problems, it is becoming important for manufacturers to add more value into their products while reducing the environmental impact (Kondoh and Salmi. 2011). Recyclable material and remanufactured products are two approaches to limit the impact on the environment. Recycling enables the reuse of materials and their components, while remanufacturing preserves the shape and adds value to the returnable products. However, research into recycling and remanufacturing is predominately focused on the automotive, aerospace and electronics industries (Ardente et al., 2014; Asmatulu et al., 2013; Hatcher et al., 2013; Henckens et al., 2014; Lee at al., 2007; Zhang et al., 2011; Zhao and Chen., 2011) while the paper industry has received insufficient attention in recent years. However, remanufacturing of waste paper is not possible and in reality it can be referred to as paper repurposing. As stated by Pullen (2014), "repurposing means taking an item and changing its use. This can be as simple as taking waste paper and repurposing this into note books, card boards etc".

The latest statistics have shown that (Rockstock. 2014) "Worldwide consumption of paper has risen by 400% in the past 40 years leading to increase in deforestation, with 35% of harvested trees being used for paper manufacture." For example, in the United States alone, waste paper accounts for approximately 40% of the total waste; this is equivalent to almost 72 million tonnes of wastepaper annually (Rockstock. 2014). In Europe, eleven million tonnes of waste are produced yearly by the European pulp and paper industry of which 70% originates from the production of de-inked recycled paper (Monte et al., 2009). In 2010 China imported 25 million tonnes of paper for recycling from Europe and North America (Paper Recycling, 2014). Furthermore, the paper industry is a major contributor to the global economy and yet, studies show that the paper industry offers little profit margin and requires large initial investments (Koskinen. 2009**)**. In the current economic climate competition to meet customers' demands is one of the driving factors that affects profit margins (Esterman et al., 2005). When a company produces a product various factors such as the upfront costs of machinery, labour, raw materials and transport will contribute to decisions about price setting. Hence, price setting is the most common problem faced by all industries. Moreover, the paper industry is under constant pressure to reduce harmful emissions to the air and water. Therefore, the paper industry is not only concerned with cost prediction, but also production efficiency and environmental impact, due to the raw materials and processes used in manufacturing.

Paper is manufactured using cellulose fibres as raw material; it can be obtained from waste paper, 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 a recyclable product since it can be recycled at the end of its first life. . The production of pulp and paper from virgin pulp generates less waste but the waste has similar properties to waste from the production of de-inked pulp. This process of de-inking of waste paper, which allows waste paper to be reused again, can be referred to as waste paper recycling (Chen et al., 2001; Monte et al., 2009). Therefore, the process of transforming recycled paper into cardboard, printer papers or newspapers is referred to as waste paper repurposing (Pullen. 2014). Repurposing of recycled paper includes refining, de-inking, as well as remoulding of the pulp.

Cost models can be used to reduce the end-of-life (EOL) cost (Cheung et al., 2015). EOL cost is a process of estimating the cost of recycling/disposing of a product. Thus, cost modelling is an important approach in production, as it plays a crucial role in price tagging. If applied effectively it can be used to reduce production cost, improve production processes and the quality of end products (Ultrich and Eppinger. 2011). This article will therefore discuss the development of a cost modelling approach by taking into consideration all operational parameters. The aim of the cost model is to predict the potential financial impacts of three important elements: (1) critical component failure in the waste paper and paper production processes; (2) availability of labour and (3) the quantity of waste paper in the recycling and repurposing processes. Based on the approach, senior management of paper manufacturers can utilise the result to prevent unexpected costs and therefore maximise waste paper reuse. The layout of this paper is as follows: Section 2 describes the relevant literature. Section 3 discusses the cost modelling approach. Section 4 describes a case study and result and, finally, discussions, conclusion and future work are presented.

2. Literature review

Recycling is not a new research topic but has emerged as a competitive strategy for manufacturers in recent years (Lee et al., 2014). Among these is the following recent recycling related research aimed at both environmental and economic challenges.

