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Waste paper procurement optimization: An agent-based simulation approach

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ABSTRACT

This paper proposes an agent-based simulation model to study and analyse the performance of various procurement and production policies in the recycled paper industry. The proposed model includes the recycled pulp production process, as well as the waste paper inventory and procurement processes. A detailed simulation model developed in partnership with a large recycled pulp producer in North America was developed in order to emulate the procurement manager's behaviour. Therefore, based on the observed behaviour of the procurement manager, a procurement behaviour model, which takes both market price and inventory requirement into account, is introduced. This paper also introduces a waste paper market model that simulates a market price and enables the control of price forecast accuracy. Two series of experiments were carried out in order to study the performance of procurement and production policies in several productions contexts. Results show that production Volume Flexibility has a negative impact on costs, inventory and quality. However, it is possible to partially reduce these issues with the introduction of contracts with Volume Flexibility, although only a limited effect has been observed in our experiments. A more significant strategy to improve costs consists in reducing production rate to the minimum level required to meet demand.

1. Introduction

The recycled pulp and paper industry is a closed-loop supply chain (Fig. 1), which differs significantly from traditional supply chains (Carr & Appleton, 1990). Because closed-loop supply chains used to be considered as less valuable, their challenges are just beginning to be more widely addressed in the literature. Like other closed-loop industries, many fundamental issues of the recycled pulp and paper industry remain partially solved at best. This introduction section proposes an overview of some of these challenges, including the specific problem addressed in this paper.

1.1. The recycled pulp and paper industry

In the recycled pulp and paper industry, raw material includes various types and quality of waste. Among many issues to be addressed, waster paper procurement is one of the most critical as it represents over 40 percent of total cost. Waste paper is an end-of-life material generated by the use of papers, virgin or recycled products, which are collected and partly sorted. The main finished product is recycled pulp. In order to be used in the paper production process, recycled pulp must meet several chemical constraints. However, to have high commercial value, important aesthetic constraints must be met, such as pulp brightness. The producers' objective is thus to produce a product with the right brightness for the specific use of their customers. To improve brightness, various chemical processes can be used with a fairly predictable, although limited, effect. Brightness is mainly a function of waste paper composition (e.g., type of fibre). The larger the content of ground wood fibre, the lower the brightness of the finished product.

Waste papers are industrial wastes, which contents and characteristics vary widely. There are two types of variations: inter-type (i.e., variations between different types of waste paper) and intra-type (i.e., variations within a specific type of waste paper). On the one hand, to reduce inter-type variability, the industry has developed segregation charts based on specific characteristics (e.g., physical, end-user type, location) to classify collected bales of waste paper. There are 52 standard grades of waste paper in North America. These charts allow recyclers to better understand the type of raw materials they purchased. Each grade has different properties, quality, brightness, and consequently, different price. Therefore, depending on the price of each grade and the pulp target brightness, a grade of waste paper can be more valuable than others. Unfortunately, these grades still contain much variability, because waste papers are poorly sorted when initially disposed of in office buildings and private homes. Per-

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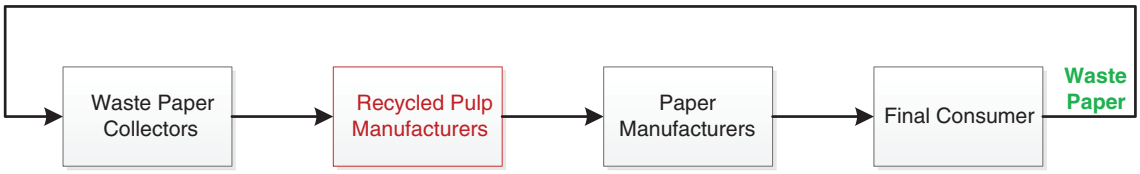

Fig. 1. Main processes of the recycled pulp and paper industry.

fect segregation at the point of generation is difficult, if even possible. Consequently, some form of testing and sorting is generally recommended. Procurement contracts with waste paper suppliers also include quality restrictions.