Duval and MacLean, (2007) developed a financial model coupled with Life Cycle Assessment technique to apply in recycling business operations. The key question this method to address was focused on the financial and greenhouse gas emissions during the set-up of a start-up network to recycle automotive plastic. This method was successfully used to estimate a trade-off between financial and environmental impact. Ghoreishi et al. 2011) developed a framework for cost benefit analysis of the take back process, such as remanufacturing, refurbishment, reuse and recycling. The focus of the approach was to determine net profit of product take back processes and offers to customers of financial incentives to purchase new products. Marques et al (2014) performed a comparative study to carry out economic analysis of recycling services which comprised the balance between economic and financial costs and the benefits of selective collection and sorting activities. The research was focused on the European Union (EU) member states' packaging waste recycling and recovering processes. They concluded that local governmental regulations and support have the greatest impact on waste management which could directly affect resource efficiency improvement targets in the EU.

Cheung et al, (2015) developed a roadmap to facilitate the prediction of disposal costs to determine a satisfactory solution of whether the EOL parts of a defence electronic system are viable to be remanufactured, refurbished or recycled from an early stage of a design concept. The research was to investigate how disposal costs were being incurred in the domain of defence electronic systems by the Original Equipment Manufacturer (OEM). It is intended that the OEM could utilise this method as part of a full lifecycle cost analysis at the conceptual design stage. The cost model also served as a useful guide to aid decision making so that it led to the design of a more sustainable product in terms of recycling, refurbishment or remanufacture with the consideration of financial impact.

In summary, the recent recycling related research was focused on mechanical or electrical and electronics sectors. As mentioned in the introduction, the paper industry and consumers produce a large amount of waste paper and the lack of research in this area is an important knowledge gap, initiating the investigation of waste reduction and the financial benefits of waste paper.

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 (Richmond. 2006).
- Retention of physical strength and chemical properties when exposed to various agents that are encountered when the paper is stored **(**Richmond. 2006).
- 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 it is highly valued in the packaging sector. Paperboard cartons are the mainstream of resources in the packaging business (Dobra. 2007). In Europe alone, demand for paperboard for the packaging industry was around 46 million tonnes per year since 2007 (Valois. 2012) where global consumption of recovered paper was 228 million tonnes (Keränen and Ervasti., 2014).

Repurposing paperboard is both economically and environmentally sustainable as large quantities of paper can be manufactured using a lesser amount of energy and raw material. The main source of raw material for repurposing paperboard is fibres which are usually obtained from waste paper. Manufacturing paperboard follows the same process as manufacturing of soft paper. Firstly, waste products are disassembled into their 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 (Guide. 2000).

From an economic perspective, studies have shown that recycling and repurposing can yield a higher profit for new product development (Ardente etal., 2014; Dhanorkar et al., 2015). From environmental perspectives, recycling and repurposing help to reduce environmental impact as it avoids post-consumption waste and requires fewer natural resources, thereby extending a product's life. In general, recycling and repurposing will have an impact on sustainability, namely: economic, environmental and societal (Zink et al., 2014). Thus, it can be concluded that recycling and repurposing products are beneficial, not only economically, but also environmentally. There may be polluting emissions during the process of remanufacturing, repairing, repurposing and refurbishment, such as heat and surface treatments (Du et al., 2012; Zink et al., 2014). However, by reusing waste material the level of harmful emissions will be reduced in comparison with virgin materials extraction, which could also improve a product's sustainability.

Cost modelling is an approach used for forecasting/estimating the future cost of a manufactured good or service based on the facts and figures accessible at the given time (Marsh et al., 2010; Xu et al., 2012). Cost estimation is also considered to be an important tool for the management during the initial stages of planning for goods production as it helps in setting a budget for allocating resources (Alizon et al., 2006). It also assists the industry by predicting the cost of alternative designs and the financial impact of the project being undertaken (Cheung et al., 2009; Cheung et al., 2014). 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 a 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 (Go et al., 2011). 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 repurposing 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 categorised 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 materials 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;
- A 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.

(Please insert Figure 1 here)

Fig. 1. Approach of evaluating waste paper recycling and repurposing costs

3.1 Functional equations and factors in recycling and repurposing

Recycling and purposing paper and paperboard from waste paper depends on numerous factors. It is important to consider and understand each of these factors and to recognise their influences on the production processes. The functional equations shown below form the fundamental standard of the factors that influence the recycling and repurposing procedures (Edgren and Moreland. 1990):

- *Waste paper demand*

The quantity of waste paper required (QWPR) is reliant on real output price (OP), present value of waste paper (PvWP) and the total quantity of paperboard produced (Z).

$$QWPR = F_1 \{OP, PvWP, Z\} \quad (1)$$

Where:

F_1 represents a function of "QWPR"

- *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).

$$LR = F_2 \{OP, Z, L, W\} \quad (2)$$

Where:

F_2 represents a function of "LR"

- *Machine operation*

The total amount spent on the working of the machinery (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 waste paper supplied (QWPR), efficiency of the machine (η) and the quantity of labour required (LR).

$$MO = F_3 \{Z, PvE, PvM, QWPR, \eta, LR\} \quad (3)$$

Where:

F_3 represents a function of "MO"

- *Capital investment required*

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

$$CIR = F_4\{OP, PvC, Z, LR, QWPR, MO, PvWP, PvE\} \quad (4)$$

Where:

F_4 represents a function of "CIR"

- *Total production*

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

$$Z = F_5\{LR, CIR, QWPR, MO\} \quad (5)$$

Where:

F_5 represents a function of "Z"

- *Total output*

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

$$WF = \frac{(\text{Amount of waste paper supplied})}{(\text{Amount of waste paper required})} \quad (6)$$

$$TO = F_6\{PvWP, Z, CWPNR, PvE, PmW, WF\} \quad (7)$$

Where:

F_6 represents a function of "TO"

3.2 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 of a particular product. The life cycle cost can be calculated as follows (Asiedu and Gu. 1998)**:**

$$LCC = (Ci + OM \text{ present value} + P \text{ present value} + RR \text{ present value} - Dis - D) \quad (8)$$

Where:

- *Ci = The initial "capital investment" required to implement 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 costs 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. Wages 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 is a type of variable cost.*
- *RR = Repair and Replacement cost is the cost incurred by the company to repair the machines which breakdown during usage and replace parts at the end of the life span.*
- *Dis = Disposal cost is the cost incurred to dispose of the waste and the products produced with defects.*
- *D = Depreciation is a cost that a company suffers because machinery depreciates every year from the time it is first in use.*

3.3 Recycling cost

Recycling cost is the cost incurred to recover the recyclable 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 (Shu and Flower. 2005):

$$RC = (QW * PVm) - OC - (T * LC * f) + EC \qquad (9)$$

Where:

RC (£) = Recycling Cost

QW (Kg) = Quantity of wastepaper used in kilograms

OC (£) = Opportunity cost

PVm (£/kg) = Present value of per kilogram of wastepaper

LC (£/hr) = Labour cost

T (hrs) = Time required for refining and deinking the wastepaper

f = Refining and deinking factor

EC = Energy cost

"f" can be calculated by:

$$\frac{\text{(Effective Residual Ink Concentration(ERIC) value of the wastepaper completely refined and deinked)}}{\text{(ERIC value of the wastepaper before ink removal and unwanted particles} - \text{ERIC value of the waste after deinking)}} \qquad (10)$$

3.4 Repurposing cost

Repurposing paper and paperboard from waste paper includes the cost of refining and de-inking 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. Repurposing cost using pulp forming and moulding can be calculated on the basis of the equation given below (Dantec. 2005):

$$RpC = ((TimeD + TimeA) \times PQ \times n \times LR) + (PF \times CF) + EC + UC \qquad (11)$$

Where: *RpC (£) = Repurposing cost*

TimeD (hrs) = time required for refining and deinking

TimeA (hrs) = Time required for molding the pulp

Repurposing cost per tonne of recycled paper can be calculated on the basis of the equation given below:

$$RpC = (TOT \times PQ \times LC \times n) + (Er \times EC) + UC + (I \times IC) + (PF \times CF) \qquad (12)$$

Where:

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

3.5 Machine repair cost

The plant operates 24 hours, 7 days a week. Continuous working of the machinery for repurposing paperboard leads the machine parts to wear out. The production is halted if a certain machine breaks down and requires immediate repair before resuming the production. Repairing any component requires expenditure. The repairing cost can be calculated using the equation given below (Shu and Flower. 2005):

$$\text{RepC} = \text{CF} + (\text{fa} \times \text{LR} \times \text{Trt}) \quad (13)$$

$$\text{Where, } \text{fa} = \frac{(\text{Number of assemblies to dissemble})}{(\text{Total number of assemblies})} \quad (14)$$