On the other hand, intra-type variability can lead to various pulp brightness due to fibre mix variations. Indeed, fibre mix can vary between two white sheets of waste paper considered identical. It is therefore difficult to reduce intra-type variability because it is physically impossible to sort industrial batches of waste paper based on fibre mix.

Waste paper procurement can be done through contracts or spot market. A pulp producer's capacity to take advantage of both approaches depends on the waste paper market, which has a complex structure. Several important buyers and suppliers influence the market. In addition, waste paper supply is not unlimited. Its availability depends on various factors including generation rate, recovery rate, and seasonality, which lead to volatile prices.

In this paper, we focus on a pulp producer and its relationships with waste paper collectors. In general, a pulp producer, also referred to as the recycler, has one production line (Fig. 2). Such a line can produce different pulp qualities from few grades of waste paper, according to several recipes. For instance, to produce pulp quality FP1, the producer uses recipe R1, which recommends a specific mix of each input grade of waste paper. The goal of the producer is to minimize procurement cost, subject to a constraint of minimum level of brightness. Therefore, production control deals with controlling the input mix, as well as the chemical whitening of the pulp.

This production process operates continuously since the cost of a shutdown and a restart is high. Temporary downtimes are planned over several days for maintenance. Furthermore, managers can adjust production rate and input mix (i.e., recipes/campaigns) according to demand, pulp market conditions and inventory levels. In this paper, this capacity to adjust production rate is referred to as Production Flexibility. It represents the ability of the production manager to increase or decrease total daily production volume, with little or no impact on profitability. Parker and Wirth (1999) defines this type of flexibility as Volume Flexibility.

In turn, the procurement strategy must be adapted in order to meet production input mix and consumption requirements. In practice, production efficiency is affected by procurement policies and vice versa. For instance, a high production rate improves operational performance, but creates waste paper scarcity problems. Along the same line, procurement policies, such as procurement contracts, reduce purchase cost, but can impact Production Flexibility by affecting available grade mix. Therefore, production and procurement policies must be analysed and optimized altogether.

This paper aims to study this coordination problem. More specifically, it aims to optimize procurement policies by assessing their value in the context of various production rates and flexibility levels. To do so, an agent-based simulation approach is used.

2. Literature review

The coordination of procurement and production activities is an essential part of supply chain management (Bhatnagar, Chandra, & Goyal, 1993), which can be challenging in rapidly evolving and changing conditions. Recycled pulp producers face such a challenge. For instance, paper utilisation decreases worldwide, which reduces waste paper availability. Similarly, fibre content decreases in virgin paper, which has also a negative impact on recycled fibre availability. Consequently, recycled pulp producers must purchase more waste paper to maintain their production output. When combined with growing global competition, these challenges lead to increasing waste paper demand and to volatile market price and availability. Therefore, pulp producers need to assess and optimize their procurement strategies.

Supply chain management and procurement decisions are often supported by traditional optimization technics, such as mathematical programming, inventory theory, and other mathematical optimization tools, including robust and stochastic optimization. The interested reader is referred to Dekker, Bloemhof, and Mallidis (2012) for a recent review of OR application in the domain of green logistics. These ever improving tools are capable of identifying optimal decisions in specific, and even uncertain, conditions. However, although they are highly effective tools for optimizing decisions, their modelling paradigm cannot yet deal efficiently with complex situations with large amounts of concurrent events and decisions influencing each other with feedback loops and emerging phenomenon. These

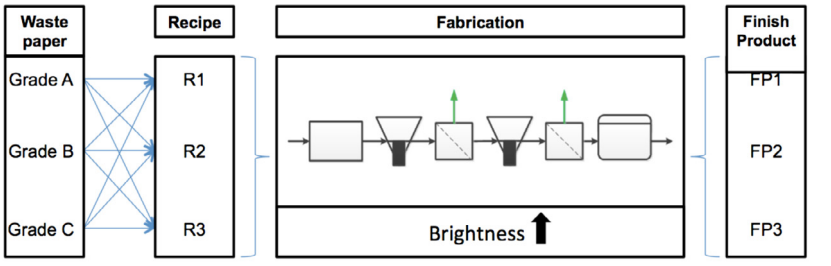

Fig. 2. Recycled pulp production processes.