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

3.6 Service cost

Service cost involves the cost incurred to pay the workforce employed to carry out the maintenance of the machinery used in the production process. The service cost can be calculated from the equation given below (Asiedu and Gu. 1998)**:**

$$LSC = ((Lt + Ltp) \times LR + (Pc + Pcp)) \quad (15)$$

Where:

LSC (£) = Labour service cost

Lt (hrs) = labour time

Ltp (hrs) = Labour time penalty

LR (£/hr) = Labour rate

Pc (£)= Material cost

Pcp (£) = Material cost penalty

3.7 The analysis and testing parameters

The focus of the analysis is based on three elements:

1) What will be the financial impact if one of the critical mechanical components failed? The pedestal bearing is used for the evaluation and the reason for the selection is based on the industrial collaborator's experience that this typical component often fails during the recycling process.
2) The second element of the cost modelling approach is to evaluate labour fluctuation. How will this affect the recycling and repurposing processes financially?
3) The last element to be considered in the evaluation is how shortage of waste paper will affect a paper manufacturer financially.

Figure 2 illustrates the three elements and based on this, five scenarios have been identified for the case study.

1. No manufacturing constraints;
2. With machine breakdown;
3. Low labour attendance;
4. More work force than required;
5. Shortage in raw materials supply.

In order to evaluate the potential impact on the costs of the five scenarios, the following experimental parameters are used in the cost models.

- Recycling 1 tonne of waste paper

- Repurposing 1 tonne of waste paper to form the pulp
- Repurposing 1 tonne of paperboard to form the pulp
- Recycling and repurposing per tonne
- Repairing
- Labour service
- Total spent on recycling waste paper for a day (50 tonnes)
- Total spent on repurposing waste paper for a day (50 tonnes)
- Total spent on repurposing paperboard for a day (depends on the amount of recyclable paper obtained at the recycling stage)

This would help senior management to visualise the financial impact under different scenarios. The resulting costs impact on each of the above scenarios would help the paper manufacturers to prevent potential shortcomings as indicated in the three elements.

(Please insert Figure 2 here)

Fig. 2. The Testing Parameters for the Case Study

4. Case study and result

The cost equations as explained in Section 3 are used to determine the cost of recycling and repurposing the paperboard under different manufacturing constraints as described in Section 3.7. The data in Table 1 was obtained from S.P. Paper and Paperboard Mill Ltd in India which was used in the cost models. The company is certified by ISO 14001 for environmental management and by ISO 9008 for quality management. The results generated from the cost models could only give an indication of the associated costs by applying different manufacturing constraints.

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

(Please insert Table 1 here)

The pedestal bearing (see Figure 3 (a)) was considered as a part of the case study to estimate its repair cost as it often breaks down and causes disruption to the production process. The amount of waste paper used for the estimation was one tonne (see Figure 3 (b)).

(Please insert Figure 3 here)

Fig. 3. Images courtesy of S.P. Paper and Paperboard Mill Ltd in India

The final costs under different scenarios are shown in Table 2. Please note that the estimated financial figures were based on Indian rupee to British Pound sterling. It can be seen that due to the breakdown of the pedestal bearing, the production cost of recycling and repurposing of 1 tonne of waste paper has been increased from £532.60 (no manufacturing constraints) to £541.33 (with machine breakdown). The production process was interrupted until the machine had been repaired and the company bore the extra cost of £42.04 in order to repair the bearing.

The labourers were 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 repurposing and recycling, it was assumed that 3 employees were absent. It is seen from Table 2 that the total cost spent on recycling and repurposing 1 tonne of wastepaper has been increased from £532.60 (no manufacturing constraints) to £576.11 (low labour attendance) and the company bore a loss as the production rate reduced from 2.1 tonnes per hour to 1.7 tonnes per hour; this figure was quoted by S.P. Paper Ltd. The reduced productivity was due to employee absence. In addition, one of the testing constraints was to consider 4 additional labourers (3 extra machine operators and an extra technician as standby). Cost is thus being evaluated with 4 excess labourers. It is seen that the total cost spent on recycling and repurposing of 1 tonne of waste paper has been increased from £532.60 (no manufacturing constraints) to £563.11 (more work force than required). The cost has been increased significantly as the labour spent extra unnecessary time for the same level of output. Very often the management wrongly believe that more employees increase the yield rate.

A further testing scenario was that the quantity of waste paper decreased from 50 to 40 tonnes. As seen in Table 2, the cost of recycling and repurposing of 1 tonne of waste paper increased from £532.60 (no manufacturing constraints) to £600 (shortage in material supply) 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.

Considering the practical application of the cost models, it is seen that in the real world the factors of production vary from day to day, thus requiring continuous changes in the input parameters. The approach developed 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 keep 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.

Table 2. Recycling and Repurposing Cost Evaluation under different constraints

(Please insert Table 2 here)

(Please insert Figure 4 here)

Fig. 4. Illustration to represent the overall evaluation of one month only

5. Discussions

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 (Section 3). The research has identified the most common forms of production constraints to estimate the costs in association with waste paper recycling and repurposing (Section 3.7). This research was focused on the costing aspect of recycling and repurposing of waste paper. The current evaluation was for a period of one day (Section 4), if it was for a period of one month or one year the final costs and reusable waste paper would be more significant as illustrated in Fig 4. During the implementation of the cost models not all data was available so both the opportunity and uncertain costs were not taken into account.

Uncertainty is one of the characteristics of the real world. The uncertainty surrounding how waste should be dealt with could be included in the cost models. The case study was based on cost modelling of the 5 scenarios (as highlighted in Section 3.7) and therefore the current approach should be further developed to include uncertainty in the scenarios. The method that copes with uncertainty can help to achieve a more realistic result. Two types of uncertainty can be used to enhance the result, for example, *parameter uncertainty* in the cost equations for unreliable parameters and *scenario uncertainty* for lack of knowledge of reliable data.

6. Conclusion and future work

This research investigated the costs-benefits involved in paper recycling and repurposing and presented these using a similar methodology such as recycling and remanufacturing to the metal-based products. It provides a useful illustration of how the methodology translates across product domains. The cost models are flexible and can be applied to all industries associated with waste paper and cardboard recycling and repurposing (as discussed in sections 3 and 4). Paper manufacturers will always consider the reuse of recyclable and repurposing waste paper because it is environmentally and economically beneficial. Considering the practical application of the cost equations, it can be seen that in the real world the factors of production vary from day to day and thus require continuous changes in the input parameters. In such a situation the approach developed has proven to be highly advantageous as it reduces the effort of inputting data and saves time considerably. Future work should include: (i) 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; (ii) uncertainty to achieve a more realistic result and (iii) data analysis to a period of at least one month to explore the significant of the overall impacts as well as with a few more paper manufacturers.

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References

Alizon F, Shooter SB, Simpson TW. Reuse of manufacturing knowledge to facilitate platform-based product realization. J Comput Info Sci Eng 2006: 6.2:1-9.

Ardente F, Mathieux F, Recchioni M. Recycling of electronic displays: Analysis of pre-processing and potential ecodesign improvements. Resour Conserv Recycl 2014: 92:158-171.

Asiedu Y, Gu P. Product life cycle cost analysis: State of the art review. Int J Prod Res 1998: 36.4:883-908.

Asmatulu, E, Twomey J, Overcash M. Evaluation of recycling efforts of aircraft companies in Wichita. Resour Conserv Recycl 2013:80:36-45.

Chen G, Qin M, Qu P, Gao P. Advances of study on waste paper deinking by cellulases. Prog Biotechnol 2001:3:003.

Cheung WM, Marsh R, Newnes LB, Mileham AR, Lanham JD. Standards and inference of design information in through-life costing of innovative defence electronic products. Proc. Inst. Mech. Eng. Part B: J. Eng. Manuf. 2009: 223.2:169-181.

Cheung WM, Marsh R, Newnes LB, Mileham AR, Lanham JD., Cost data modelling and searching to support low-volume, high-complexity, long-life defence system development. Proc. Inst. Mech. Eng. Part B: J. Eng. Manuf. 2014: doi: 10.1177/0954405414534226

Cheung WM, Marsh R, Griffin P, Newnes LB, Mileham AR, Lanham JD. Towards Cleaner Production: a Roadmap for Predicting Product End-Of-Life Costs at Early Design Concept. J Clean Prod 2015: 87: 431-441.

Dantec D. Analysis of cost of recycling compliance for the automobile Industry. Thesis for a Master of Science in Technology and Policy, Massachusetts Institute of Technology (MIT), Engineering Systems Division; 2005.

Dhanorkar S, Donohue K, Linderman K. Repurposing Materials & Waste through Online Exchanges: Overcoming the Last Hurdle. Prod Op Manag, Special Issue on 'Socially Responsible Operations'. 2015. DOI: 10.1111/poms.12345

Dobra A. Software proposal for cutting corrugated boxes. 2007. http://imtuoradea.ro/auo.fmte/files-2007/TCM_files/Dobra_Andreea_1.pdf [cited October 2014].

Du Y, Cao H, Liu F, Li C, Chen X. An integrated method for evaluating the remanufacturability of used machine tool. J Clean Prod 2012: 20.1:82-91.

Duval D, MacLean HL. The role of product information in automotive plastics recycling: a financial and life cycle assessment. J Clean Prod 2007: 15.11:1158-1168.

Edgren JA, Moreland KW. An econometric analysis of paper and wastepaper markets. Res Energ 1990: 11.3:299-319.

Esterman M, Gerst, P, Stiebitz PH, Ishii K. A framework for warranty prediction during product development. In ASME 2005 International Mechanical Engineering Congress and Exposition, January 2005: 381-388.

Ghoreishi N, Jakiela MJ, Nekouzadeh A. A cost model for optimizing the take back phase of used product recovery. J Remanuf 2011, 1. 1: 1-15.

Go TF, Wahab DA, Rahman MA, Ramli R, Azhari CH. Disassemblability of end-of-life vehicle: a critical review of evaluation methods. J Clean Prod 2011:19.1:1536-1546.

Guide Jr VDR. Production planning and control for remanufacturing: industry practice and research needs. J Op Manag 2000: 18.4: 467-483.

Keränen JT, Ervasti I. Amounts of non-fibrous components in recovered paper. Resour Conserv Recycl 2014: 92: 151-157.

Hatcher GD, Ijomah WL, Windmill JF. Design for remanufacturing in China: a case study of electrical and electronic equipment. J Remanuf 2013.1:1-11.

Henckens MLCM, Driessen PPJ, Worrell, E. Metal scarcity and sustainability, analyzing the necessity to reduce the extraction of scarce metals. Resour Conserv Recycl 2014: 93: 1-8.

Kondoh S, Salmi T. Strategic decision making method for sharing resources among multiple manufacturing/remanufacturing systems. J. Remanuf 2011:1:1-8.

Koskinen P. Supply chain strategy in a global paper manufacturing company: a case study. Ind. Manag. Data. Syst 2009:109.1: 34-52.

Lee, HM, Lu, WF, Song, B, 2014. A framework for assessing product End-Of-Life performance: reviewing the state of the art and proposing an innovative approach using an End-of-Life Index. J. Clean. Prod. 66, 355-371.

Lee, JC, Song HT, Yoo JM. Present status of the recycling of waste electrical and electronic equipment in Korea. Resour Conserv Recycl 2007: 50.4: 380-397.

Marques RC, Cruz NF, Simões P, Ferreira S, Cabral M, De Jaeger S. Economic viability of packaging waste recycling systems: a comparison between Belgium and Portugal. Resour Conserv Recycl 2014: 85: 22–33

Marsh R, Jonik M, Lanham J, Cheung WM, Newnes LB, Mileham AR. Modelling an assembly process using a close coupled generative cost model and a discrete event simulation. Int J Comput Integr Manuf 2010: 23.3:257-269.

Monte MC, Fuente E, Blanco A, Negro C. Waste management from pulp and paper production in the European Union. Waste Manag 2009: 29.1: 293-308.

Paper Recycling. Nurturing Success. 2014. http://www.waste-management-world.com/articles/print/volume-13/issue-1/features/paper-recycling-nurturing-success.html [cited October 2014].

Pullen K. Repurposing Ideas. 2014. http://greenliving.lovetoknow.com/Repurposing_Ideas [cited October 2014].

Richmond M. Paperboard Cartons Offer Growth Opportunity. 2006 [http://www.dairyfoods.com/articles/packaging-points-paperboard-cartons-offer-growth-opportunity?v=preview] [cited October 2014].

Rockstock - Environmental attributes. 2014. http://www.stonepaper.co.nz/about-rockstock/environmental-attributes [cited October 2014].

Shu LI, Flower WC. Reliability modelling in design for remanufacture. J Mech Des: Tran ASME 2005: 120:615-627.

Ultrich KT, Eppinger SD. Product Design and Development, McGraw Hill, New York, 2011:12-72.

Valois M., Paper, paperboard and woodpulp markets, 2011-2012, UNECE/FAO Forest Products. Ann Mark Rev 2012: 79-94.

Wang X, Chan H.K. An integrated fuzzy approach for evaluating remanufacturing alternatives of a product design. J Remanuf 2013:3.1:1-19.

Xu Y, Elgh F, Erkoyuncu JA, Bankole O, Goh Y, Cheung WM. et al: Cost engineering for manufacturing: current and future research. Int J Comput Integrd Manuf 2012: 25.4/5:300-314.

Zhang T, Chu J, Wang X, Liu X, Cui P. Development pattern and enhancing system of automotive components remanufacturing industry in China. Resour Conserv Recycl. 2011:55:6: 613-622.

Zhao Q, Chen M, A comparison of ELV recycling system in China and Japan and China's strategies. Resour Conserv Recycl 2011:57: 15-21.

Zink T, Maker F, Geyer R, Amirtharajah R, Akella V. Comparative life cycle assessment of smartphone reuse: repurposing vs. refurbishment. The Int J Life Cycle Assess 2014:19:5: 1099-1109.

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

	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	50000	50000	50000	40000	50000
PVm	0.08	0.08	0.08	0.08	0.08
T	18	18	18	18	18
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
OC	0	0	0	0	0
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
UC	0	0	0	0	0
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	50000	50000	50000	50000	50000
TO	50	50	40	43	50
IC	0.8	0.8	0.8	0.8	0.8
n	26	27	24	26	29
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

(This is a 2-column fitting table)

Table 2. Recycling and repurposing cost evaluation under different constraints

Costs in British Pound Sterling (GBP) converted from Indian Rupee (INR)					
	No manufacturing constraints	**With machine breakdown**	**Low labour attendance**	**Shortage in waste paper supply (40 tonnes per day)**	**More work force than required**
Recycling 1 ton of waste paper	41.86	41.86	52.33	30	41.86
Repurposing 1 ton of waste paper to form the pulp	8.6	9.45	10.77	10	8.6
Repurposing 1 ton of paperboard to form the pulp	482.12	490.02	513.02	560	513.37
Recycling and Repurposing 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 (50 tonnes)	2093	2093	2616.5	1200	2093
Total spent on repurposing wastepaper for a day (50 tonnes)	430	472.5	538.5	400	430.63

(This is a 2-column fitting table)

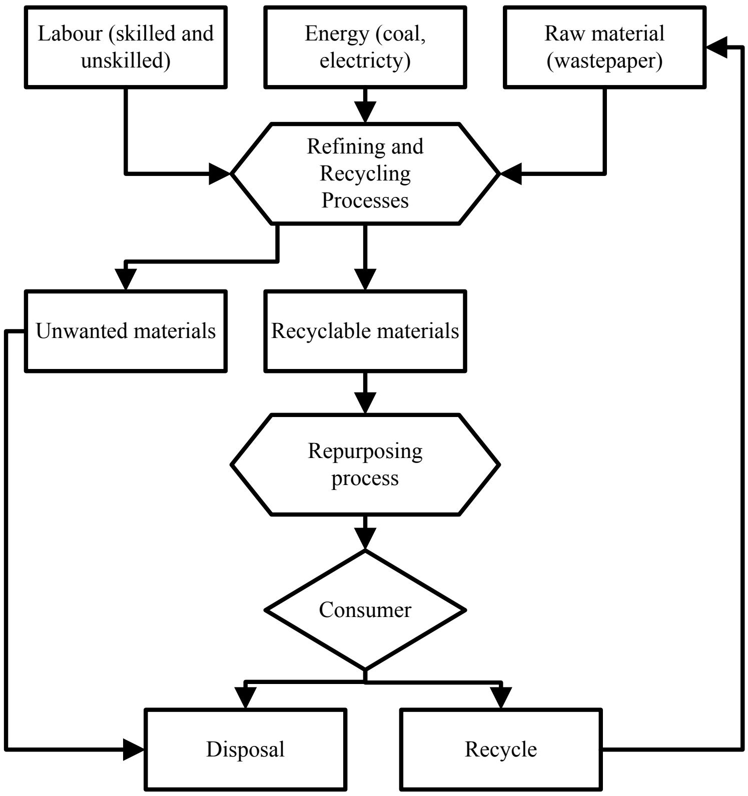
Figure Captions:

Fig. 1. Approach of evaluating waste paper recycling and repurposing costs

Fig. 2. The Testing Parameters for the Case Study

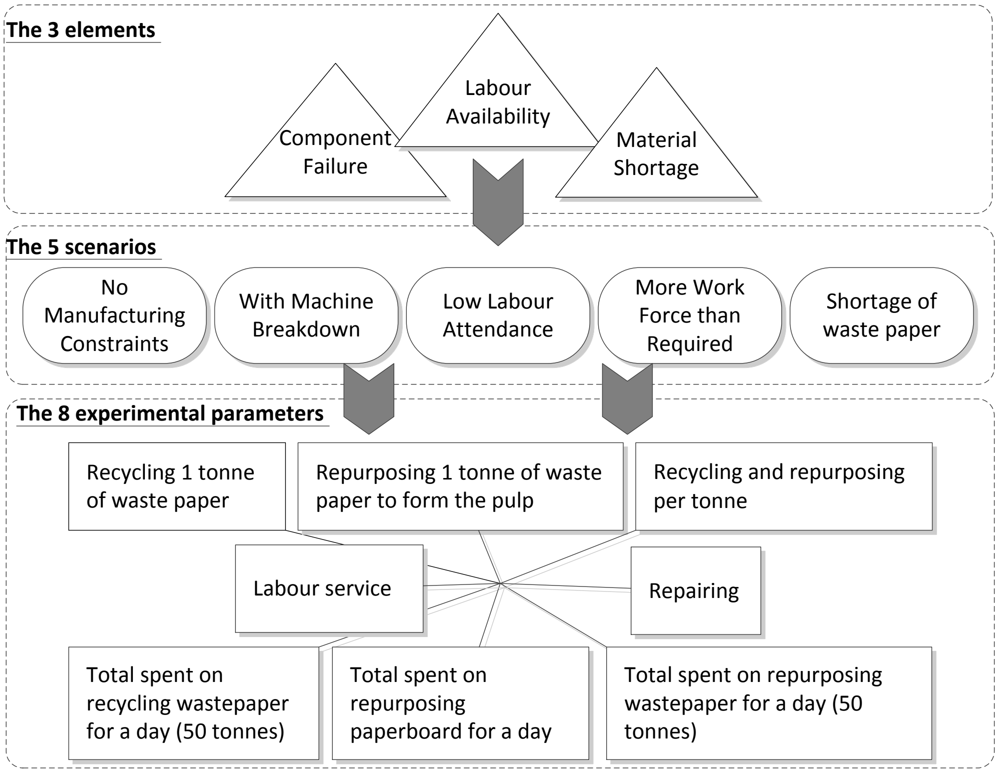
Fig. 3. Images courtesy of S.P. Paper and Paperboard Mill Ltd in India

Fig. 4. Illustration to represent the overall evaluation of one day only



(This is a 1-column fitting image)

Fig. 1. Approach of evaluating waste paper recycling and repurposing costs



(This is a 2-column fitting image)

Fig. 2. The Testing Parameters for the Case Study

(a) Pedestal bearing

(b) Waste paper

(This is a 1-column fitting image)

Fig. 3. Images courtesy of S.P. Paper and Paperboard Mill Ltd in India

Fig. 4. Illustration to represent the overall evaluation of one day only
(This is a 2-column fitting image)